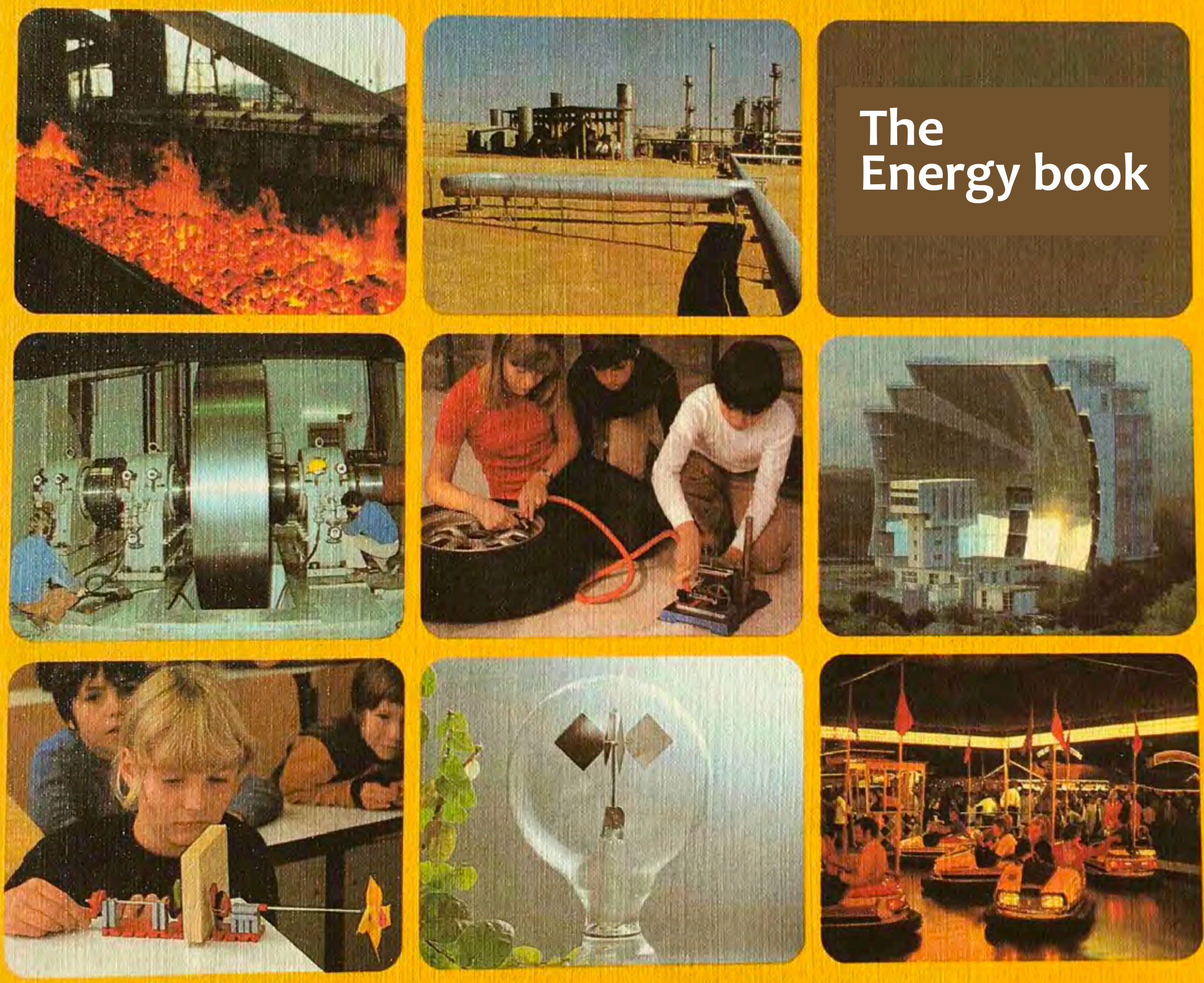
Falk
Herrmann

New Physics

The Energy book



Preface

Maybe you think physics is hard, because a lot of people say so. You have to be mathematically talented, they say, to understand physics. Nor is physics for girls. These are all prejudices. What you really need to understand physics is common sense. Physics is not there to make your life difficult, but to make it easier for you to understand the world.

In physics lessons you will learn that many processes that seem to have nothing to do with each other follow the same rules. For example, it is the same whether cars consume gasoline or whether people and animals eat. And just as humans and animals breathe, a car engine also has to “breathe”, namely suck in air.

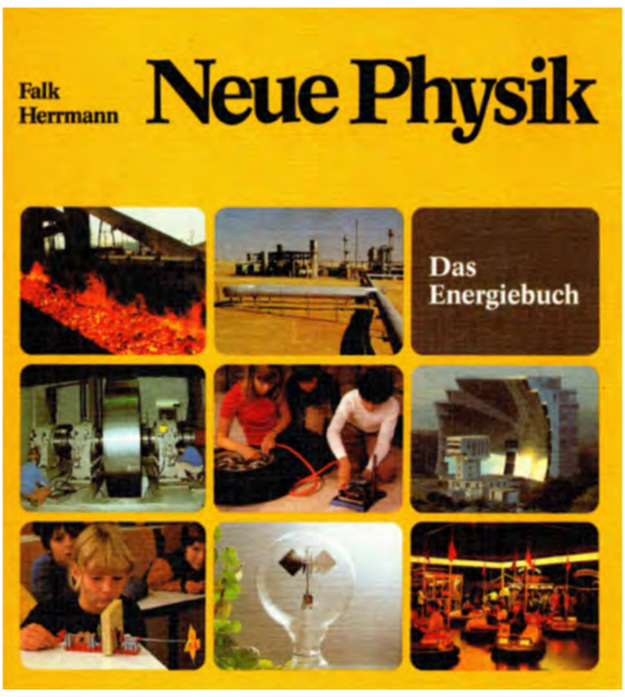
So it often happens in physics that you just have to try to understand one thing and you automatically learn how to understand three others. For example, once you understand how the hydraulic drive of an excavator works, you won’t have much trouble building an electrical circuit.

Everything in the world: Humans, animals, plants, stones, machines are governed by the rules and laws of physics. Those who know physics can answer many interesting questions. Nevertheless, physics doesn’t explain everything – on the contrary, it only answers a very small part of the questions that interest you. Questions that cannot be answered with the help of physical rules are e.g.

“Why is a flower beautiful?”

“Why do people make wars?”

“Why do many people enjoy physics?”



The Energy book

The Energy Book (in German: *Das Energiebuch*) first was published in 1981, 37 years ago.

The pupils on the pictures have long since grown up and have their own children. The adults in the photos are old people now. The equipment and other devices explained and shown in the illustrations are obsolete: Incandescent lamps, fluorescent tubes, oil heaters, night storage heaters and coal cellars, cassette recorders and much more. One can say that technical progress is that fast. Or one could say: This is normal; 37 years have passed.

The amazing thing is that the physics that the book wanted to change has not taken a step forward.

But what progress did we, the authors, expect? Can there be any progress in the laws of physics? Do they not differ from the laws of the human society in that they are eternal?

Yes and no. Nature continues to run according to its own laws – at least that is what we believe. And we gradually discover new ones and little by little we progress in understanding how nature is working, or how the good Lord made the world.

But it’s probably not that simple. What we physicists call laws does not come from the notebook of the Almighty God. It's our own invention. The physical theories are the work of man. They are made by us in such a way that they describe nature as well as possible. But even if they do, they remain the work of men.

Accordingly, they also contain clumsiness, to put it carefully.

The energy book was about eliminating such clumsiness:

The completely superfluous and confusing forms of energy; the whole theatre with the exchange and storage forms; the differential forms dQ and dW, which appear in the disguise of physical quantities – called process quantities. These are all concepts that were born of necessity in the second half of the 19th century. One had introduced a quantity, the energy, which was obviously of the greatest importance but which had a flaw: one did not know any quality for which it was a measure. This state lasted until 1905, when it turned out that energy and mass are the same physical quantity, i.e. that energy is indeed a measure of a property, namely inertia (and gravity).

The Energy book wasn’t a success. It had been written and elaborately produced by the Schroedel publishing house as a textbook for the newly introduced orientation level in North Rhine-Westphalia. It failed because of the admissions committee.

PS: It may come as a surprise that entropy does not appear in the Energy book. In fact, we were already familiar with Job’s ideas at the time. However, we were still of the opinion that entropy could at best be expected in the upper secondary school.

Karlsruhe, July 2018

Friedrich Herrmann

Literature on the basics of the Energy book:

http://www.physikdidaktik.uni-karlsruhe.de/publication/ajp/energy_forms_and_carriers.pdf

http://www.physikdidaktik.uni-karlsruhe.de/publication/forme_di_energia.pdf

THE ENERGY BOOK

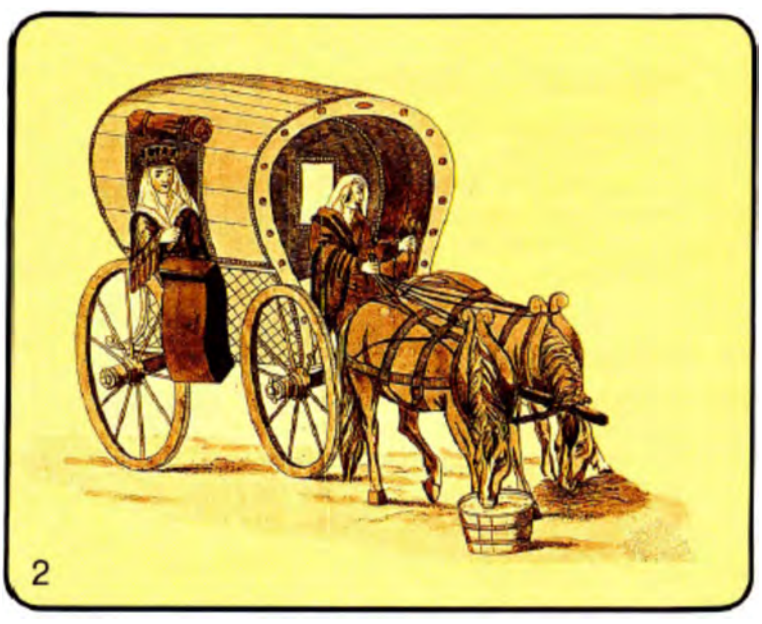
1. Energy and energy carriers

1.1 What gasoline, biscuits, coal and electricity have in common

Flying carpets exist only in fairy tales. It would be nice if they existed in the real world. With a flying carpet one could save a lot of money, since it doesn't need any fuel. In reality when we want to travel we always need a fuel, whatever the kind of traveling.

An airplane is refueled.

If we take the car, we need gasoline. If we take the train, diesel fuel, electricity or coal is needed, depending on the type of the railway locomotive. It we go by airplane a fuel is needed that is called kerosine, Fig. 1. Even when traveling with a horse, by bike o walking we need a fuel: The horse needs oats and hay, Fig. 2; when going by bike or walking we need food and indeed, we need more food as when going by car. Thus, in any case we need a kind of fuel in order to travel. We need gasoline, diesel oil, electricity coal, oats or food.



This is what a gas station used to look like.

If it does not matter how we get to the end of our travel destination, then is does not matter which fuel we are using. All of them have in common that they enable us to make our journey. The reason is that they all contain something: energy. Gasoline, diesel fuel, electricity, coal, oats and food contain energy.

For making a journey we do not need any particular fuel. What we need is the energy that is contained in any of them.

Not only for traveling energy is needed. We need energy for many other purposes, for instance for heating. Just as for traveling we need any fuel, for heating we also need a fuel which in this case is called combustible. A combustible can be heating oil, coal, natural gas, wood or electricity. Here too, we do not need a particular fuel. What we need in any case is what all combustibles have in common: the energy.

Transportation means need energy in order to go. Stoves and radiators need energy in order to heat. There are many other engines and technical devices that need energy in order to run: The motor or the lawn-mover gets energy with gasoline or electricity. A tractor gets energy with diesel fuel, a crane and a light bulb get energy with electricity, a gas cooker and a gas boiler get it with natural gas.

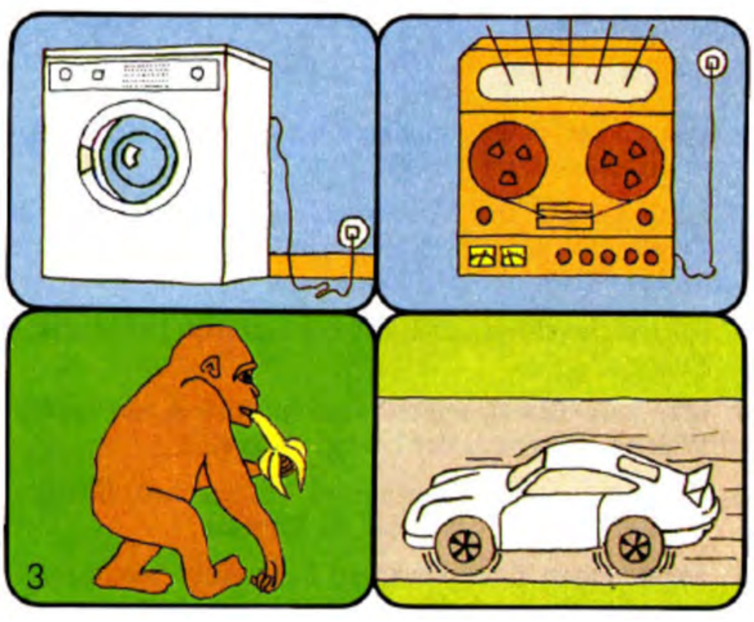
Summary: Many devices and machines, as well as men and animals need energy. They get the energy with fuels, combustibles or food.

Supplements S 1.1 and S 1.2

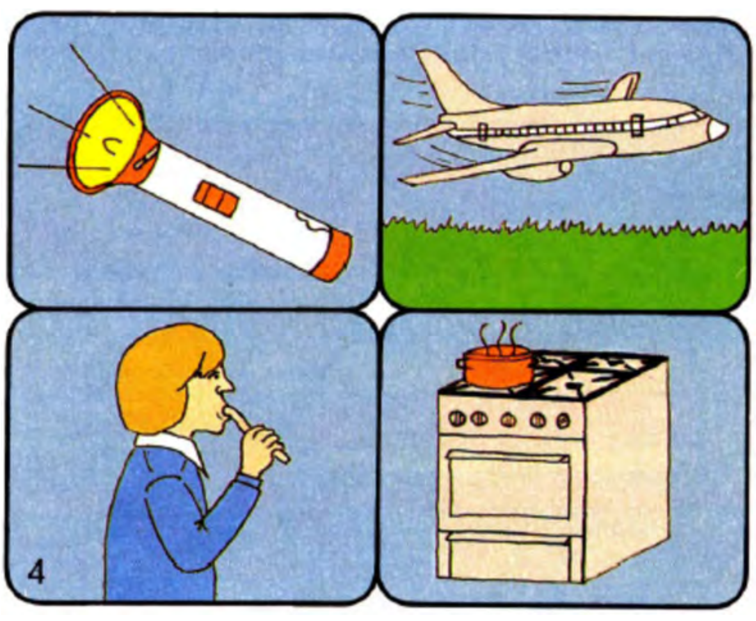
Exercises

1. Which fuel is used in each case?

2. In the small pictures of figures 3 and 4 energy is consumed. What is the corresponding fuel?



Which fuel is used?



Which fuel is used?

3. Specify some other machines or devices and indicate the fuel with which they get their energy.

4. What do fuels, combustibles and food in common?

1.2 No energy without a carrier

Every fuel and combustible contains energy. We call these “substances” *energy carriers*.

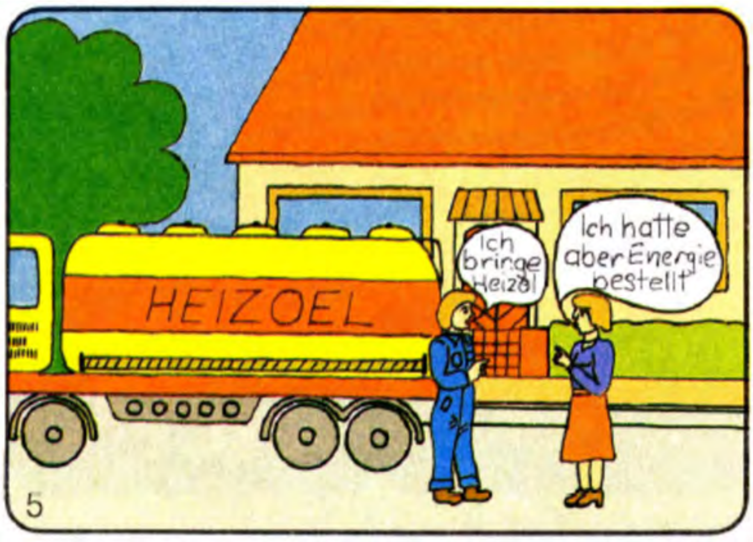
The combustibles coal, heating oil, natural gas and wood are energy carriers. They carry the energy into the furnace or oven.

Electricity is an energy carrier. It carries energy into the electric stove, into the light bulb, into the electric cooker and in all the other electric devices.

The fuels gasoline and diesel oil are energy carriers. They bring the energy into the gasoline engine and into the diesel engine.

Food is an energy carrier. Human beings need energy for living. The greater the physical effort they make, the more energy and thus the more food they need.

If for heating only the energy matters, why then we do not put simply the energy into the stove, without the cumbersome coal (which produces smoke and ashes) or without the electricity (which needs thick cables)? If this were possible it surely would be done. But it is not possible. There is no energy without a carrier, Fig. 5.



I’m bringing heating oil.

But I had ordered energy.

You can imagine the energy as a kind of stuff, that is contained within the fuels and the combustibles, similar to the water that is contained in a sponge. However, we can squeeze out the water from the sponge, so that we get pure water. This is not possible with the energy. There is not energy without a carrier.

Summary: Fuels, combustibles, electricity and food are energy carriers. Energy without a carrier does not exist.

Supplements S 1.3 and S 1.4

Exercises

1. Why do we not use pure energy without a carrier for traveling or for heating?

2. Specify engines or devices which get energy with (a) electricity, (b) diesel fuel, (c) heating oil, (d) coal and (e) uranium.

3. With which energy carriers do you get energy in your home?

4. The lawn can be mowed in various ways. Which is the energy carrier in each case?

5. A sheep “moves” a lawn. With which energy carrier does the sheep get the energy.

6. Machines on a construction site: What is the energy carrier with which they get energy?

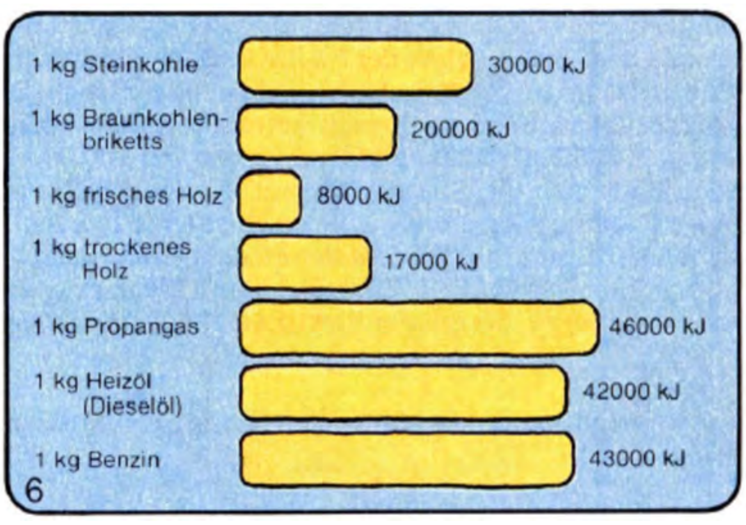
1.3 How to bill energy

When building a house, you have to decide what kind of heating you want. Is it better to heat with domestic fuel oil, or rather with coal or natural gas? The decision will certainly depend on how expensive the heating will be.

Let's assume that 1 kg of fuel oil costs € 0.60, 1 kg of lignite briquettes only € 0.25. Should you heat with briquettes at these prices? The answer to this question is not as easy as you might think. How warm the apartment is depends not simply on the amount of fuel, but on the amount of energy you put in the stove. The amount of energy carried by 1 kg of heating oil, 1 kg of briquettes and other fuels is shown in Fig. 6. 1 kg of hard coal carries, for example, 30,000 kJ.

kJ is the abbreviation for Kilojoule. Joule is the measuring unit of energy, just as meter is the unit of length or gram is the measuring unit of weight. The prefix "kilo" means "times 1000". You know this prefix from kilogram or kilometer. 1 kg = 1000 g and 1 km = 1000 m. Likewise, 1 kJ = 1000 J.

We can see from Fig. 6 e.g. 1 kg of fuel oil contains more than twice as much energy as 1 kg of brown coal briquettes.



6

stone coal
lignite
fresh wood
dry wood
propane gas
fuel oil
gasoline

Fig. 7 shows a similar table where you can see how many kJ are carried by different foods. The numbers refer again to 1 kg of the food. 1 kg lean meat for instance contains 5000 kJ. On average, humans need 10,000 kJ per day.

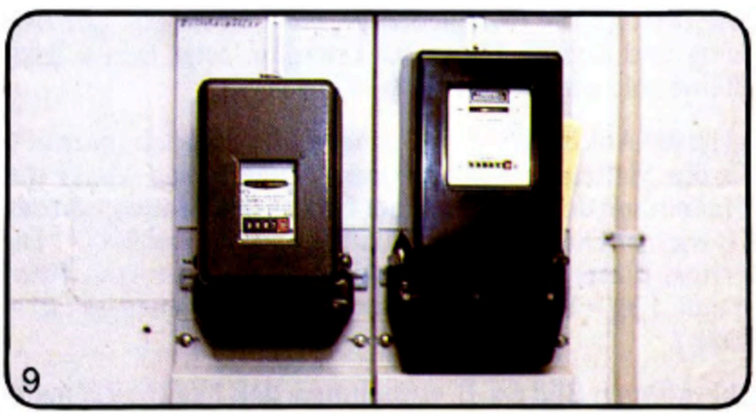
1 kg mageres Fleisch	5000 kJ	lean meat
1 kg fettes Fleisch	16000 kJ	fat meat
1 kg Fisch	3000 kJ	fish
1 kg Speck	32000 kJ	bacon
1 kg Salami	22000 kJ	salami
1 kg Edamer Käse	13000 kJ	Edamer cheese
1 kg Butter	32000 kJ	butter
1 kg Mehl	15000 kJ	flour
1 kg Brot	11000 kJ	bread
1 kg Reis	16000 kJ	rice
1 kg Nudeln	16000 kJ	noodles
1 kg Kartoffeln	4000 kJ	potatoes
1 kg Kopfsalat	500 kJ	lettuce
1 kg grüne Erbsen	3000 kJ	green peas
1 kg Hühnerei	6000 kJ	eggs
1 kg Zucker	16000 kJ	sugar
1 kg Schokolade	24000 kJ	chocolate
1 kg Nüsse	28000 kJ	nuts
1 kg Äpfel	2500 kJ	apples
1 kg Wasser	0 kJ	water
1 kg Apfelsaft	2000 kJ	apple juice
1 kg Bier	2000 kJ	beer
1 kg Schnaps	10000 kJ	liquor

7

When buying food, the amount of energy they contain is often printed on the pack. 100 g of the crispbread in the box, which is shown in Fig. 8, contains 1640 kJ.

8

Neither in the table of Fig. 6 nor in that of Fig. 7 do you find the energy content of electricity, which is also an energy carrier. It is not there, because you can not measure the electricity in kg. You can not say: "1 kg of electricity contains so manyv kJ". Nevertheless, you can measure the energy that comes into your house with electricity, which is done with the so-called "electricity meter", Fig. 9, which you know for sure. It should actually be called energy meter, because it measures the energy that comes into the apartment with electricity.


9

Summary: The unit of measurement for the energy is the joule.

Supplements S 1.5 to S 1.7

Exercises

1. Which of the fuels in Fig. 6 contains a) most, b) the least energy?

2.What does the prefix "kilo" mean?

3. At home, check on which foods there is an indication of how much energy they contain. Compare this information with the values in Fig. 7.

4. Which foods contain much energy, which ones contain few?

5. Why is it that fruits and vegetables contain so little energy?

6. You need about 10,000 kJ every day to live. How many bars of chocolate (100 g) contain this amount of energy?

1.4 People and cars need more than just energy

A car needs gasoline because it gets its energy this way. But it also needs oil and tires and water for the windscreen washer. None of that gives the car energy.

What applies to the car, also applies to humans. The food a person eats serves only as part of the person's energy supply. Only the so-called carbohydrates and fats contained in food are the carriers of energy Fig. 8, that is, the fuel of man. The proteins are needed to rebuild used cells of the human body (much like a car needs new tires when the old ones are worn out). The vitamins containing the food are needed to control the processes inside the body. They are necessary "so that everything goes well" (one can compare it with the lubricating oil, which needs the car engine).

Summary: Not everything that consumes a machine or a living being, serves the energy supply.

Supplement S 1.8

Exercises

1. What does a car consume except gasoline?

2. Energy is needed on a construction site. With which energy carriers does the energy come to the construction site? What is needed on a construction site other than energy and its carriers?

3. Why does humans need carbohydrates and fats, why proteins and why vitamins?

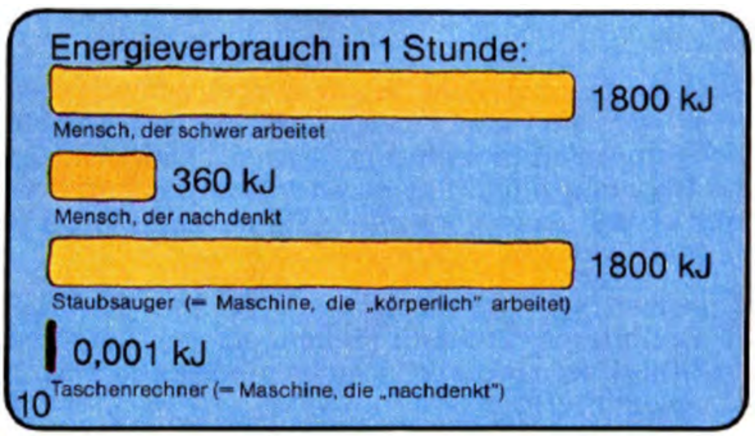
1.5 For what you need a lot and for what you need little energy

For which activities much energy is needed, for which little? Of course, that depends on how long the activity lasts.

Heating a room for 2 months requires twice as much fuel and twice as much energy as heating it for just one month.

To compare the energy consumption of two machines or living things, we look at how much energy both consume in the same time. Fig. 10 shows the energy consumption in one hour for

- a person who works hard physically
- a person who thinks
- a vacuum cleaner (i.e. a household appliance that works “physically”)
- a calculator (i.e., a machine that “thinks”).



energy consumption in 1 hour

a person who works hard

a person who thinks

vacuum cleaner (machine that works physically)

pocket calculator (machine that thinks)

You see what you need a lot and what you need little energy for. Both machines and people need a lot of energy in “physical exertion” and little in “thinking”.

Summary: A lot of energy is needed to do a physically demanding job.

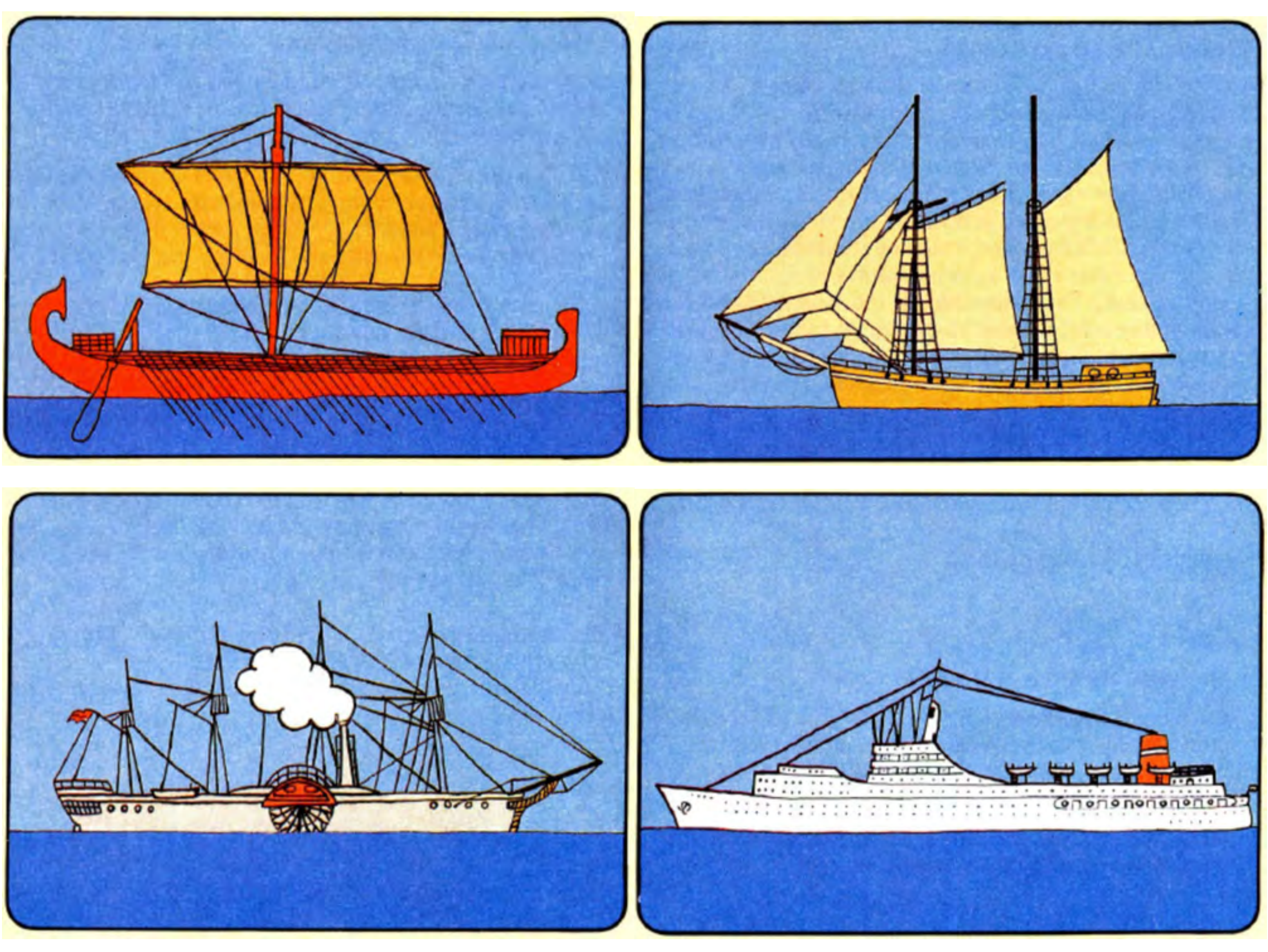
For reflection and calculation little energy is needed.

Exercises:

1. Name activities where a) a lot of energy, b) few energy is needed.
2. Name devices that consume a) a lot, b) little energy.

S 1.1 The different fuels of ships

What fuel do the ships get their energy from?



S 1.2 Heating oil = diesel oil

Diesel oil and heating oil are different names of the same substance. However, if one buys this substance under the name diesel oil at the filling station, one pays considerably more than if one buys it under the name fuel oil at the fuel dealer. The price difference is a tax that is partly spent on road construction.

To prevent people from refueling their cars with heating oil, a dye is added to the substance sold for heating. A fuel check can then easily determine whether someone has paid the fuel tax or not.

S 1.3 Not only energy has a carrier

There's nothing unusual about something needing a carrier.

All means of transport, i.e. bicycles, cars, trains, ships and airplanes could be called people carriers. In contrast to energy, however, people can also move without a means of transport, i.e. without a carrier.

Buckets, pipes, riverbeds and tankers are different "water carriers".

A bill, a coin, a cheque, a piece of gold, a stamp are different "value carriers".

S 1.4 Invisible things

You can't see energy. Maybe you'll think, "What you can't see doesn't exist." But you have often dealt with invisible things in your life.

Air is not visible, i.e. you don't "feel" it with your eyes, but you feel it differently, e.g. when breathing or you feel it as wind.

When you dissolve a piece of sugar in water, the sugar becomes invisible. But you certainly don't doubt that the sugar is still there. You can tell that it is still there because the water tastes sweet.

The energy is similar. You can't see it, but you can recognize it by its effects. Energy can be used, for example, to heat the home or drive a vehicle.

You will learn many other invisible things during physics classes, such as electricity, atoms and X-rays.

S 1.5 kcal; kJ?

One often hears that something edible contains a lot of calories (usually it is something you especially like to eat). What does that mean? The calorie is an outdated unit of energy. It was replaced by the new unit Joule.

Probably you know that there are different units of measurement for many things. The length used to be measured in foot, today we have the meter as a unit.

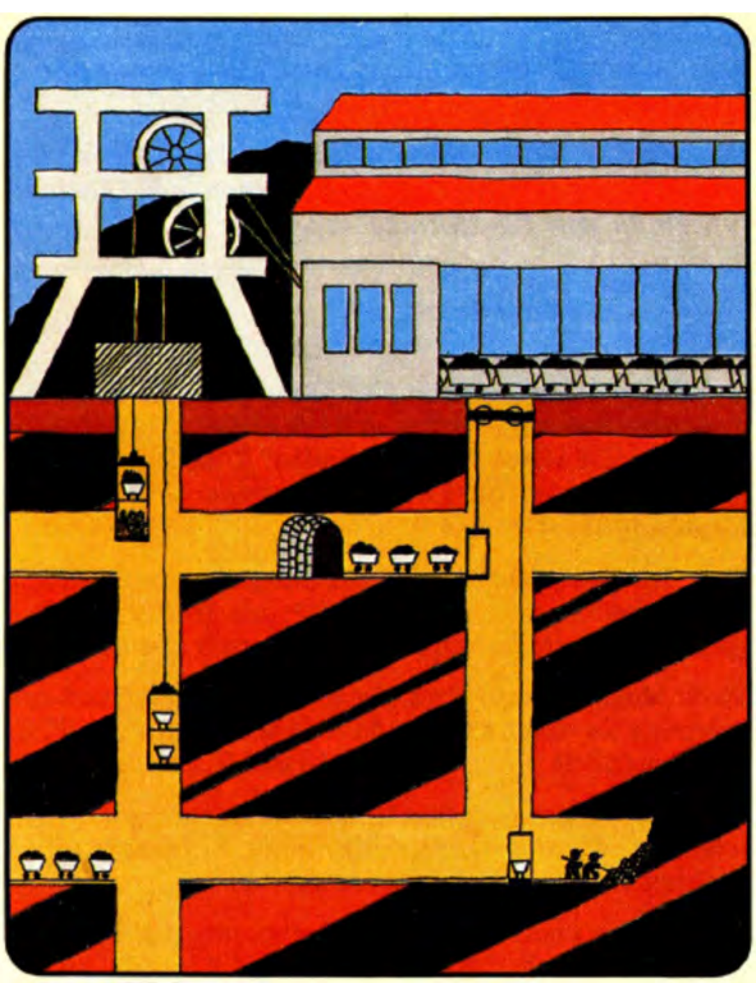
Many units also vary from country to country. In America, "feet" are still used today as a unit of length. One foot is the same as 0.305 meters.

Joule is, just like meters and kilograms, one of the internationally recognized units. All countries will switch to these units.

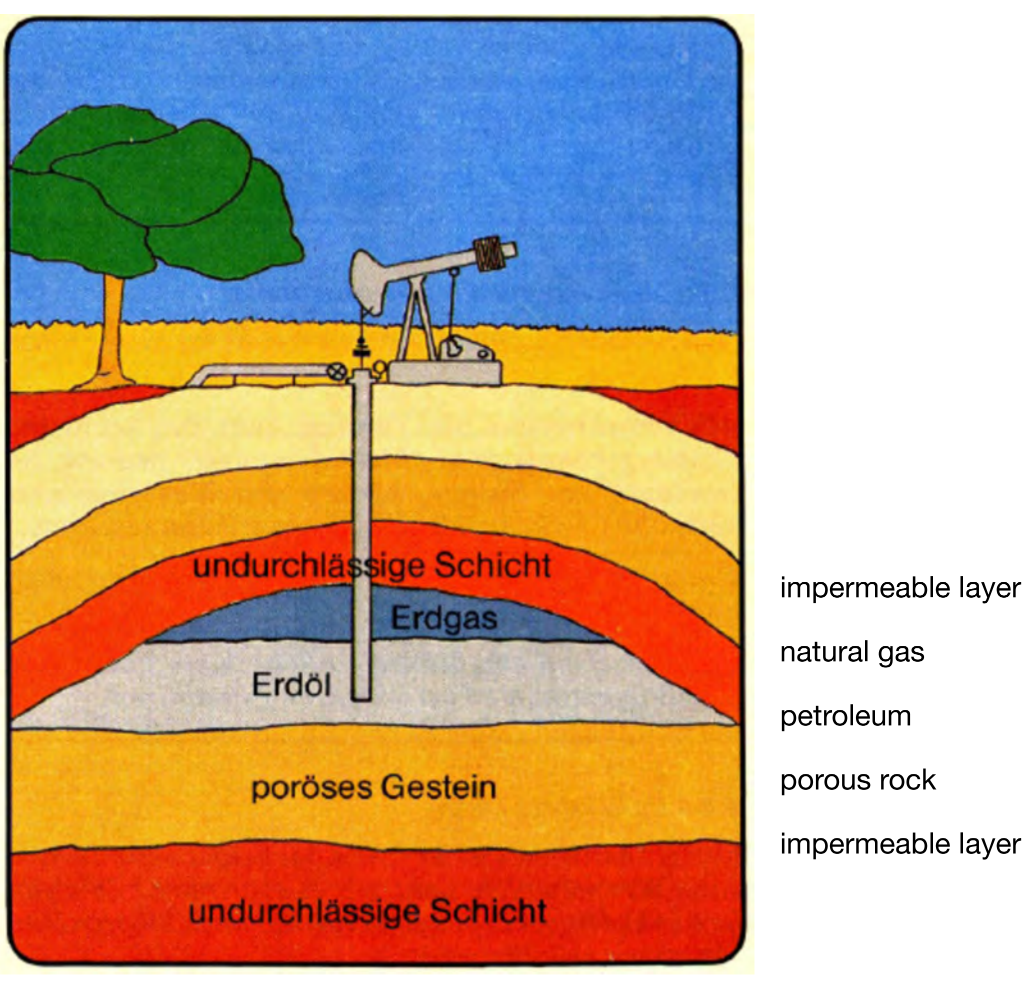
If you need to convert an old energy value into joules: 1 calorie (1 cal) = 4.2 joules.

S 1.6 Where do coal, oil and natural gas come from?

Coal is in the ground. It originated from trees that grew about 300 million years ago and were gradually covered by the earth. It is mined in mines (see picture).



Sometimes the coal is so high on the earth's surface that it can be mined in opencast mines.

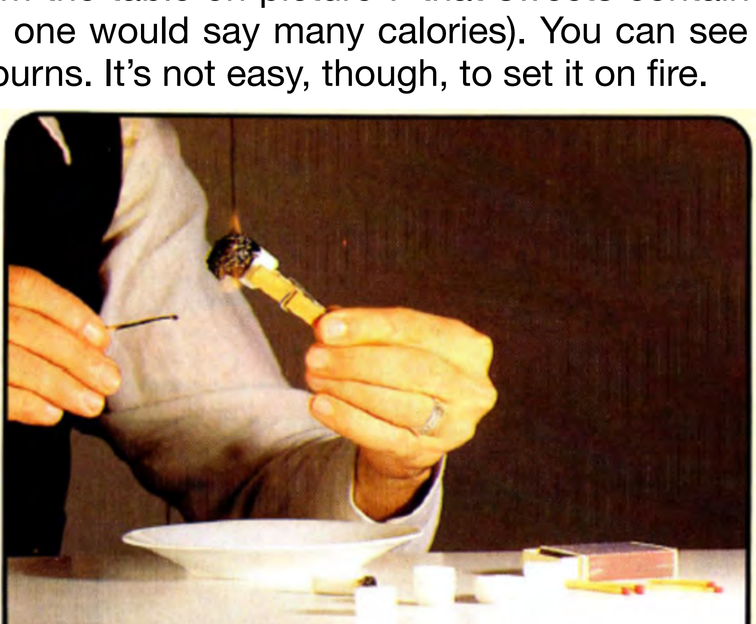


Crude oil and natural gas probably originated from small creatures. To extract crude oil and natural gas, holes are drilled in the earth. Through these, the oil or gas often comes up on its own.

Crude oil is a mixture of different fuels: gasoline, kerosene, heating oil (= diesel oil) and others. These substances are separated in the refinery.

S 1.7 Sugar is flammable

You can see from the table on picture 7 that sweets contain many kilojoules (in former times one would say many calories). You can see this also by the fact that sugar burns. It's not easy, though, to set it on fire.



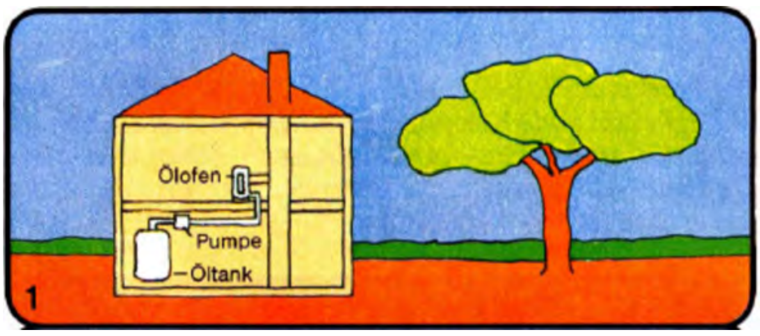
Take a lump of sugar and hold a burning match to it. The sugar won't burn. But if you now dab the piece of sugar with very little cigarette ash and then hold it in the match flame, it starts to burn. What burns is not the ashes, but the sugar. The ashes do not diminish during firing.

You can see that sugar could be used as fuel. If it were cheaper, maybe one would do it. In Brazil there are cars that use sugar as fuel – but by a detour. The sugar is first converted into alcohol (it is said that it is "fermented into alcohol"). The energy that used to be in the sugar is now in the alcohol. You can get the alcohol just like gasoline or diesel oil at the gas station.

2. Energy sources and energy receivers

2.1 Where does the energy come from, where does it go?

Fig. 1 shows an oil stove and the the system that is needed for its energy supply. The stove is in the living room, the oil tank is in the basement. The heating oil is pumped through a pipe from the tank to the stove. It carries energy from the tank to the stove. The oil tank is called the *energy source* and the stove is the *energy receiver*.

