Additional information

Atomic model

All substances are made of atoms. Each atom consists of a positively charged atomic nucleus at the centre surrounded by negative charges, the electrons. The nucleus is composed of positively charged and electrically neutral particles (protons and neutrons). Viewed as a whole, an atom is electrically neutral; the number of electrons in the shell corresponds to the number of protons in the nucleus. Although strong attraction forces exist between the particles with different charges, the electrons in the shell do not combine with the protons in the nucleus. Fig. 1 on the right side shows a schematic atomic model. Electrons are moving in different orbits around the nucleus. This movement is extremely fast and prevents the electrons from falling into the nucleus. The model with fixed electron orbits is somewhat outdated, although you still

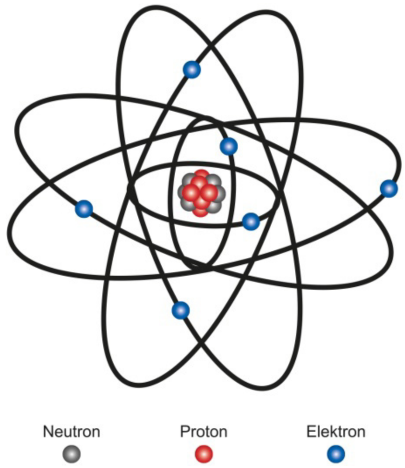

Fig. 1: Schematic atomic model.

find it in many books. In a more abstract and viable model, the electrons occupy only very specific energy levels in the atom due to their wavelike properties. The inner electrons close to the nucleus are bound very tightly, and by contrast the outer electrons can be separated from the atom with less energy expenditure. Removing an electron from the atom results in an unbound (free) electron and a positively charged atom (an ion).

Electrical conductivity

Countless atoms are connected together in any substance. The outer electrons of the atoms play an important role in bonding. Depending on the substance class (for example, metals, salts, carbon compounds), there are different types of bonds. The bonds significantly determine the substance properties(for example, stability, colour, electrical conductivity).
In principle, a substance needs free charge carriers to be electrically conductive. Negatively charged electrons or ions (positively or negatively charged atoms) are possible charge carriers.

In a metal, the free electrons are responsible for the fact that electric current can flow. The metal atoms are arranged in a regular lattice structure. The outer electrons are no longer bound to certain atoms, but move throughout the entire metal as electron gas. Like the temperature-dependent movement of the particles of a gas, their movement is chaotic; the electrons are constantly changing their direction due to collisions with atoms and other electrons (Fig. 2). Substances which do not contain any free charge

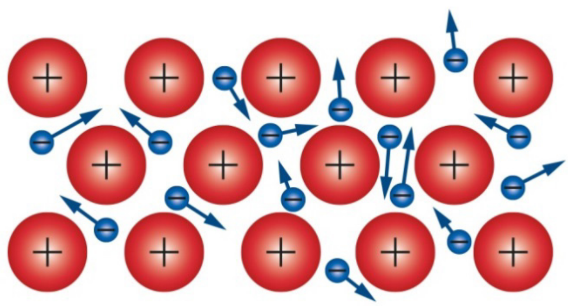

Fig. 2: Model of the electron gas in a metal.

carriers and therefore do not conduct current, such as plastic, glass, ceramic, or table salt, are called insulators. Table salt crystals consist of a regular arrangement of positively charged sodium ions and negatively charged chlorine ions. Only when the salt is heated to a high temperature or dissolved in water do the ions become mobile, giving rise to ion conduction. The current is carried by both the positive and the negative ions, which move in opposite directions.

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In electrical engineering and electronics, so-called semiconductors are an important group of substances. In semiconductors, the number of free charge carriers depends on the level of purity of the substance. The purity can be influenced over a wide range by the addition of impurity atoms (doping) and through external influences (for example, temperature, light). Unlike the mechanism of electronic conduction in metals, positive charges (electron holes) can contribute to the current in semiconductors. Components with complex functions can be produced through the combination of semiconductor materials with various conduction properties. Without the group of semiconductors, modern information and communication technology (computers, mobile phones, Internet and much more) would not be possible. These components are also playing an increasingly important role as energy converters.