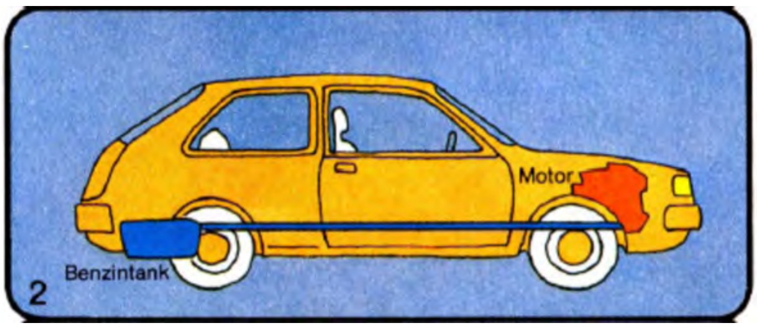


oil stove

pump

oil tank

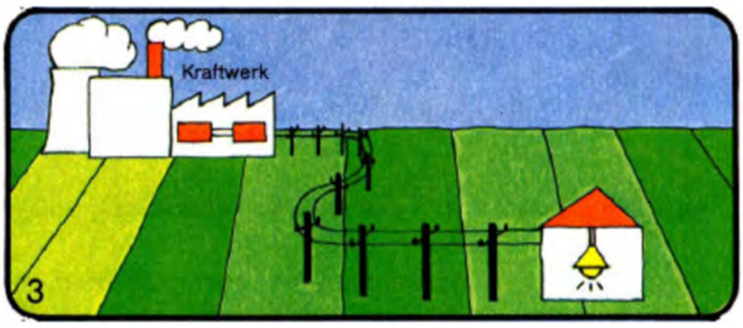
Fig. 2 shows the engine of a car with its energy supply system. In most cars the engine is in the front part, whereas the gasoline tank is in the back. The gasoline is pumped through a pipe from the tank to the engine. It carries the energy from the tank to the engine. The tank is the energy source, the engine it the energy receiver.



engine

gasoline tank

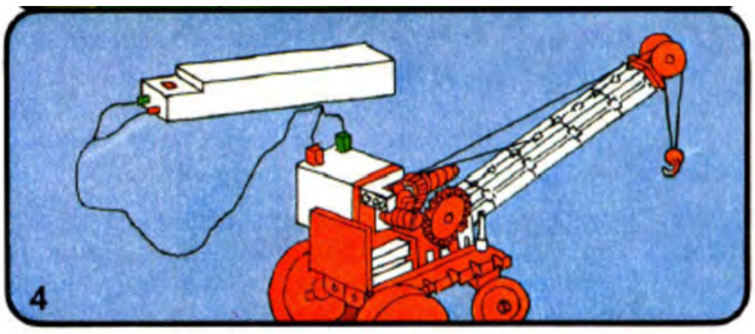
Fig. 3 shows a light bulb with its energy supply system. The energy comes from the power plant with the carrier electricity. The power plant is the energy source, the light bulb is the energy receiver.



power plant

In Figure 4, the batteries in the white box are the energy source, the motor or the toy crane is the energy receiver.

Whenever energy is flowing somewhere (together with its energy carrier), you can specify an energy source and an energy receiver. If you go back on the way of the energy carrier you finally come to the energy source. If you follow the energy carrier in its forward direction you eventually arrive at the energy receiver.

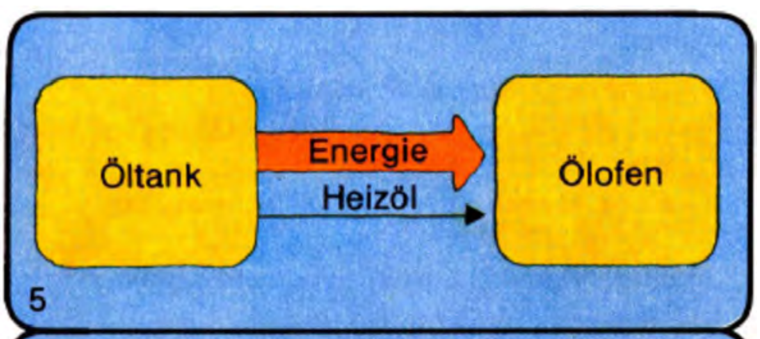


Summary: Specify some energy carriers and indicate to each of them a suitable energy source and energy receiver.

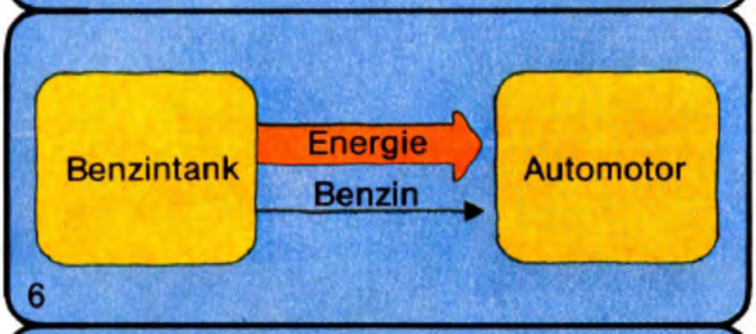
2.2. Energy flow diagrams

The figures 1 to 4 have something in common, although at first glance they seem rather different: In each figure energy is flowing from a source to a receiver and in each figure also an energy carrier is flowing from a source to a receiver. If we are not interested in the details, if we want to single out the similarity of the processes, it is better to draw the pictures in another way: We shall use symbols.

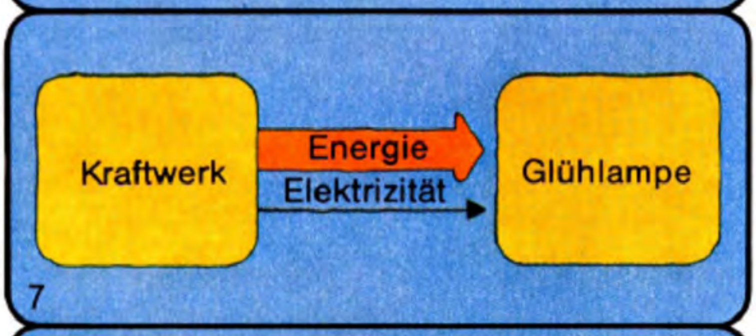
The figures 5 to 8 show the result. Both energy source and energy receiver are represented by a box, into which the name of the source or the receiver is written. The boxes are connected by a thick arrow for the energy and by a thin arrow for the energy carrier.



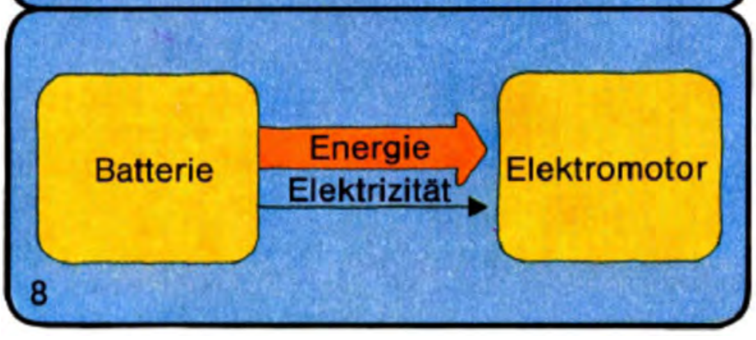
heating oil tank
energy
heating oil
oil stove



gasoline tank
energy
gasoline
car engine



power plant
energy
electricity
bulb



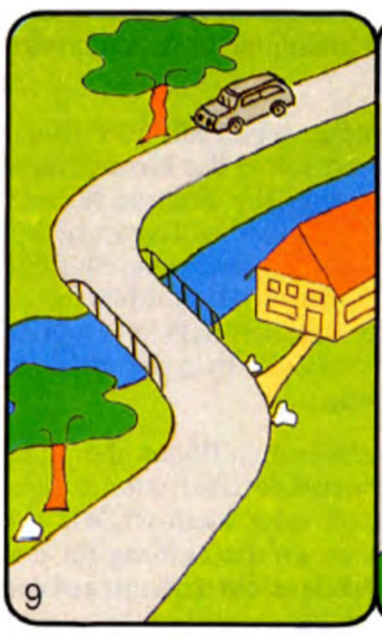
battery
energy
electricity
electric motor

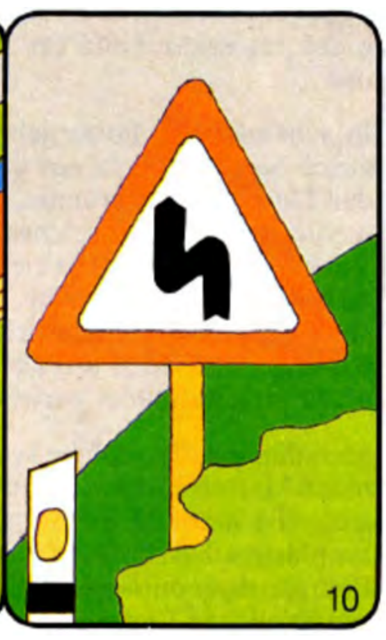
These symbolic pictures are called *energy flow diagrams*. Figure 5 shows the energy flow diagram of the oil heating system, figure 6 shows the energy flow diagram of the tank and engine system of a car, etc.

In this schematic form all the four processes look similar. It is easily seen where the energy comes from, where it goes and what is its carrier. This is often an advantage. Moreover, it is easier to draw such a symbolic picture than the picture of the real objects. It is easier to draw figure 5 than figure 1, or figure 6 than figure 2. In this book we will often use energy flow diagrams.

Sometimes however, these pictures do not help. We do not learn from them how the energy source and the energy receiver looks like, we do not learn if it is big or small and do not learn which way the energy carrier takes. All that can only be seen on the normal figures 1 to 4.

It is a quite normal thing to represent a complicated matter symbolically. Figure 10 shows symbolically the street of figure 9. Why do we not show a photo of the real road on the triangular traffic sign?





In order to solve the exercises in this book you often have to draw energy flow diagrams. When doing so do always respect the rules. Then there will be no misunderstandings when looking at your drawing. That means: The carrier arrow must be under the energy arrow. The energy arrow is thick, the carrier arrow is thin.

Summary: An energy flow diagram shows where the energy is coming from, where it is going to and which is its carrier.

Supplements S 2.1, S 2.2 and S.2.3

Exercises

1. Draw the energy flow diagrams for:

a) a camping cooker, that is connected to a gas bottle;
b) a person that gets its food from a supermarket;
c) a coal stove, whose coal is coming from the basement;
d) the engine of a truck that runs on diesel oil.

2. What is the advantage of a symbol compared with a natural picture of an object? What is the disadvantage?

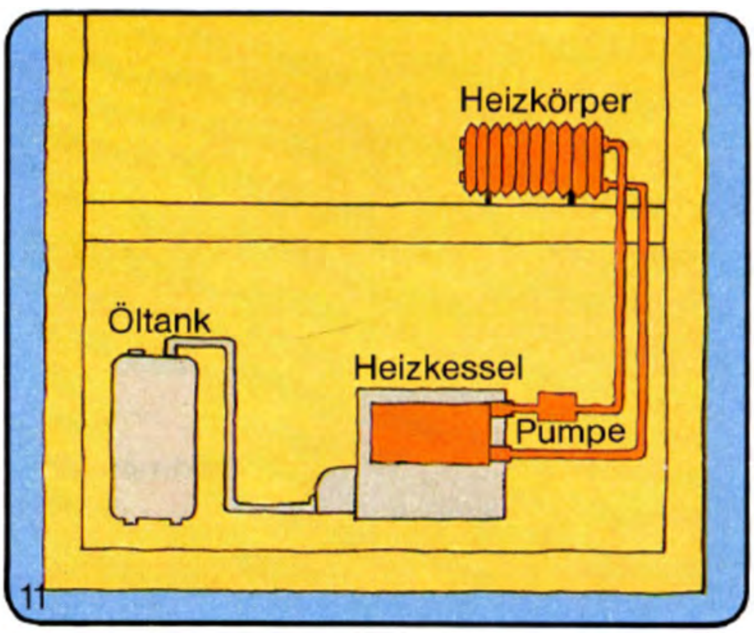
3. Give examples of the use of symbols in other subject matters.

2.3 Central heating, district heating, forced-air heating

In a household there are many appliances that need energy, such as heating, washing machine, lamps, TV. The device that needs the most energy is the heater. We now want to see how the different heaters work.

In the past, most houses had an oven with a wood or coal fire in each room. Later, these ovens were replaced by oil stoves. Instead of using the coal bucket, you carried the energy with the fuel oil to the stove. A slightly more modern oil heating shows Fig. 1. Here you no longer need to carry the fuel oil.

Today, most houses have central heating, Fig. 11. The heating fuel in Fig. 11 is fuel oil. But you can operate a central heating just as well with coal, wood or natural gas.



radiator

oil tank

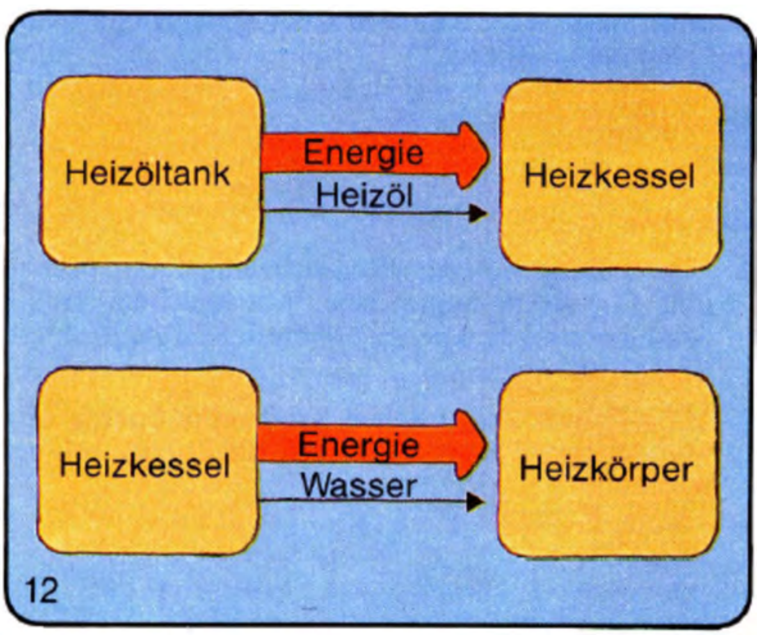
boiler

pump

In central heating, the fuel is burned in the boiler, which is in the basement. In the boiler, water is heated. This can be expressed as follows: In the boiler energy is transferred from the fuel to the water. The hot, energy-laden water is pumped through pipes into the rooms of the house. In each room it flows through the radiators. In the radiator, it releases its energy to the air of the room. The air gets warmer, the water gets colder. The cooled water then flows through a second pipe back to the boiler and is charged here again with energy.

The carrier of energy between the boiler and the room is the warm water.

For the central heating system of Fig. 11 we can draw two flow diagrams, one for the energy flow from the tank to the boiler, Fig. 12 above, and one for the energy flow from the boiler to the radiators, Fig. 12 below.



oil tank

energy
heating oil

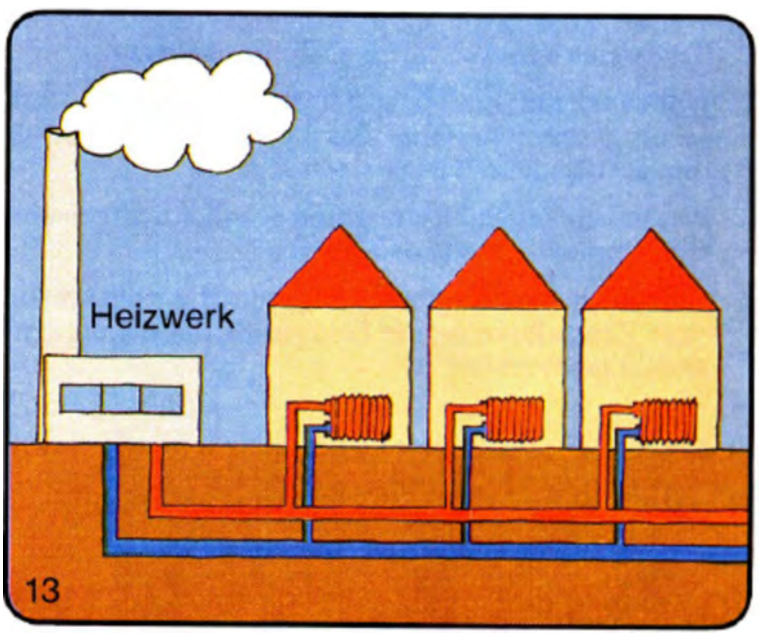
boiler

boiler

energy
water

radiator

A special type of central heating is district heating. A very large boiler in the heating plant supplies many houses at the same time, sometimes even a whole district, Fig. 13. From the heating plant to the houses run pairs of water pipes. Through them the hot water flows from the heating plant to the houses, and the cooled water flows back to the heating plant.



heating plant

For central heating and district heating, the water carries the energy from the boiler in the rooms. There are also houses where warm air is used as an energy carrier. The heating system of a car works this way. The engine, which gets hot anyway, heats air. The warm air is passed through hoses into the passenger compartment.

Summary: Hot water and hot air carry energy.

Exercises

1. Describe the structure of a central heating.

2. How can one recognize in the radiator of a central heating, through which of the two tubes flows the energy-laden water?

3. What do central heating and district heating have in common, what is their difference?

4. With which energy carrier do central heating radiators release the energy that they get with the water?

2.4 From where the energy source gets its energy, and what the energy receiver makes with the energy

Energy comes from a source. But how did it get into the source? We have seen it when considering the central heating system.

The boiler is the source for the energy that is carried by the water, Fig. 12, lower part. However, it is simultaneously a receiver for the energy that is carried by the heating oil, Fig. 12, upper part. Little by little you will see, that each energy source gets its energy from somewhere else. That means: every energy source is also an energy receiver. And every energy receiver is also an energy source.

An energy source is in this respect similar to a water source: The water which comes from the water works (our water supply) has come from somewhere else to the water works.

Supplement S 2.4

Exercises

1. Specify some devices that are simultaneously energy sources and energy receivers. With which carrier do they receive the energy? With which carrier do they give it away?

2. What is the carrier of the energy given away by a power plant? Which can be the carriers of the energy it receives?

Supplements to chapter 2

S 2.1 A game

The 2nd and 3rd columns of a list of energy sources, energy carriers and energy receivers have got mixed up. Fix it! If you have succeeded, the letters in parentheses form three words.

Energy source	Energy carrier	Energy receiver
Power plant (S)	Natural gas (A)	Car engine (E)
Battery (R)	Diesel fuel (R)	Excavator engine (E)
Natural gas storage (C)	Fuel oil (E)	Cooker (R)
Gasoline tank (R)	Food (E)	Immersion heater (U)
Diesel tank (R)	Gasoline (I)	Person (I)
Fridge (C)	Electricity (O)	Oilstove (R)
Oil tank (V)	Electricity (C)	Small lamp (E)

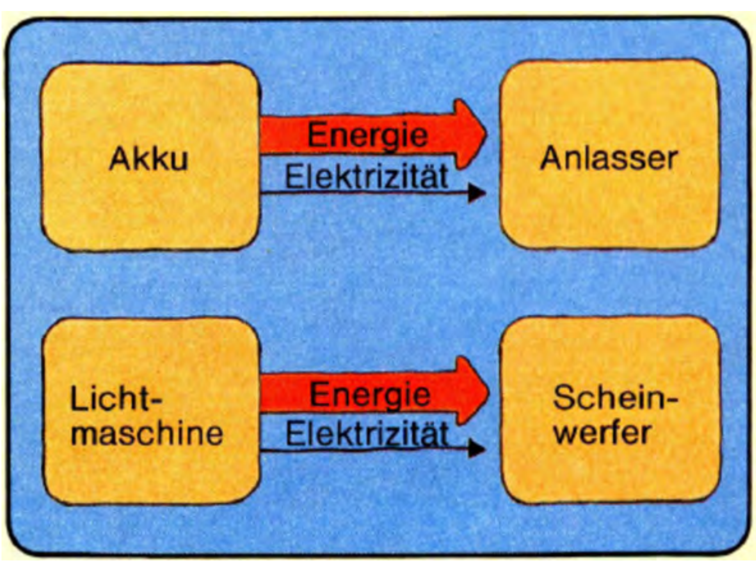
S 2.2 Energy sources and receivers within the car

Fig. 2 in section 2.1 shows a "source-receiver pair" in the car. This is certainly the most important pair of this kind in the car. But there are others. Here are two more:

The car engine doesn't start running by itself when you turn on the fuel supply. The engine must be started. In the old days, it was done with a crank.

Today the petrol engine is started by a small electric motor, the starter. When you turn the ignition key, you also switch on the starter. The starter needs energy, of course. It gets the energy via a cable from the battery in the car.

The headlights of the car need energy. They're getting them from the car's alternator. The alternator is the same thing which is called dynamo on a bicycle.

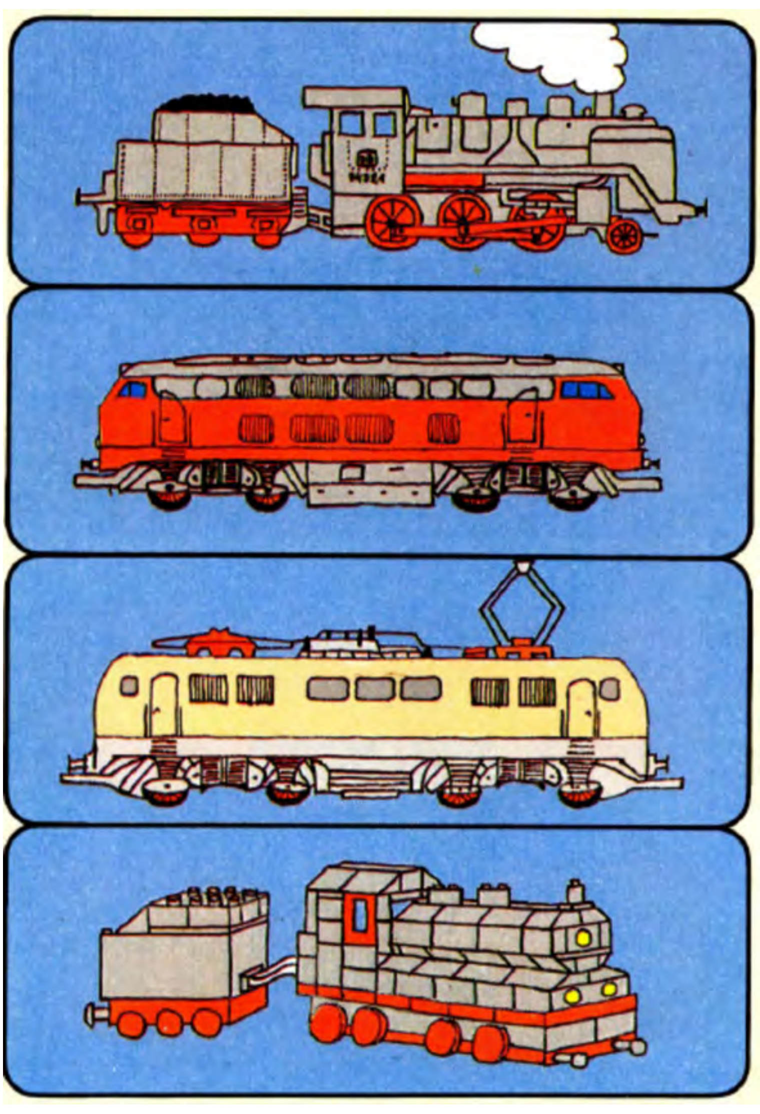


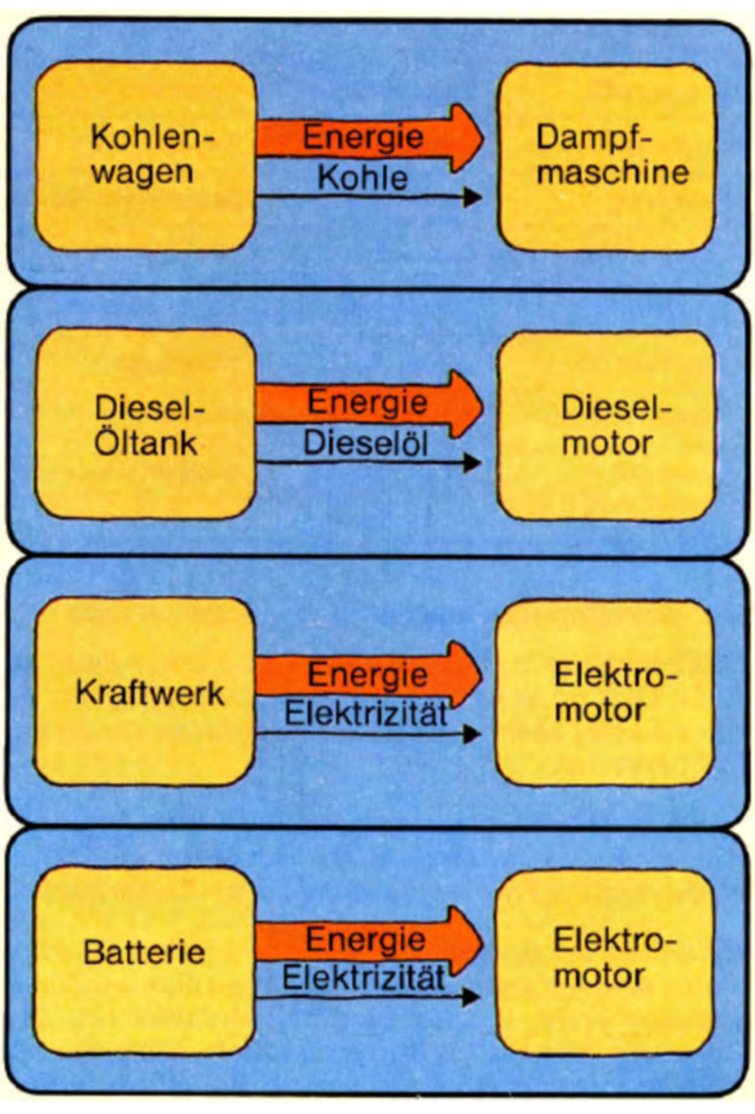
battery
energy
electricity
starter

alternator
energy
electricity
headlight

S 2.3 Various locomotives

The pictures show four different locomotives. The flow diagrams next to it show where the engines of the locomotives get their energy from and with which carrier. Three of the locomotives always have their energy source with them, one draws its energy from a source that does not move with it.





coal lorry
energy
coal
steam engine

diesel tank
energy
diesel oil
diesel engine

power plant
energy
electricity
electric motor

battery
energy
electricity
electric motor

S 2.4 Power plants

From the socket we get energy with the carrier electricity. But how does the energy get into the socket? Where does it come from? The socket is connected by cable to a power plant. Electricity is loaded with energy in the power plant. But even the power plant has to get its energy from somewhere.

The power plant has a different name depending on the carrier with which it receives the energy. Most power plants are coal-fired. They get their energy with the carrier coal. In the picture you see the coal with which the energy arrives.

A nuclear power plant gets its energy with uranium. Uranium is a very rare metal. Like coal, it is extracted from the ground in mines.

A hydroelectric power plant gets its energy from the water of a river. Moving water is also an energy carrier. A wind power plant gets its energy from the wind, i.e. with moving air.

A solar power plant receives it with the light. So light is also an energy carrier.

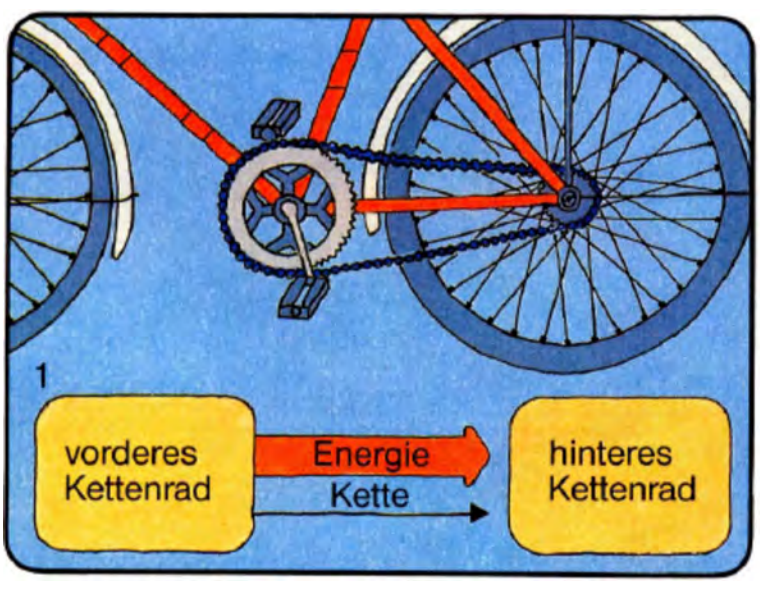
All power plants have one machine in common, the generator. The generator is the same as a bicycle dynamo, only it is much bigger. It is the machine that charges the electricity with energy.

Depending on the type of power plant, the generator is driven by another machine: In coal and nuclear power plants by a steam turbine, in hydroelectric power plants by a water turbine and in wind power plants by a wind turbine. You will learn more about all these machines in this book.

3. The energy carriers drive belt, hydraulic oil and compressed air

3.1 Chains and drive belts

Energy is needed for cycling. The cyclist supplies the energy via pedals and cranks to the front sprocket. But the energy is needed at the rear wheel. It is transferred from the front to the rear sprocket with the chain, Fig. 1, above. The chain is the energy carrier here. Fig. 1, below, shows the corresponding flow diagram.



front sprocket

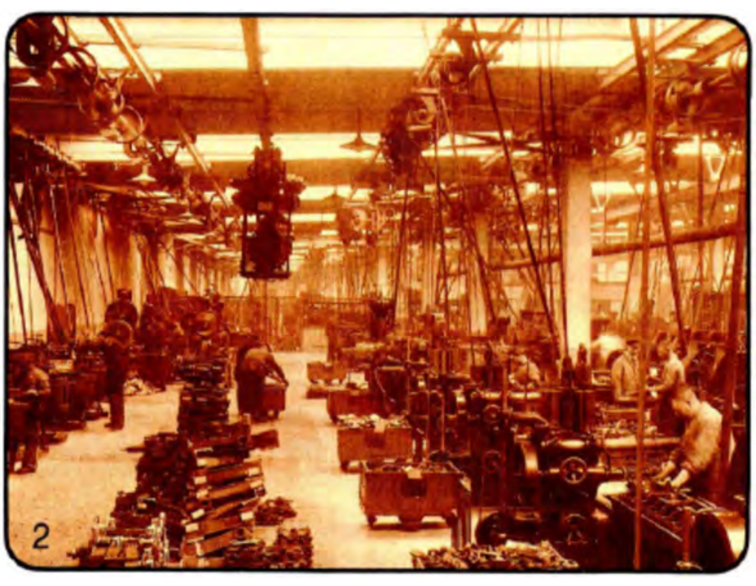
energy chain

rear sprocket

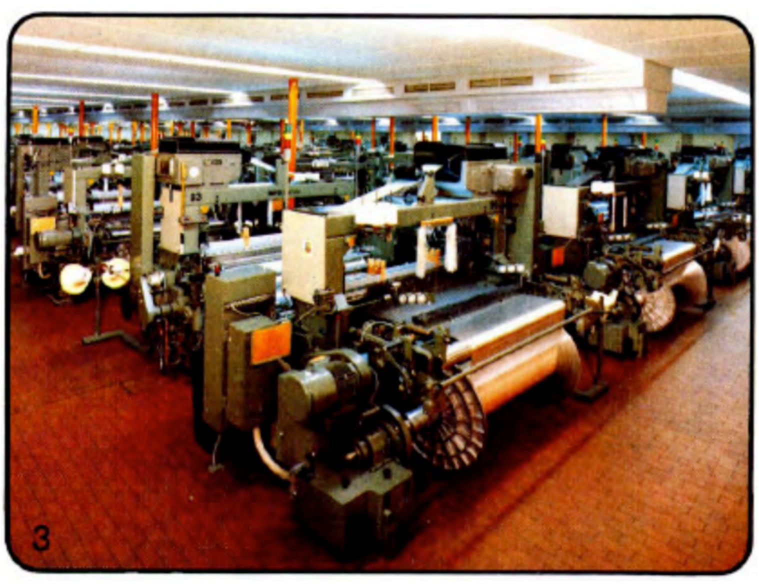
Energy transmission through a bicycle chain

The drive belt works much like the bicycle chain. If you want to drive a circular saw with a steam engine, you can use a drive belt. This is a belt that is wrapped around the wheel of the steam engine and the drive wheel of the circular saw. If the shaft of the steam engine rotates, then the wheel of the saw also rotates.

In the past, when electricity could not be used as an energy carrier, drive belts were often used to transport energy over long distances. Fig. 2 shows an old machine factory; the energy for the individual machines came with drive belts from a steam engine. From the tangle of belts you can see how impractical this type of energy transfer is. In a modern factory, Figure 3, the machines get their energy with the carrier electricity.



Old factory



Modern factory

In Fig. 4, a drive belt carries the energy from the diesel engine, right, to the threshing machine, left.

Nowadays it is easier for the farmers. The grain is mowed and threshed by one and the same machine. Fig. 5 shows such a combine harvester.

The combine harvester drives across the field and cuts off the corn with its mower. The corn is automatically transported into the machine and threshed there, i.e. the grains are knocked out of the ears. The empty straw comes out the back of the machine. The grain is collected in a large container on top of the machine and emptied now and then. The combine harvester also uses power transmission belts to transfer energy from the engine to the various parts of the machine.

Summary: Transmission belts and chains are energy carriers.

Supplements S 3.1 and S 3.2

Exercises

1. Give examples of the use of transmission belts for energy transmission.

2. What disadvantage does the energy carrier transmission belt have over the energy carrier electricity?

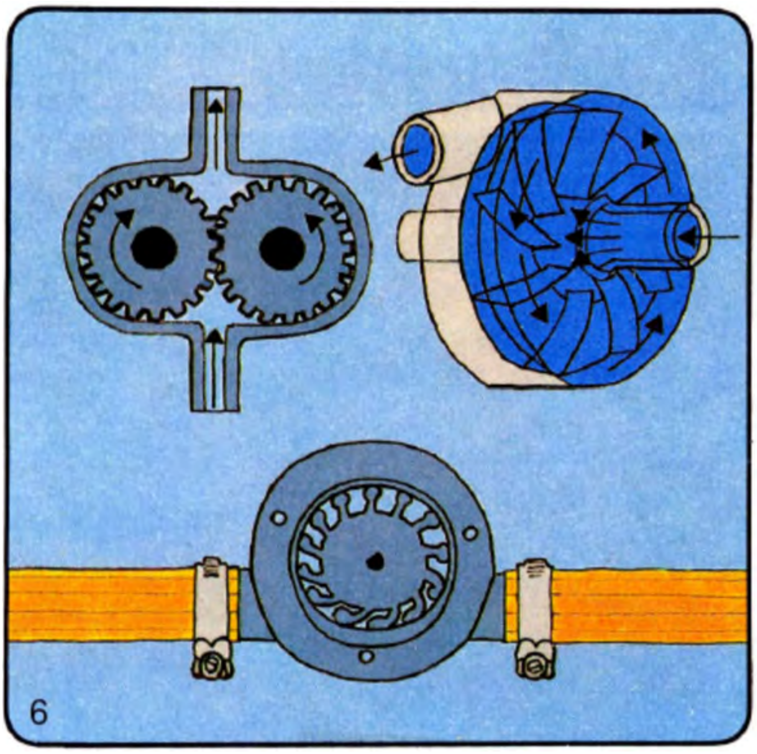
3.2 Water pumps, hydraulic pumps, gasoline pumps

Pumps are used for a wide variety of tasks. The central heating system includes a pump which pumps the warm water from the boiler to the radiators and another one for pumping fuel oil into the boiler, see Fig. 11, section 2.3.

In the car there is a gasoline pump. It pumps the gasoline from the gasoline tank to the engine. The oil pump of the car pushes the lubricating oil to the bearings to be lubricated. There is also the cooling water pump, which ensures that the cooling water flows from the engine to the radiator and back again. Finally, there is usually a pump for the water of the windscreen washer.

In the washing machine there is a water pump. It is there to pump out the dirty water from the washing machine.

In some households there is a small water pump, Fig. 6 below, which can be powered by the electric drill.



There are so many types of pumps as there are applications. We want to take a closer look at two pumps.

Fig. 6 shows a gear pump in cross section on the left. The oil pump in the car is a gear pump. When the gears rotate in the direction of the arrows, oil is taken from the gaps between the teeth and pushed upwards.

On the right in Fig. 6 is a centrifugal pump. The pump of the washing machine is a centrifugal pump. The incoming water gets into the middle of the wheel between the wings. As the wheel turns, the water has to rotate. It is thrown outwards (similar to a car in a sharp curve) and pushed out to the exit opening.

Can you describe how the pump in Fig. 6 below works?

Exercises

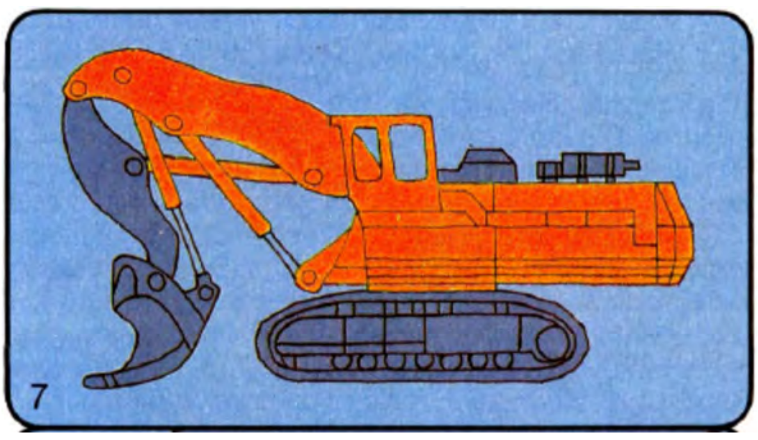
1. What are household water pumps used for?

2. What are pumps used for in the car? Try to locate the pumps under the hood of a car.

3. Describe the operation of a gear pump and a centrifugal pump.

3.3 The hydraulic circuit of the excavator

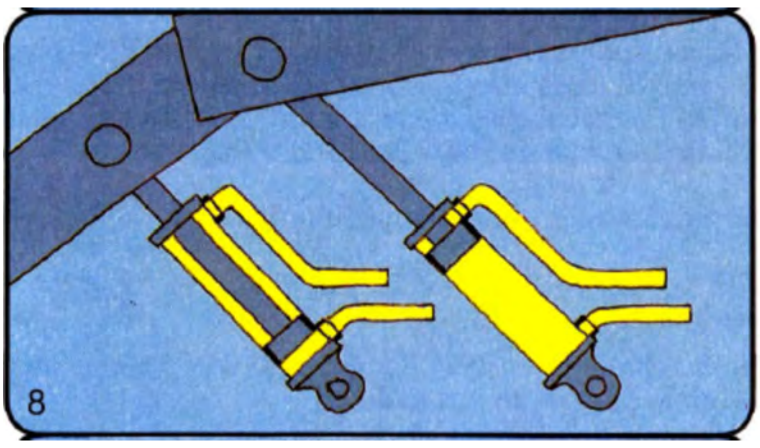
The excavator, Fig. 7, is a machine that needs a lot of energy. It needs the energy for various activities: for driving the chains, for turning the upper part of the excavator, for pivoting and bending its arm and for tilting the shovel.



For these activities, it needs the energy at various different places. It would be very expensive to install a separate diesel engine at each of these points. Instead, the excavator has a single diesel engine. This drives a pump. The pump pushes a liquid, the hydraulic oil, through hoses to the various places where something is to be moved, thus, where energy is needed. Where a rotary motion is needed, there is a hydraulic motor and where something is to move back and forth, there is a hydraulic cylinder.

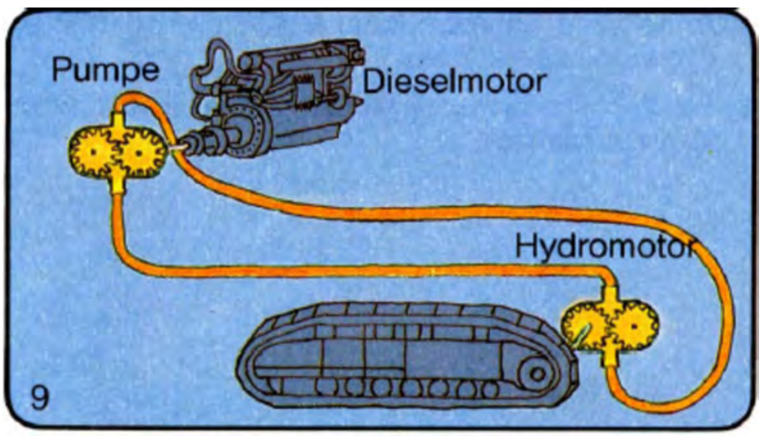
A hydraulic motor is similar to a gear pump, only used in reverse. Running as a pump, Fig. 6, you turn on one of the two gearwheel shafts and push out the liquid at the top. If the same device is used as a hydraulic motor, then hydraulic oil enters from below at high pressure. As a result, the teeth of the gears at the outside are pushed upwards: they rotate in the directions of the arrows.

The operation of a hydraulic cylinder is described in Fig. 8. In the cylinder, a piston can reciprocate. When oil is pushed in from above into the cylinder, the piston moves down and lowers the arm of the excavator. In the hose, which leads from the pump to the cylinder, there is a valve that the excavator operator can open and close. If he wants to move the arm of the excavator, he opens the valve. From each cylinder and each hydraulic motor, the oil flows through a second hose back to the pump.



Instead of hydraulic oil you could also use water, but water has the disadvantage that it freezes in winter.

Fig. 9 shows schematically the pump and one of the hydraulic motors. The pump is the energy source. It loads the energy carrier, the hydraulic oil, with energy. The oil carries the energy to the receiver, the hydraulic motor. This discharges the energy from the energy carrier again. The empty energy carrier flows through the second tube back to the source. Whether the carrier is charged with energy or not can be recognized by its pressure. In the forward direction it has a high pressure, it carries energy. In the return line it has a low pressure, it carries no energy.



pump
diesel engine

hydraulic motor

Summary: The hydraulic drive uses a fluid under high pressure as an energy carrier. The energy source is a pump, the energy receiver, a hydraulic motor or hydraulic cylinder.

Supplements S 3.3 and S 3.4

Exercises

1. Describe the path of the energy from the diesel engine of an excavator to the wheels.

2. In which other construction machinery is energy transferred hydraulically?

3. Which agricultural machines have an hydraulic drive?

3.4 The hydroelectric power plant

We have come to know two ways to charge oil or water with energy:

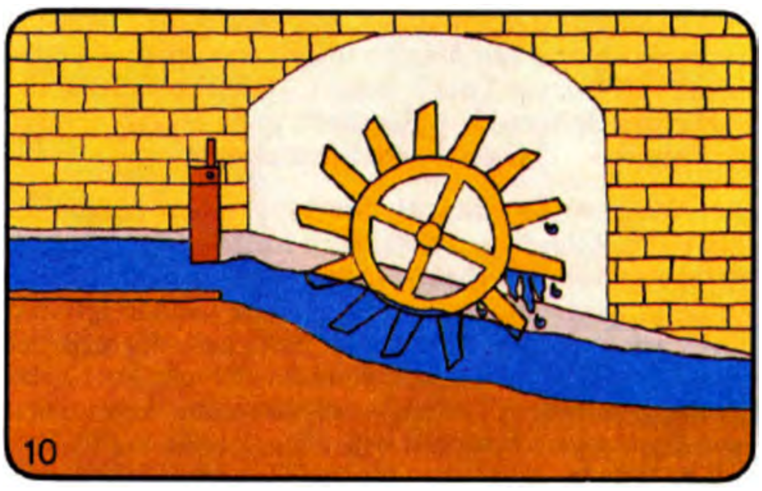
- by heating it (as in central heating),
- by putting it under pressure (with a pump).

There is yet a third kind:

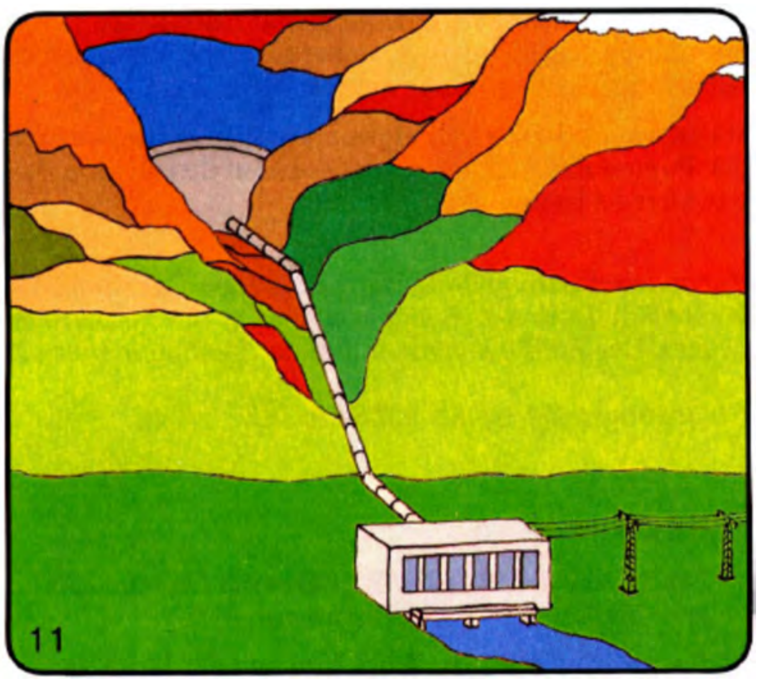
- by setting the water in rapid motion.