Electric current and voltage

Electrons move very quickly inside a metal wire. Electric current is the movement of charge carriers in a common direction. This directed movement requires an external drive – an electric voltage. Current does not flow without voltage; in other words, voltage gives rise to current. Figure 3 to the right illustrates the current in a conductor as a directed movement of the conduction electrons.

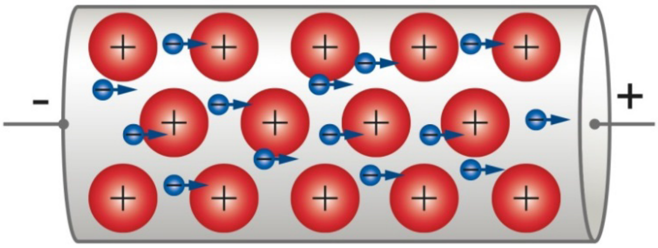

Fig. 3: Model of electric current in a metallic conductor.

This schematic representation shows the average electron velocity elicited by the applied voltage. The much stronger random movement of the electron gas is not shown here (see Figure 2).

For the students' initial encounter with the concept of voltage as part of the introduction to electric circuits, it is sufficient to assume the voltage is a given variable ("Voltage is what is indicated on the battery or what a voltmeter displays"). It is measured in volts (abbreviated V). The electric voltage of a battery comes about when a surplus of electrons exists at the negative pole and a shortage exists at the positive pole. If the poles are conductively connected, electrons flow from the negative pole to the positive pole through the conductor. This current would very quickly equalize the charge difference between the poles, but the battery continues to provide additional charge carriers. Inside the battery, chemical processes take place that maintain the charge difference and thus also the electric voltage. The reactions are complex and will not be explained here in detail. If suffices to state that the chemical processes inside the battery transport electrons from the positive pole to the negative pole. When the chemical substances are "used up", the battery is "dead". Electric voltage cannot be built up and the current stops.
Here is an explanation to help define and differentiate the concepts of voltage and current: the amount of voltage, its numerical value, is a measure of the power of the drive. The higher the voltage, the more electrons flow through the conductor in the same amount of time, and the greater the power of the current.

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Electrical circuit

Electrical devices like incandescent bulbs or electric motors require a closed circuit to operate: The electrons flow from the battery's negative pole to the device via a conducting connection and back to thebattery's positive pole via another conductor. The chemical processes inside the battery close the circuit.

It may not be immediately apparent to the students that a closed circuit is present. First, only the two external connections from the battery to the device are visible and tangible; the internal processes of the battery, which close the circuit, remain inaccessible and go unnoticed. Second, many people (not only children) associate a rather "energetic" image with electricity: It is generated and consumed. They assume that electricity/current is stored in the battery, flows to the device via the cable, where it becomes "consumed". The term "consumer" (synonym for "load") used in everyday language for electrical devices reflects this perception. If you discuss and reflect on energy, clarify that no charge carriers are lost in the consumer and no energy is consumed (during energy conversion).

Electrical resistance (conductors and insulators)

The strength of the electric current in a circuit depends on the applied voltage. In addition, the current strength depends on the quality of the connected devices and the connecting cables. For a given voltage, a stronger current flows through a thick copper wire than through a thin wire. An iron wire does not conduct as well as a copper wire of the same diameter and length. A stronger current flows through an incandescent bulb than through an equally bright LED. The property of substances and electrical devices to oppose the passage of current is called resistance. For a given voltage, the lower the resistance of a device or conductor, the stronger the current through the device or conductor. Good conductors (copper, gold, aluminium) have low resistances. At very low temperatures, the resistance of some conductors disappears completely; they become superconductors. In contrast, the resistance of an insulator is (nearly) infinite.

In the experiments, the relation between current and resistance is discussed only qualitatively. Beyond comparative formulations ("the higher the voltage, …"), many students can grasp basic proportional correlations: A doubling of the voltage results in a doubling of the current. The idea of proportionality between current and voltage is stated in Ohm's law. If you are interested, the following two experiments (voltage divider, current divider) nicely link resistance, voltage and current.