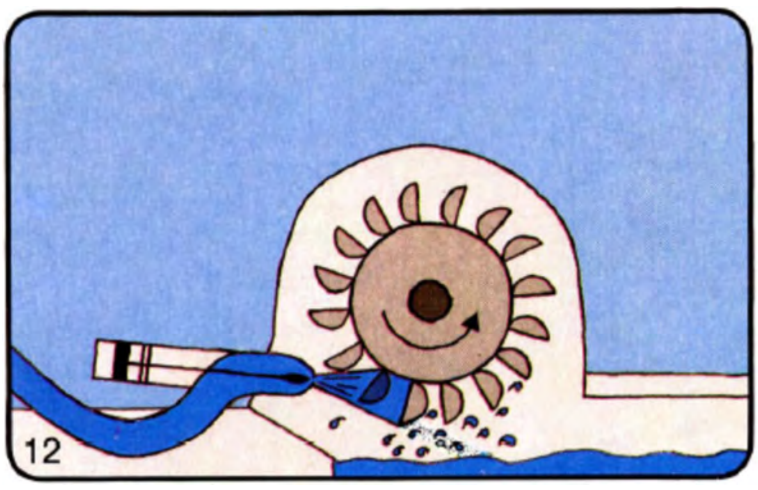
That fast-moving water carries energy, becomes obvious when considering a torrential river. The river has so much energy that it carries away stones or whatever gets in its way.

It is possible to discharge the energy from the moving water with a mill wheel, Fig. 10. The wheel has this name because in former times it was used to drive mills.



Today, the energy of moving water is usually discharged by water turbines. They are an important part of the hydropower plant, Fig. 11. The water that flows through pipes to the turbine comes from a reservoir. In the turbine, Fig. 12, it first flows through a nozzle. A nozzle is simply a contraction in the pipe. From the nozzle, the water shoots at high speed against the blades of the turbine wheel and sets the wheel in rotation.





The turbine drives the generator via a shaft. A generator is the same as a bicycle dynamo, only is it much bigger. From the generator, the energy then flows via electrical lines to your home.

Summary: Fast moving water carries energy. With a turbine the energy of the water can be unloaded.

Supplement S 3.5

Exercises

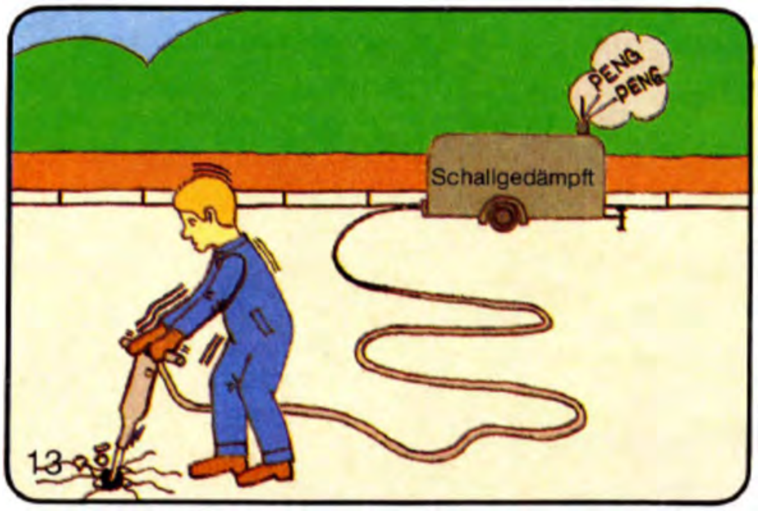
1. How does a turbine work?

2. How is a hydroelectric power plant constructed?

3.5 The energy carrier compressed air

If you want to lay a pipe under a concrete road, you first have to break the concrete. You could do that with a hammer and a chisel. That is very tedious. It is more convenient to use a jackhammer.

What is commonly called a jackhammer is actually a hammer and a chisel in one, Fig. 13. Below is the chisel. Above it sits a heavy piece of iron, which is moved up and down, beating like a hammer on the chisel each time.



boom boom

noise reduced

How is this hammer powered, where does it get its energy from? It gets it through a hose, similar to the hydraulic motors of an excavator. However, no liquid flows in the hose, but air. Since the air is under high pressure, it is called compressed air. The compressed air carries the energy to the jackhammer.

The charging of the air with energy happens, as with the hydraulic drive, with a pump, which is driven by a diesel engine. A big air pump is called a compressor. Compressor and diesel engine are often in a two-wheeled car.

When you inflate a bicycle tire, you use the pump to generate compressed air. You feel in the arms, that it costs energy.

Summary: Compressed air carries energy. The compressor charges air with energy by compressing it. The jackhammer unloads the energy.

Supplements S 3.6 to S 3.8

Exercises

1. Describe the path of the energy from the diesel engine to the chisel of the jackhammer.

2. At which other facilities is energy transferred with compressed air?

3.6 The energy carrier moving air

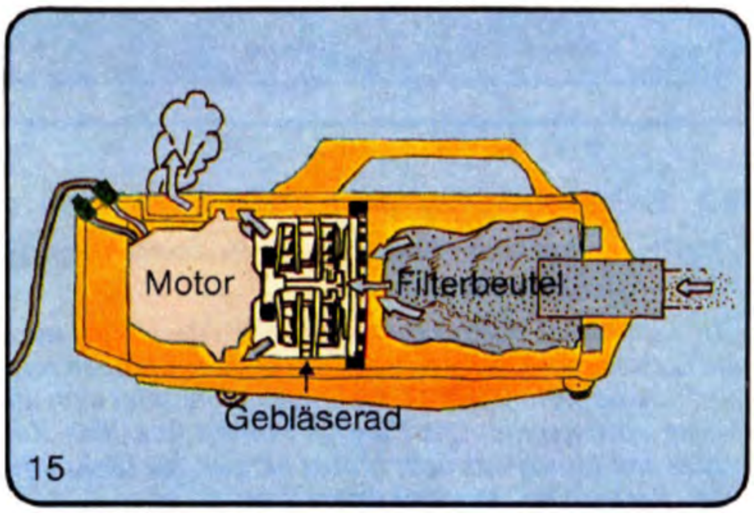
Not only air, which is under high pressure, is an energy carrier, but also fast-moving air.

The wind shows that fast-moving air carries energy. It drives windmills and sailing ships, it can even destroy houses and tear down trees.

The energy that the wind carries is exploited in wind power plants, Fig. 14. The wind sets a large wind turbine in rotation, and the wind turbine drives a generator. Sailboats, windmills and wind turbines are receivers that receive energy with the carrier "moving air". They discharge the energy from the wind. You also know devices that set the air in motion, that charge energy to the carrier "moving air": a Fan and a vacuum cleaner. Both are similar: An electric motor moves an blower wheel. The blower wheel sets the air in motion.

14

In the vacuum cleaner, Fig. 15, the incoming air flows through a pipe. The strong flow at the inlet of the pipe takes away the dust. Before the air reaches the blower wheel, it must flow through the filter bag. The dust particles are caught in the filter bag. The clean air comes out through an opening in the vacuum cleaner.



15

motor filter bag

blower wheel

Summary: Fast moving air carries energy. Windmills, sailing ships and wind power plants unload energy from moving air. Fan and vacuum cleaner load air with energy.

Supplement S 3.9

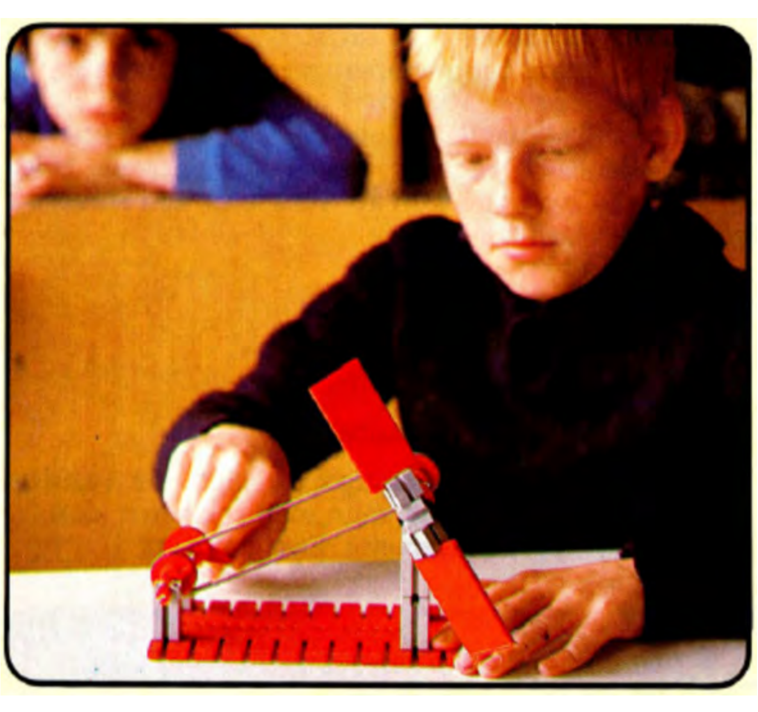
Exercises

1. How does a vacuum cleaner work?

2. Find the outlet of the air in your home vacuum cleaner. How can you tell that the air that comes out of here carries energy?

S 3.1 A belt drive to build yourself

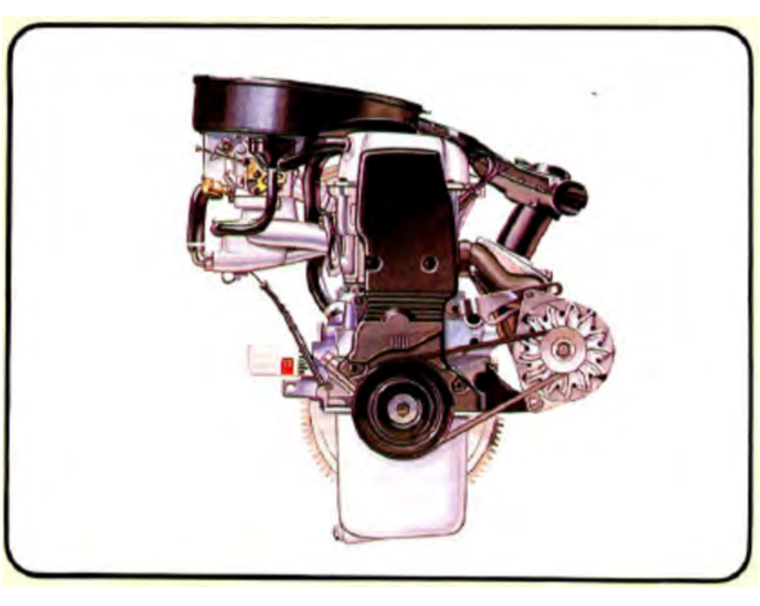
You can build yourself a fan. The belt carries the energy from the crank to the propeller.



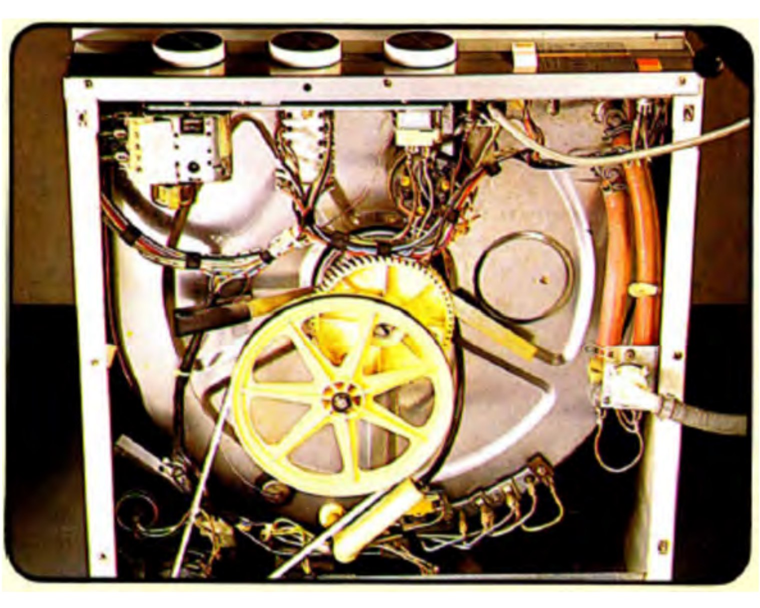
S 3.2 V-belts in the car and in the washing machine

Drive belts are often used to transport energy over short distances.

A car engine must drive the alternator in addition to the wheels of the car. The picture below shows a car engine. The alternator is located on the far right of the engine. The energy comes out of the engine via the wheel at the bottom of the engine. It flows over the "V-belt" to the alternator.



In the washing machine, a V-belt carries the energy from the electric motor to the washing drum.

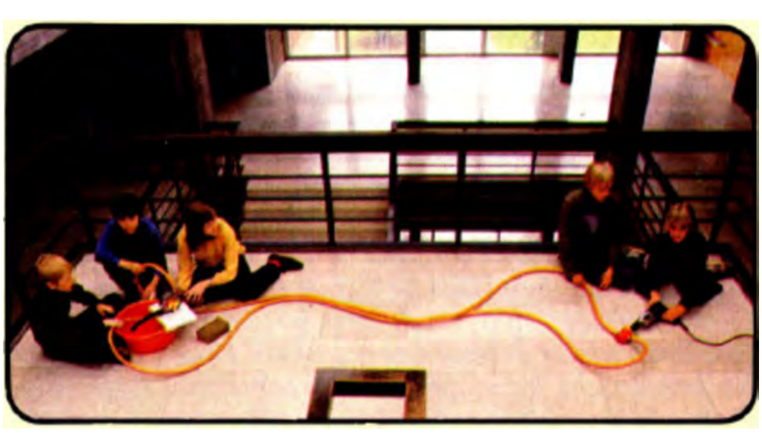


S 3.3 The aircraft landing gear

The landing gear of an aircraft is retracted after take-off to reduce the air resistance of the aircraft. It is extended again before landing. The energy for retracting and extending comes hydraulically to the chassis. The picture shows the hydraulic cylinders.

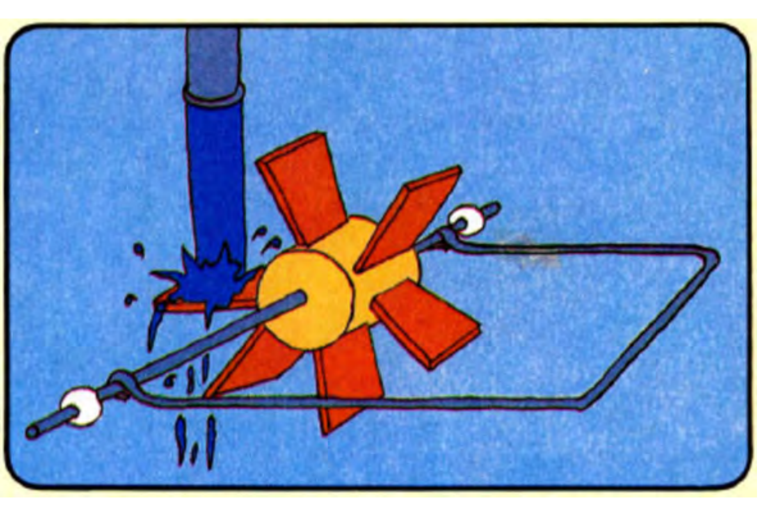
S 3.4 A hydraulic drive to build yourself

With a small pump attached to a portable drill and a small turbine you can build a hydraulic drive yourself. The pump, on the right in the picture, is the energy source. It pushes water through one hose to the turbine, left, and sucks it back through the other. In this way, energy flows from the pump to the turbine.

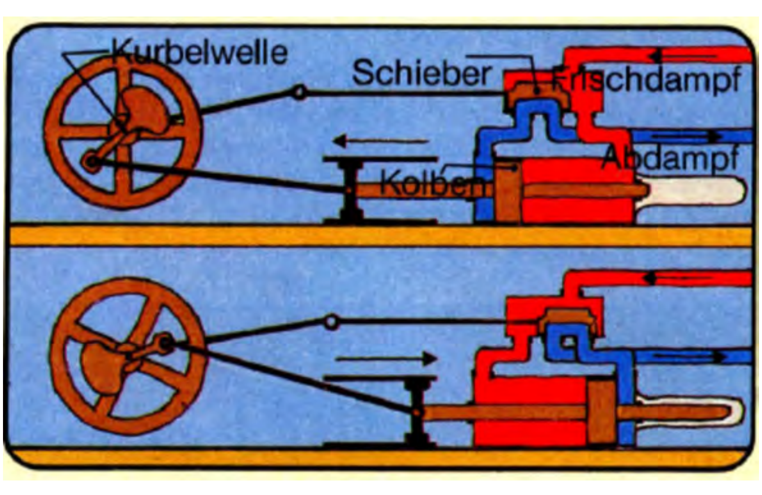


S 3.5 A water wheel to build yourself

The picture shows a water wheel that is easy to build yourself. A knitting needle is used as the shaft for the water wheel. The shovels are wooden plates that are spiked into a cork. To prevent the wheel from sliding sideways in its holder, 2 beads are glued to the knitting needle.

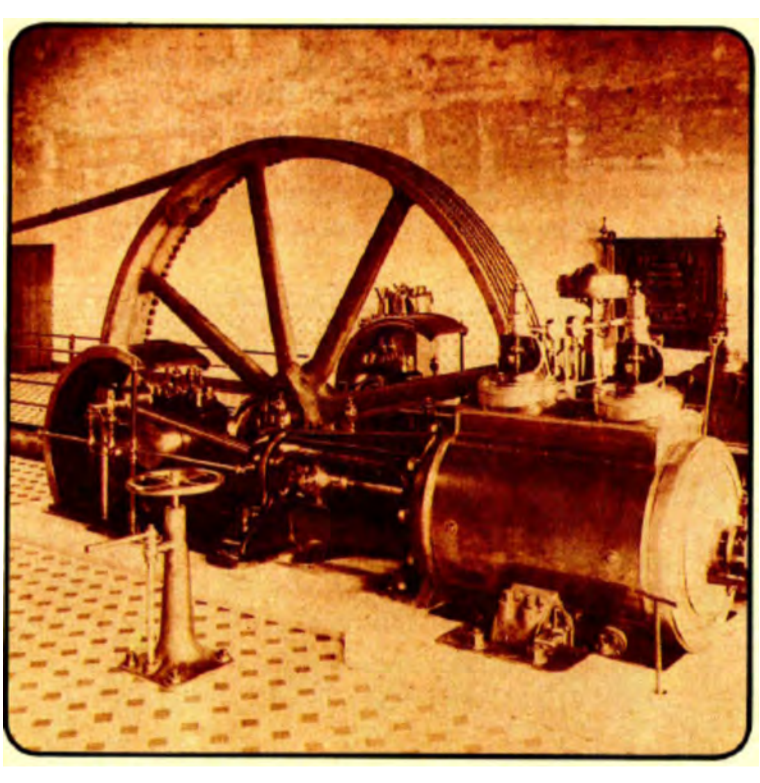


S 3.6 The steam engine



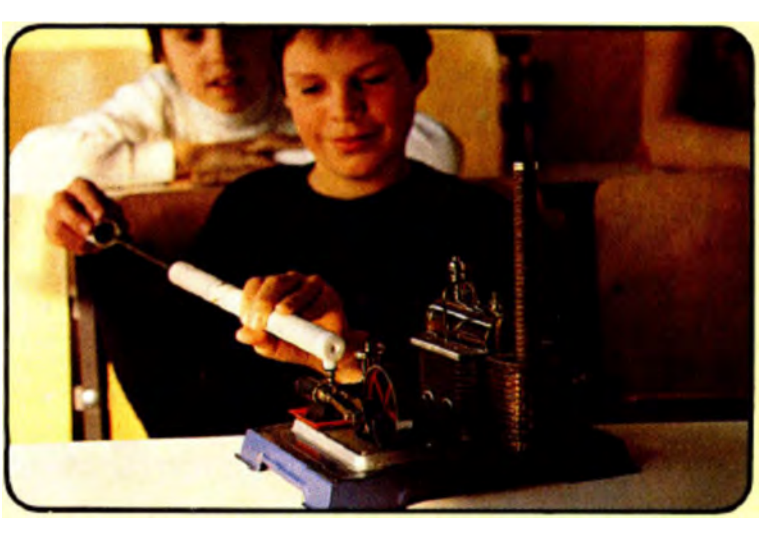
crank shaft
glider fresh steam
exhaust steam
piston

Water is heated in the boiler of the steam engine until it evaporates. Since the water vapor cannot escape into the open air, it gets a high pressure. It flows through a pipe to the actual machine. You can see how it works in the picture above. The steam presses alternately from the right and left against the piston. The slider ensures that the steam is always pressed from the correct side. While new steam presses under high pressure against the piston from the left, the steam at the right side can flow out and vice versa. The movement of the piston is transmitted to the crankshaft via a rod. The slider is moved by the crankshaft.



S 3.7 Energy transmission with compressed air – to build yourself

A bicycle pump generates compressed air, it loads air with energy. The compressed air flows into the machine instead of the steam. The steam engine discharges the energy from the compressed air.



S 3.8 The steam turbine

In modern steam power plants, a steam turbine is used to drive the generator. A steam turbine works similarly to a water turbine. The steam flows through nozzles at high speed against a paddle wheel. The picture shows the steam turbine of a large nuclear power plant during assembly.

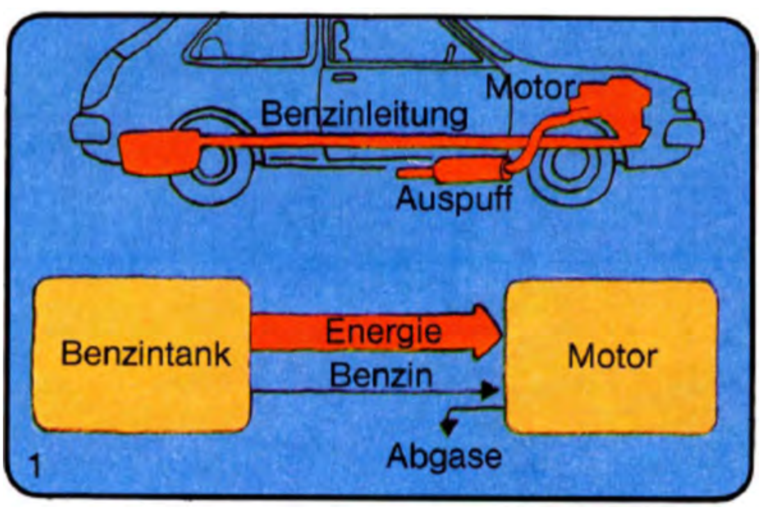
The picture below shows a simple steam turbine to build yourself. A paddle wheel made of thick aluminium foil, which rotates on a piece of wire, when held in the steam jet of the water kettle.

S 3.9 Hairdryer and fan heater

The hair dryer and fan heater load air with energy in two ways: First, the air is set in rapid motion by a fan or blower, and then it is heated by an electric heating coil.

4. One-way-bottle energy carriers and deposit-bottle energy carriers

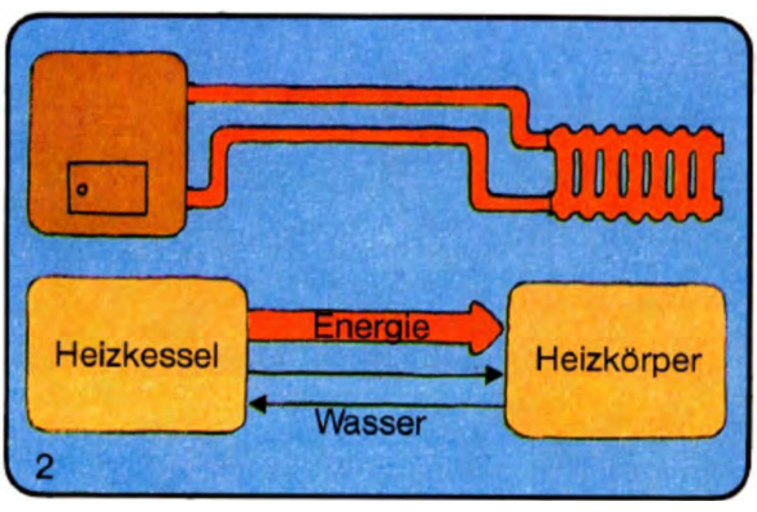
In order to run, a car engine needs gasoline. The gasoline carries the energy into the engine. Within the engine it discharges its energy. Thereby it transforms into *exhaust gases*. These leave the engine via the exhaust pipe, Fig. 1. That means: what is left from the energy carrier is "thrown away".



The gasoline is one-way-bottle energy carrier.

Thus, the "empty energy carrier" is thrown away like an empty bottle of mineral water. Such bottles are called one-way-bottles. We shall call *one-way-bottle energy carrier* an energy carrier that is discarded when it has discharged its energy.

There are bottles that are reused after being emptied: the deposit-bottles. When they are empty they are sent back to the supplier and filled again with mineral water. There are also energy carriers, which are reused. After having unloaded their energy in the receiver they are sent back to the energy source. An example is the central heating system. In the radiators it discharges its energy, Fig. 2. However, after that it is not thrown away. It is pumped back to the boiler instead. In the boiler it is charged with energy again. We will call such an energy carrier a *deposit-bottle energy carrier*.



The water in the central heating is a deposit-bottle energy carrier.

In the future we shall express the fact of being a one-way bottle energy carrier or a deposit-bottle energy carrier also in the energy flow diagram. If the "empty" energy carrier is returned to the supply we shall draw another arrow that goes back from the receiver to the source, Fig. 2. If the empty carrier is discarded we draw an arrow that bends downwards, Fig. 1.

Often it is easy to recognize whether an energy carrier is of the one-bottle or of the deposit-bottle type, even without knowing exactly what the carrier actually is. If there is just one connection between the source and the receiver, Fig. 3, we have a one-way-bottle energy carrier.

Oil pipeline

If there are two connections, Fig. 4, then in one of them the carrier, that is loaded with energy, flows from the source to the receiver, and in the other the empty carrier flows back from the receiver to the source. In this case we have to do with a deposit-bottle energy carrier. These deposit-bottle carrier always flow in a *closed circuit*.

District-heating pipes

Summary: A one-way-bottle energy carrier is thrown away after having unloaded its energy in the receiver. A deposit-bottle energy carrier goes back to the source. There it is again loaded with energy.

Exercises

1. Where is the exit of the empty energy carrier of a coal stove? Is coal a one-way-bottle or a deposit-bottle energy carrier?

2. Is the compressed air that goes from the compressor to the jackhammer a one-way-bottle or a deposit-bottle energy carrier? How can this be recognized in the figure in section 3.5?

3. Which of the following energy carriers is of the one-way-bottle type, which is of the deposit-bottle type?

(a) The air of a hot air heating system;
(b) the hydraulic oil of a digger;
(c) the water of a hydraulic power plant;
(d) the drive belt.

4. What would a central heating system be like, where the water is a one-way-bottle energy carrier? Why do such heating systems not exist?

5. How could one realize a jackhammer where the air is a deposit-bottle energy carrier? Why do such jackhammers not exist?

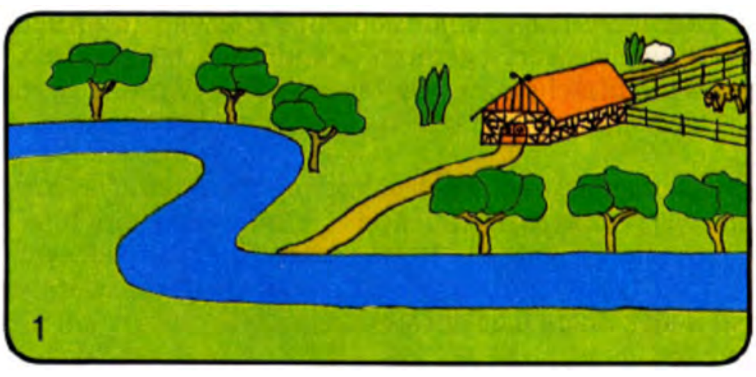
6. Draw the energy flow diagram for the following source-receiver pairs:

(a) oil tank – oil stove
(b) compressor – jackhammer
(c) hydraulic pump – hydraulic motor
(d)electric motor – circular saw.

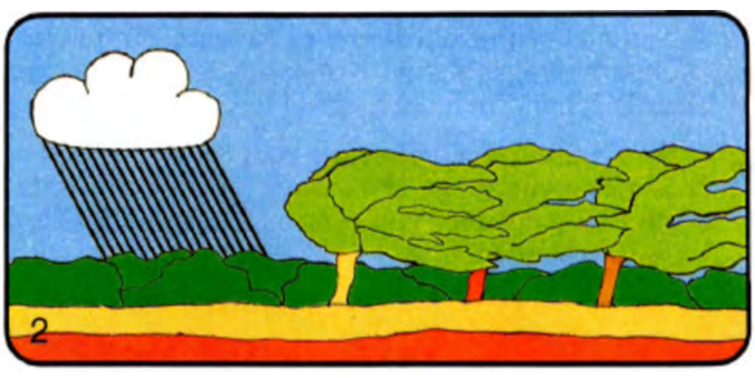
5. The energy carrier electricity

5.1. What is a current?

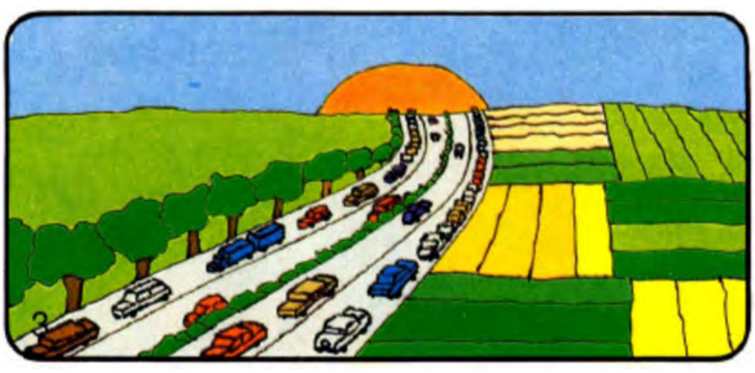
We always have to do with a current when something is flowing. Water flows in a river, Fig. 1. Therefore the river is a water current. The wind is a current of air, Fig. 2. The cars on the highway form a “car current”, Fig. 3. When the children come out the door of the school after the last lesson, they form a current of people. In a vein flows a blood current and in a pipeline a petroleum current.



Water current



Air current



Car current

Have you noticed what is necessary to get a current? You need a large amount of things (e.g. cars or humans) or a substance (for example water).

As long as these things or substances do not move, they do not represent a current. The water in a pond flows just as little as the cars in a parking lot or the children during class, Fig. 4.

No current

In order to obtain a current, a movement is necessary. But the movement alone is not enough. As long as everything moves around, we have not a current. The children in the schoolyard are moving around, but they do not form a current, Fig. 5.

No current

The moving things or the parts of a moving substance must also take the same route, such as the water in a river, the cars on the highway or the running children, Fig. 6.

A people current

Physics deals with the most diverse currents. One of them is the energy current. You already know that it flows from a source to a receiver. You also learned that every current of energy requires an energy carrier current.

Between the fuel tank and the engine of a car, an energy current flows together with a gasoline current. Between the boiler and the radiator, an energy current flows together with a water current. Between the power plant and a light bulb flows a current of energy together with a current of electricity, in short, with an electric current.

This electric current is what most people simply call current. Since there are so many different currents, we recommend that you use the exact name, not just “current” but “electric current”.

Summary: When many things move and take the same path, they form a current. Also a flowing substance can form a current.

Exercises

1.Enumerate some examples of currents.

2. Why do the children who play in the schoolyard during the break not represent a current? What would they have to do to create a current?

3. A current of energy never flows alone, but always together with .... Complete the sentence!

5.2 Electric energy sources and receivers

Look around your house for energy receivers. You'll find that most devices get their energy with electricity. Lamps, the washing machine, the spin dryer, the iron, the vacuum cleaner, the fridge, the TV and many other appliances get energy through a cable. The cable shows that the energy carrier is electricity.

The energy for these devices comes from the socket. The socket is connected via lines to the generator in the power plant. The energy source is thus a generator.

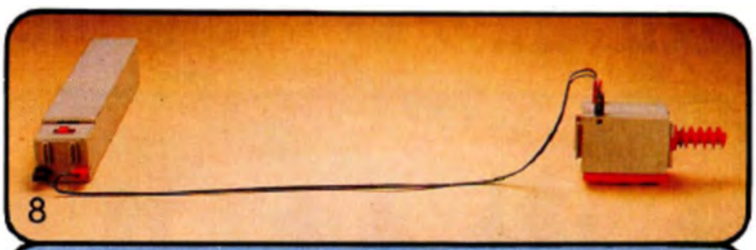
There are electrical appliances, i. e. receivers for energy carried by electricity that you do not need to connect to the socket, such as the smart phone, the wristwatch or the pocket calculator. These devices have a battery as an energy source, Fig. 7. Batteries have the advantage over the power plant that you can carry them around. Their disadvantage is that they become empty. When they are empty, you can not do anything with them anymore. You throw them away.

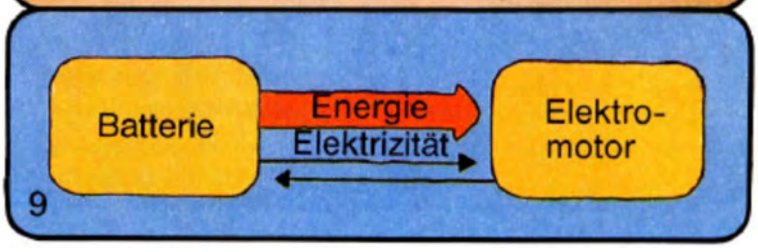
Disposable and rechargeable batteries

Another mobile energy source is the rechargeable battery. Every car has such a battery. It provides the energy for the starter. Charging means refilling it with energy.

A car battery is bigger and heavier than a flashlight battery. Therefore much more energy can be stored in it. From a charged car battery you can get about 2000 kJ – as much as from a bar of chocolate –, from a flashlight battery only 10 kJ.

The energy flows from the source to the receiver through a cable. Look at the plug, which is attached to a cable. It has two pins. The cable itself consists of two wires. These are connected at the end with the pins of the plug. The electricity flows through the wires. In one, it flows with energy from the source to the receiver. In the other, it flows back without energy. Electricity is therefore a returnable bottle energy source.





battery

energy
electricity

electric motor

Fig. 8 shows a toy motor, which gets its energy via a cable from the battery box, left in the picture. You can see clearly the two wires that belong to the cable. Fig. 9 shows the energy flow diagram belonging to Fig. 8. Often, cables even have three wires. What the third serves, you can read in the supplement S 5.4.

Summary: Power plant, disposable battery and rechargeable battery are sources, all electrical devices are receivers for energy, which is carried by electricity. The electricity is a deposit-bottle energy carrier.

Supplement S 5.1

Exercises

1. Name some sources and some receivers for energy carried by electricity.

2. Name some devices that get their energy from batteries.

3. Why does the car need a battery?

4. What is a battery charged with when you charge it?

5. Compare the two energy sources “power plant” and “battery”. What advantages and disadvantages do they have?

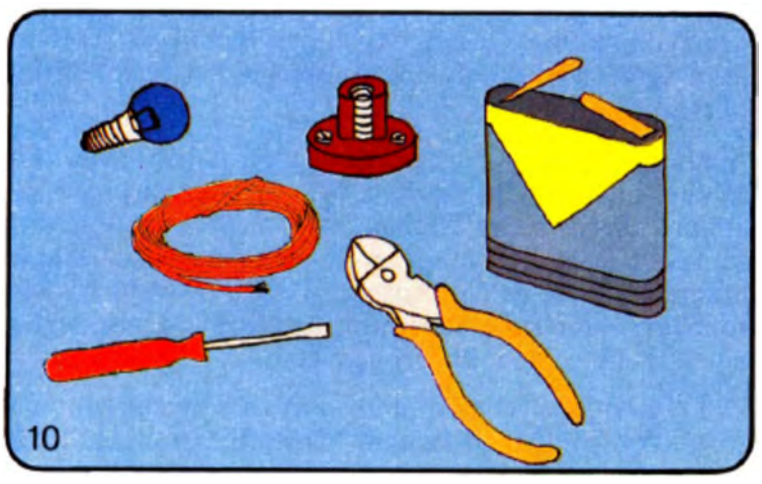
6. From which source does a gas stove get its energy, from which a gas lighter? What are the advantages and disadvantages of these sources? (Compare with exercise 5.)

7. Some electrical appliances can either get their energy from batteries or from the mains. What are the advantages of such appliances?

5.3 The electric circuit

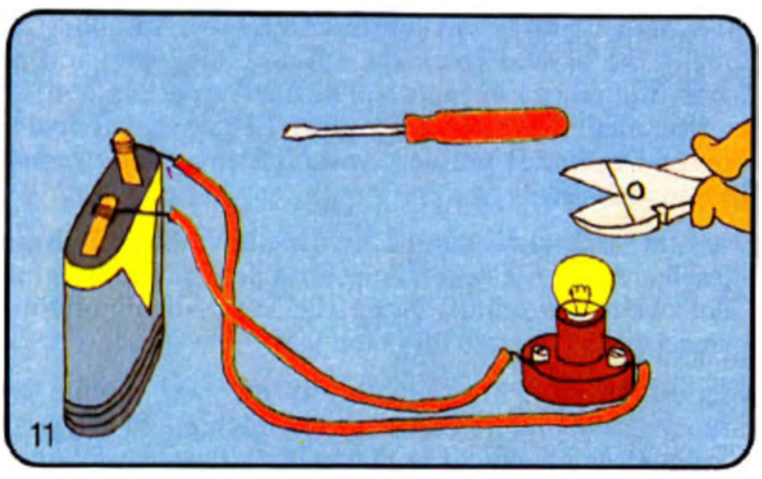
In other words, the headline could also read: “How to connect a bulb to a battery”.

What you are told here, you should actually find out for yourself. Get the things shown on picture 10 and try it yourself. If you succeed, the rest of this section will not bring you much new.



Each electrical energy source has two “terminals”. In the battery of our figure, it is the two metal tabs on its top. These terminals are called plus and the minus terminal.

Electric energy receivers also have two terminals. One is the thread of the light bulb, the other the metal plate at the bottom. Usually you screw the lamp into a socket. On Fig. 10 you can see the two terminals of the socket. As a conductor for the electricity one uses copper wires, which are covered with a plastic layer.



To connect the receiver to the source you proceed as follows, Fig. 11: Remove the plastic cover from both ends of a piece of wire so that the bare copper wire looks out. Attach one end to one terminal of the source, the other to one of the terminal of the receiver. You have to make sure that the copper of the wire touches the metal of the terminals. It is enough that you wrap the bare wire end around the terminal once or twice.

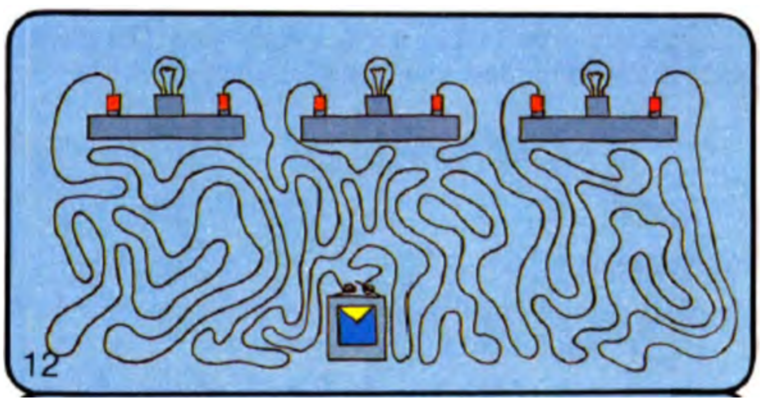
So far, the lamp is not lit yet. Now connect in the same way the second terminal of the receiver to the second terminal of the source. If you have done everything right, the lamp lights up.

Do you find it surprising that you need two wires to light the lamp? You know that electricity is a deposit-bottle energy carrier. Like every deposit-bottle energy carrier, it flows around in a closed circuit. You have built an electrical circuit.

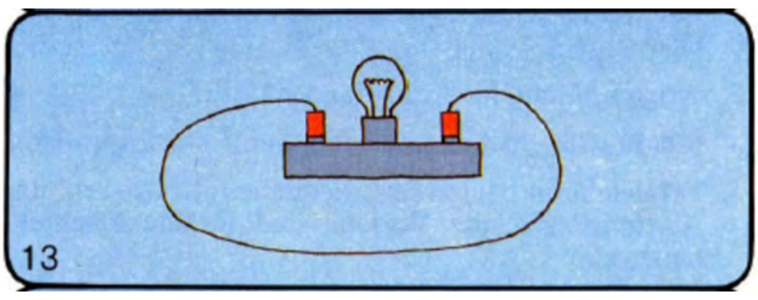
Summary: To create an electrical circuit, connect the two terminals of the source with copper wires to the two terminals of the receiver.

Exercises

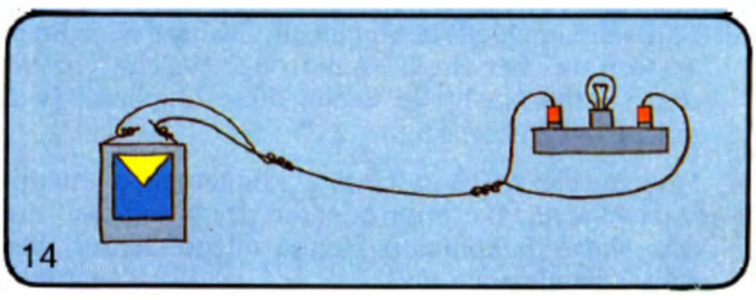
1. Which of the 3 lights on Fig. 12 lights up?



2. In Fig. 13 the electricity could flow in a closed circuit. Does the lamp light up?

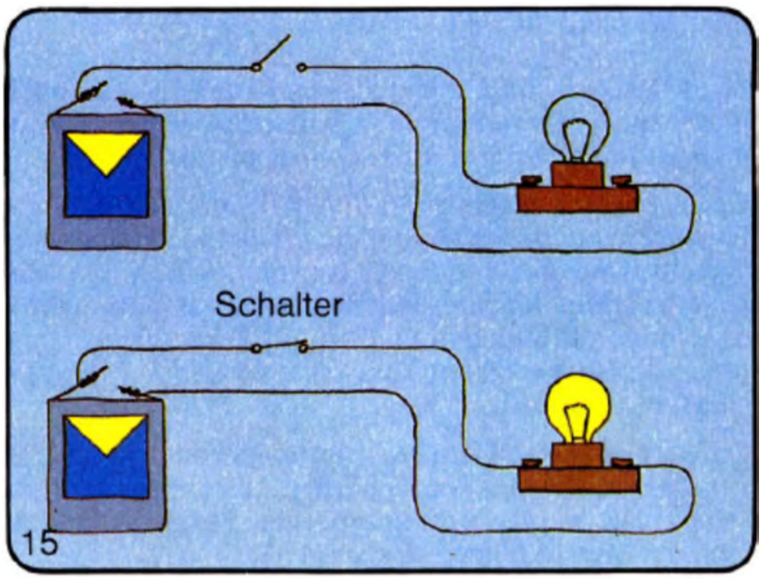


3. In Fig. 14 both terminals of the the source are connected with both connections of the receiver. Does the lamp light up?