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8.5b Additional Experiment: The voltage divider and the current divider

Research question

What are the voltages U1 and U2 if you use different resistors R1 and R2 in a circuit?

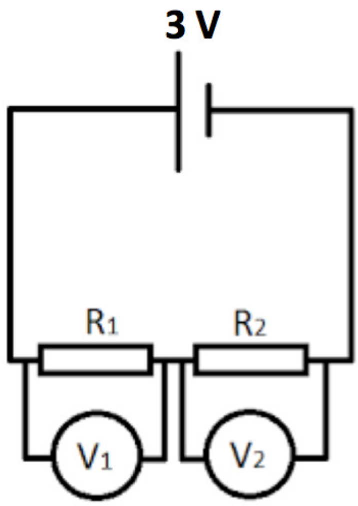
Setting up and conducting experiments

Set up:

- two batteries
- various resistors

Build the pictured circuit: two resistors in a row. Using the digital multimeter, measure the voltages U1 at R1 and U2 at R2. Also measure the total resistance RT for both resistors.

Write down your results in the table below.



Observing and documenting

Series	R1 Ω	R2 Ω	R total	R1 : R2
A				
B				
C				

U1 (V)	U2 (V)	U total	U1 : U2

Doing further research

Draw the circuit diagram of two resistors that are connected in parallel and find out about U1, U2 and RT in the parallel circuit.

Analysing and reflecting

Unlike the previous series resistor circuit, in a parallel resistor network the current can take more than one path as there are multiple paths for the current.

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Concept of energy and energy phenomena

The concept of energy is complex and does not allow for a simple definition. In all processes that have been scientifically explored to date, energy is converted from one form of energy to another. Energy is not created from nothing. Similarly, it is not consumed and does not disappear without a trace. Energy is indestructible. The total amount of energy remains unchanged.

On the other hand, matter can be converted to or generated from energy. Having emerged only relatively recently in the development of science, a universal concept of energy is associated with abstract principles of symmetry and conservation.

At a phenomenological level, the experiments address the following aspects of energy that are worth being further discussed and reinforced in your science teaching.

- Description of the effects of energy:
  Energy is necessary to generate current, light, heat, movement and to lift matter.
- Conversely, energy is found in current, light, heat, moving bodies and lifted matter.
- Fuels (heating oil, gasoline) and food also contain energy.
- Various energy sources or manifestations of energy occur in everyday energy conversion processes.
- Typical forms of energy are: chemical energy, electrical energy, thermal energy (heat), magnetic energy, mechanical energy (potential and kinetic energy), nuclear energy and radiant energy.
- Typical energy sources are: light (radiant energy), oil (chemical energy),
  wind (kinetic energy of air), water (kinetic energy or thermal energy), etc.
- Energy can be transported from one location to another, e.g. oil in a tanker,
  natural gas in a pipeline, petrol in a jerry can, …
- Energy can also be transported without transporting matter; for instance, the sun’s energy comes through empty space to the Earth as radiant energy (light, heat radiation).
- Electrical energy can be used in many ways and transported relatively easily via power lines, also across great distances and with relatively low loss. However, electricity is not identical to energy, although “electricity” and “electrical energy” are often used synonymously in everyday life. Drawing upon mechanical models of energy conversion may clarify the correlations.
- On a related note, in mechanics, force is frequently mixed up with energy.
  A clear delineation between energy and force proves difficult. During the lesson, choosing the correct terminology can be tricky, but you as the teacher should emphasize the correct vocabulary.
- For many people, biological energy is something completely different from physical energy. Some people may resist the idea that the same energy conversion processes that occur in inanimate natural and technical systems also play a role in living organisms. In this respect, it is important to include the energy conversion process in organisms in the discussion.
  In health education, it is also very important to discuss the energy content of foods
  (their caloric value).