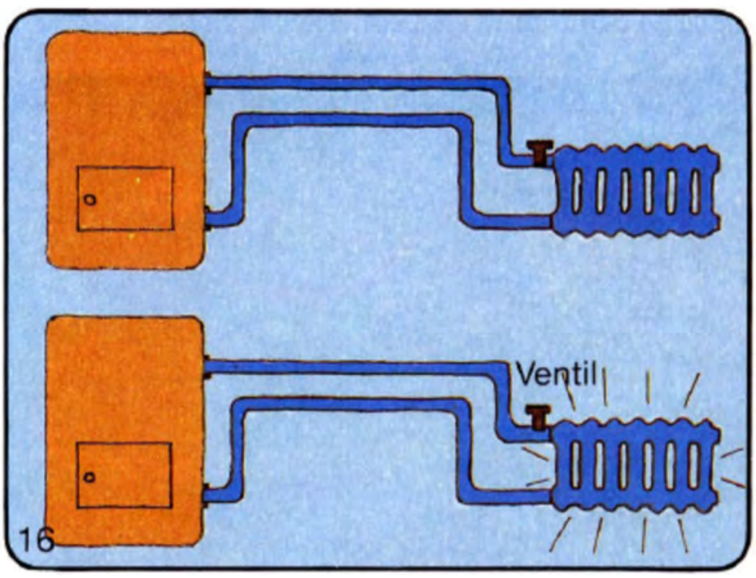
5.4 Switches and valves

One wants to turn a lamp on and off. Therefore, one inserts a switch in the circuit, Fig. 15. The switch can be used to interrupt the circuit at one point. The electricity can then no longer flow in all other parts of the circuit. It does not matter where the switch is placed in the circuit: in the forward or in the return line, at the beginning or end of a line.



Switch in an electric circuit

It is the same situation as for a water circuit, such as the central heating, Fig. 16. A "valve" is installed at any point in the water circuit. Closing the valve prevents water from flowing at any point of the circuit.



Valve in a water circuit

Summary: A switch can be installed anywhere in the circuit.

Supplement S 5.2

Exercises

1. There are switches or valves not only for the electric current and the water flow. Auto flows can also be switched on and off. Do you know where?

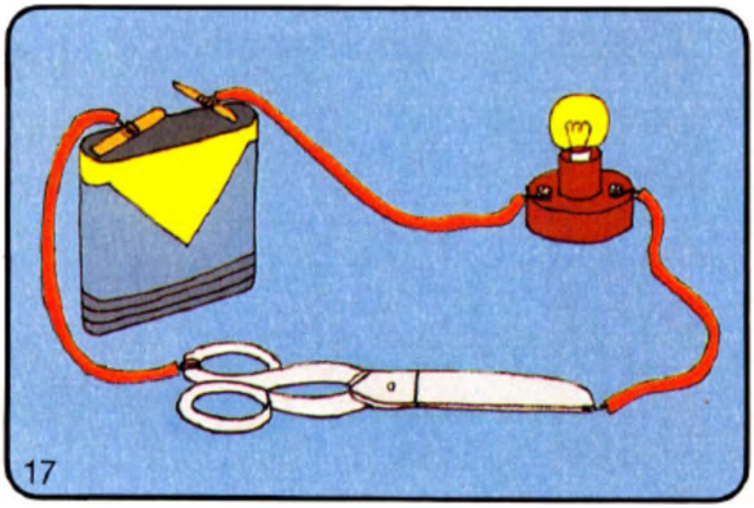
2. Take a discarded switch apart. How does it work?

3. How does a switch differ from a bell button?

5.5 Which substances conduct electricity

Does electricity only flow in copper wires or does it also flow in other objects? With the circuit you have built, you can try it yourself.

Interrupt the circuit at any point, and place the two free ends that you obtain at two different points of an object, Fig. 17. If the lamp is lit, the electricity can pass through the object. It is said that the object conducts the electricity. Do this experiment with many different objects.



The scissors conduct the electric current.

Whether an object conducts the electric current depends on the material of which it is made. We have already seen that copper conducts electricity. All other metals also are conductors.

You will surely have noticed that plastic does not conduct the electricity. You see now, why you have to remove the plastic cover at the wire ends.

Summary: Metals conduct electricity.

Supplement S 5.3

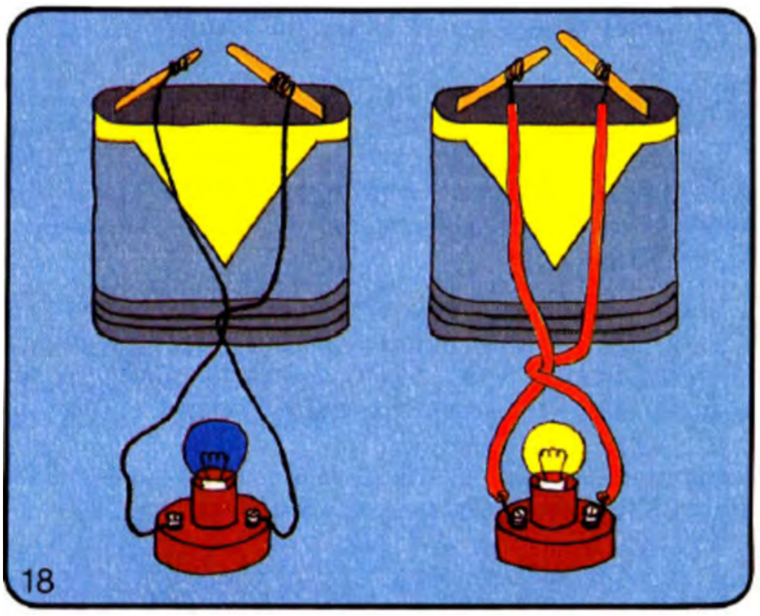
Exercises

1. On what does it depend whether an object conducts electricity or not?
2. Does a pencil conduct the electric current? Also examine the pencil lead.
3. Name substances that conduct electricity and substances that do not.

5.6 The short-circuit

The wires used for the transport of electricity are covered by a plastic layer, they are insulated. What is the insulation for?

Connect a lamp to a battery with bare copper wires. If one wire touches the other, the lamp goes off, Fig. 18 left. You have made a *short-circuit*. When isolated wires touch, there is no short circuit, Fig. 18 right.



18

In the event of a short-circuit, the electricity no longer flows to the lamp, but only from the battery to the point of contact and from there back to the battery. You notice that an electric current flows, even though the lamp does not burn, by the fact that the battery and the wires get warm.

The electric current in the circuit is even greater than before, when the lamp was still burning. Thus, the battery looses more energy than before. The battery will empty very quickly. However, the energy does not go to the lamp. It is unloaded from the electricity in the wires and within the battery. This causes the wires and the battery to get warm.

If the source of energy is not a battery but the power plant, a short-circuit could be dangerous – if you had no fuses.

Without fuses, a short circuit would cause a lot of electricity to flow through the wires. They would become so hot that they could start to glow and cause a fire. The fuse, Fig. 19, interrupts the circuit as soon as too much electricity flows.

19

Summary: In the event of a short-circuit, much electricity flows through the wires between the source and the contact point. This brings much energy out of the source. This energy is unloaded in the wires.

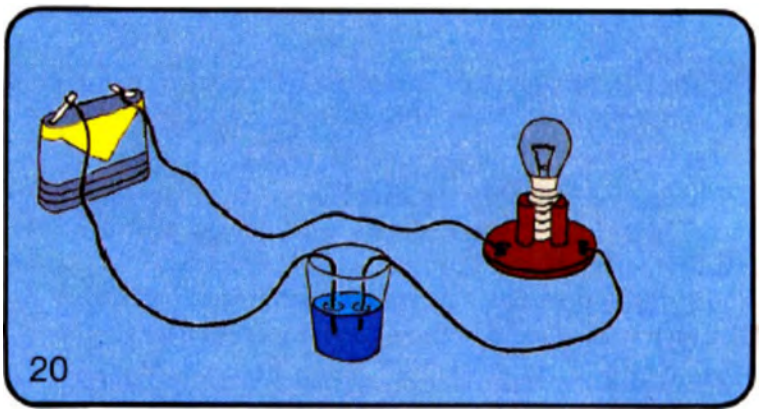
Exercises

1. Describe the path of the electric current when there is a short-circuit in the line.

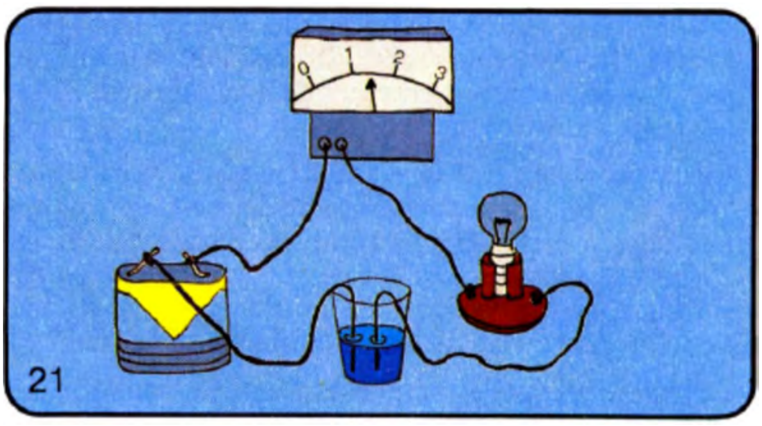
2. Why can a short-circuit be dangerous?

5.7 Does water conduct electricity?

Fig. 20 shows how you can find out. The lamp does not light up. So water does not seem to conduct electricity. If you now dissolve some salt in the water (about a teaspoon), the lamp starts to glow weakly. Salt water thus conducts the electric current.



You will later get to know a device that indicates very low electrical currents, an ammeter. With this device it can be shown that also water from the tap conducts the electric current somewhat, Fig. 21.



Summary: Tap water conducts electricity a bit, salt water conducts it better.

Exercises

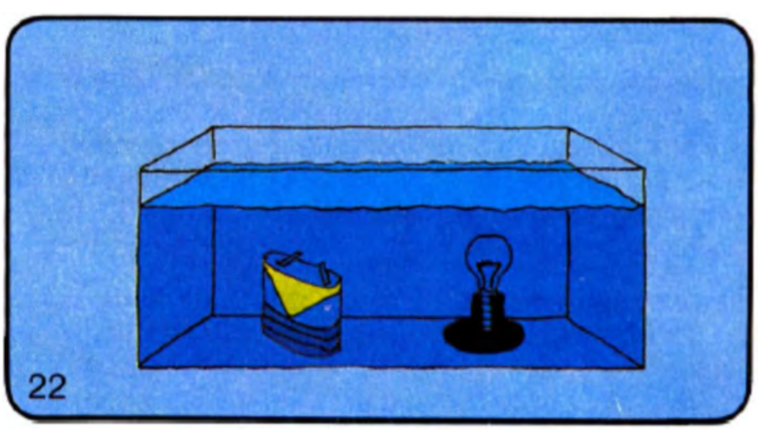
1. There is a small lamp and a battery in a water tank, Fig. 22.

Does the lamp burn when the tank is filled with salt water?

Does the lamp burn when the tank is filled with tap water?

Does the lamp burn when the lamp and battery in the water are connected to wires?

2. Does air conduct electricity? Justify your answer.



5.8 Electricity is dangerous

Every human being needs energy to live. Like any other energy receiver, it can not absorb the energy with any arbitrary energy carrier. The energy must be delivered with a very specific energy carrier: the food. If the energy comes with the wrong carrier, it can be uncomfortable, even dangerous.

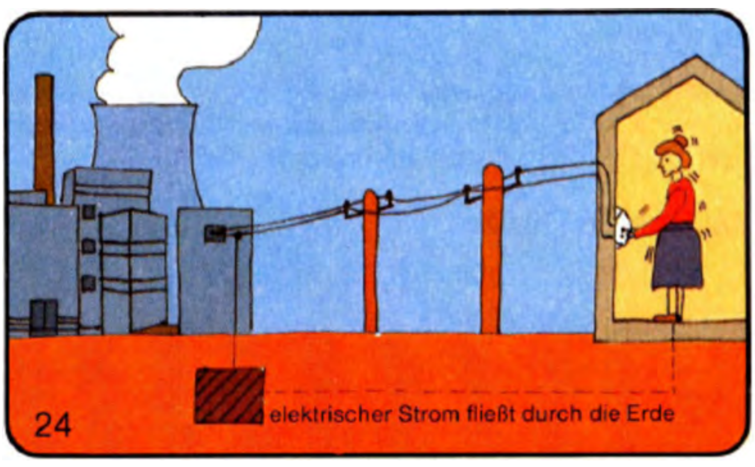
In Fig. 23 people get energy with different carriers. In which case is that unpleasant, in which dangerous?

Which type of energy intake is dangerous?

It is especially dangerous when a person gets energy with electricity. We say they receive an electric shock. Unintentionally, such an energy intake can happen in several ways:

– If you touch the two terminals of the socket at the same time, you are connected in the same way as an electrical device. You can be killed. It is especially dangerous if you have wet hands. The electric current can then flow even better.

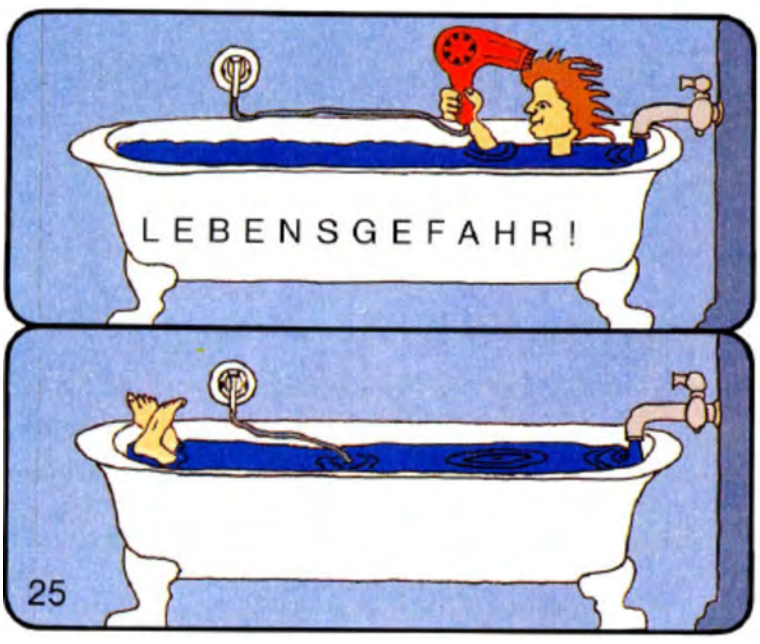
– One of the two poles of the socket is connected in the power plant with the earth. If you now touch the other pole and at the same time you are connected to the earth (i.e. no wooden or rubber shoes), the circuit is closed, Fig. 24. You receive an electric shock. Thus, it is also dangerous to touch only one terminal of the socket, although only one of the two terminals is dangerous. But you can not see from the socket, which one it is.



electric current flows through the earth

Do not touch even a single terminal of the socket!

If you touch an electric device that is wet, the current can flow from one of the terminals through the water on the device to your hand, and then through you to the earth and back to the power plant, Fig. 25.



LIFE DANGER

If you touch the connections of a flashlight battery or a car battery, you will get very little energy. Dealing with these sources is not dangerous.

Summary: Never touch the terminals of a socket! Do not use an electric device if you have wet hands or if you are standing on a wet floor!

Supplement S 5.4

Exercises

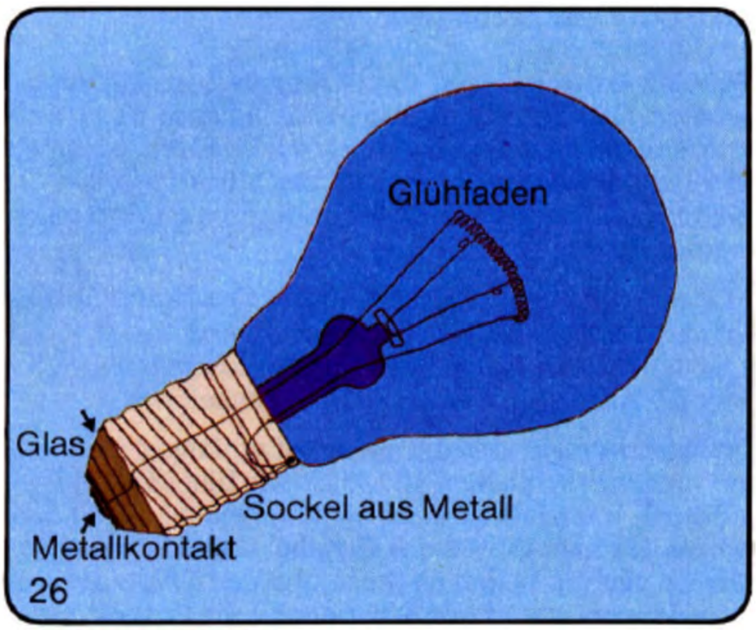
1. In what ways can you receive an electric shock?

2. Why does a bird on a high-voltage power line not receive an electric shock?

5.9 Light bulb and electric iron

Do the experiment described in S 5.5. A thin wire, which is traversed by an electric current, becomes warm. The electric current discharges energy in it.

Fig. 26 shows an incandescent lamp. The base is shown in cross-section, so that you can follow the path of the electric current. The filament is a very fine, spiral wire. If it is traversed by an electric current, it gets so hot that it glows brightly.



filament

glas

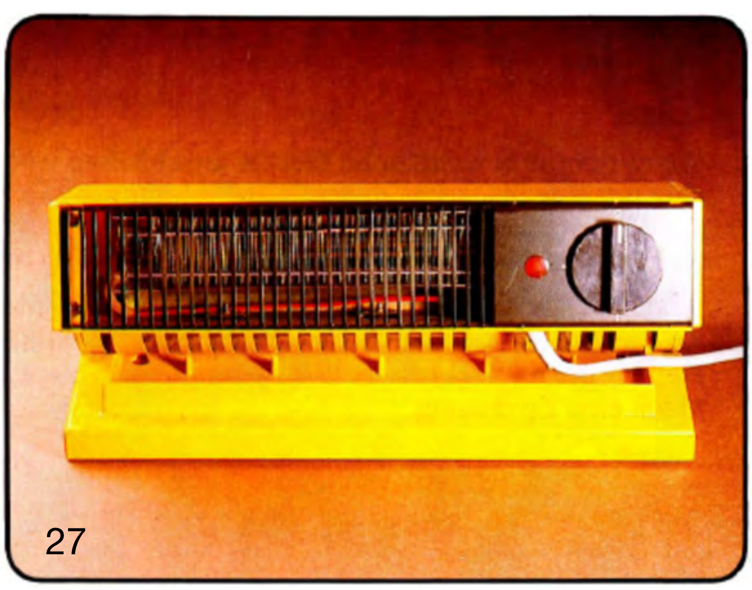
metal contact

metal socket

An iron works much like an incandescent lamp: the electricity flows through a thin wire, discharging energy. The heating wire in the iron is longer and not as thin as the incandescent lamp. That’s why it does not get so hot and does not shine.

A heating wire is found in many other electrical appliances: electric ovens, fan heaters, electric cookers, immersion heaters, coffee makers, hair dryers, toasters, water heaters, washing machines, clothes dryers ...

On some of these devices you can see the heating wire from the outside, Fig. 27.



Heating wire in a fan heater

Summary: If an electric current flows through a thin wire, the wire becomes warm. The electric current discharges energy in the wire.

Supplement S 5.5

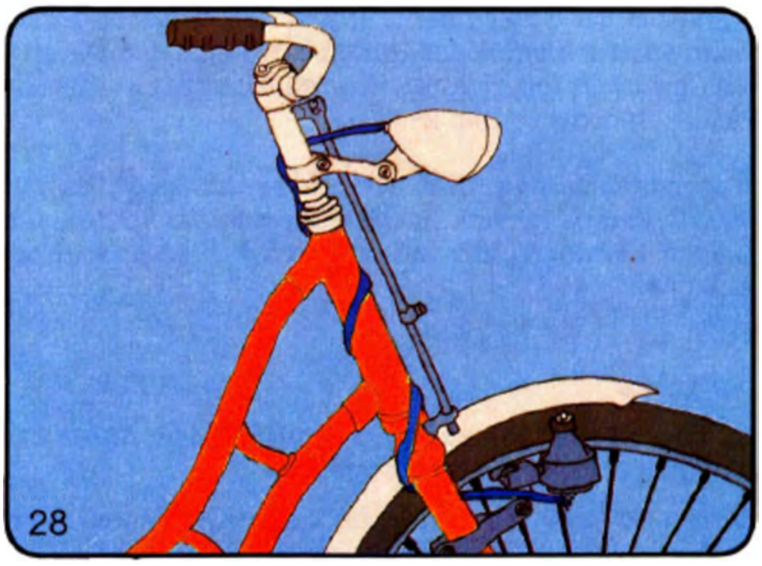
Exercise

1. Describe the path of the electric current in a light bulb.
2. Try to find out where the heating wire is on some home appliances.

5.10 Bicycle lighting

The energy source for the bicycle lighting is the dynamo. It is powered by one of the two wheels of the bicycle.

Examine how your bike dynamo and lamp are connected. You'll find that there are not two wires, but only one, Fig. 28. It looks like electricity is a one-way-bottle energy carrier. But that cannot be.

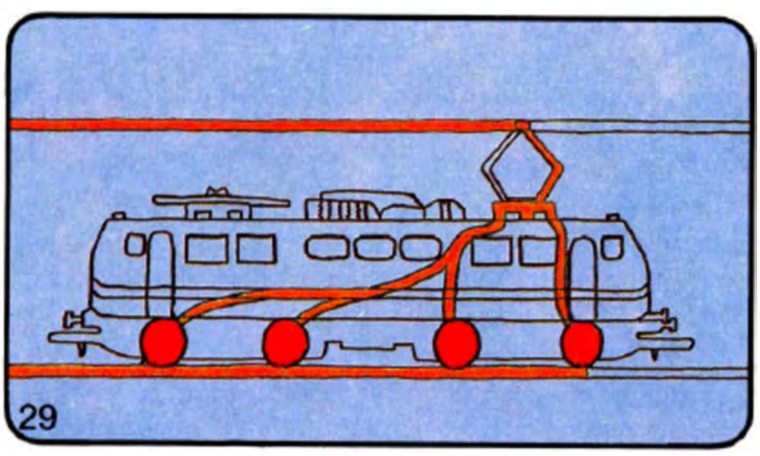


One-way-bottle energy carrier? That cannot be.

In order to track the second connection, we mount the lamp from its holder, but without loosening the wire leading to the dynamo. If now the dynamo is driven, the lamp does not light. Only when the lamp housing touches the holder does it light up. Lamp housing and bicycle frame thus form the sought second connection. Fig. 28 shows the path of the electric current.

It's the same in the car. To each electrical energy receiver, i. e. to the headlights, taillights, the wiper motor, etc. leads only a single insulated wire. The second line is the chassis and the body of the car.

Even with the tram and the electric train one saves one of the two lines. The one line is the overhead line, the second line is the rails, Fig. 29.



Summary: One of the two conductors leading to the bicycle lamp is the bicycle frame. One of the two conductors leading to the electric locomotive are the rails.

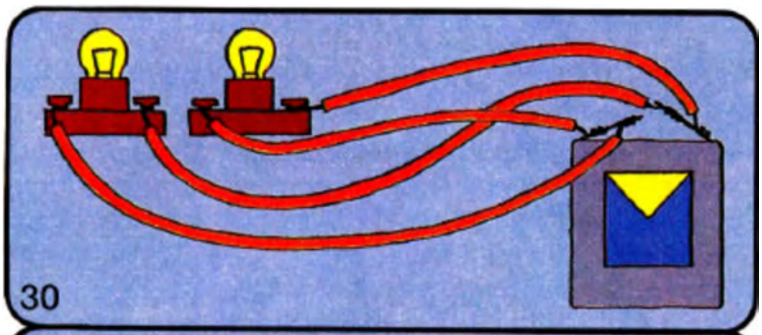
Exercise

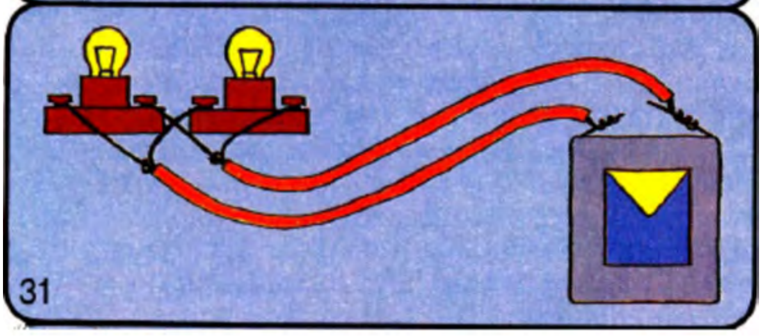
1. Why are bicycle dynamo and lamp connected by a single wire?

2. Give other examples where source and receiver are connected by a single wire. Where is the second connection?

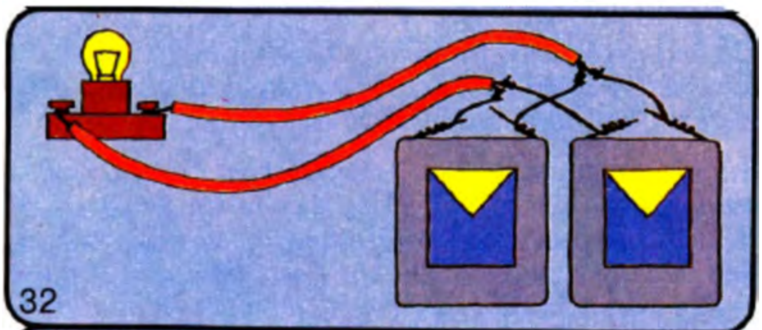
5.11 The electrical grid

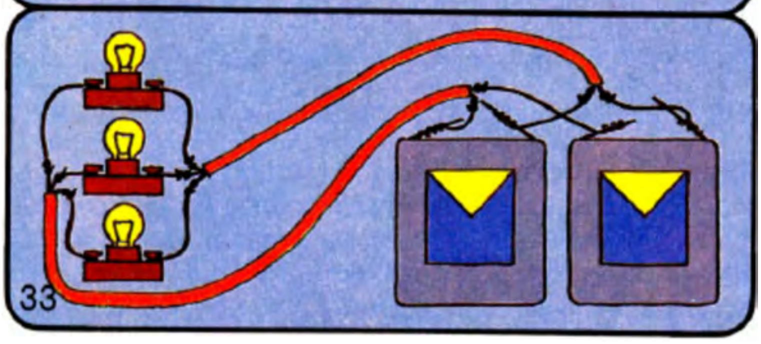
Two light bulbs are to be connected to one battery. Fig. 30 shows how to do that. But wire was wasted here. On Fig. 31 you can see how a part of the wires, namely the piece between the battery and the bifurcation, was shared for both lamps.





As it is possible to connect several receivers to one source, it is also possible to connect one receiver to several sources, Fig. 32. The batteries share the work here, they do not empty so quickly.





Of course you can also connect more receivers to more sources, Fig. 33. In principle the electrical grid has the same structure as the circuit of Fig. 33. All power plants in the country are connected by cables both to each other and to all houses and receivers in the houses. Think about the advantages that such a network has.

Exercises

1. If you want to connect three electrical devices, but you have only one so-cket in the wall, you can connect to the wall socket first a triple socket and then to this the three devices. How is the triple socket constructed?

2. Several radiators are connected to the central heating boiler. How are the pipes going? Make a drawing.

5.12 Electricity costs nothing

Each house has a so-called electricity meter (Fig. 9, section 1.3). The meter is read regularly and we receive a “electricity bill” which we have to pay.

We pay for a commodity that the power plant has delivered to us. Which product is that?

Do we pay the electricity? Did the power plant supply us with electricity? Delivering a good means that the goods are brought to us and that we then keep it. But you know that we do not keep the electricity. We only unload the energy from it and send it back to the power plant. (Electricity is a deposit-bottle energy carrier.) What we keep is not electricity, but energy, and we pay for it.

Summary: The “electricity meter” measures the energy that the power plant supplies.

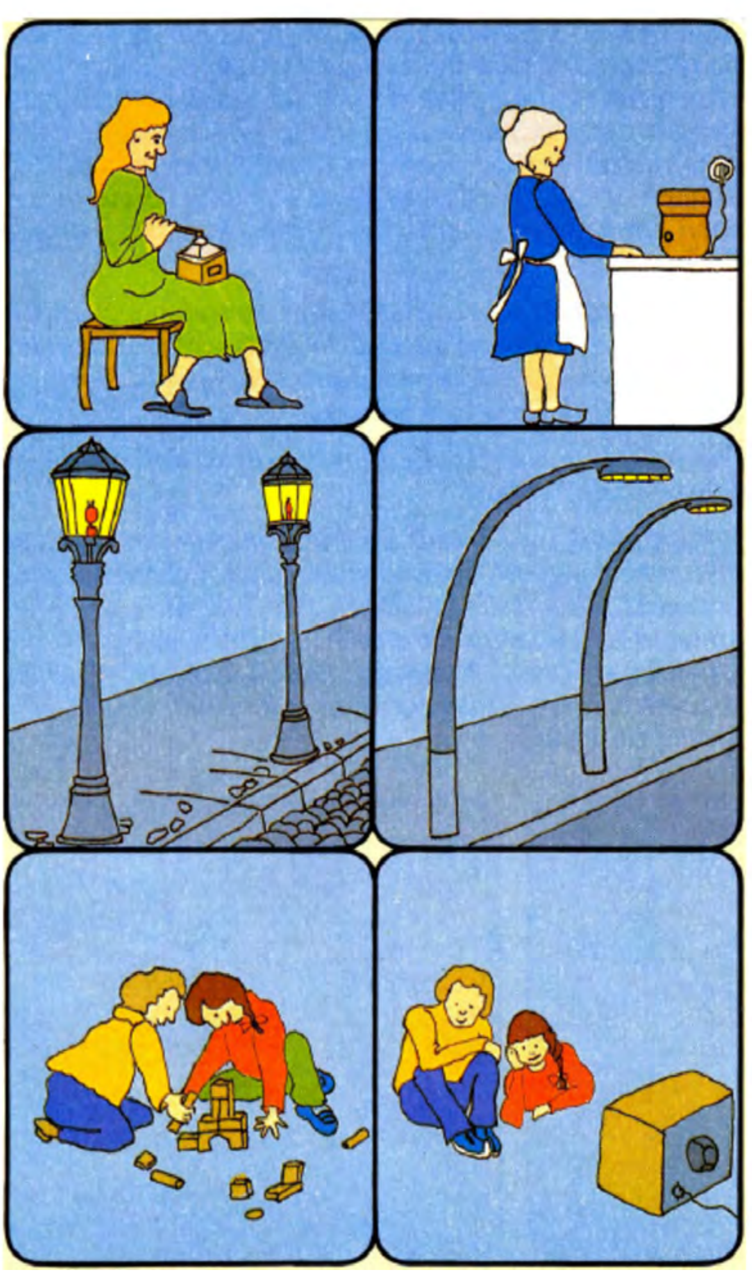
Exercises

1. Look closely at the “electricity meter” in your house. How can you tell if a lot of energy is being consumed?

2. How do you determine how much energy was used in a month?

S 5.1 Advantages and disadvantages of electricity as an energy carrier

The use of electricity as an energy carrier has brought a lot of relief to people.



In the past, people themselves supplied energy for many activities: washing clothes, grinding coffee, cutting bread, sweeping and sewing. Today, devices with an electric motor are used. The electric motor gets its energy with electricity.

In the past, energy carriers that were more impractical than electricity were used for other purposes. For example, candles, petroleum lamps and later gas lamps were used for lighting. Energy carriers here were wax, petroleum and light gas. The disadvantages of these light sources are obvious. In factories, the energy was carried to the machines by drive belts. The drive belts took up a lot of space, they used up, and switching the machines on and off was complicated.

Today we also use many devices that could not be built with other energy carriers than electricity: Radio, TV, telephone.

In addition, electricity is a very environmentally friendly energy source. For example, compare an electric lawn mower with a gas mower. The gas mower makes noise and emits exhaust fumes (= the empty energy carrier). The electric lawnmower runs quietly and no waste is produced, the empty energy carrier flows back to the power plant.

However, electricity does not only have advantages.

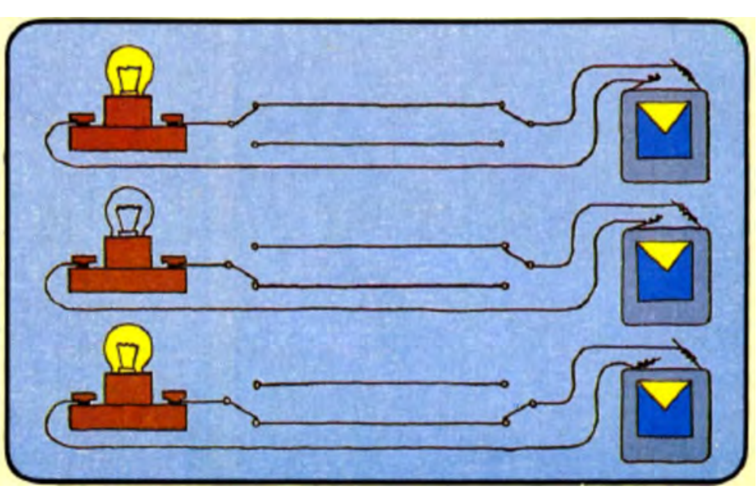
Once the energy has been charged onto the electricity in the power plant, it is very difficult (and expensive) to store the energy, it must be consumed immediately. In other words: the power plants may only release as much energy as is currently needed. When little energy is needed, the power plants cannot work on stock, some power plants have to be shut down, they stand around uselessly.

Another disadvantage is that 2/3 of the energy is lost in power plants when transloading energy from coal, oil or uranium to electricity. In addition, energy is also lost during transport from the power plant to the receivers.

The fact that electrical appliances are environmentally friendly is also only half the truth, because exhaust gases and other pollutants are now produced at another location, namely in the power plant.

S 5.2 The changeover circuit

Often you want to be able to switch a lamp on and off from two different positions. This cannot be achieved with ordinary switches. You need a changeover switch for this. The figure shows what the corresponding circuit looks like.



S 5.3 Electricity can be filled up

When water flows through a pipe, we have a current of water in front of us. Water in a bucket, on the other hand, is not a current of water, but unmoved water.

When electricity flows through a wire, we have an electric current in front of us. Can electricity also be collected in a container in which it rests, just like the water in the bucket?

In fact, it can. The container is simply a metal object, e.g. a metal sphere. This does not have to be hollow like the water bucket, because the electricity is in the metal, not in any cavity. The sphere must have a handle that does not conduct the electric current. Otherwise the electricity could flow off through the handle.

To bring electricity to the metal sphere, it could be connected to the one pole of a battery. In this way, however, very little electricity flows onto the sphere. You can get more electricity on the sphere with a Van de Graaf generator.

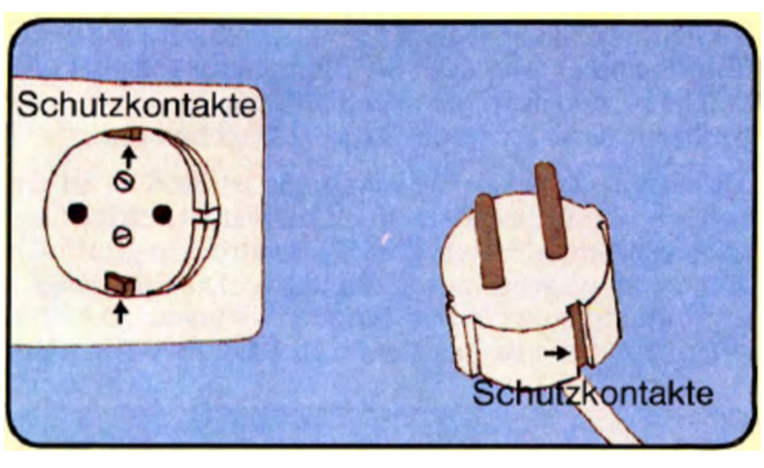
If the Van de Graaf generator is touched with the sphere for a short time, electricity flows onto the sphere, left picture. You can now carry around the electricity sitting on the sphere, middle picture. To see that it is still sitting on it, touch the sphere with a glow lamp. The electricity flows off to earth via the glow lamp. It lights up briefly, right picture.

You can also determine whether there is electricity on the sphere by touching it with your finger. You will then get a slight (harmless) electric shock.

So the sphere is the same for electricity as the bucket for water.

If you walk around on a certain type of carpet for a longer time, you also collect electricity. You become "electrically charged". If you now touch another object, such as a door handle, you will get an electric shock. An electric current flows through your hand to the door handle and from the door handle to earth.

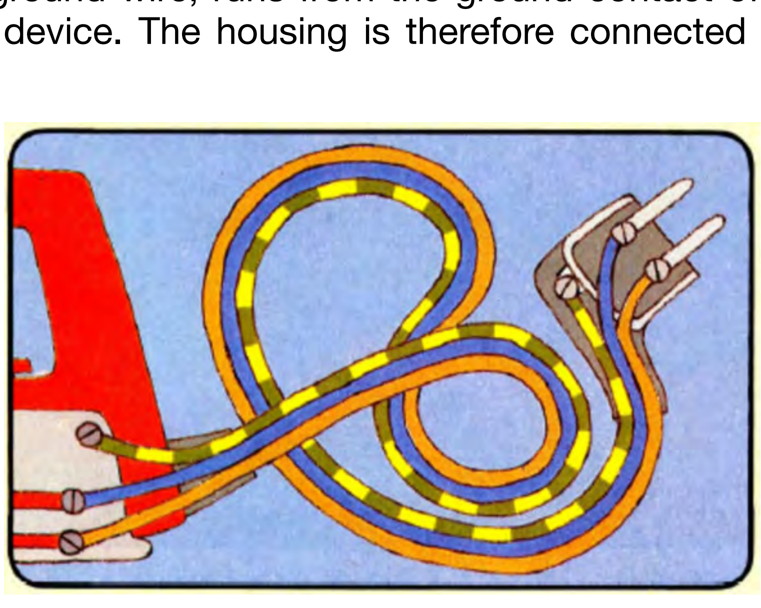
S 5.4 The ground wire



grounding contact

grounding contact

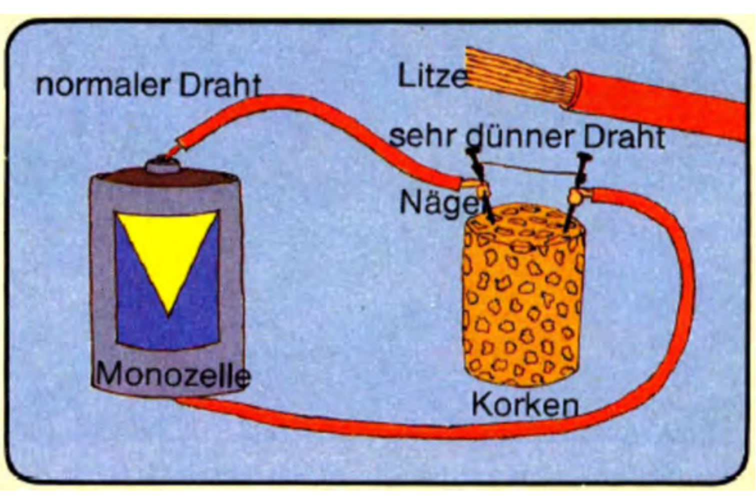
The two holes in a socket are the connections for the electricity to and fro. In addition, the socket outlet has a third connection, the ground contact. (There are two metal brackets, but they are connected to each other inside the socket. They therefore only form one contact.) The ground contact of the socket is connected to earth via a wire. Many electrical devices have a cable with three wires and a plug with two pins and a double ground contact. The third wire, the ground wire, runs from the ground contact of the plug to the housing of the device. The housing is therefore connected to earth via the ground wire.



If one of the poles in the device accidentally comes into contact with the housing, the electricity flows to earth via the ground wire. You can't get an electric shock.

S 5.5 The electric current causes a wire to glow

Connect the two poles of a monocell to the ends of a short, very thin wire, as shown in the picture. The wire begins to glow.



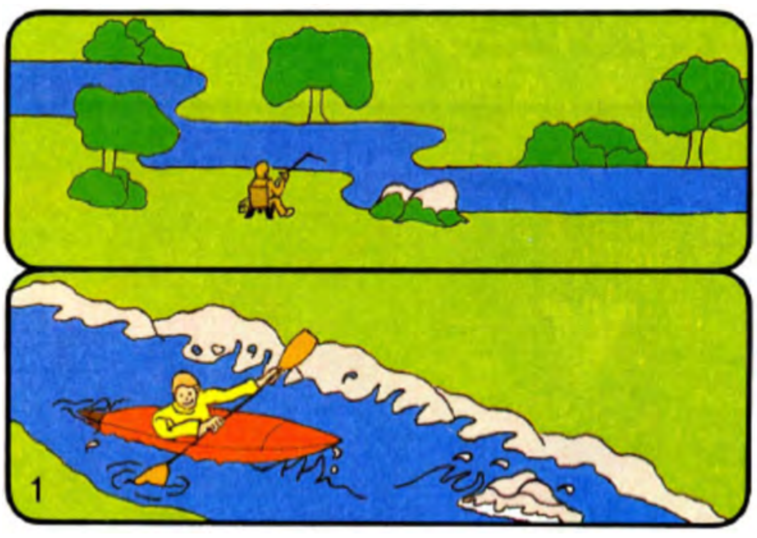
normal wire
copper cable
very thin wire
nails
monocell
corc

You can get a wire that is thin enough when you pull a piece of copper cable apart. The cores of each conductor consist of very many thin copper threads. (The advantage of this kind of conductor over a thick wire is that it is flexible.)

6. Currents of energy and of energy carriers

6.1 The current strength

It happens that one wants to compare two currents or streams, e.g. two water streams. So one may ask, “Which of the two streams is wider?”, Or “Which of the two flows faster?”. In Fig. 1, the upper water stream is wider than the lower one, but the lower one is faster. Often you are not interested in the width, nor the speed, but in the current strength.

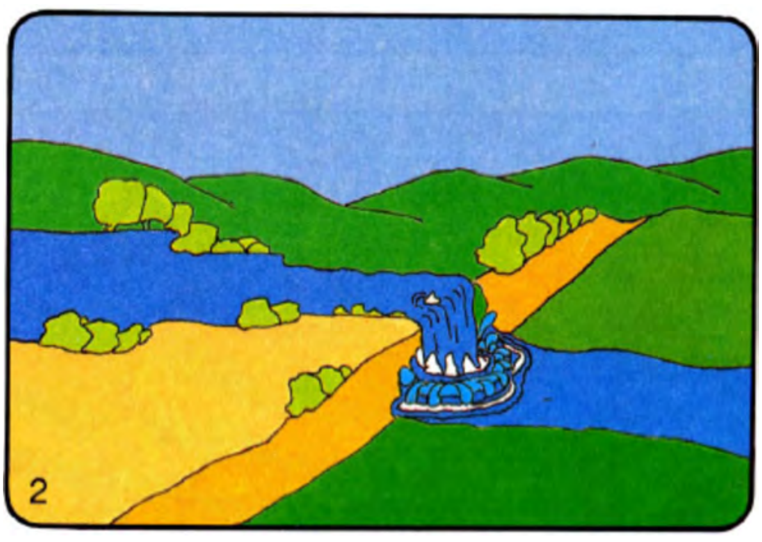


Water streams can be of different widths and different speeds.

The current strength of a water flow indicates how many liters of water flow by at any position in a second. For example, in the Rhine river around 1,500,000 liters of water flow every second past Karlsruhe. If you were to draw a wall through the Rhine, you would have to scoop 1,500,000 liters of water per second over the wall, so that the Rhine continues to flow quietly. It is said that the *current strength* of the Rhine is 1,500,000 liters per second or, in short, 1,500,000 l/s.

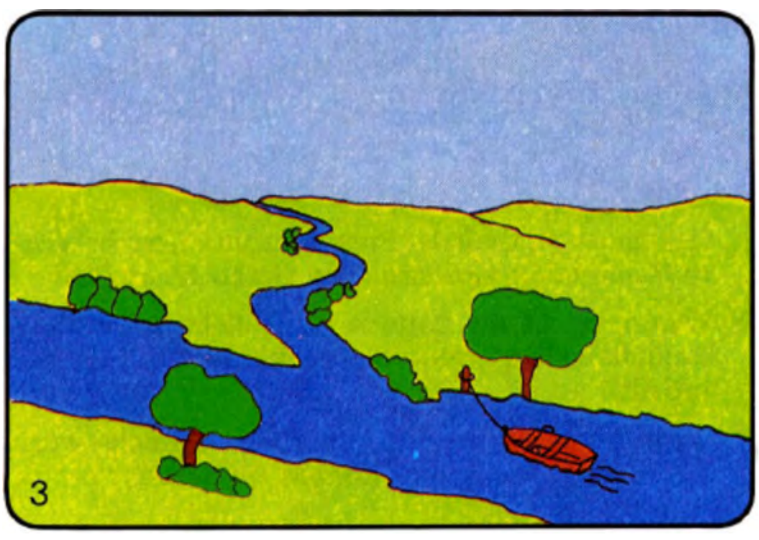
The strength of the “stream of cars” on one side of a highway is about one car per second.

One easily confuses the strength of a current with its speed. The river on picture 2 has the same current strength everywhere. If 1000 liters flow on the left side in a second, 1000 liters must also flow in one second at the narrow place in the middle of the picture and also in the waterfall, because between the trees to the left and the waterfall neither water has disappeared nor is it added. At the narrow point, the current is narrower and faster than at the wide, but the current strength is the same.



The water current strength is the same at every cross section of the river.

The river in Fig. 3 does not have the same current strength everywhere. If its strength before the confluence of the brook is 1000 l/s, and 100 l/s flow through the brook, the current strength on the right side next to the boat must be 1100 l/s.



Before the confluence, the current strength is smaller than behind.

“The current strength of the water stream is large“ is a rather cumbersome sentence. Often one makes it easier by simply saying, “The water current is great.” When saying “The current is great”, one means, “The current strength of the current is great.“ Regarding Fig. 2 we can say: “The water current next to the tree is just as great as in the waterfall.”

Summary: The water current strength indicates how many liters of water flow in one second through any cross section of the stream. The current strength of a stream of cars indicates how many cars pass in any one second at any position of the road.

Exercises

1. In what can two streams of water differ?

2. What does the current a) of a water flow, b) of an car current express?

3. Measure the strength of the water current coming out of a fully opened faucet.

4. Why is the strength of the water current at each position of the river in Fig. 2 the same?

5. A bathtub that holds 120 liters will fill up in 10 minutes. What is the strength of the water current that flows into the bathtub?

6.2 The energy current

What is more expensive: If you forget to switch off the oven of the electric cooker or if you forget to switch off a light bulb? Of course, keeping the electric stove on is much more expensive. It needs more energy.

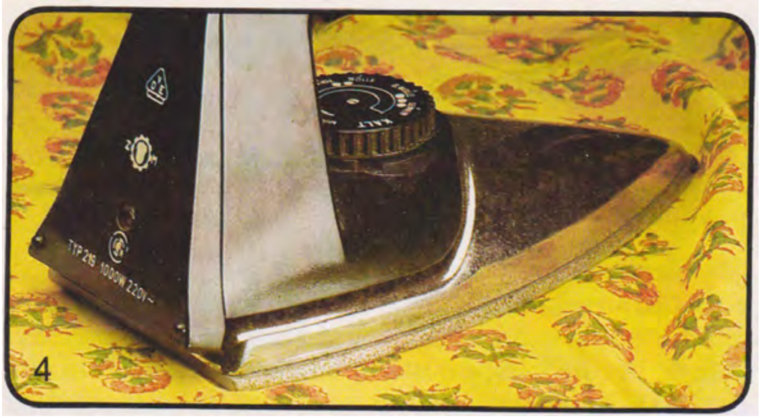
A stove needs more energy than a lamp? Something about this sentence can not be correct. If the stove has been running for an hour, but the lamp has been running for a month, the lamp has certainly needed more energy. A device needs more kilojoules the longer it is switched on. If you let a lightbulb burn for two hours, it takes twice as much energy as in an hour.

But what does it mean when you say that an electric stove needs more energy than a lamp? Without being explicit, it is said that the stove needs more energy than the lamp when it is turned on for as long as the lamp. The stove needs 2000 J in one second, the lamp needs 100 J in one second.

This can be expressed as follows: The energy current that flows into the stove is 2000 joules per second, and the energy current flowing into the lamp is 100 joules per second. The stove needs 20 times as much as the lamp.

On many devices that are energy receivers, the energy flow, or “energy consumption”, is indicated. Since the measuring unit “joules per second” (abbreviated J/s) occurs so often, it has been given its own name: Watt.

Probably you have already encountered this measuring unit. It is printed on most electrical appliances, Fig. 4. If a “500 W” vacuum cleaner is used, this means: When the vacuum cleaner is switched on, 500 J will flow into it through the cable every second.



4

The number of Watts indicates the energy current that flows into the device.

For large values of the number of watts, the kilowatt (kW) is used: 1 kW = 1000 W and for even larger megawatts (MW): 1 MW = 1000 kW = 1,000,000 W.

Summary: The strength of the energy current is measured in Watts. Watt is an abbreviation for joule per second.

Supplements S 6.1 and S 6.2

Exercises

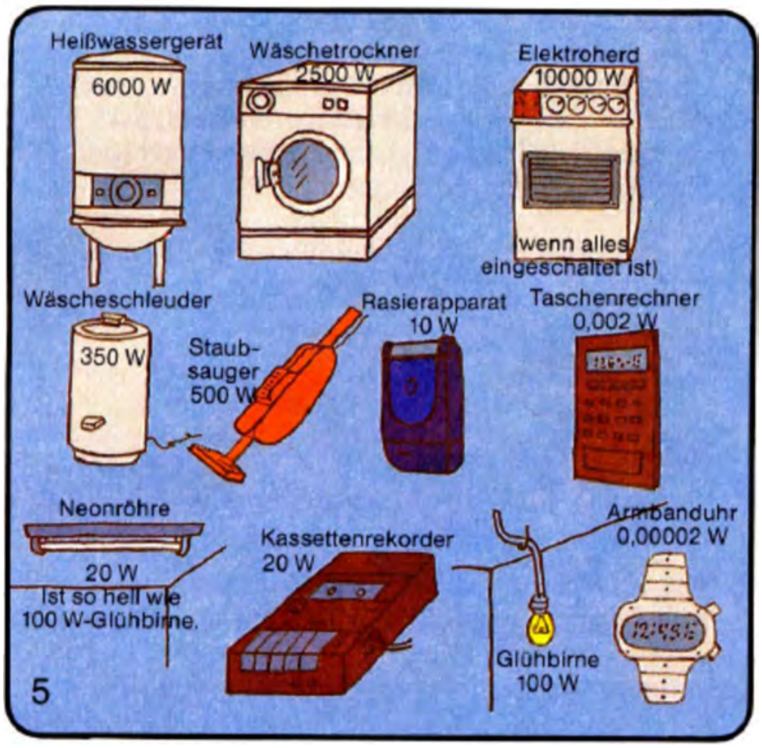
1. Why is a number of watts printed on electrical appliances and not a number of joules?

2. A light bulb needs 1000 joules in 10 seconds. A stove needs the same amount of energy in one second. What is the strength of the energy current that flows a) into the light bulb, b) into the stove?

3. How long does a 2 W lamp burn when connected a) to a full flashlight battery, b) to a full car battery? (The flashlight battery contains 10 kJ, the car battery 2000 kJ.)

6.3 Energy currents in the household

The energy currents that flow into electrical appliances in the household have a wide range of values. On Fig. 5 they are indicated for some devices. If you look closely at the picture, you can find a rule.



boiler

washing machine

electric cooker
(if everything is switches on)

spin-dryer
vacuum cleaner
electric shaver
pocket calculator

fluorescent lamp
20 W is as bright as a 100 W incandescent lamp
cassette recorder
incandescent lamp
wrist watch

Appliances that heat something have the greatest energy demand: the water heater, the tumble dryer, the cooker, the electric oven, the dishwasher. Less energy is needed in devices that move something or that illuminate: spin dryers, vacuum cleaners, razors, lamps. And much less energy is needed by electronic devices, such as the calculator or the electric wristwatch.

If you want to save energy, make sure that the “heaters” do not run unnecessarily.

Summary: Devices that heat something need much energy, devices that move or illuminate need less, and electronic devices need very little energy.

Supplement S 6.3

Exercises

1. Find out how big is the energy current that flows into the various devices in your home.

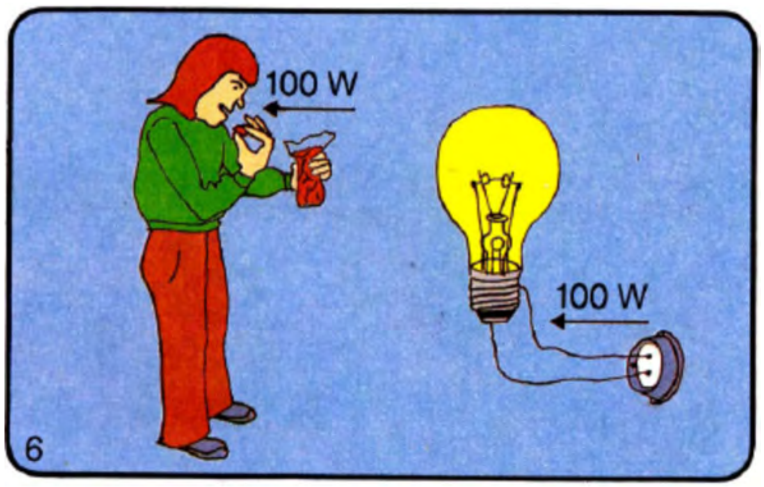
2. Why does the battery of an electric watch last so long, even though it contains very little energy?

3. Which electrical devices do you have to run as little as possible if you want to save energy?

6.4 The energy consumption of humans

The energy that humans needs to live, they get with the food. How big is the flow of energy that flows into people with food? How much energy does one need per second?

It certainly depends on what one is doing, whether one makes an exhausting walk or sits in the armchair and looks at the TV, for example. But we can ask how big the energy consumption of the person is on average.



We can calculate this average energy flow. We know that humans need about 10,000 kJ per day or 10,000,000 J. One day has 86,400 seconds. Thus, on average, in one second a human needs

$$10\,000\,000 \text{ J} : 86\,400 \text{ J} \approx 116 \text{ J}$$

The average human energy consumption is thus 100 J per second, or 100 W. This is the same as the energy consumption of a strong incandescent lamp.

So far, we have only taken into account the energy that the human receives when eating. But he or she also needs energy for heating, and for a variety of household appliances. In addition, much energy is consumed in industry, agriculture and transport. For a resident of the Federal Republic this amounts to a little more than 5 kW.

Summary: On average, humans consume an energy current of 100 W with food. The energy consumption in household, industry, agriculture and traffic is about 5 kW per capita.

Supplements S 6.4 to S 6.6

6.5 The strength of the electric current

We have learned to measure the strength of the energy current in watts. The energy carrier currents also have measurement units. You can probably specify most of them yourself.

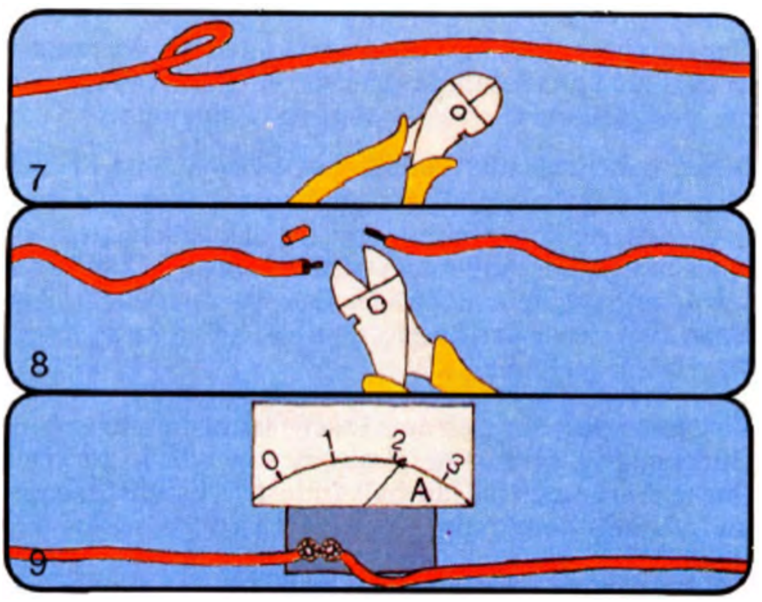
Water, hydraulic oil, gasoline or heating oil currents are measured in liters per second (l/s).

Currents of coal or food can be measured in kilograms per second (kg/s).

Only for the electric current we still lack the unit of measurement. It is called amperes, abbreviated A. If a lot of electricity flows through a wire per second, then the ampere-number is large, if little electricity flows, it is small.

To measure the electric current in a wire, one uses an ammeter. Dealing with an ammeter is very easy.

The strength of the current flowing through the wire in Fig. 7 should be measured. First cut the wire. Two new ends are created, Fig. 8. Connect these ends to the two terminals of the ammeter, Fig. 9. The electricity now flows through the ammeter and the current is displayed.



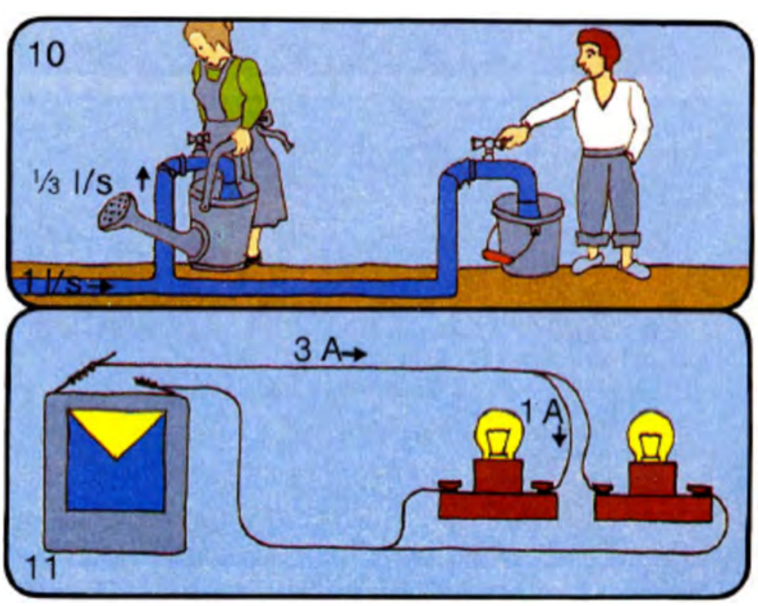
Summary: The measurement unit for the strength of the electric current is the ampere.

Supplement S 6.7

Exercises

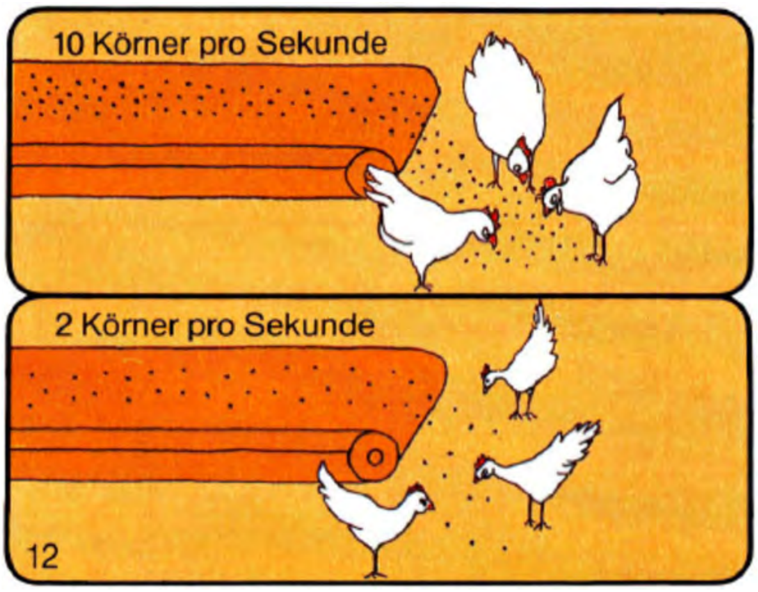
1.How large is the water current on the right tap in Fig. 10?

2. How big is the electric current through the right lamp in Fig. 11? (Help: Supplement S 6.7)



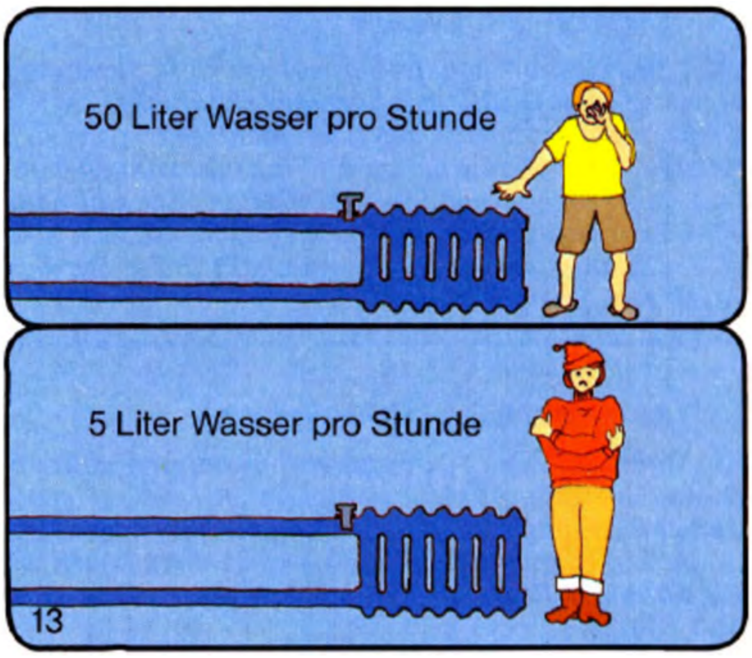
6.6 Many carriers carry much

Compare the three pictures 12, 13 and 14. They have something in common. In each picture, a large carrier current flows at the top and a smaller one at the bottom. This always has the consequence that above a large current of energy flows and below a smaller current. The larger the current of the energy carrier, the greater the energy current.



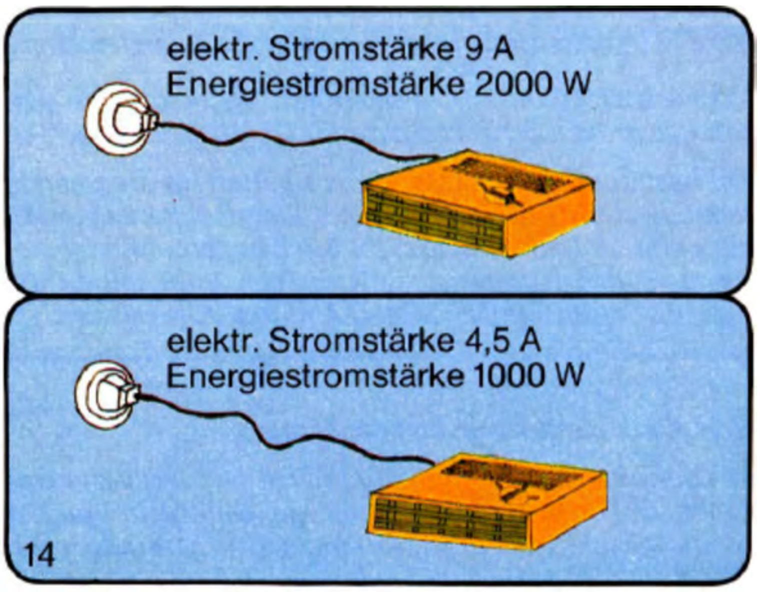
10 grains per second

2 grains per second



50 l of water per second

5 l of water per second



electric current: 9 A
energy current: 2000 W

electric current: 4.5 A
energy current: 1000 W

So you can make the energy flow larger or smaller by making the current of the energy carrier larger and smaller.

But you can still make the energy current big or small in a second way. You will see in chapter 7 how this is done.

Summary: You can make the energy flow bigger or smaller by making the flow of energy carriers bigger or smaller.

S 6.1 Power = energy current

Instead of energy current, the word “power” is often used. They say: “The lamp has a power of 100 W”. However, this way of speaking is not very happily chosen. Two devices of the same wattage can achieve very different powers. For example, a 40 W fluorescent tube emits five times as much light as a 40 W incandescent lamp. We therefore prefer to stick to the term “energy current”.

S 6.2 A third unit of measurement for energy

The meter of the “electricity meter” shows how much energy has flowed into the house. Unfortunately, the meter does not display the energy in the unit J or kJ, but in kilowatt hours, abbreviated kWh. One kilowatt hour represents the same amount of energy as 3600 kJ, i.e.

1 kWh = 3600 kJ.

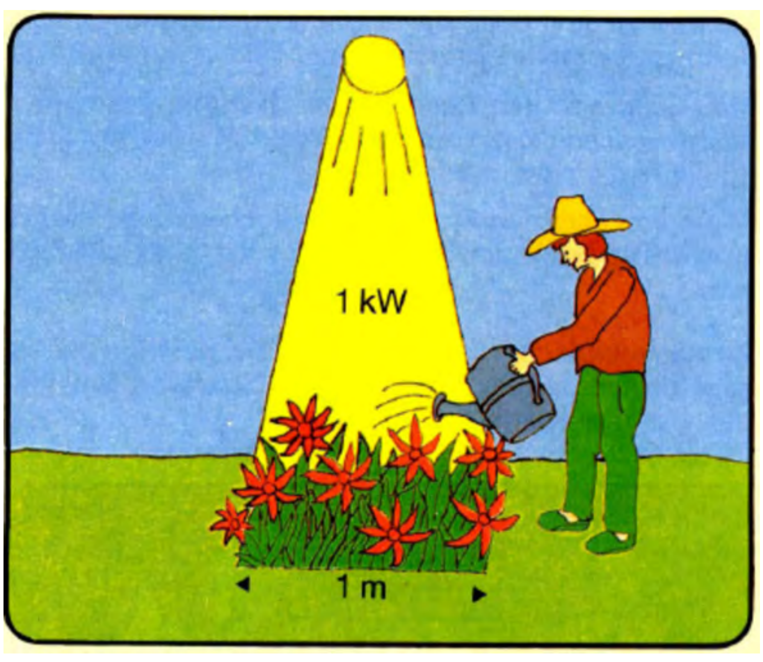
One kilowatt hour is therefore a large amount of energy.

Do not confuse the unit of measurement kilowatt for the energy current with kilowatt hour for the energy itself!

You have already learned three units of energy: kJ, kcal and kWh. To avoid confusion, we only use one of them in this book: kilojoules. Imagine measuring the length alternately in meters and feet.

S 6.3 The energy current from the sun

The sun sends energy to the earth. The energy carrier is light. For every square meter illuminated vertically by the sun, about 1000 J per second arrive, i.e. for every square meter an energy current of 1000 W is flowing. If you want to use solar energy, you have to capture it. That’s not easy. But sunshine costs nothing and it is inexhaustible. That’s why it’s worth thinking about how to capture solar energy.



S 6.4 The Energy consumption of humans and various animals while resting

mouse	0.2 W
rat	1.6 W
rabbit	6 W
dog	25 W
man	80 W
bull	600 W
elephant	2400 W

S 6.5 hp and kW

hp (horse power) is an outdated unit of measurement for the strength of the energy current.

1 hp = 0.734 kW.

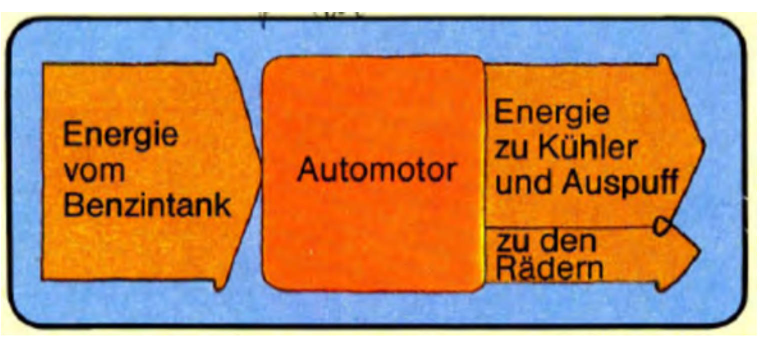
You can remember that approximately 1 hp = 3/4 kW. If the horsepower value is divided by 4 and multiplied by 3, the kW value is obtained.

S 6.6 The kW-indication for cars

A large car “has” 100 hp or, which is the same, 73 kW. What does that actually mean? You can see from the unit of measurement that it is an energy current.

If 100 W is written on an incandescent lamp, this means that the lamp consumes 100 J per second.

One could think that the 73 kW car engine consumes 73 kJ per second. But that’s not correct. The energy consumption of the motor is much higher. Three quarters of them leave the car unused through the radiator and the exhaust pipe.



energy from the gasoline tank

car engine

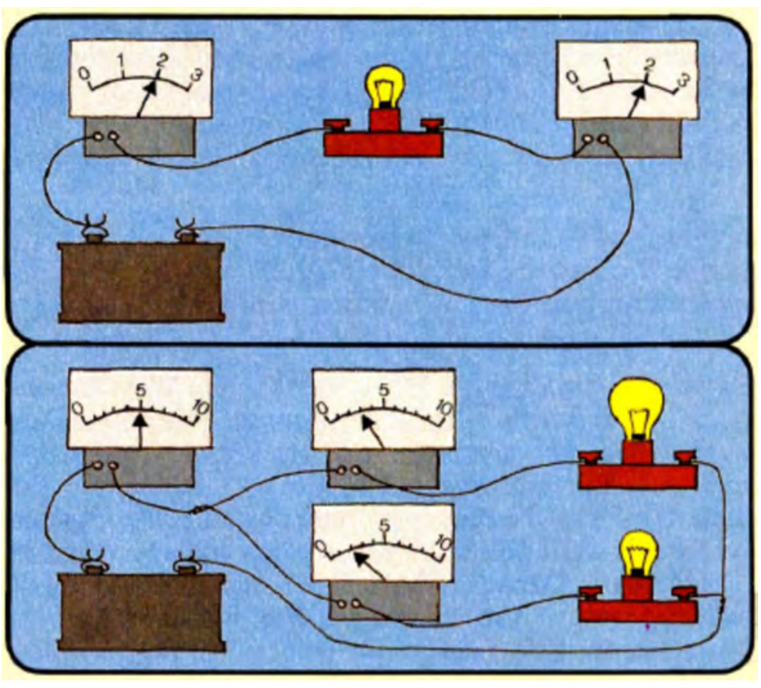
energy that goes to the radiator and the exhaust

to the wheels

Only the remaining quarter is passed on to the wheels. The specification of 73 kW means that the energy current to the wheels can amount to a maximum of 73 kW.

S 6.7 Electricity is not lost

With the help of two ammeters you can show that an electrical device does not consume electricity. The electric current is measured in the forward and in the return line. Both ammeters indicate exactly the same value. All the electricity that is flowing from the source to the receiver flows through the other line back to the source.

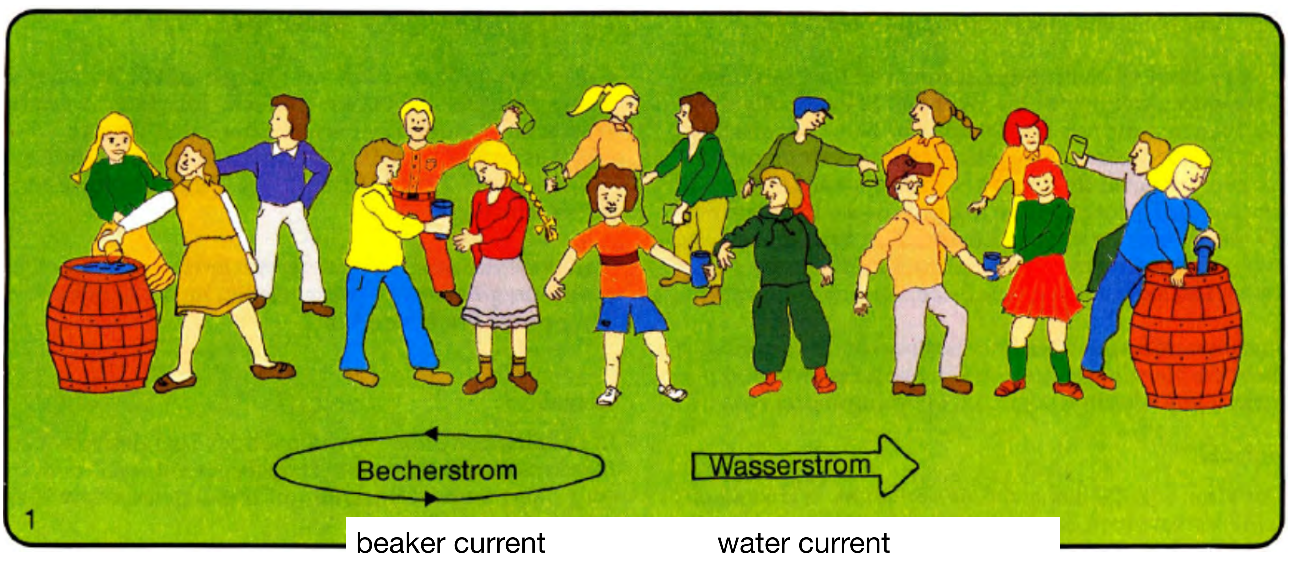


At the forking point, the electric current coming from the battery divides. One part flows to the small lamp, one part to the large lamp. To see how much, we have installed an ammeter in front of each lamp. One shows 2A, the other 3A. To check it out, we put another ammeter in front of the fork. It naturally displays 5 A.

7. The loading of the energy carrier with energy

7.1 We transport water

Forget the energy for a moment. Imagine transporting water rather than energy, from one big barrel to another.

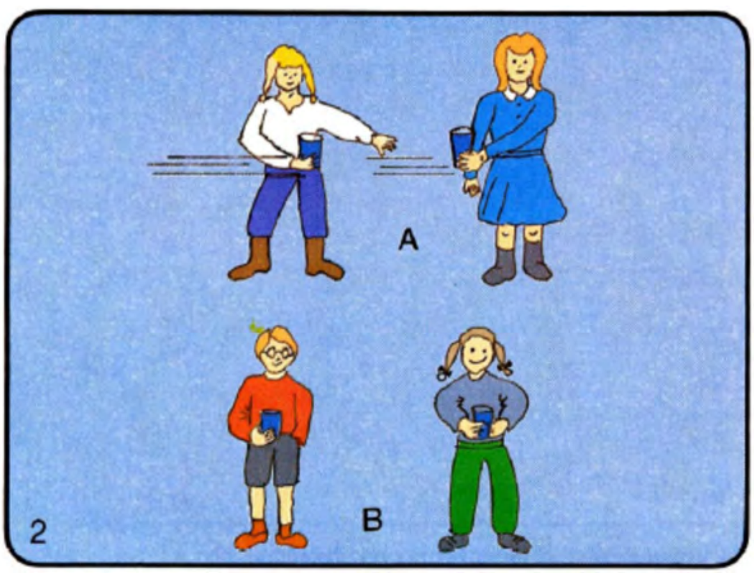


beaker current water current

We are 17 people and transport the water as shown in Fig. 1. Everyone has a beaker in their hands and everyone stays in place. The one closest to the full barrel scoops water from the barrel with his beaker and hands it to his neighbor. This one gives the cup to the next one and so on. The last in the chain spills out the beaker, into the second barrel. The empty beakers go back through a second chain. You see that the beaker current is a deposit-bottle current.

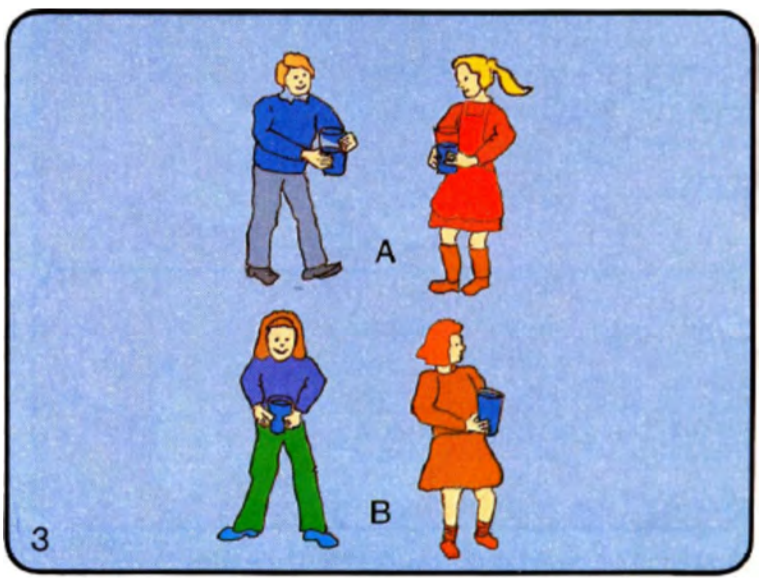
Make sure that in this game not energy but water is transported. When dealing with energy we have an energy carrier, here we have water carriers: the beakers.

Now we ask ourselves how we can make the water current stronger or weaker. How can we get more or less water from the left into the right barrel in one minute? This is very simple: We fill the beakers very quickly and pass them on quickly, Fig. 2A. So we get a big water current. Then we fill them slowly and pass them slowly to the neighbor, Fig. 2B. So we get a small current of water. The water current is greater the greater the current of water carriers.



Do you notice that this sentence is almost the same as the summary in section 6.6? Only the word water is replaced by the word energy.

There is another way to make the water flow large and small. We always let the beaker current equal, say one beaker every two seconds, that is 30 beakers per minute. But we first make the beakers only half full, Fig. 3A. We get a small current of water. Then we make the beakers full, picture 3B. This gives us a water current that is twice as big as before. The water current is thus greater, the more water is in each beaker; In other words, the more the water carriers are loaded with water, the greater the water flow.



This sentence also remains correct if the word water is replaced by the word energy: the energy current is greater the more the energy carrier is loaded with energy.

It is easy to fill a beaker, i.e. a water carrier, with more or less water. But how can we fill an energy carrier, electricity, the bicycle chain or compressed air with more or less energy? We will see that in the next sections.

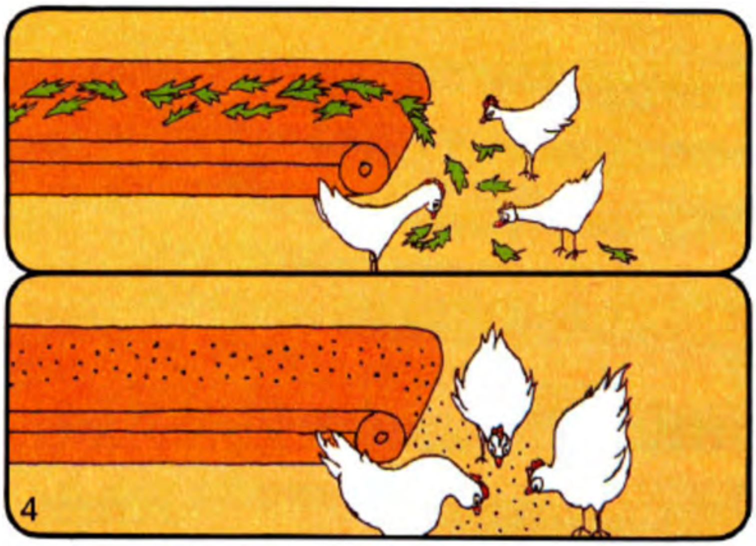
Exercises

1. What in our game corresponds to energy, what corresponds to the energy carrier?

2. In which two ways can you make the current of water bigger or smaller?

7.2 Loading of food with energy

Is it possible that, 1 kg of food has much energy and another 1 kg has few energy? Of course. You only need to look at the table in section 1.3. Fig. 4 shows two equal food currents. Each time the current strength is 2 g/s, but in the first case it is dandelion and in the second it is grains. In the case of the grains the energy current is 20 times that of the case of the dandelion. We can also put it this way: The food current is loaded in the first case with little energy, in the second with a lot.



Grains are loaded with more energy than dandelion.

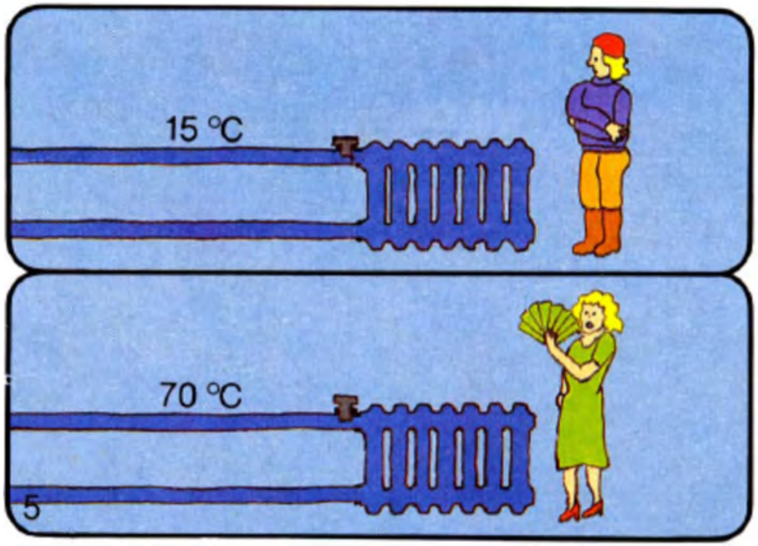
Summary: The energy flow is greater the more the food is loaded with energy, i.e. the more kilojoules a kilogram of food contains.

Exercise

The hare eats 20 times more than the fox. How can that be? Use the word "loaded" in your answer.

7.3 Loading water with energy

Is it possible that, 1 l of water has much energy and another 1 l has few energy? Of course. One liter of warm water has more energy than one liter of cold water. Hot water is charged with more energy than cold water. Therefore, the woman on Fig. 5 is cold, and the one on Fig. 5 is warm.



Warm water is charged with more energy than cold water.

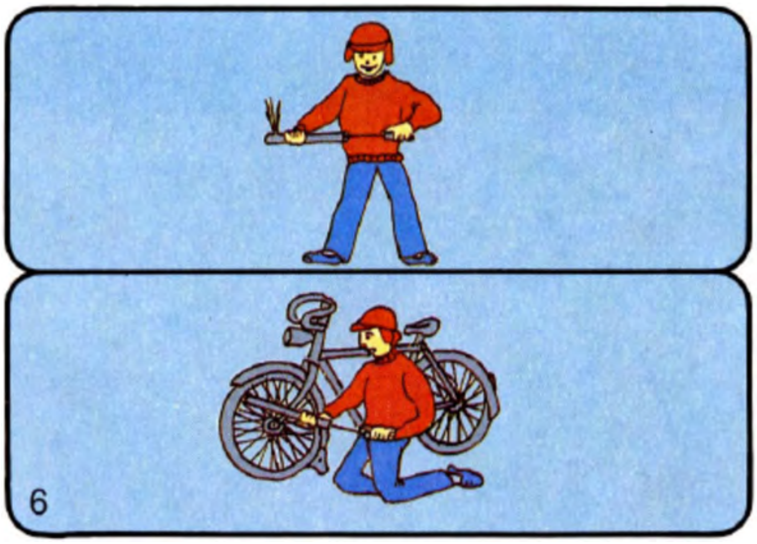
Summary: The energy current is greater, the more energy is charged on the water, i.e. the higher the temperature of the water.

Exercise

It's getting colder. Therefore, the energy current from the boiler in the basement to the radiators in the rooms should be increased. This can be achieved in two ways. How?

7.4 Pressure

Take a bicycle pump in your hand and simply pump out into the open, Fig. 6. Make about two strokes per second. Count until you've made 40 strokes Is it exhausting? Now attach the pump to a bicycle tire from which you have previously let out the air. Pump again with two strokes per second and pay attention again to whether it is exhausting. After 40 strokes, you know for sure (if you can do it at all): It's harder to inflate the tire than just push the air out into the open.



Air at high pressure carries more energy than air at low pressure.

To inflate the tire you need more energy. The air that you pressed into the tires carries more energy than the air that has flowed outside. Since you made two strokes per second in both cases the airflow is the same. But in the second case the air current has carried more energy.

How can we see, wether an air current is loaded with much or little energy? We recognize it by the pressure. The pressure is measured in bar. The air you have pressed in the tires has 2 to 2.5 bar. It is called compressed air. The air you have just pushed into the open has a pressure of 1 bar. Also the pressure in liquids is given in bar. The water in your water pipe has a pressure of about 4 bar.

Summary: The energy flow is greater the more energy is charged to the air, i. e. the higher the pressure of the air.

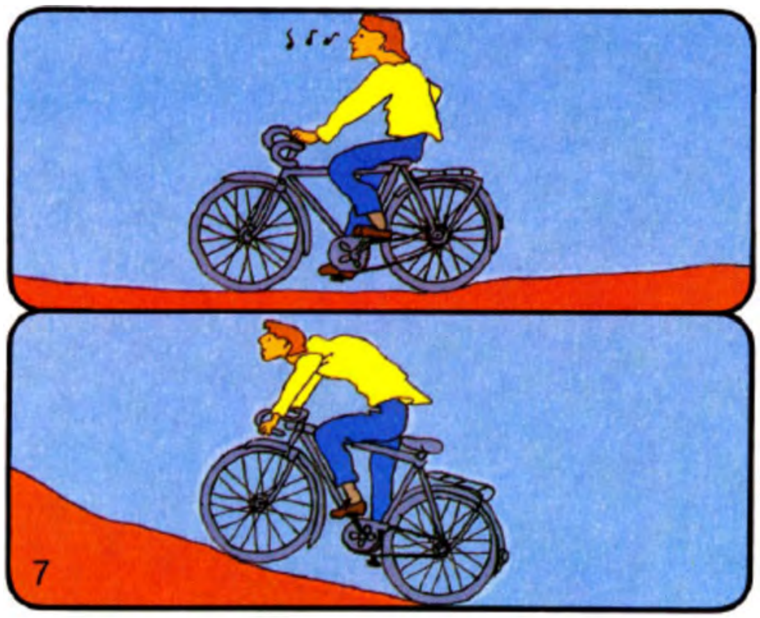
Supplements S 7.1 to S 7.3

Exercise

How do you know whether a current of air is loaded with much or little energy?

7.5 Loading the bicycle chain with energy

Imagine riding a bike, once on a level track and once up a steep hill, Fig 7. Every time you pedal one turn in one second. In both cases, the same number of chain links flows over the gears per second. If the front sprocket has 46 teeth, there are 46 links per second. In both cases, the current of the energy carrier “bicycle chain” is the same.



The chain in the lower Figure is more strained then that in the upper figure. It carries more energy.

Nevertheless, the energy current from front to back is not the same in the two cases. When driving uphill, it is greater. You notice that very clearly in the effort you have to make. Since the carrier current is the same in both cases, the energy carrier must be loaded with more energy in the second situation.

You also notice from the chain, whether it is loaded with much or little energy. The more it is loaded with energy, the more the upper part of the chain is strained.

Summary: The energy flow is greater, the more energy is loaded on the chain, i.e. the more the chain is strained by pedaling.