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Relevance of the topic of energy

Despite its abstract nature as a physical variable of conservation and balance, energy manifests itself in concrete forms permeating our lives in numerous ways. Energy moves, changes, enables and drives all dynamic processes in the natural and human-made worlds. Economic and societal developments are driven by energy. Development depends on the successful transformation of energy systems. Advancements in technology must balance the sometimes conflicting demands of security of supply, efficiency and sustainability. In light of these multifaceted challenges, educational processes are focusing more and more on the topic of energy.

Energy efficiency

Any use of energy builds upon energy already present. The term “power generation” can be misleading. Instead of talking about power generation, you can use the more neutral wording of “provision of energy”, or you can talk about energy sources.

Chemical energy
Kinetic energy
Potential energy

Energy conversion results in useful energy and a certain portion of energy without further use “no energy conversion without loss”). When an incandescent bulb is operated, electrical energy is converted to light (useful energy). At the same time, the heated filament gives off energy as heat that dissipates unused into the environment. The graphic below uses arrows of different widths to visualize the respective amounts of energy that are transformed during the conversion processes in an incandescent bulb.

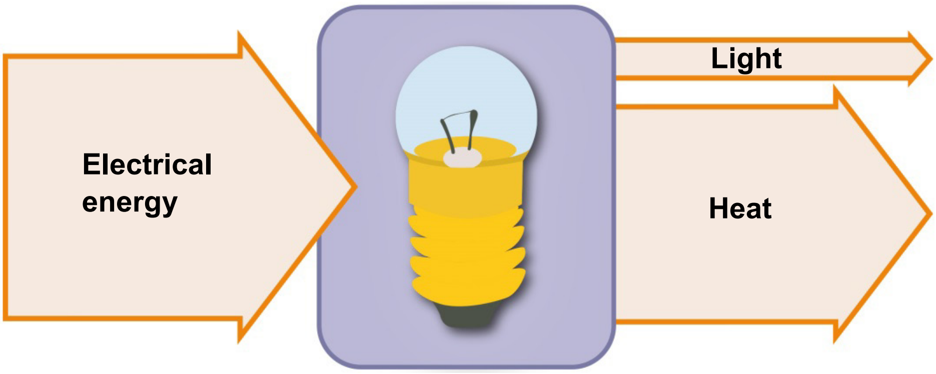

Fig. 4: Energy conversion in an incandescent lamp.

The electrical energy (left arrow, 100%) used is equal to the sum of the useful energy (light, upper right arrow, 10%) and the unused energy losses (heat, lower right arrow, 90%) during the conversion. In other words, in an incandescent bulb, only approximately 10% of the electrical energy is converted to light. In terms of energy efficiency, the incandescent bulb is not very efficient.
In an LED, the percentage of unused energy is much lower compared to the incandescent bulb. An LED is highly energy efficient, but is more expensive to purchase. The term efficiency ratio describes the ratio between the useful output of an energy conversion machine and the input, in energy terms. For example, the efficiency ratio of a gas turbine converting chemical energy to electrical energy is up to 40%. The energy efficiency of a wind turbine converting kinetic energy to electrical energy is up to 59%.

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Energy efficiency should be an important factor when you buy electrical appliances, weighing the price of the appliance relative to the saved energy costs. In many parts of the world, electrical appliances are categorized in classes according to their energy efficiency: A+++ stands for a highly efficient appliance, A++ for a slightly less efficient appliance, B for even less efficiency, and so on with decreasing efficiency from C to G.

Renewable energies

Renewable energies require an energy source to provide replenishment. Renewable energies can be traced back to the sun's energy. This is most obvious with solar heat and photovoltaics where the solar radiation is directly converted to heat or current.

The sun is also the source of energy in biomass (chemical energy). The chemical energy there stems from energy-rich substances that were formed in plants during photosynthesis. Photosynthesis is a process used by plants and other organisms to convert the light energy absorbed from the sun to chemical energy which can later be released to fuel organisms' activities. This chemical energy is stored in carbohydrates, such as sugars, which are synthesized from carbon dioxide and water.

Even hydroelectric and wind power plants are ultimately driven by the sun.