Supplement S 7.4

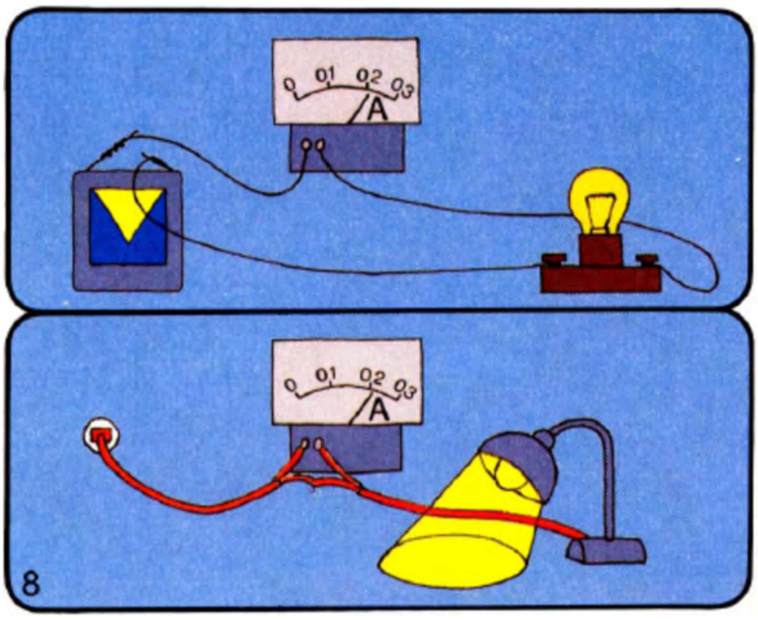
Exercise

Two children ride moped. Both travel at the same speed, but one goes against the wind, the other goes with the wind. Is the energy flowing through the moped chain the same for both? How does one see from the chain, whether the energy current is small or large?

7.6 Voltage

We will make an experiment, the result of which will surprise you. A large light bulb is connected to the socket, and a small flashlight bulb to a small battery. In which circuit does a larger electric current flow? In the circuit with the big bulb?

We install an ammeter in both circuits. The two measuring devices show almost the same, Fig. 8.



In the battery, the electric current is charged with less energy than in the power plant.

The energy current that flows into the small lamp is much smaller than that which flows into the large one. You can tell it from the fact that the small lamp emits less light and warms less than the big one. You can also see it on the watts printed on the bulbs. On the big one it is 60 W, so 60 J per second, on the small one it is 2 W. The small one gets 30 times less energy than the big one.

Why is the energy flow to the lamps so different, although the current of the energy carrier is almost the same? This can only be because once much and once little energy is charged on the energy carrier.

The power plant to which the socket is connected charges the electric current with more energy than the battery. It is said that the socket has a higher *voltage*. Sometimes instead of voltage one says electric tension.

The value of the voltage is indicated in volts, abbreviated V. Our battery has (as long as there is still energy in it) 4.5 V. The socket has 220 V, a monocell 1.5 V and a transistor battery 9 V.

An energy source of high voltage charges the electric current with more energy than a source of low voltage.

Summary: The energy current is greater the more energy is charged on the electricity, i.e. the higher the voltage.

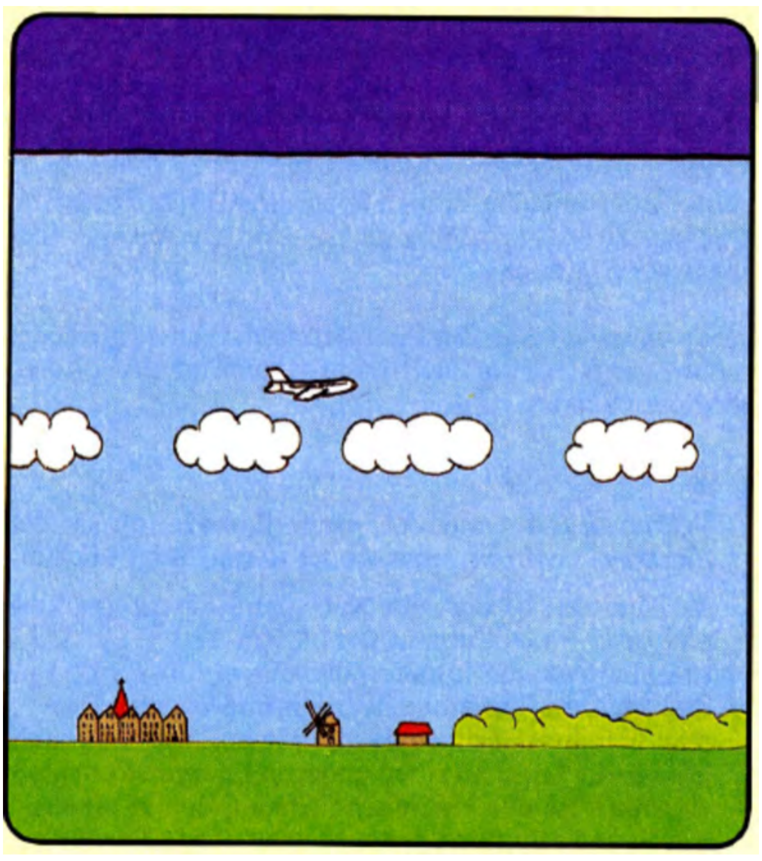
Exercises

1. How can you tell if a battery is charging the electric current with much or little energy?

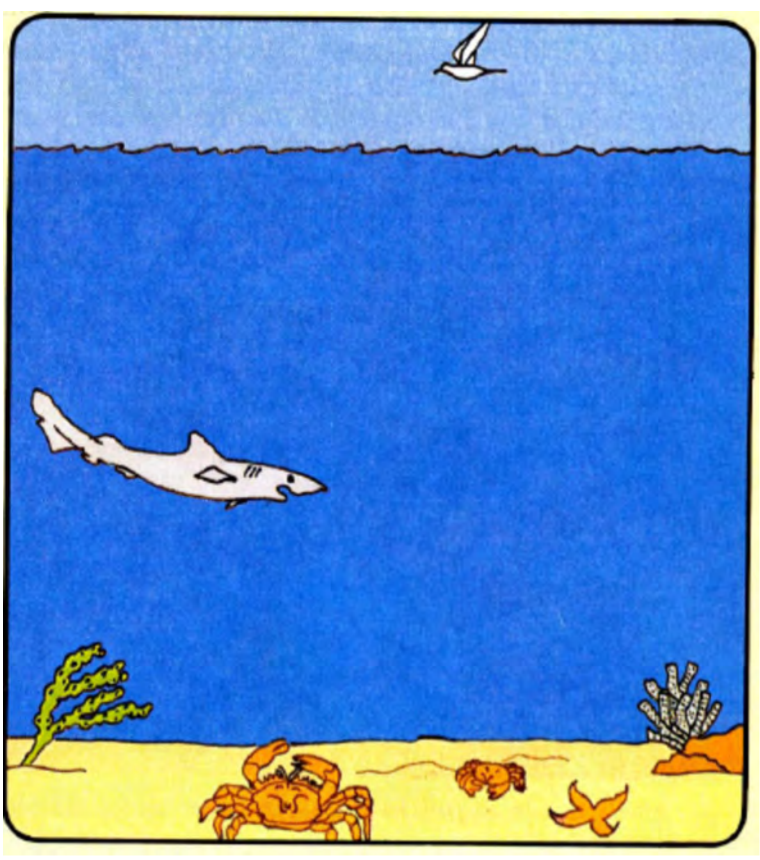
2. In America, the mains voltage is 110 V. Many electrical devices can therefore be switched from 220 V to 110 V. So they can be used both in Europe and in America, and of course they perform equally in America and in Europe. Does a hair dryer in America need a different energy current than in Europe? Is the electric current flowing in America through the hair dryer just as great as in Europe?

S 7.1 Air pressure

Above the earth's surface lies a layer of air about 50 km thick. The people on the surface of the earth live on the bottom of a 50 km deep "sea of air", similar to crabs that are crawling around on the bottom of the sea.



At the bottom of the sea or a lake you can feel the weight of the water above you. This water creates a pressure. The pressure increases from top to bottom. At the bottom of our sea of air we are exposed to the weight of the air above us: on the earth's surface there is an air pressure of about 1 bar. If you climb up, it gets lower. At an altitude of 50 km it is practically equal to 0 bar.



The air pressure on the earth's surface constantly changes its value. It varies between about 960 and 1060 mbar (1 bar = 1000 mbar, i.e. millibar).

There is a relationship between air pressure and weather. In bad weather, the air pressure is usually lower than in good weather.

S 7.2 The true thickness of the layer of air above the earth's surface

In S 7.1 it was said that the air layer of the earth was 50 km high. In fact, however, the air layer has no sharp upper boundary; it is simply becoming thinner and thinner. At an altitude of 10 km it is already about 4 times thinner than at sea level. The 50 km are only a rough guideline. Maybe you think 50 km is much. But just imagine this layer of air on a globe on the right scale. The diameter of the earth (12800 km) corresponds to the diameter of the globe, the 50 km thick layer of air then corresponds only to a very thin skin on the globe.

S 7.3 The air pressure in the car tire

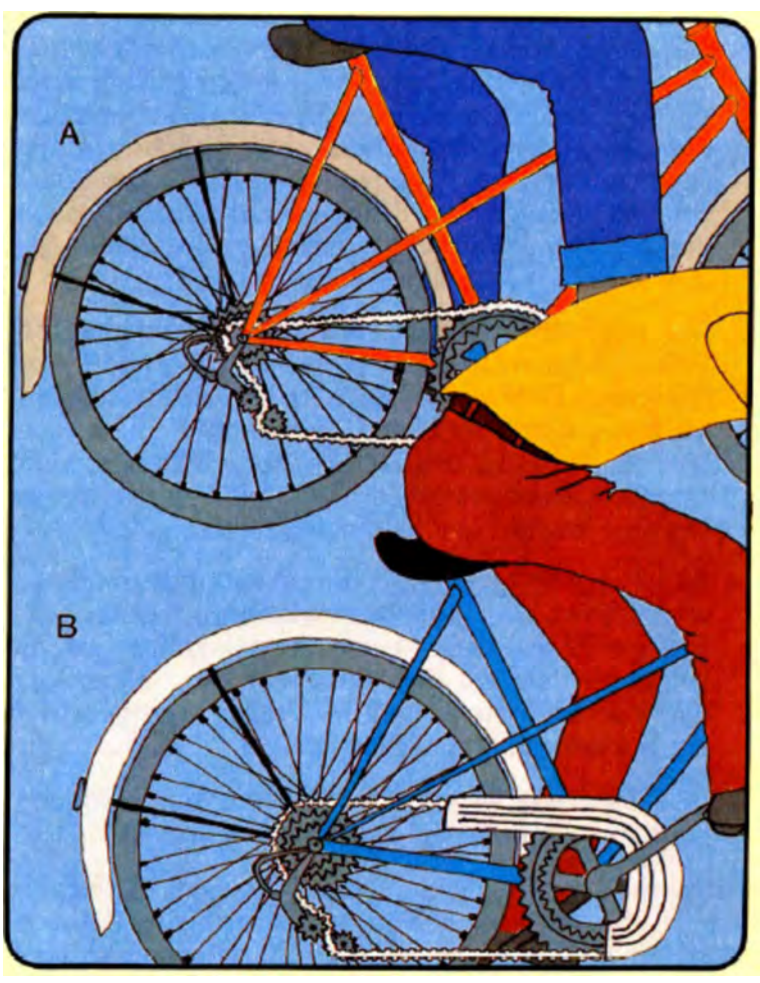
What is the pressure of the air in a car tire from which one has "let the air out"? The same as the air outside the tire, i.e. 1 bar. If the pressure gauge is connected to the filling station, it does not display 1 bar, but 0 bar. This device only indicates the overpressure inside the tire. When the tire is inflated to 3 bar, its overpressure is 2 bar, because the air in the tire has 2 bar more than the air outside.

S 7.4 Bicycle gearshift

Two cyclists ride side by side at the same speed. Since both are equally heavy and have the same bikes, both need the same energy. Both have the same energy flow from the muscles to the rear wheel.

Nevertheless cyclist A steps slower than cyclist B, because A has engaged a larger gear than B.

Slower pedaling means that the "chain current" is also lower. In order for the same energy current to flow through the chain, the chain of A must be loaded with more energy. This means that the chain is more strained.



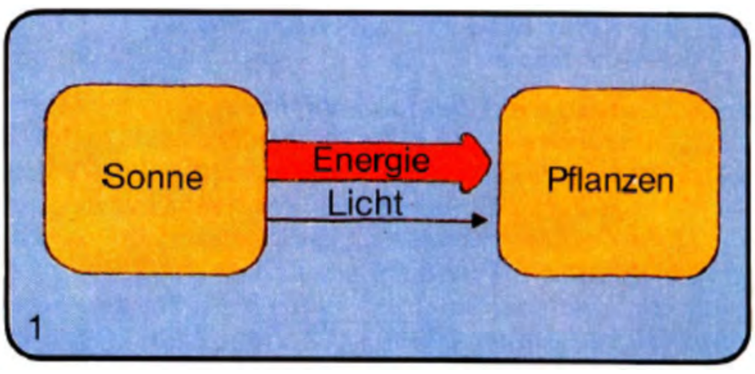
The carrier current at A is smaller than at B, but it is loaded with more energy.

8. The energy carrier light

8.1 Energy that comes from the sun

The sun illuminates the earth, it constantly sends light to the earth. With the light of the sun we get energy. Light is therefore an energy carrier. That can be seen in several ways:

- During the day, when the sun is shining, it is warmer than at night. “In the sun” it is warmer than in the shade. When you are in the shade of a passing cloud, you immediately feel how the warming by the sun rays stops. You need energy, as you know, for heating. The sunlight therefore carries energy. The whole earth is heated by the sun. We say the earth is an energy receiver that gets energy with the carrier light. The sun is the corresponding energy source.
- Plants need energy to grow. A tree trunk contains a lot of energy, otherwise you could not heat by burning wood. The plants get energy with the light from the sun – not from the earth. In the dark, plants can not grow. Plants are energy receivers that receive the energy with the carrier light, Fig. 1.



sun

energy
light

plants

- Figure 2 shows solar cells to which an electric motor is connected. The electric motor needs energy when it is running. It gets the energy from the solar cells, and they get the energy with the light from the sun.

- Fig. 3 shows a light mill. If you place it in the sunlight, their wheel starts to rotate.

Not only sunlight, but also the light of a light bulb warms. Plants thrive even under artificial lighting. The electric motor in Figure 2 can also be operated by illuminating the solar cells with a strong incandescent lamp, and the light mill also runs in the lamplight. Not only sunlight carries energy, but every other light as well.

Summary: Light is an energy carrier. The sun sends energy with the energy carrier light to the earth.

Supplements S 8.1 and S 8.2

Exercises

1. How do you know that sunlight carries energy?

2. How can one recognize that the light of a light bulb also carries energy?

3. In the picture in S 8.1, the proportions of the sun and the earth are not reproduced to scale. Make a correct image of earth and sun on a scale of 1: 10,000,000,000, i. e. 10 billion cm in reality correspond to 1 cm in your picture. To do this, cut out of paper two disks that represent the earth and the sun. Lay them on the floor so that their distance is true to scale. For the task you need the following numerical values:

diameter of the earth 12,800 km
diameter of the sun 1,400,000 km
distance between sun and earth 150,000,000 km

8.2 Light sources

Besides the sun, there are other sources of energy that supply energy with the carrier light. They are all called *light sources*. They include all kinds of lamps, but also the flash, the firefly and the TV screen. With electric light bulbs, the light comes from a glowing wire. In fact, this wire is the light source. For a candle and or a kerosene lamp the light comes from a flame. Here the flame is the light source.

Not every object that gives away light is a source of light. A piece of paper, a white house wall, a cloud or the blue sky are bright. Lights go out from them. But they do not shine by themselves. They got the light that emanates from them from elsewhere. They just pass it on.

Sometimes it is not easy to decide whether something is a light source or not. The moon for instance does not shine by itself, although light emanates from it. It just reflects the light it receives from the sun.

However, most of the stars seen in the sky shine themselves, so they are sources of light. These self-luminous stars are called *fixed stars*. But some stars do not shine themselves. They get light from the sun and throw it back in the most different directions, just like the moon. These are the *planets*. You can learn more about them in S 8.3.

Summary: Light sources emit energy with the energy carrier light. They produce light. All other objects only give away light that they receive from another source of light.

Supplements S 8.3 and S 8.4

Exercises

1. Which of the following objects are light sources: firefly, fire, mirror, lighthouse, sun, snowman, window?

2. Name light sources that are not listed in the previous exercise.

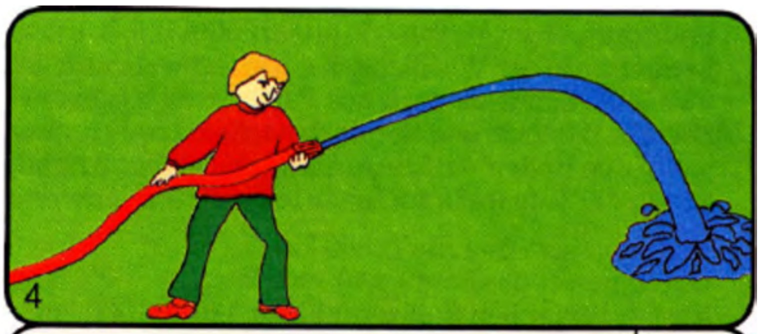
3. Which stars shine themselves? Which stars only throw back light that they receive from elsewhere?

4. On clear nights, the part of the moon can be seen, which complements the sickle to the full lunar disc. The dark part of the moon is also illuminated, only much less than the bright part. Where could the light come from?

5. Are the digits on digital clocks light sources, or are they just throwing back the light they receive from another light source?

8.3 The propagation of light – light guides

Fig. 4 shows a water jet. It is bent towards the earth, because the water is heavy and falls down. Fig. 5 shows a light beam. (It is best to use a laser to create a well-bundled beam of light). The light beam is not curved. That’s because light does not weigh anything.



Since light rays are straight, one can transmit energy with the carrier light without a conductor over long distances. However, if one wants to direct light over a complicated path that might go around several corners, one will not get along without a conductor. One uses a light guide, Fig. 6.

The light enters the light guide on the left, it comes out on the right.

A light guide is a kind of hose or cable for the light. It consists of a bundle of very fine glass fibers. It is flexible (bendable) like an electrical cable. The light, which is sent into the light guide at one end, comes out at the other end, regardless of whether the light guide is straight or bent or knotted. Light guides are used for example, by the doctor if she wants to look into the stomach of a patient. To do this, she pushes two light guides through the esophagus into the stomach. Through one light is sent into the stomach for illumination. Through the other, the light thrown back from the stomach wall comes out again.

Summary: Light propagates in a straight line. With a light guide one can direct light around corners, just as water through a pipe.

Supplements S 8.5 and S 8.6

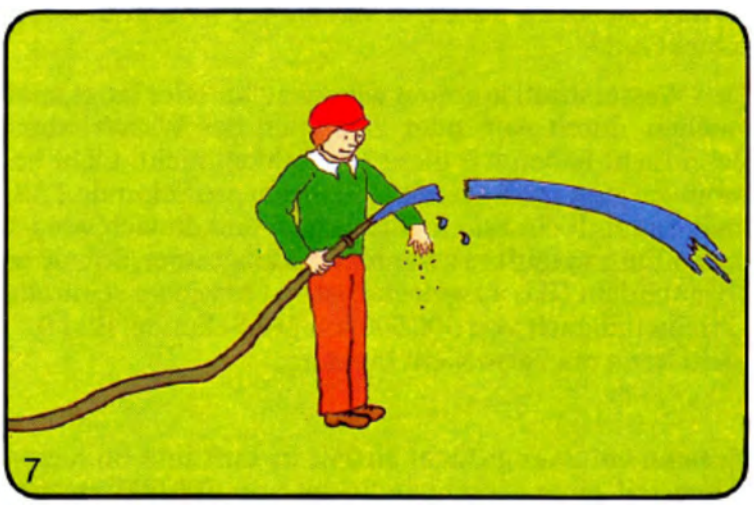
Exercises

1. To see that light propagates in a straight line, you do not need a laser. Do you know how to do so?

2. How can you guide light around the corner without a light guide? Where is that done?

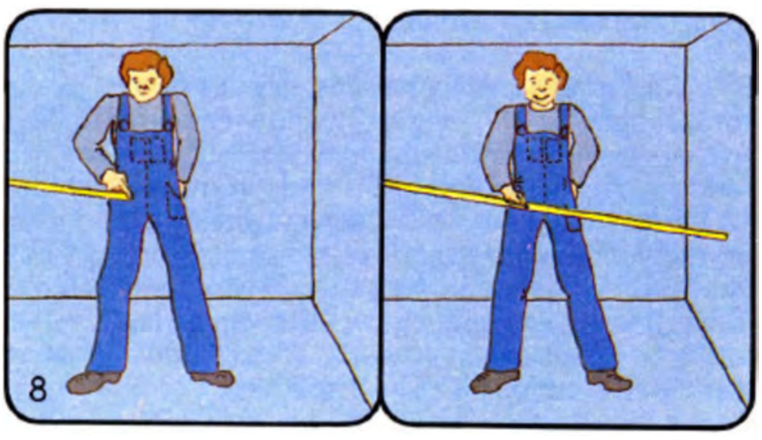
8.4 The velocity of light

The water of a jet of water coming from a garden sprayer has a certain velocity. If you open the faucet further on, the velocity increases, if you reduce the flow, the velocity becomes smaller. In order to see the velocity you can pass your hand through the jet just behind the sprayer: the beam is interrupted for a short time, and the interruption moves as fast as the water, Fig. 7.



The interruption of the jet moves as fast as the water.

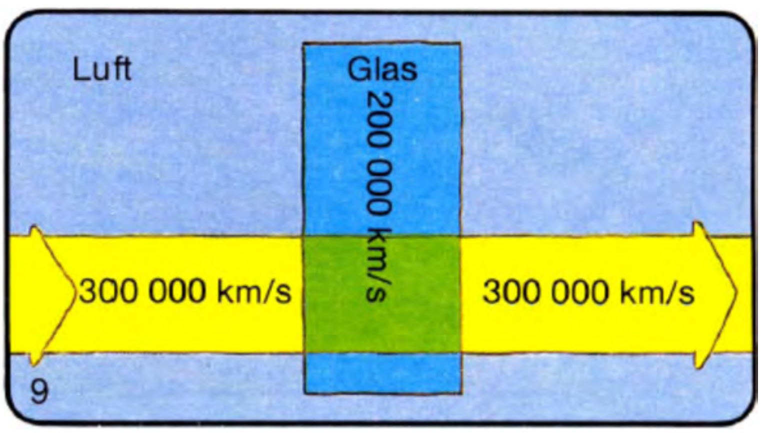
Try the same with a beam of light, Fig. 8. Briefly interrupt the light beam with one of your fingers. How long does it take to get dark at the point where the light beam hits the wall? Apparently it is instantaneous.



The light does not seem to need time to run from the finger to the wall. In fact, the light needs some time. However, so little that it is difficult to notice. Light moves very, very fast: in air and in empty space at 300,000 km per second. This is much faster than the fastest rocket can fly. In glass, it moves a little slower: at about 200,000 km per second.

For the way from the earth to the sun a space probe needs several months. The light needs only 8 minutes from the sun to the earth. If you look into the sun now, you will see the light that was emitted 8 minutes ago.

The water jet could be made faster or slower by turning the water tap on or off. For the light we do not have this possibility. Light always moves in air at 300,000 km per second. If you let it run through a piece of glass and then through air again, it will run slower in the glass. But once it has left the glass, it has its old velocity of 300,000 km per second, Fig. 9. So light can not be slowed down.



air glas

Summary: Light flows in air and in empty space at a velocity of 300,000 km per second.

Supplement S 8.7

Exercises

1. Does the light of a strong flashlight move faster than that of a dimly lit one?

2. How long does it take the light to get from the moon to the earth? The moon is 380,000 km from Earth.

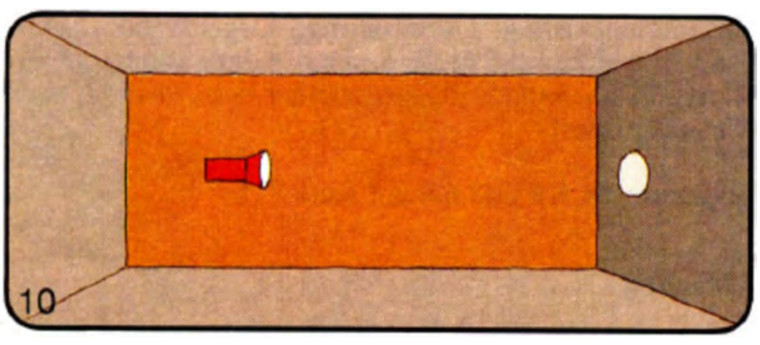
3. Sound moves at a speed of 300 m per second. How much faster is light than sound?

4. If between the instant you see a flash and the moment you hear the thunder, 3 seconds pass, the flash was about 1 km away from you. How do you explain this?

5. With a flashlight you make a flash of 1/10 second duration. How long is the correponding light beam?

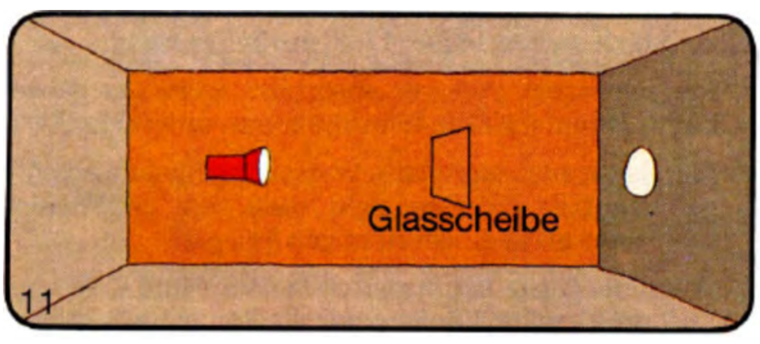
8.5 Transparent, white and black objects

We want to investigate what happens to light when it hits different objects. For this we need a darkened room and a strong beam of light, such as the beam of a powerful flashlight or a slide projector. As long as you do not hold an obstacle in the beam, the beam hits the wall straight ahead and you see a bright spot there, Fig. 10.



A light beam hits a wall.

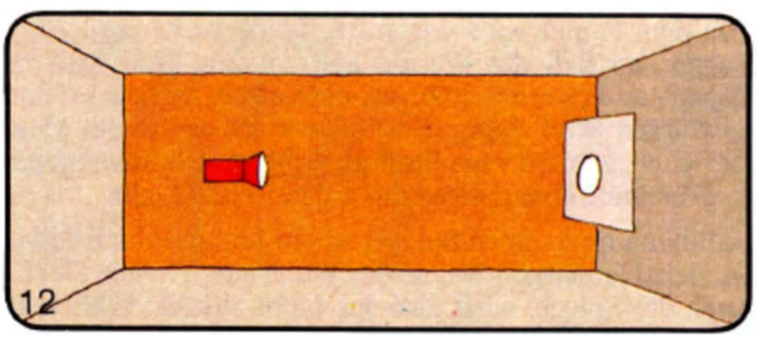
Now hold a pane of glass in the beam, as shown in Fig. 11. The beam passes through the glass and continues to create a bright spot on the wall. So there are materials through which light simply passes. These materials are transparent. Besides glass, some plastics are also transparent. Many crystals found in nature are also transparent, such as quartz or diamond. But light also goes through water and gasoline and of course also through air.



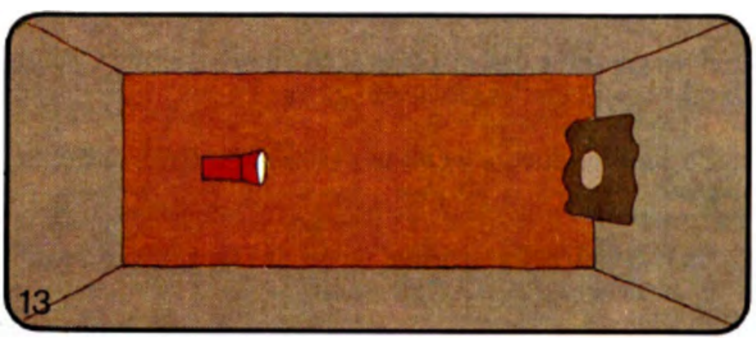
pane of glas

A light beam traverses glass.

Now place alternately a sheet of white paper and a piece of black paper or a piece of black cloth into the light beam, Figures 12 and 13, and observe the walls of the room. In both cases, the spot on the wall has disappeared. As long as the white paper is in the light beam, the other walls of the room are dimly lit. If, on the other hand, the black cloth is in the light beam, the walls are dark. How can that be explained?



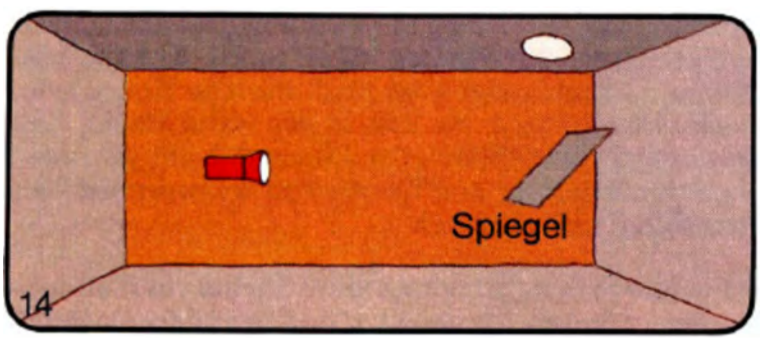
A sheet of white paper scatters the light.



A piece of black paper or black cloth absorbs the light.

From the white paper the incident light is thrown back, so that the walls become bright. All white objects throw the light back in alle directions. It *scatters* the light that falls on them. In the black cloth, on the other hand, the light disappears. It is also said that it is *absorbed* by the material. All black objects absorb the incident light.

Now hold a mirror in the beam of light, Fig. 14. You see a bright spot somewhere on the wall. The mirror also throws back the light. But while the sheet of paper scatters the light in all directions, the mirror directs the light beam in a particular direction. The mirror kinks the light beam.



The mirror kinks the light beam.

You have seen that with the light that hits an object, three things can happen:

- It goes through when the object is transparent.
- It is thrown back if the object is white or if it is a mirror.
- It is absorbed when the object is black.

Usually not only one of these three possibilities occurs, but two or even all three happen simultaneously. For example, a gray wall throws a part of the incident light back, the rest is absorbed. A piece of white paper throws back most of the incident light, with a small part going through the paper. You can see that when you hold the paper against a light source and look at it from behind. A small part of the light is even absorbed in the paper. Through a window pane, most of the light goes through, but not all of it. Do you know what happens to this rest?

Summary: Transparent objects let the light pass through, white and reflective objects throw it back, and in black objects it disappears, it is absorbed.

Supplements S 8.8 and S 8.9

Exercises

1. Name some transparent and some opaque objects. What material are they made of?

2. What is the difference between the way a mirror and a piece of white paper throw light back?

3. A black sweater does not absorb all the light falling on it. What would it look like if it did?

4. You can also use a smooth water surface as a mirror. Why is the image worse in the water than in a real mirror?

5. If the whole space between the sun and the earth were filled with air, we would not be able to see the sun. Can you say why?

8.6 Light receivers

You've probably already noticed that black objects in the sun become particularly warm, e.g. black clothes or a black asphalt road. Why is that? When light falls on a black object, it is absorbed, it disappears. However, the energy that the light carries can not disappear. It gets stuck in the object. As a result, the object gets warm.

Light is generated in the source and charged with energy. In the receiver, it discharges its energy and disappears. Light is therefore a one-way-bottle energy carrier.

White things throw the light back together with its energy, they do not get warm. If an object should not get warm in the sun, it is painted white. In warm countries, for example, the houses are painted white. Sometimes it is necessary to protect something from solar energy. Propane tanks for example, are white painted (Fig. 15) so that the gas does not get warm and the tank does not burst.

15

Propane gas tank

Summary: Black objects are receivers for energy with the carrier light. They discharge the energy from the light. The light disappears. Light is a one-way-bottle energy carrier.

Supplements S 8.10 and S 8.11

Exercises

1. How do you know that black objects are discharging energy from the light?

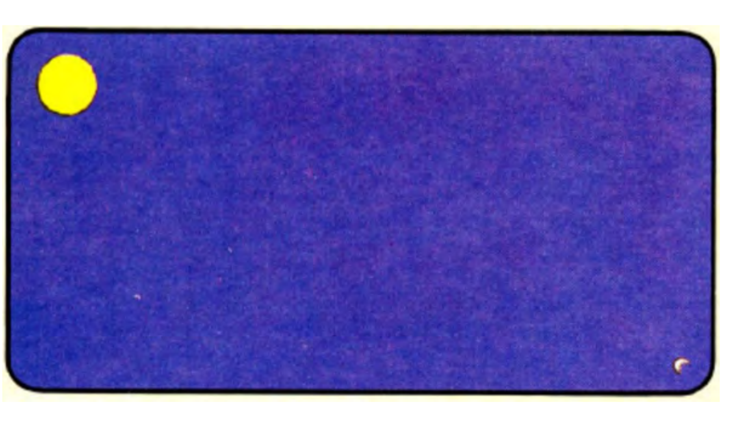
2. What happens to the light when it has discharged its energy?

3. Why is it beneficial to wear white clothes in hot countries?

4. Why are refrigerator cars painted white? Would a reflective coating be better?

S 8.1 Where the energy emitted by the sun goes

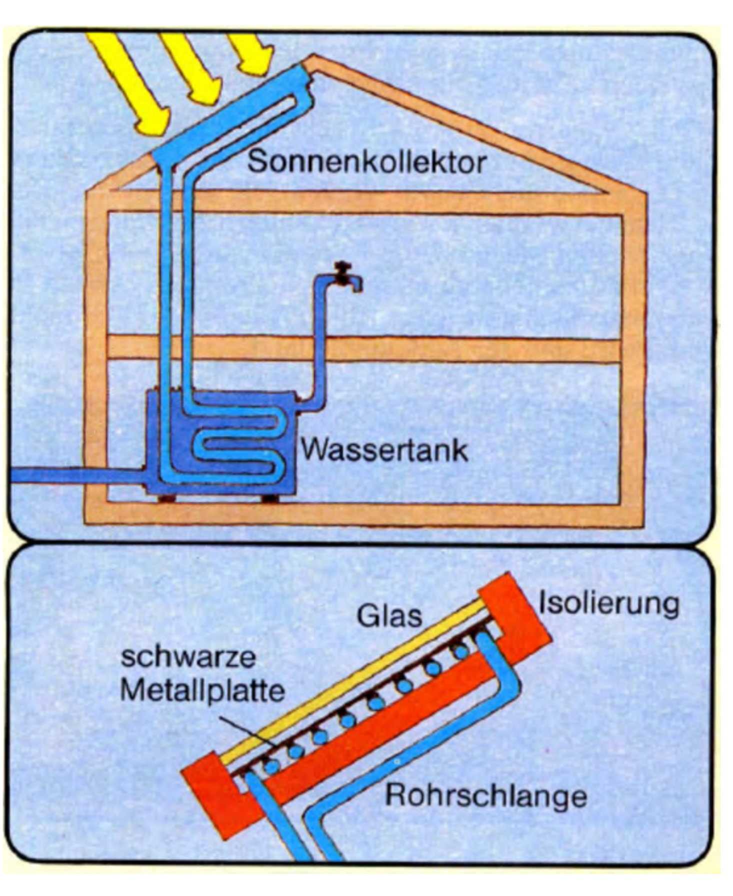
The amount of energy radiated by the sun is unimaginably high: 380,000,000,000,000,000,000,000,000 kJ per second. Only the two billionth part of it hits the earth. Most of it goes into space. The figure tries to give an impression of the tininess of the part that falls to the earth (sun on the upper left, earth on the lower right). However, it could not be drawn to scale. You have to imagine the earth much smaller and the distance of the earth from the sun much larger.



Nevertheless, the energy flow hitting the earth is still enormous. On one m^2 falls per second about 1 kJ.

S 8.2 The solar collector

In some houses, solar energy is used to heat water for the household. Solar collectors are mounted on the roof of the house. The picture below shows the construction of a solar collector. The sunlight falls through a glass pane onto a black metal plate.

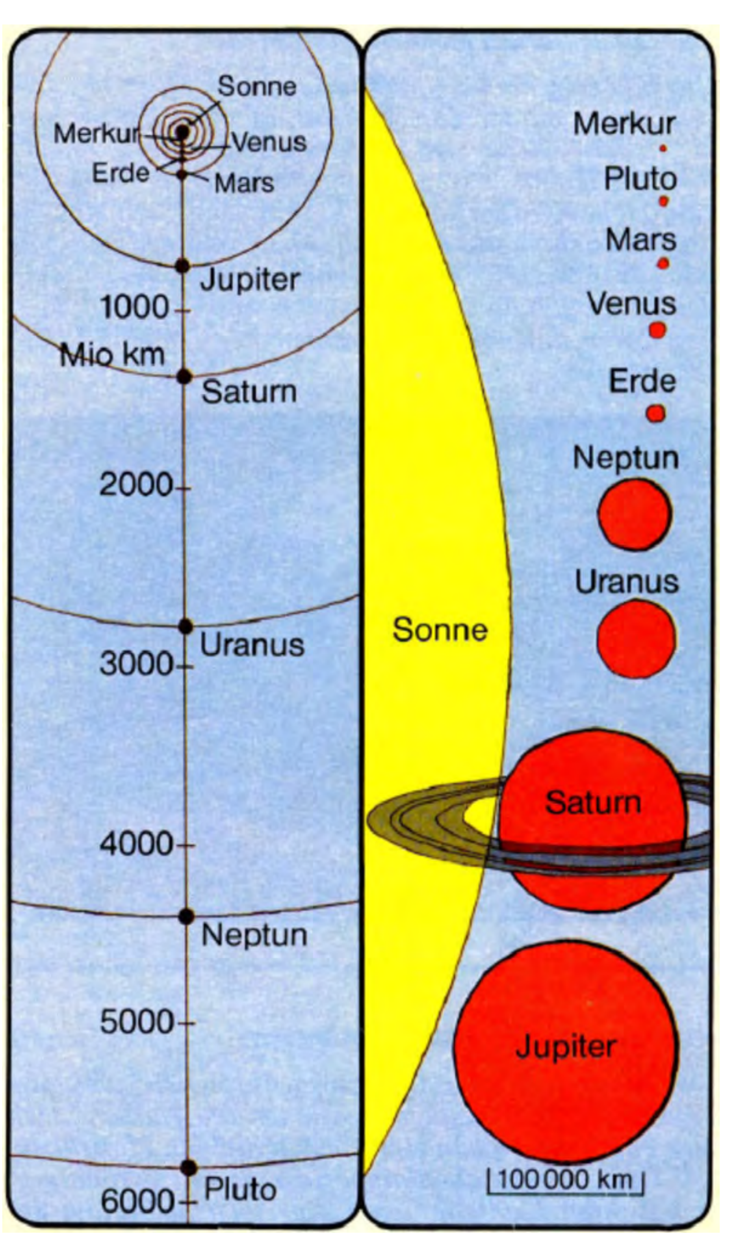


solar collector
water tank
glas insulation
black metal plate
pipe coil

The metal plate is heated by the energy of the sunlight. Behind the metal plate runs a pipe coil through which water flows. The metal plate transfers the energy to the water by heating the water. The warm water flows through a pipe into the cellar of the house, where it gives off its energy to other, colder water in a large water tank. The water coming from the collector becomes colder and the water in the tank becomes warmer. The water of the tank is used in the household.

S 8.3 The Solar System

The 9 planets move in almost circular orbits around the sun. The sun is the center of the circles. All circles are approximately in the same plane. The two pictures show the size of the planets and their orbits. Unlike the sun and the other stars, the fixed stars, the planets are cold, they do not glow themselves. Like the moon, they are illuminated by the sun and reflect part of the sunlight.



Mercury
Pluto
Mars
Venus
Earth
Neptune
Uranus
Sun
Saturn
Jupiter

S 8.4 The fixed stars

Almost all the stars you see in the sky at night are self-luminous. The self-glowing stars are called fixed stars. The word "fixed star" means that the star looks as if it were "fixed" in the sky. In contrast to the planets, the fixed stars seem to stand still. In reality, the fixed stars also move against each other. But the distances between us and the fixed stars and the fixed stars among each other are so great that their movement was not noticed for a long time.

About 3000 fixed stars can be seen with the naked eye. With the largest telescopes you could see several billion fixed stars if you had enough time to look at them all. The fixed star closest to the sun is Proxima Centauri. It is about 100,000 times further from the Earth than the Sun.

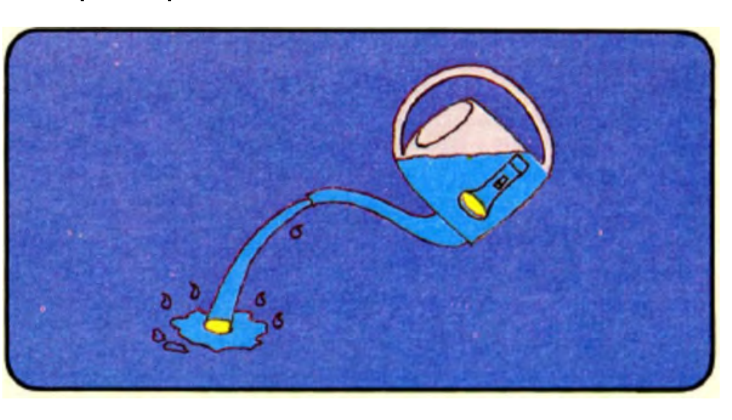
While a journey to the planets is quite conceivable, it is certain that we will not send any spacecraft to a fixed star in the near future. The "short" distance to Saturn took "Pioneer 11" 6.5 years. It would take much more than a lifetime to get to a fixed star.

S 8.5 Lights rays cannot be seen

The picture shows a photo of the earth taken from the moon. You can see a part of the globe: the part that is illuminated by the sun. The rest of the sky is black. Does that mean there's no light here? That can't be. The light that illuminates the earth flows into the picture from above. Only below the earth, in its shadow, there is no light. The photo is black where there is light is due to the fact that one cannot see rays of light "from the side".

S 8.6 A light guide to build yourself

The picture shows how you can make an unusual light guide, a light guide made of water. Put a flashlight in a waterproof plastic bag. Hold the torch in a watering can and direct its beam of light at the water outlet. Pour water through the spout of the watering can. At the point where the water hits the ground you will see a light spot. The light rays follows the water jet. The light cannot escape from the water jet, because whenever it hits the surface of the water, it is reflected back inside the water jet. Fibre optic cables work according to the same principle.



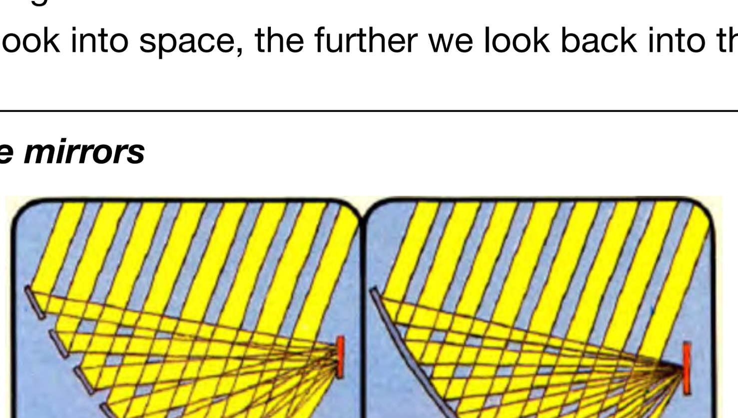
S 8.7 How to look into the past

To get from the sun to the earth, the light takes 8 minutes. When you see the sun, you see it not as it is now, but as it was 8 minutes ago. However, the sun does not change much in 8 minutes.

The light that comes to us from the star Pollux (in the constellation twins) has already taken 36 years for its journey. They say Pollux is 36 *light years* away from us. So when you look at this star, you see what it was like 36 years ago. There are stars that can still be seen with the naked eye - i.e. without a telescope - and that are 2 million light years away from us. So what we're looking at here are stars as they were two million years ago. Some of them may not exist for a long time.

The further we look into space, the further we look back into the past.