Circuit models and the direction of energy transport

The following two models are suitable for conceptualizing electricity and energy.
The first example, the water model, is frequently used during class. It illustrates the closed circuit by means of a water circuit. A pump drives the water stream. The drive component builds up a pressure difference, which corresponds to the voltage source. The liquid stream drives a turbine (waterwheel), which corresponds to an electrical device in the circuit. The water flows in a circle, but the energy flows only in one direction – from the pump to the turbine. The electric current flows in a closed circuit, and the energy flows only in one direction – from the energy source (e.g., generator, battery) to the electrical device (e.g., motor, lamp).

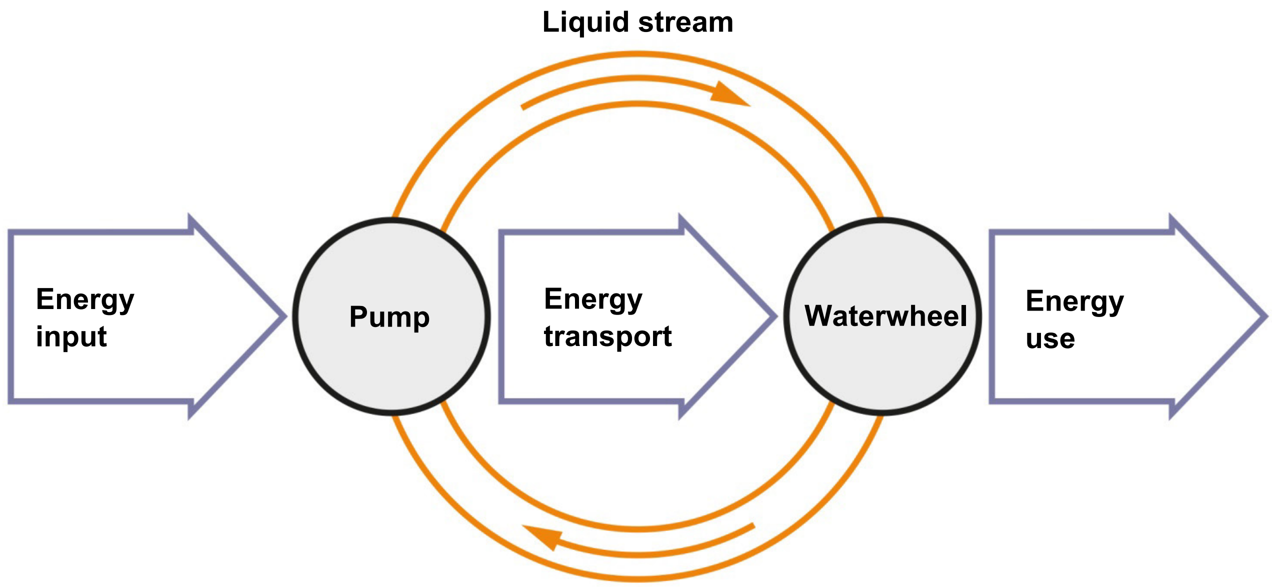

Fig. 5: Water circuit model and the "one-way street" of energy transport

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The second model, the marble track model, is more complex and primarily designed to provide a theoretical background for the teacher. In the model, a lift, representing a drive, transports the marbles upward. A paddle wheel is driven by the marbles and can be used as a motor. The lift corresponds to the electron transport in a battery.

In the model, potential energy can be visualized as the height above the entire circuit. An excess of negative charges exists at the negative battery pole. Energy must be spent to transport an electron from the positive to the negative pole. In the model, this corresponds to the mechanical lifting of a marble from a lower level to a certain height (potential energy). When the marble rolls down, it “loses” potential energy and “gains” kinetic energy (or, in other words, converts potential to kinetic energy). The kinetic energy operates a device.