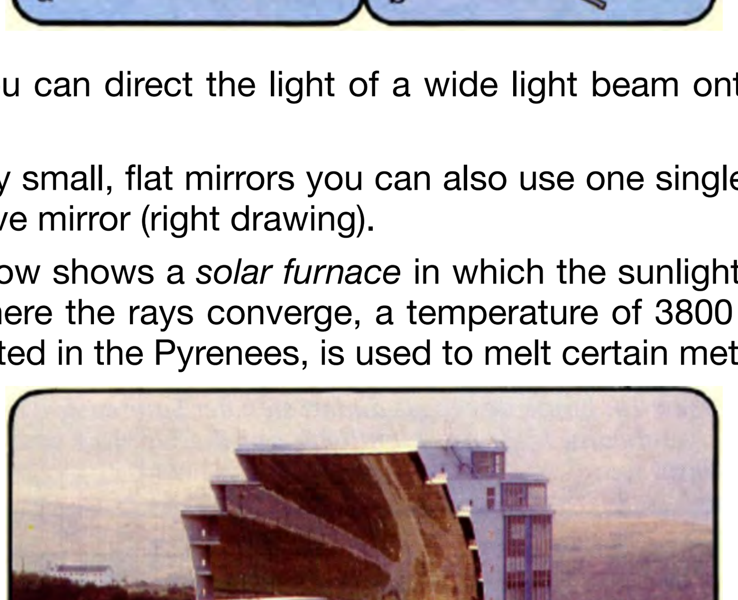
S 8.8 Concave mirrors



With mirrors you can direct the light of a wide light beam onto a small spot (left drawing).

Instead of many small, flat mirrors you can also use one single, large, curved mirror, a concave mirror (right drawing).

The picture below shows a *solar furnace* in which the sunlight is "collected". At the point where the rays converge, a temperature of 3800 °C is reached. This plant, located in the Pyrenees, is used to melt certain metals.

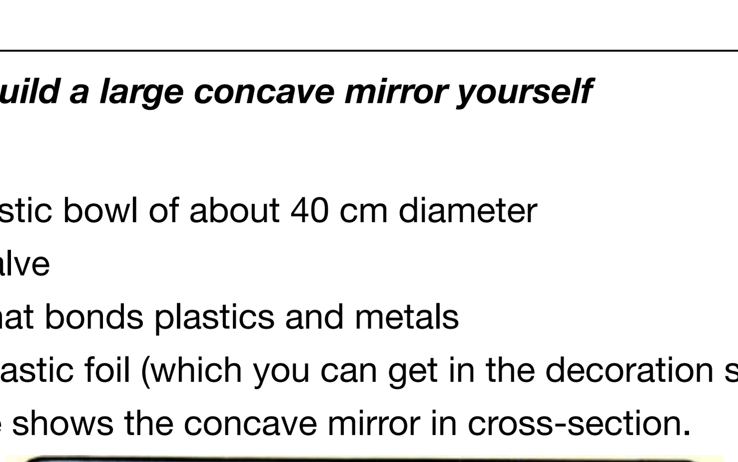


S 8.9 How to build a large concave mirror yourself

You need

- a round plastic bowl of about 40 cm diameter
- a bicycle valve
- Adhesive that bonds plastics and metals
- reflective plastic foil (which you can get in the decoration shop).

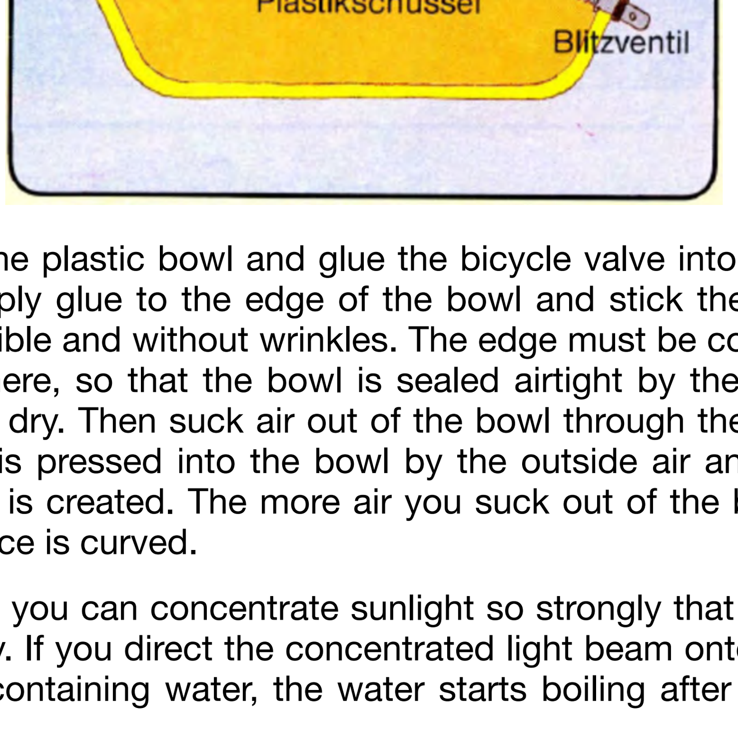
The first picture shows the concave mirror in cross-section.



reflective plastic foil
plastic bowl
bicycle valve

Drill a hole in the plastic bowl and glue the bicycle valve into it as shown in the picture. Apply glue to the edge of the bowl and stick the mirror film as tightly as possible and without wrinkles. The edge must be covered with adhesive everywhere, so that the bowl is sealed airtight by the foil. Wait until the adhesive is dry. Then suck air out of the bowl through the bicycle valve. The mirror foil is pressed into the bowl by the outside air and stretched. A concave mirror is created. The more air you suck out of the bowl, the more the mirror surface is curved.

With this mirror you can concentrate sunlight so strongly that paper catches fire immediately. If you direct the concentrated light beam onto a small soot-blackened tin containing water, the water starts boiling after a few minutes (picture below).



Attention!
The experiments with the concave mirror are dangerous! Handling the concave mirror is more dangerous than handling burning matches. You see the flame of a burning match. Consequently, you also know where not to hold a flammable object. You cannot see the point at which the light of the concave mirror is concentrated (light cannot be seen, see S 8.5). If it falls on your clothes, your clothes will burn. If it falls on your skin, your skin burns. The worst thing would be if it fell on your eyes. Burnt skin grows back, a burnt eye does not.

When not using the concave mirror, place it face down. Imagine it was near a window with the reflective side facing up. The position of the sun changes during the day. At some point the light spot runs onto the curtain and then...

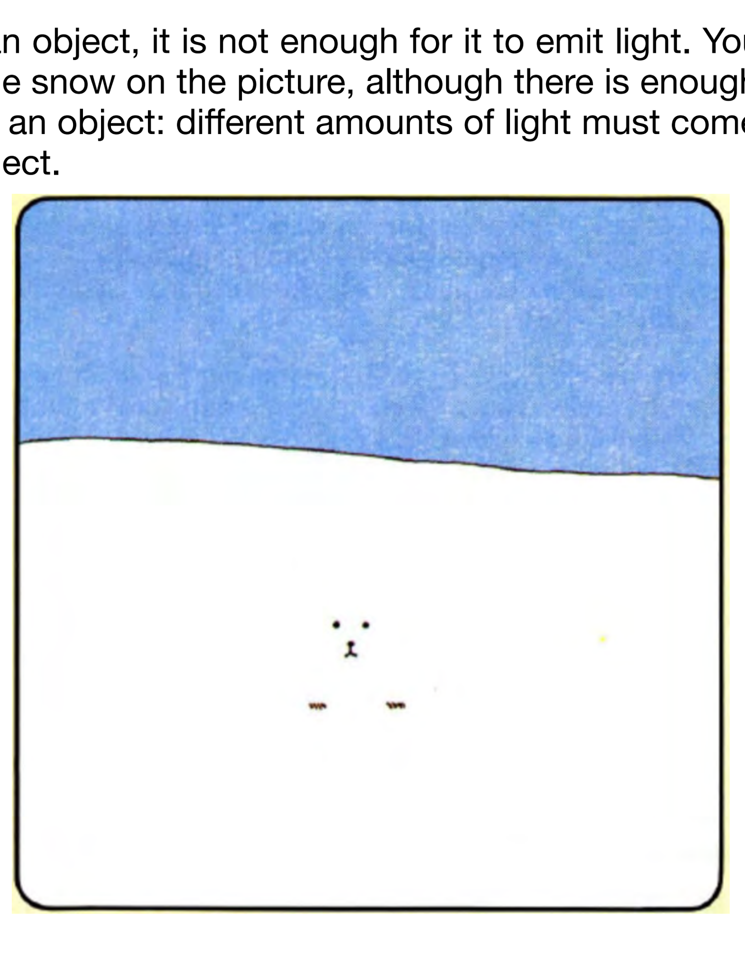
S 8.10 What did the citizens of Schilda do wrong?

The citizens of Schilda have built a town hall without windows. To make the rooms of the town hall bright, they wanted to carry the light in bags inside the building. Once the light is in, it stays in, they thought. You think you can't do that? Why the hell not?
Can you imagine how a house would have to be built to keep the light you brought in?

S 8.11 What is "seeing"?

We see a thing when light emanating from it enters our eyes. Our eyes are light receptors. The pupil is a hole closed by a transparent cornea. Through the pupil the light enters the eye. Do you understand why the pupil looks black?

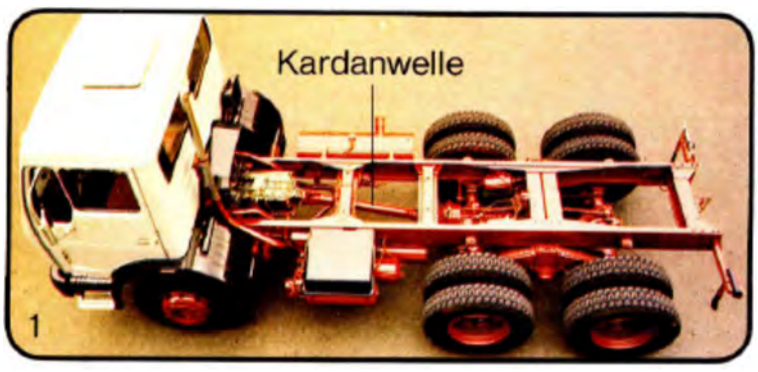
For us to see an object, it is not enough for it to emit light. You don't see the polar bear in the snow on the picture, although there is enough light. There is more to seeing an object: different amounts of light must come from different parts of the object.



9. The energy carrier angular momentum

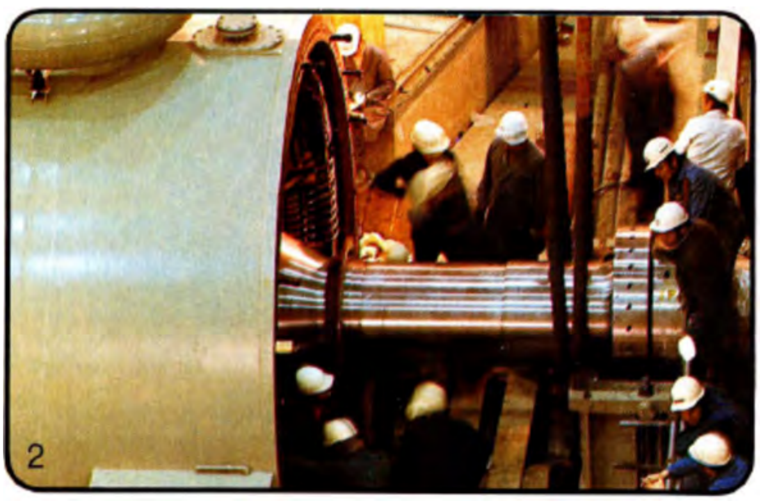
9.1 Energy is flowing through a drive shaft

In many machines, energy is transferred from one place to another with the help of a rotating bar, a so-called drive shaft. Thus, the energy flows in these machines by a drive shaft.



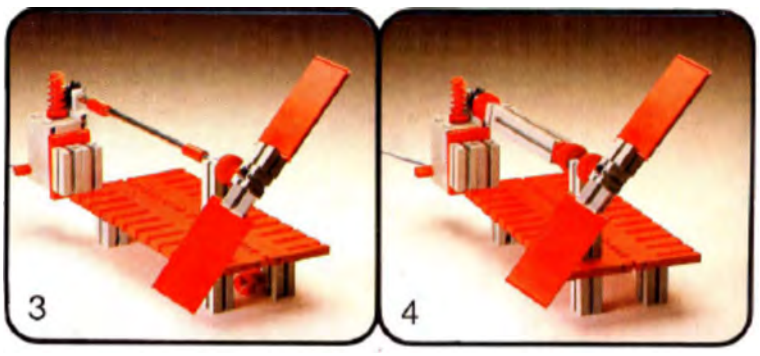
Cardan shaft

If you take a look under a truck, you may notice the Cardan shaft, Fig. 1. Through it, energy flows from the engine to the rear wheels.



The shaft between the turbine and the generator of a power plant is being mounted.

Fig. 2 shows the shaft connecting a turbine and a generator. Through it, the energy flows from the turbine to the generator. Fig. 3 shows an electric fan, how to build it yourself. The energy flows through a shaft from the motor to the propeller. Drive shafts are mostly round and made of iron. But they do not have to be. Fig. 4 shows the fan of Fig. 3, in which the round iron shaft has been replaced by a plastic shaft with a square cross section.



On the left, the energy flows through a round iron shaft, on the right through a plastic shaft with a square cross-section.

Which is the energy carrier for all these machines? Maybe you think it's the shaft itself. But that can not be. The energy carrier is supposed to move from the source to the receiver, but the shaft does not do that. It only revolves around itself. The shaft is not the energy carrier, it is just the conduit through which the carrier is flowing. The energy carries is something else that flows along with the energy through the shaft.

Maybe one of the energy carriers that we already know flows through the shaft? Water or gasoline or compressed air are out of question, because the shaft is not hollow. So there is still electricity left. But it can not be that either. Electricity can only flow through metals, but a shaft can also be made of plastic, as shown in Fig. 4.

The carrier that carries the energy through a shaft is new to us. It is called *angular momentum*. It is a carrier that you can neither see nor touch. Nevertheless, as we shall see, you can feel it.

From the engine to the rear axle in Fig. 1 energy flows with the carrier angular momentum. In the power plant, the angular momentum carries the energy from the turbine to the generator.

Summary: If energy flows through a shaft, it is carried by angular momentum.

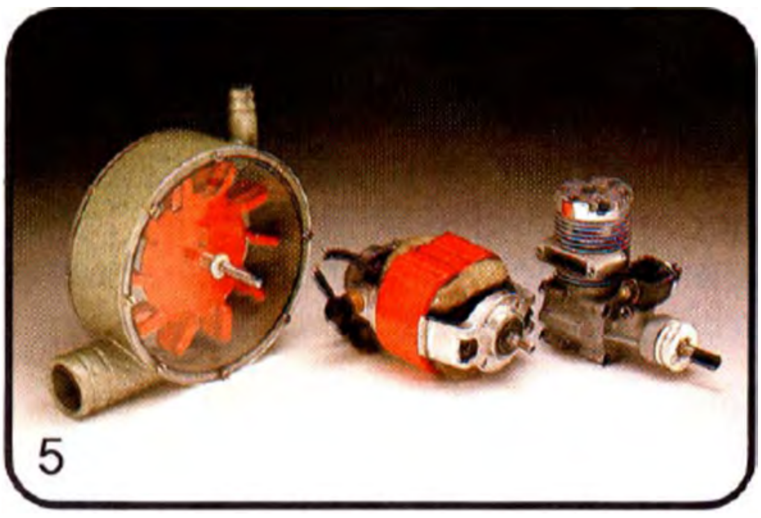
Supplements S 9.1 and S 9.2

Exercises

1. List some examples where energy flows through shafts.
2. Which invisible energy carriers do you know?

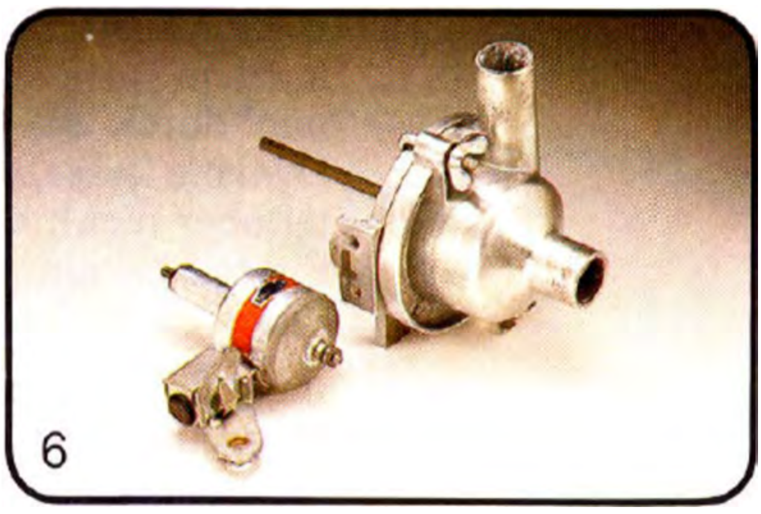
9.2 Sources and receivers of energy that is carried by angular momentum

Energy sources that load energy onto the angular momentum are easy to spot. They almost always have a shaft as a connection, Fig. 5.



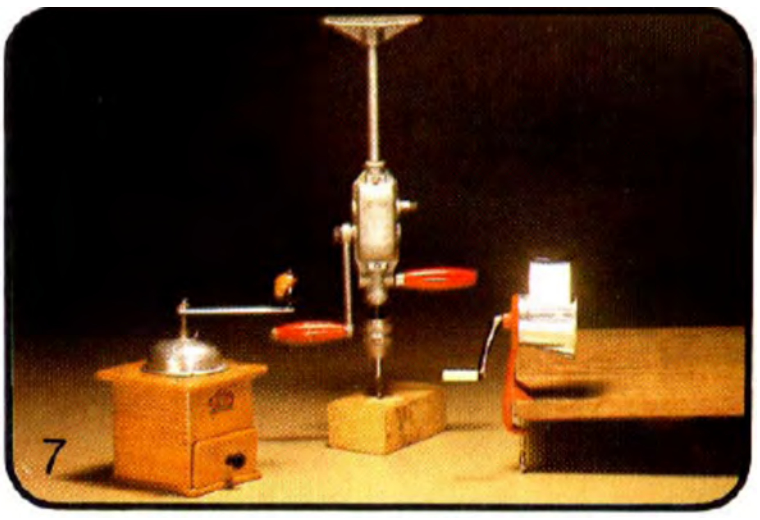
Sources of energy with the carrier angular momentum: water turbine, electric motor, gasonline engine

Such sources include the electric motor, the gasoline engine, the wind turbine, the water turbine. You too can give off energy with the carrier angular momentum. You always do that when you are rotating something, e.g. the coffee grinder or the pencil in the pencil sharpener.



Receivers of energy with the carrier angular momentum: bicycle dynamo, water pump

It is equally easy to recognize receivers that discharge energy from angular momentum. They also have a shaft, Fig. 6. They include the dynamo, the propeller, water pumps. If the receiver does not receive the energy from a machine, but from a human, it usually has a crank: the coffee grinder, the almond grinder, the drill, Fig. 7.



Receiver for energy with the carrier angular momentum: drill, coffee grinder, almond grinder

Summary: Sources and receivers for energy with the carrier angular momentum are recognized by having a shaft.

Supplements S 9.3 and S 9.4

Exercises

1. Name sources that supply energy with the carrier angular momentum. How do you recognize them?

2. Name receivers that receive energy with the carrier angular momentum. How do you recognize them?

3. Car engines give off energy with the energy carrier “angular momentum” and “drive belt”. Where does the energy flow with the angular momentum and where with the belt?

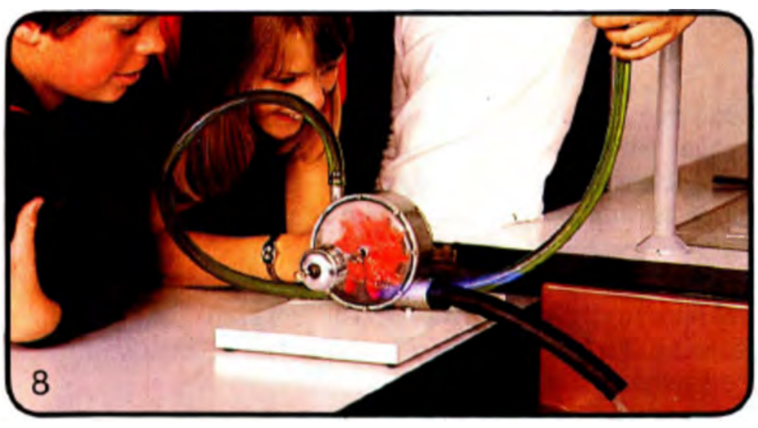
4. How can one recognize devices that receive energy from a human being with the carrier angular momentum? Name some such devices.

9.3 Angular momentum needs a return line

Angular momentum is not visible. Nevertheless, we can try to find out more about it. Until now, we had been able to determine for each energy carrier whether it was a one-way-bottle or a deposit-bottle energy carrier. What about the angular momentum? A deposit-bottle energy carrier can be recognized by the fact that source and receiver are connected by two lines. There is a forward line and a return line. On the other hand, one-way-bottle energy carriers have only one connection.

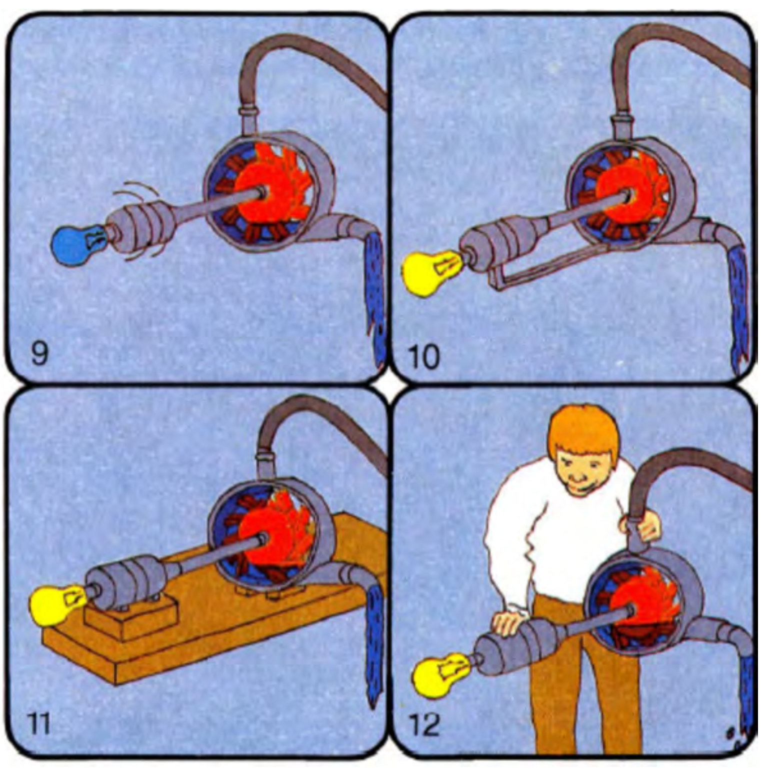
Are the source and receiver for an energy transport with angular momentum connected by one or two lines? The answer seems clear at first glance: source and receiver are connected by a single shaft. The angular momentum should then be a one-way-bottle energy carrier. But let's take a closer look.

Fig. 8 shows the model of a hydropower plant. In the back is the water turbine, in front the dynamo. A light is connected to the dynamo. Turbine and dynamo are connected by a shaft. We now let water flow into the turbine. The turbine wheel begins to rotate and the shaft of the dynamo, which is connected to the turbine wheel, rotates with it. If now energy flows through the shaft from the turbine to the dynamo, the light should shine, but it's not shining. Apparently it didn't get any energy from the dynamo, and that means the dynamo didn't get any energy from the turbine.



Model of a hydropower plant

What happened? A mistake was made in the construction of the "power plant". The dynamo is hanging free in the air. That's why not only the shaft of the dynamo rotates, the whole dynamo is rotating including the lamp, Fig. 9.

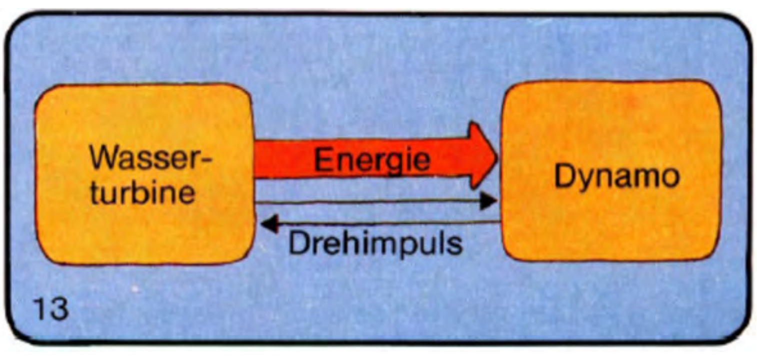


For the "power plant" to work, the dynamo must be held. Fig. 10 shows the power plant after this was done. The dynamo was attached to the turbine with a second rod. This time the light is on. Turbine and dynamo must therefore be connected by two connections. The energy-loaded angular momentum flows through one of them from the source to the receiver. Through the other, the angular momentum flows back again without energy, i.e. empty. The angular momentum needs a return line. See how hasty we were when we called the angular momentum a one-way-bottle energy carrier. The angular momentum is a deposit-bottle energy carrier.

Instead of using a second rod as a return line, we could have simply screwed the turbine and dynamo to one and the same base plate, Fig. 11, in which case the base plate would have been the return line. Or we could have held them both with our hands, Fig. 12, and then the angular momentum would flow back through our arms and our body.

If the source and receiver are heavy enough, it's even enough to just put them both on the table. Then the angular momentum flows back through the table.

We can now draw the energy flow diagram of our model power plant, Figure 13.



water turbine

energy
angular momentum

dynamo

Summary: The angular momentum needs a return line. It is a returnable bottle energy carrier.

Supplement S 9.5

Exercises

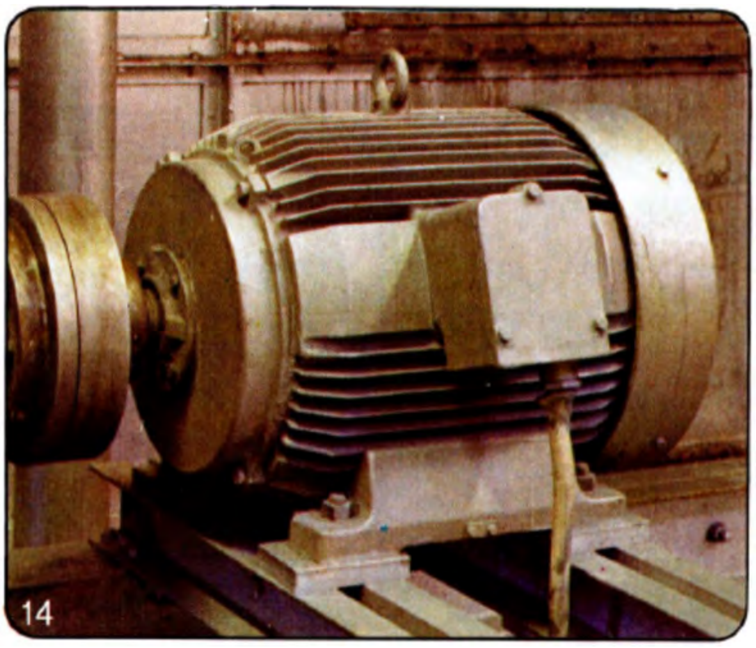
1. Draw the energy flow diagram for a coffee grinder driven by an electric motor.

2. Imagine, the turbine and the dynamo in Fig. 12 are not held by one person, but by two: One holds the turbine, the other the dynamo. Does the dynamo get energy? Is the angular momentum current circuit closed? Which way does the angular momentum flow?

9.4 Why the second connection for the angular momentum is usually not noticeable

It is obvious that two connections are needed when the energy carrier is electricity: the plug for an electrical device has two pins. At first glance, one does not see that two connections are needed for the angular momentum. In a steam power plant, the angular momentum flows back through the foundation on which the steam turbine and generator are fixed. In an electric coffee grinder, it flows back from the grinder to the electric motor via the housing.

The “base” on which the source and the receiver are mounted is therefore always used as the return line. You don’t notice this return line, because the base is there anyway. No special connection has been made for the return line, thus saving material.


14

This is a trick we’ve seen before. You do the same with the bicycle lighting, only with another energy carrier, namely electricity. Bicycle dynamo and lamp are connected by a single wire, although electricity always requires two connections. (Electricity is a deposit-bottle energy carrier!) For bicycle lighting, the second connection is the bicycle frame. This saves one wire. For angular momentum currents, the base is used as a second connection, saving the second shaft.

Nevertheless, it must be ensured that the second connection is also OK, especially if the angular momentum currents are very great. Fig. 14 shows how a powerful electric motor is attached to the steel beam. The angular momentum flows through the bolts from the foundation back to the motor.

Summary: The base on which the source and receiver are mounted is often used to return the angular momentum.

Supplement S 9.6

Exercises

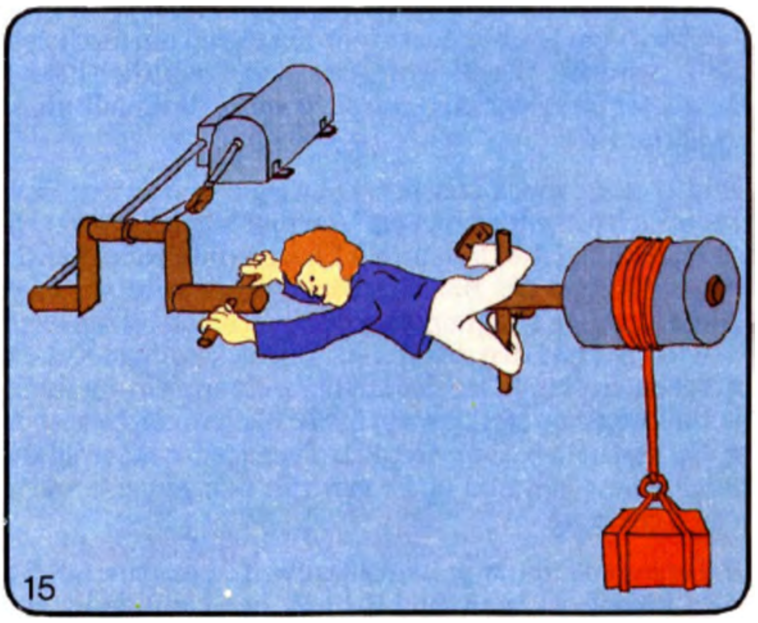
1. If you want to drill a hole in a piece of iron, you clamp it in a bench vice. Why?

2. Somebody drills a hole in the wall with a drill. Which way does the energy take? Which way does the angular momentum take?

9.5 Angular momentum currents can be felt

You know that it is unpleasant or dangerous when electricity flows through your body. Only if the current is very weak, you won’t feel it. The same is true for angular momentum. Very small angular momentum currents, such as in the experiment in Fig. 12, are not noticeable. However, large angular momentum currents can be felt very well, and they can also become dangerous.

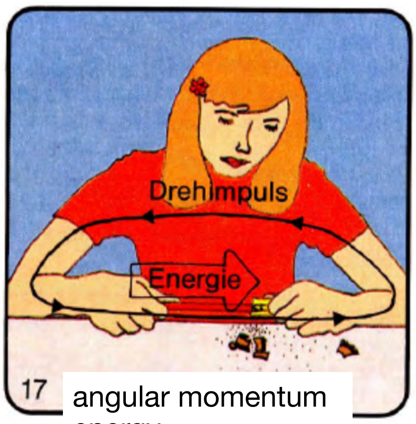
The feeling that you get when angular momentum flows through you can be described like this: The angular momentum current wants to "twist" you, Fig. 15.



The angular momentum current wants to twist the person.

If the angular momentum does not flow through a person but through any object, the object “senses” the twisting. Sometimes you can even see it.

Cut out a rectangular piece of plastic and insert it into an angular momentum circuit, Fig. 16. The plastic strip is twisted by the current flowing through it. Of course, the pencil itself feels the same as the plastic strip, but you can’t tell because it’s harder.



angular momentum
energy

Fig. 17 shows schematically how energy and angular momentum flow when a pencil is sharpened. From the muscles of the right hand, the angular momentum carries energy through the pencil to the blade of the pencil sharpener. Here it is discharged and the angular momentum flows through the left arm, the body and the right arm back to the muscles of the right hand. You can easily see that the angular momentum current in the forward line is just as strong as in the return line. Simply insert the plastic strip into the return line, Fig. 18. It twists in the same way as in the forward line.

It is the same with other angular momentum circuits. In the circuit shown in Fig. 2, the angular momentum flows from the turbine to the generator loaded with energy. The turbine shaft feels a twist. Through the foundation, the angular momentum flows back to the turbine without energy. The foundation also feels a twist.

Summary: An angular momentum current tries to twist the object through which it flows.

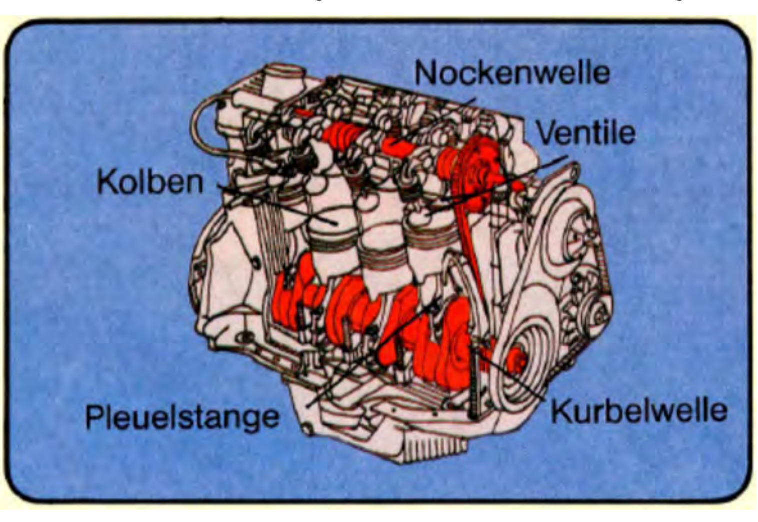
S 9.1 Shafts

Some shafts that perform certain tasks have their own name. Here are a few examples:

Cardan shaft: In many cars the engine is at the front, but the rear wheels are driven. The energy flows through the cardan shaft from the front to the rear. Since the rear axle is not rigidly connected to the chassis, this shaft has two joints, the cardan joints. For trucks, this shaft is clearly visible, Figure 1, Section 9.1.

Crankshaft: The shaft of gas and diesel engines to which the pistons transfer energy via the connecting rod is called, because of its shape, crankshaft.

Camshaft: The crankshaft drives the camshaft, usually with a chain. The camshaft opens and closes the engine valves via a linkage.



camshaft
valves
piston
connecting rod
crankshaft

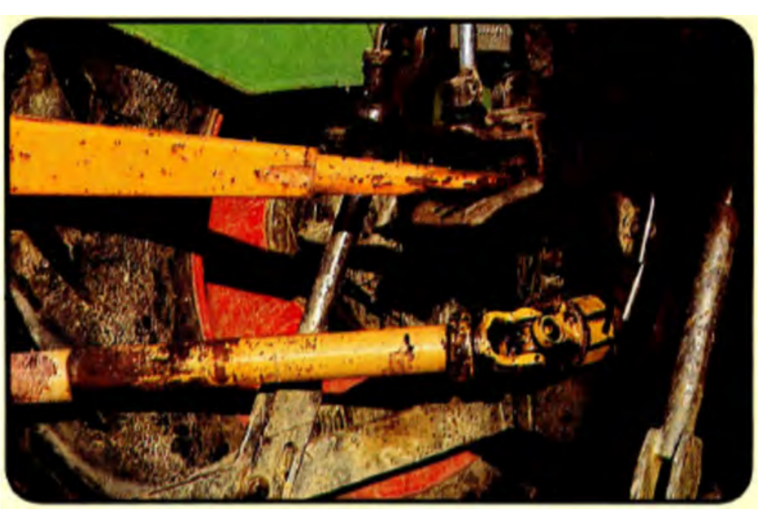
PTO (power take off): Ancillary equipment can be attached or hitched to a tractor. Many additional equipment requires energy with the carrier angular momentum, e.g. the straw press, the self-loading wagon or the beet harvester. These implements get their energy from the tractor via the PTO shaft. The PTO shaft is located at the rear of the tractor under the trailer coupling (illustration in S 9.2).

S 9.2 PTO and hydraulic drive

Tractors have two power connections:

1. a PTO connection. Here you can take energy with the carrier angular momentum.

2. two connections for hydraulic hoses. Here you can take energy with the carrier hydraulic oil. One hose connection is for the forward line and the other for the return line.

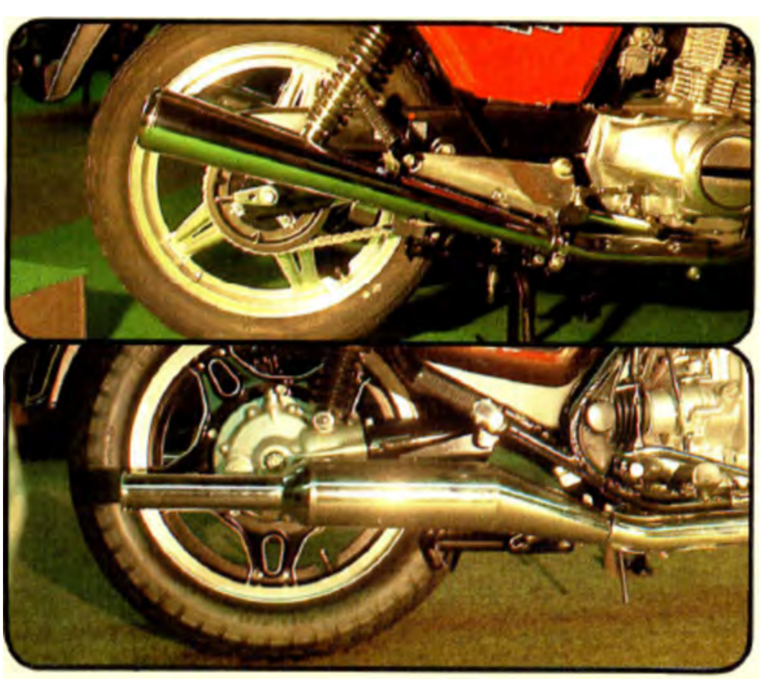


Today, more and more accessories are equipped with hydraulic drives, as laying hoses is more convenient than laying shafts, especially if the energy is to flow around several corners.

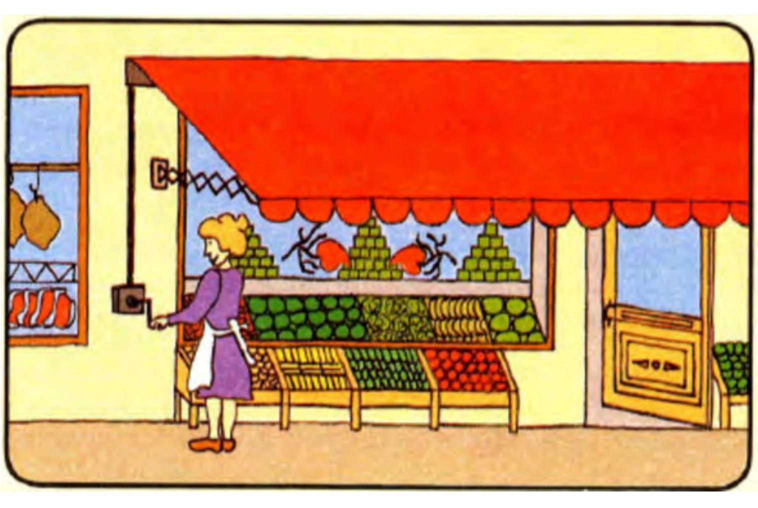
S 9.3 Shafts and drive belts

We had already got to know sources that deliver energy with the angular momentum on another occasion. They can also load the energy onto another energy carrier: drive belts or chains. All you need to do is attach a pulley or sprocket to the shaft. Likewise, the receivers we have listed can receive their energy not only with the angular momentum, but also with a belt or chain.

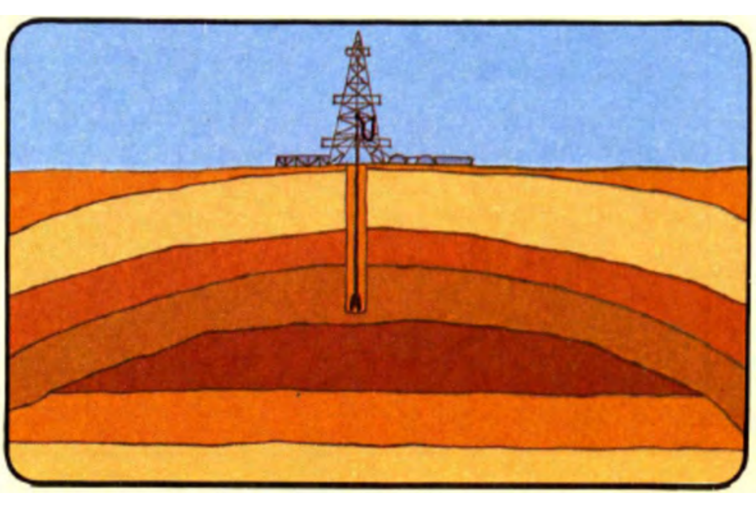
The picture shows two motorcycles. In both cases, the motor is the energy source and the rear wheel is the corresponding receiver. In the upper figure the chain is the energy carrier. The second motorcycle has cardan shaft drive. Motor and rear wheel are connected by a shaft. So here the energy carrier is angular momentum.



S 9.4 Two examples for the transport of energy with angular momentum



Energy is needed at the top to roll up the sunroof (picture above). There is a crank at the bottom. From the crank to the roll, the angular momentum carries the energy. It flows, together with the energy, through the vertical shaft (left in the picture).

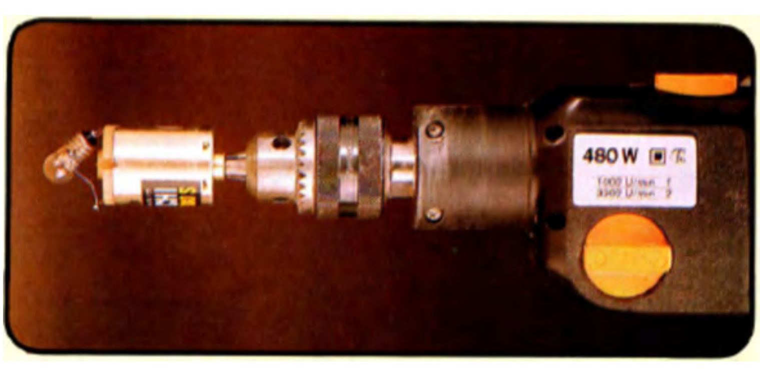


Energy is needed at the lower end of the borehole. The energy source is a motor that stands at the earth's surface. The energy is carried downwards by angular momentum. It flows together with the energy through the drill pipe.

S 9.5 A simple angular momentum circuit

You need

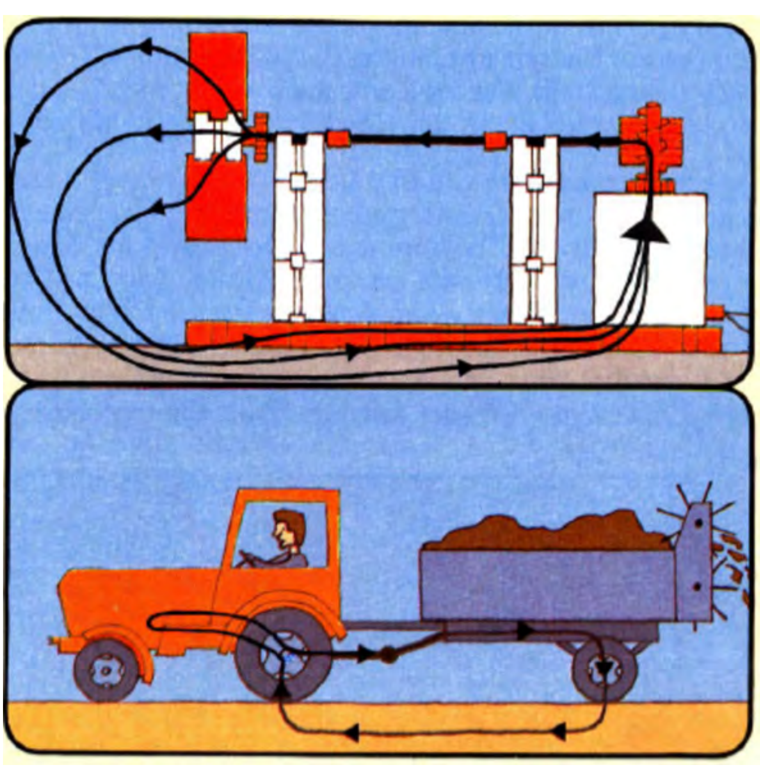
- an electric hand drill,
- a small dynamo (most toy motors can be used as a dynamo),
- a flashlight bulb.