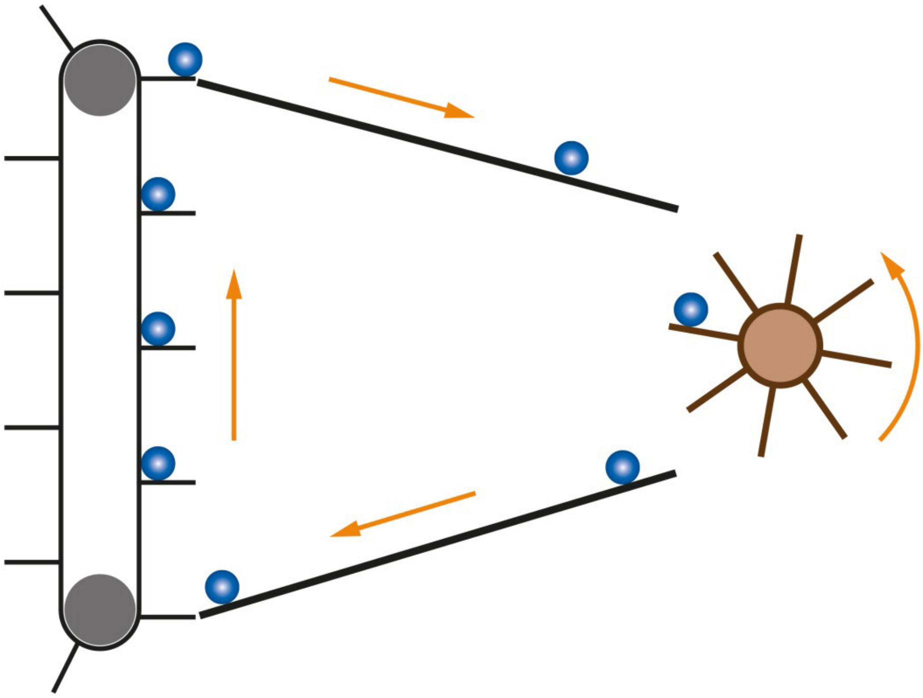

Fig. 6: Marble track model of electric current.

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How to set up an electrolytic cell (Experiment 8.5)

Material required for each cell:

- one cup
- two graphite electrodes
- two pieces of copper cable
- two sections of tubing
- two syringes
- two one-way cocks (see figure)

Figure 7: Parts for the electrolytic cell

Remove the insulation (about 2 cm) from the ends of the supplied copper cables and bend the cables according to the following figure.

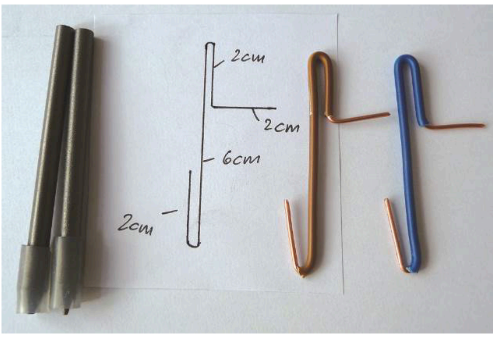

Figure 8: Copper cables bent into shape

Connect each bent copper cable to a graphite electrode using a piece of tubing.

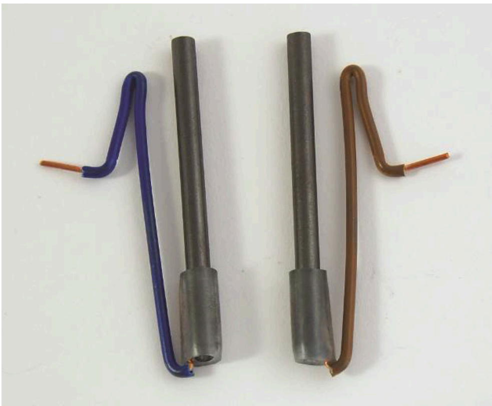

Figure 9: The ends of the copper cables are inserted between the tube and the electrode

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Mount the two electrodes on the rim of the cup.
Now the electrodes are upright in the cup,
and you can place the syringe cylinders over them.

Figure 10: Final assembly of the cell

Remove the plungers from two 10-ml syringes and screw a one-way cock on each syringe.
With the cocks open, place the syringe cylinders on the graphite electrodes.
Pour about 100 ml of saturated soda solution into the electrolytic chamber.
Attach a piece of tubing to a 10-ml syringe. Suction the remaining air from the syringe and close the cock. Repeat this step for the second syringe.

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