First, the bulb is connected to the dynamo. The electric drill should now drive the dynamo, in other words: the dynamo should receive energy from the drill with the carrier angular momentum. For this purpose, the shaft of the dynamo is clamped into the drill chuck of the drilling machine. Now take the drill in both hands and let it run. Is the bulb lit? Then the drill is held with one hand and the dynamo with the other. Does the bulb light up when the drill is running? Which way does the angular momentum take?

S 9.6 The unexpected paths of angular momentum

Often it is not easy to find the return path of the angular momentum, because the angular momentum sometimes takes unexpected paths.



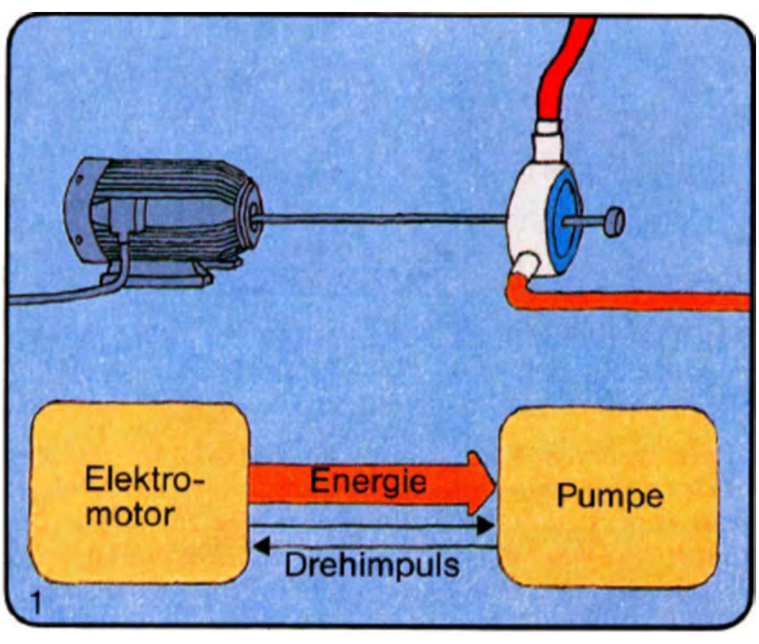
In the fan, it flows from the motor to the propeller, from there through the air to earth and from earth back to the electric motor.

When a machine that is pulled by the tractor is driven by the engine of the tractor, the angular momentum flows from the engine through the PTO to the machine, through the wheels of the machine into the ground and from the ground through the rear wheels of the tractor back to the tractor engine.

10. Energy transloaders

10.1 Sources and receivers transfer energy

Energy sources give off energy – the name says it all. But from where do they get the energy they give off? Do they get it from other sources? Look at Fig. 1. Here the electric motor is the energy source and the pump is the energy receiver. This is shown in the lower part of the Figure.

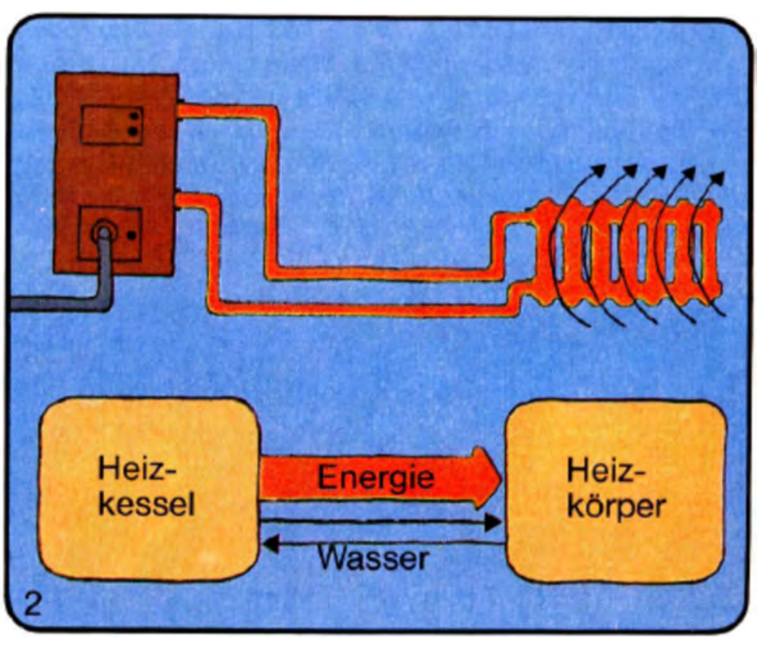


electric motor

energy
angular momentum

pump

In the central heating system in Fig. 2, the boiler is the source, the radiator is the receiver.



boiler

energy
water

radiator

In the upper half of Fig. 1 you can see that the electric motor itself gets energy through a cable. Likewise, the boiler in Fig. 2 gets energy with the heating oil through a pipe. The sources not only have an output for the energy, they also have an input. So the electric motor and the boiler are not only a source of the energy, they are also receivers at the same time. The energy carrier with which they receive the energy, however, is not the same as the one with which they release the energy.

Now look at the receivers in Figures 1 and 2, the pump and the radiator. What happens to the energy they receive? The energy that flows into the water pump with the angular momentum comes out again with the water, and the energy that flows into the radiator with the warm water leaves it again with the air that flows past the radiator. The receivers also have an input and an output for the energy. They are not only receivers, they are both receivers and sources at the same time. However, the energy carrier with which they release the energy is not the same as the one with which they receive the energy.

So what we have called a source is also a receiver, and what we have called a receiver is also a source. All these devices actually do the same thing: they transship or transfer or transload the energy from one energy carrier to another. We call them *energy transloaders*.

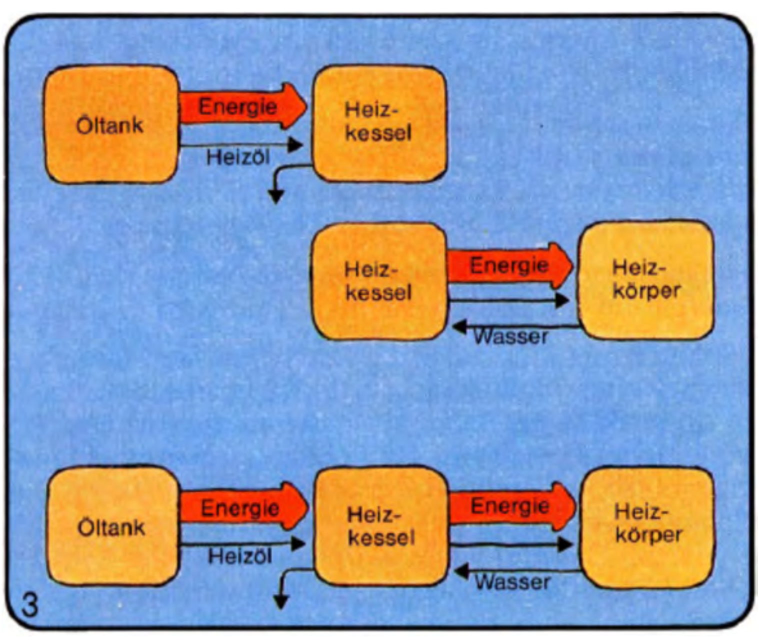
The electric motor transloads energy from electricity to angular momentum.

The water pump transloads the energy from angular momentum to the water.

The boiler transfers the energy from the heating oil to the water.

The radiator transfers the energy from the water to the air.

Since many devices are energy transloaders, it is worth introducing a particular symbol for the them. You can construct such a symbol from those you already know. This is how it looks for the transloader “boiler”: Once the boiler is an energy receiver, Fig. 3 above, once it is an energy source, Fig. 3 centre. If the two images are superimposed, the diagram at the bottom comes out.

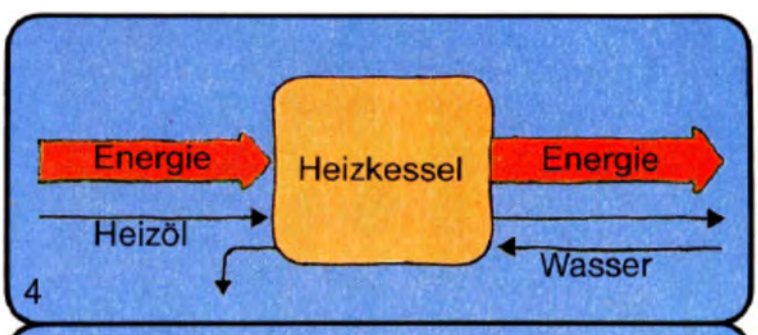


oil tank
energy
heating oil
boiler

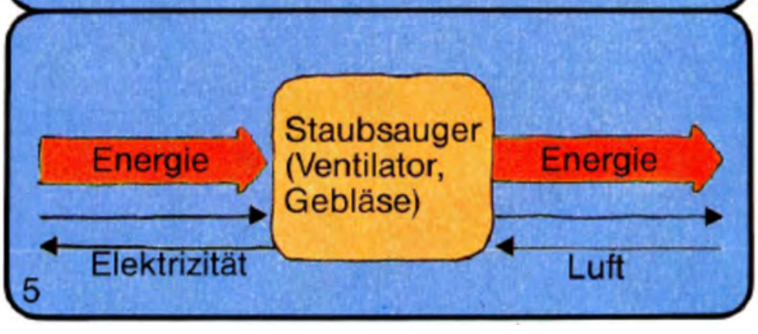
boiler
energy
water
radiator

oil tank
energy
heating oil
boiler
energy
water
radiator

Fig. 4 shows the symbol of the boiler alone. You can clearly see what the boiler does: it transfers energy from heating oil to water.



energy
heating oil
boiler
energy
water



energy
electricity
vacuum cleaner (fan, blower)
energy
air

A symbol is a very simplified image of a device. You can’t tell from the flow diagram in Fig. 4 whether it represents the boiler of a central heating system or the boiler house of a large power plant.

The symbol in Fig. 5 can be: the flow diagram of a vacuum cleaner, a fan or a blower. Although these three devices differ in many respects, they have one thing in common: they transfer energy from electricity to moving air.

Summary: Electric motor, water pump, boiler and radiator are energy transloaders. They transfer the energy from one energy carrier to another.

Supplement S 10.1

Exercises

1. List some energy transloaders; indicate with which carrier they get the energy and with which they release it.

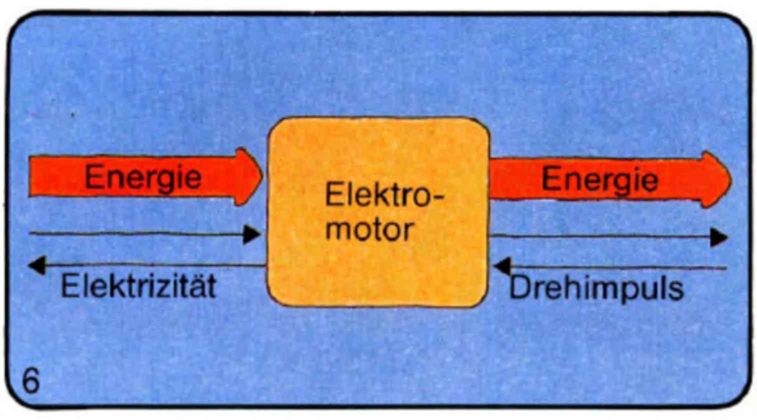
2. Draw the energy flow diagram of a) a gasoline engine, b) an incandescent lamp, c) a wind turbine, d) a dynamo.

3. Which energy transloader tranfers energy

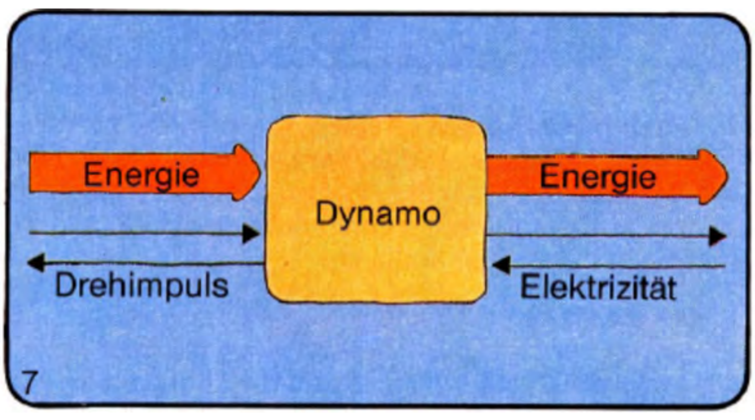
a) from angular momentum to electricity
b) from light to electricity
c) from food to angular momentum
d) from air to angular momentum
e) from heating oil to air
f) from diesel oil to angular momentum?

10.2 An electric motor becomes a dynamo

Figures 6 and 7 show the energy flow diagrams of an electric motor and of a dynamo. Someone who does not know what an electric motor and what a dynamo is can easily see from the pictures what the two devices do: The electric motor transfers energy from electricity to angular momentum and the dynamo from angular momentum to electricity. The dynamo does the opposite of the electric motor.

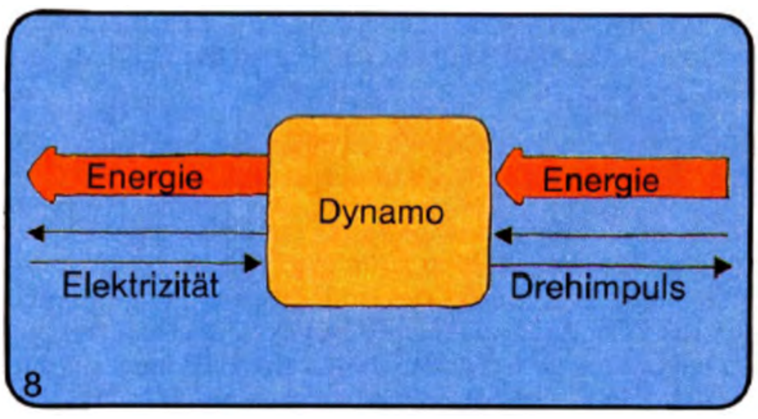


energy
electricity
electric motor
energy
angular momentum



energy
angular momentum
dynamo
energy
electricity

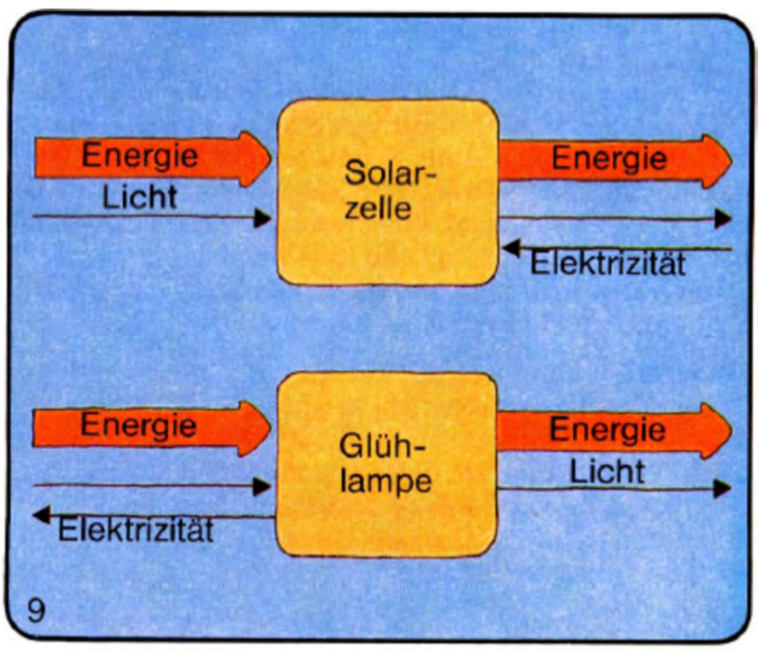
You can easily transform the motor's energy flow diagram into that of the dynamo: You only need to reverse the direction of all arrows, as shown in Fig. 8.



energy
electricity
dynamo
energy
angular momentum

If it bothers you that the energy now flows from right to left and not from left to right, then turn the image as a whole. (The image remains the flow image of a dynamo.) Thus you get Fig. 7.

Just like "electric motor and dynamo", the "solar cell and light bulb" pair have energy flow diagrams that only differ in the direction of the arrows. The solar cell transfers energy from light to electricity and the lamp from electricity to light, Fig. 9.



energy
light
solar cell
energy
electricity

energy
electricity
incandescent lamp
energy
light

Usually, energy transloaders, whose flow diagrams differ only in the direction of the arrows, are quite different devices. However, sometimes the to and fro transfer can be done with the same device.

Connect a toy motor to a battery. It transfers energy from electricity to angular momentum.

Now, connect the motor connections to a small light bulb and connect the engine shaft to an electric hand drill (as described in S 9.5). Hold the drill and toy motor in place and keep the drill running. The light's on. The toy motor now works as a dynamo. Similarly, some water pumps can also be operated as turbines or as hydraulic motors.

Summary: Electric motor and dynamo, solar cell and incandescent lamp, water pump and water turbine are pairs with inverted flow diagrams. Some electric motors can also run as dynamos, some water pumps as turbines.

Supplements S 10.2 and S 10.3

Exercises

1. Draw the flow diagram of a water pump and a water turbine. How do you get one from the other?

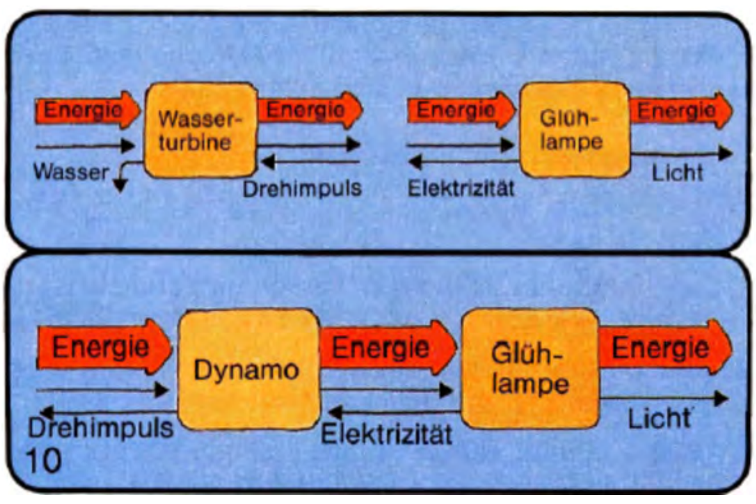
2. Draw the flow diagram of a wind turbine. Is there an energy transloader with the reverse flow diagram?

3. Name devices through which the energy can flow both "forward" and "backward".

10.3 How to couple energy transloaders to each other

So far we have only looked at individual transloaders. But you've probably already noticed that transloaders can be coupled together. We've done this before. However, there is one rule that must be observed. You might be able to find it out for yourself by looking at Fig. 10. Why can you not connect an incandescent lamp to a water turbine (Fig. 10 above), but to a dynamo (Fig. 10 below)?

energy
water
water turbine
energy
angular momentum



10

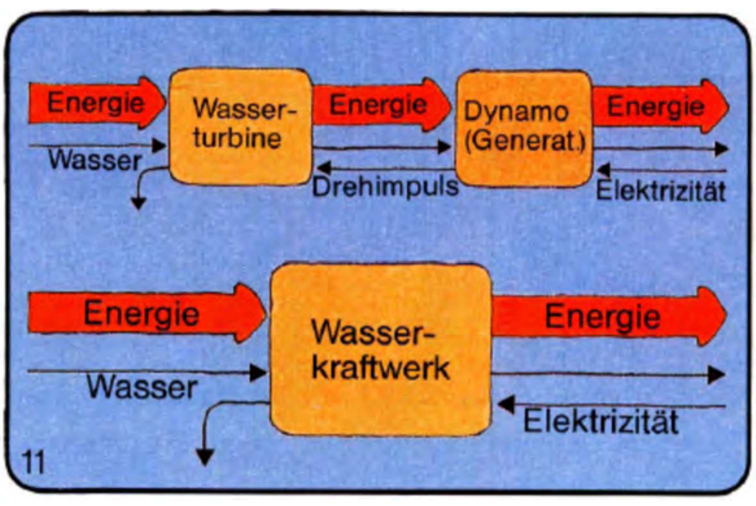
energy
electricity
incandescent lamp
energy
light

energy
angular momentum
dynamo
energy
electricity
incandescent lamp
energy
light

The energy can come out of the turbine only with the carrier angular momentum. However, it can enter into the lamp only with the carrier electricity. The two transloaders do not fit together. The dynamo and the lamp, on the other hand, fit together because the energy comes out of the dynamo with the same carrier with which it flows into the lamp.

The rule for coupling together is therefore: the carrier that carries the energy out of the first transloader must be the same as the carrier that carries it into the second.

A dynamo can be coupled to a water turbine, Fig. 11 above, because both the energy coming out of the turbine and the energy flowing into the dynamo is carried by angular momentum. (Both machines have a shaft.)



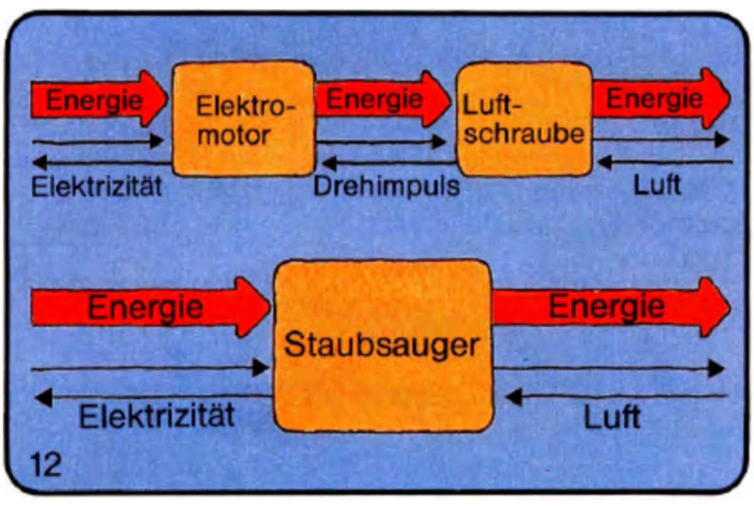
11

energy
water
water turbine
energy
angular momentum
dynamo (generator)
energy
electricity

energy
water
hydroelectric plant
energy
electricity

You've probably noticed that what we just put together is a hydroelectric plant. Instead of two linked symbols, we can also represent the hydroelectric power plant by a single symbol. If we are not interested in the internal structure of the power plant, the flow diagram in Fig. 11 below is sufficient.

Figure 12 below shows the flow diagram of a vacuum cleaner. The disassembled flow diagram is shown above.

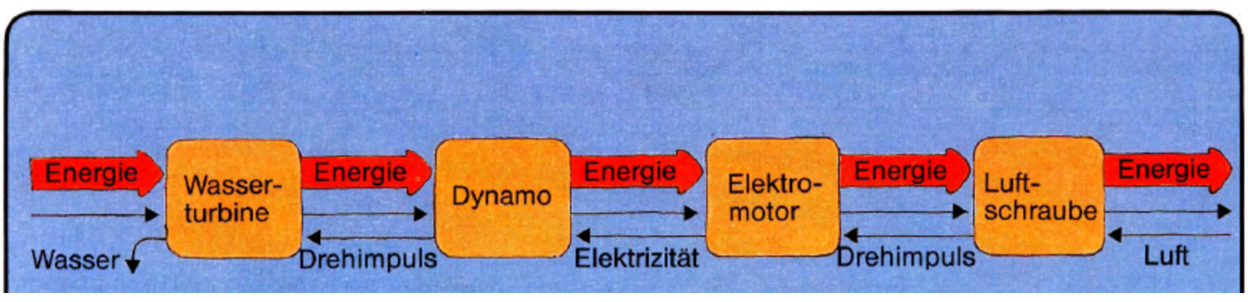


12

energy
electricity
electric motor
energy
angular momentum
blower
energy
air

energy
electricity
vacuum cleaner
energy
air

Of course, it is also possible to couple more than two transloaders to each other. You can build whole chains of transloaders. Fig. 13 shows the flow diagram of a vacuum cleaner that gets its energy from a hydroelectric power station. On the way from the water of the power plant to the air of the vacuum cleaner, the energy is transferred four times.



energy water | water turbine | energy angular momentum | dynamo | energy electricity | electric motor | energy angular momentum | blower | energy air

13

Summary: Two energy transloaders combined form a new transloader. The energy carrier must be the same at the output of the first transloader as at the input of the second.

Supplement S 10.4

Exercises

1 What do you have to pay attention to if you want to couple two energy transloaders to each other?

2 Which transloader must be inserted between a gasoline engine and a light bulb if the light bulb is to be operated with the gas engine?

3. Draw a long fantasy transloader chain.

4. Draw the longest possible transloader chain that really exists.

5. Draw an electric water pump

a) by using a single symbol
b) by two linked symbols.

6. Assemble the flow diagrams of the following devices from two symbols each:

a) electric pump, b) water pump with gasoline engine, c) wind-driven water pump (there are such pumps on Mallorca).

10.4 A catalogue of energy transloaders

Many of the devices you have encountered in this book are energy transloaders. We have arranged them in a table. We want to see what you can do with the table. If you move from the word “solar cell” to the far left, you will find the carrier with which the energy flows into the solar cell: Light. When you go up from the word solar cell, you find the carrier with which the energy flows out of the solar cell: Electricity. In the same way you can see from the table, for example, that the transloader “radiator” gets the energy with the carrier “warm water” and releases it again with the carrier “warm air”.

	Carrier of the energy that leaves the transloader						
Carrier of the energy that enters the transloader	**compressed air, moving air**	**liquid under high pressure, moving liquid**	**electricity**	**angular momentum**	**light**	**warm air**	**warm water**
compressed air, moving air			wind power plant	wind turbine			
liquid under high pressure, moving liquid			hydroelectric power plant	water turbine, hydraulic motor			
electricity	fan, vacuum cleaner	electric pump		electric motor	incandescent lamp	electric stove	electric boiler
angular momentum	compressor	water pump	dynamo, generator				
light			solar cell	light mill		asphalt road	solar collector
warm air							
warm water						radiator	
fuel	Diesel compressor		coal-fired power plant	gasoline engine, steam engine	fire	oil stove	furnace

The table shows both compound transloaders, such as the hydroelectric power station, and those that we no longer dismantle, such as the water turbine.

Supplement S 10.5

Exercises

1. a) All motors are in the same column of the table. Why?

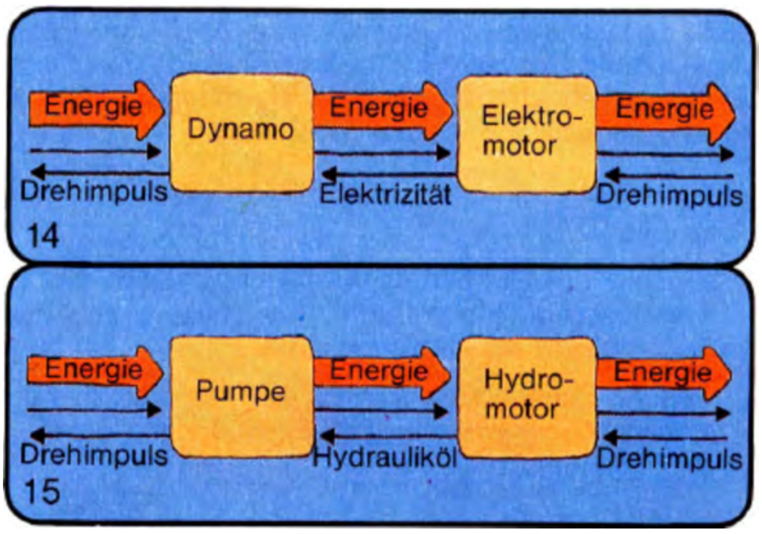
b) All furnaces are in the same column of the table. Why?

2. Which column of the table contains
   a) Pumps,
   b) Lamps?

3 What do devices that appear in the same line of the table have in common?

10.5 Energy transport over long distances

The transloader chain in Fig. 14 seems pointless at first glance. A dynamo transfers energy from angular momentum to electricity, the electric motor transfers it back to angular momentum. You could leave the energy directly on the angular momentum, then you would save two transloaders. Nevertheless, this chain is often used, and for good reason. In the power station, the energy comes out of the steam turbine or water turbine with the angular momentum. In the houses to which the energy is to be brought, it is partly used with angular momentum, namely in all the devices that have an electric motor. Couldn't we save the generator in the power plant and the electric motors in the household? Yes, but only at a high price. One would have to transport the energy from the turbine of the power plant to the household appliances with the angular momentum. Instead of laying the electrical lines between the power plant and the houses, shafts would have to be laid. You can imagine what an effort that would be.



energy
angular momentum
dynamo
energy
electricity
electric motor
energy
angular momentum

energy
angular momentum
pump
energy
hydraulic oil
hydraulic motor
energy
angular momentum

Even at shorter distances, it is often preferable to take the detour via electricity. In every car there are electric motors: one for the windscreen wipers, one for the fan (for cooling the engine), one for the heater fan, one for raising and lowering the windows, one for extending the antenna, one for opening the sunroof... All these motors get their energy from the alternator. The alternator transfers energy from angular momentum to electricity, the electric motors transfers it back to angular momentum,

A similar chain is used in many construction machines, Fig. 15. An excavator has a large diesel engine. This transfers energy from the diesel oil to angular momentum. A pump transfers the energy from the angular momentum to the hydraulic oil. The wheels or chains of the excavator are equipped with hydraulic motors that transfer the energy back to angular momentum. The reason for the back and forth loading is that energy transport with hydraulic hoses is more convenient than through shafts.

Summary: It is not convenient to transport energy over long distances with angular momentum. Therefore, it is transferred from the angular momentum to electricity or hydraulic oil for transport, and then back to angular momentum.

Exercises

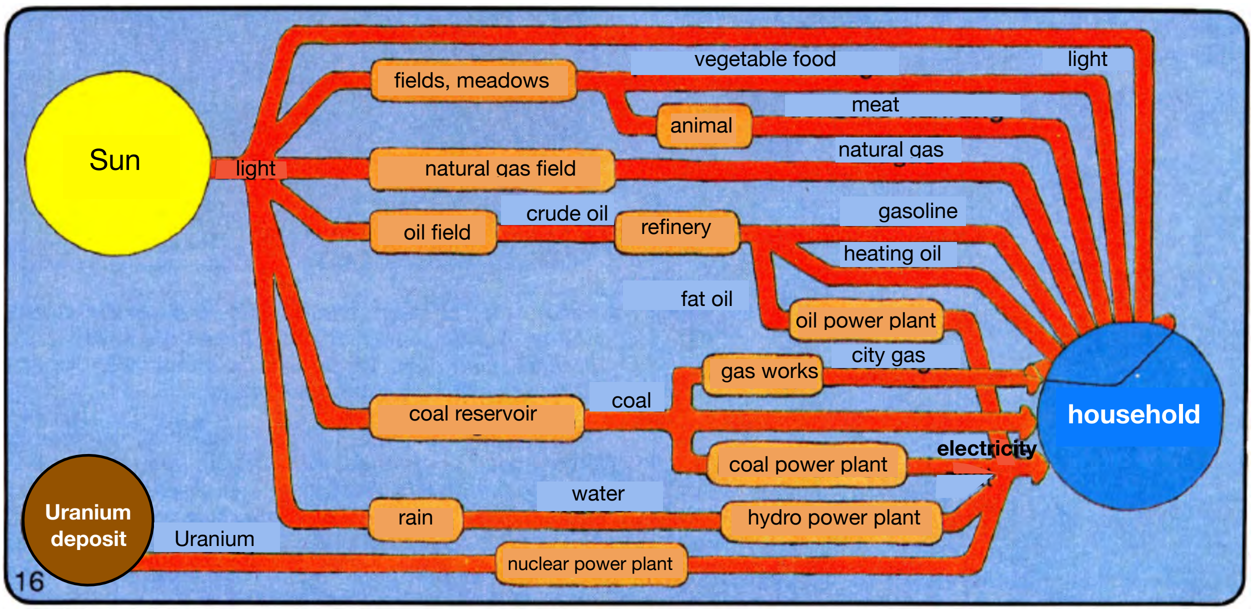
1. Draw the flow diagram of the transloader chain car engine - alternator - electric motor of the heater blower.

2 Which energy carriers are suitable for transporting energy over long distances and which are not?

10.6 Where the energy consumed in the household comes from

Every household gets energy from several energy sources. The energy for lighting, irons, vacuum cleaners, washing machines and TV sets comes into the house with electricity. Houses with solar panels get the energy for the warm water with the light. The cars, motorcycles and mopeds in the household get their energy from gasoline. After all, people in your house also want to eat, so energy comes into the house with food.

Where does the energy used in the household come from? We are following the paths of the energy carriers that we have listed backwards, see Fig. 16.



Plant foods get their energy from the light of the sun. Since animals eat plants, the energy we absorb when eating meat, butter or eggs also comes from the sun. All fuels, i.e. coal, heating oil, gasoline and natural gas, come from deposits that were formed many millions of years ago by the decomposition of plants or animals. The energy of these fuels also comes from the sun.

Most of the energy carried by electricity comes from coal-fired power stations. So it also comes from the sun. A small proportion comes from hydroelectric power stations. However, the water that drives the turbines has also received its energy from the sun. (If you want to know how the sun does that, read S 10.6.)

Only a very small proportion of the energy consumed in the household, less than 5%, comes from nuclear power plants. Nuclear power plants get their energy from uranium, and the uranium deposits did not get their energy from the sun.

Most of the energy we consume comes from sources that eventually run dry. In order for the coal, oil and gas deposits to develop, the sun had to shine for millions of years. We are about to use up these reserves in a few decades or centuries. The uranium reserves will no longer be sufficient either. So it is high time to think about how we can still get enough energy in the future.

Summary: Almost all the energy we consume has come from the sun. Most of the energy we consume comes from sources that dry up in a few decades or centuries.

Supplement S 10.6

Exercises

1 Which carriers do you use to bring energy into your home? Where does this energy come from? Track its path back.

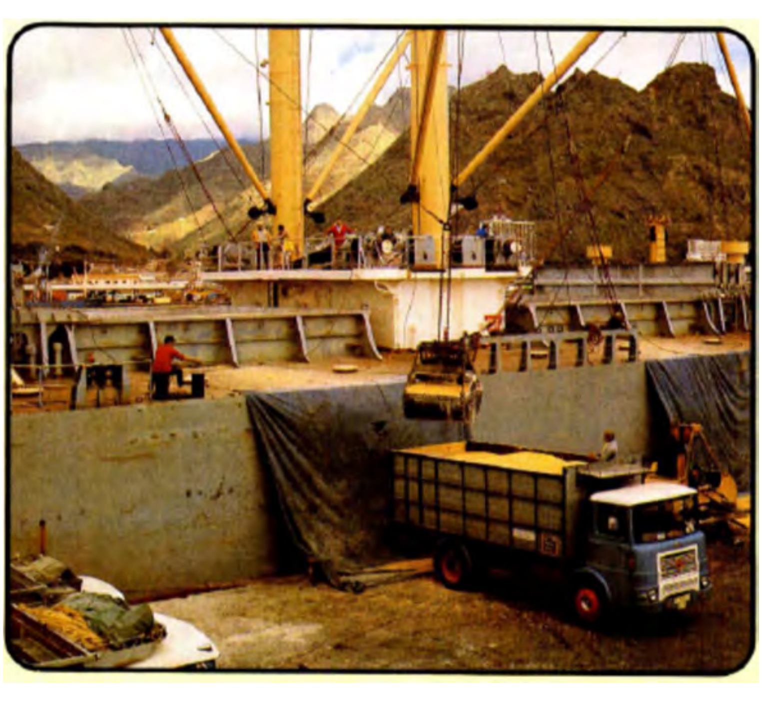
2. On Fig. 16 you can get from the sun to the household in several ways. Draw the energy flow diagram for some such paths.

3. Pike feed on smaller fish. Does the energy you consume when you eat pike come from the sun?

S 10.1 Gravel transloader – people transloader

There are transloaders not only for energy, but also for other things.

The picture shows a port in which gravel is transferred from a ship to trucks. The gravel enters the port with the carrier "ship". The crane transfers it to trucks. The gravel leaves the port with the carrier "truck". The port is therefore a "gravel transloader". By the way, ships and trucks are "deposit-bottle gravel carriers".



You may have noticed that every port, every airport and every train station is a transloader – not for energy, but for goods or people. In an airport, for example, people are unloaded from the carrier car to the carrier airplane and vice versa.

S 10.2 The bicycle dynamo as motor

Just as many electric motors can be used as dynamos, dynamos can also be used as electric motors. You can try it yourself with a bicycle dynamo if you have a transformer that has about 8 V at the exit. You need a transformer because it requires alternating current. The experiment doesn't work with batteries.

Turn your bike upside down. Hook up the dynamo. (If you turn the wheel of the bike, the dynamo shaft must rotate.) Connect the two terminals of the dynamo (screw and housing) to the two sockets of the transformer. The dynamo drives the bike's wheel. You may have to start the dynamo (- motor).

S 10.3 An experiment with model locomotives

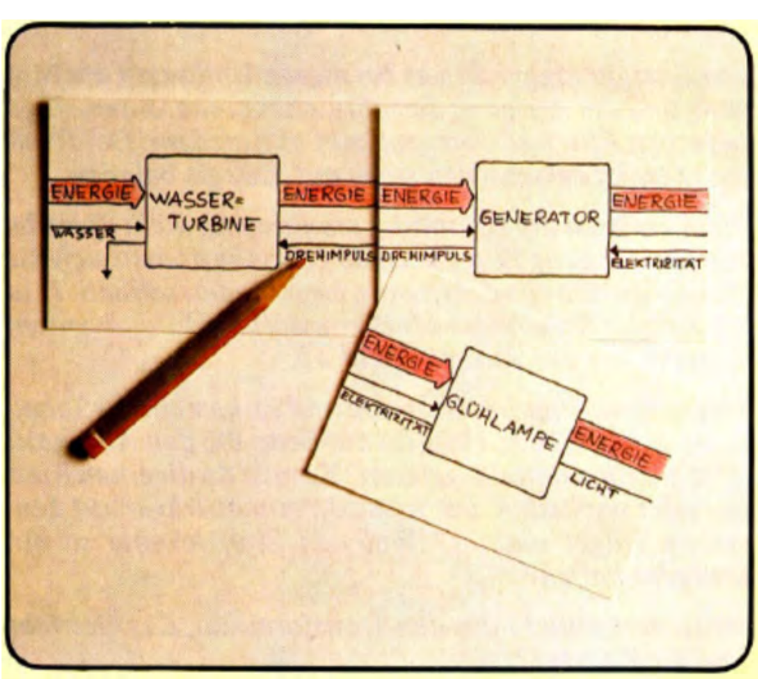
Some model locomotives have a motor that can work as a dynamo. With such locomotives you can make a surprising experiment.

Normally the busbars are connected to a power supply. The locomotives get their energy from the power supply unit via contacts that slip on the two conductor rails. On the picture, however, the busbars are not connected to the power supply unit. The conductor rails connect only the motors of the two locomotives.

If one of the two locomotives is now pushed by hand, the second locomotive also moves, although it does not touch the first one. Where does the second locomotive get its energy from?

S 10.4 A domino game with energy transloaders

In many of the exercises in this book, you will need to couple energy transloaders in various ways. There is a lot to draw. However, you can make your work easier if you draw the flow diagram of each individual transloader on a small card. If you now want to link transloaders to each other, you only have to put the corresponding cards together. You can then use them again for the next exercise.



energy
water
water turbine
energy
angular momentum

energy
angular momentum
generator
energy
electricity

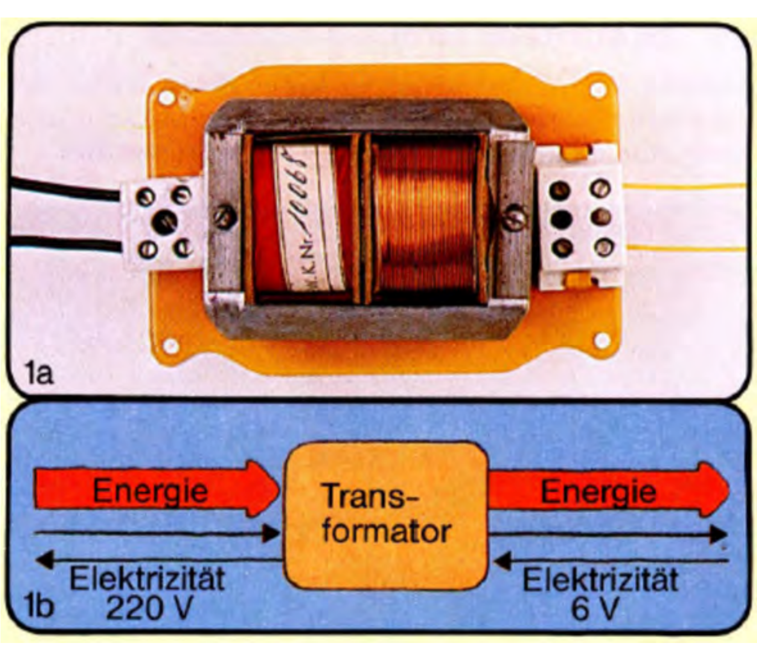
energy
electricity
incandescent lamp
energy
light

The picture shows how the cards have to look like. It is important that the arrows at the edges of the map end at the same height. But only make cards for transloaders that can no longer be decomposed.

The rule for putting the cards together is the same as that for putting dominoes together.

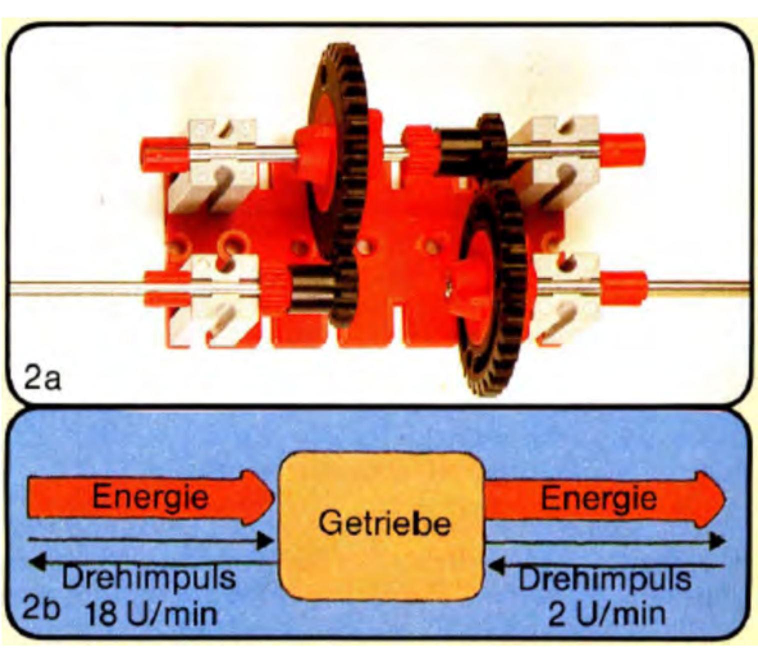
S 10.5 Transformer, gearbox and coking plant

In the table in section 10.4, the diagonal boxes were left free from top left to bottom right. In devices that would belong there, the energy would be transferred from one carrier to the same carrier, for example from electricity to electricity. Such a device would be pointless, you might say. Really? Let's take a closer look.

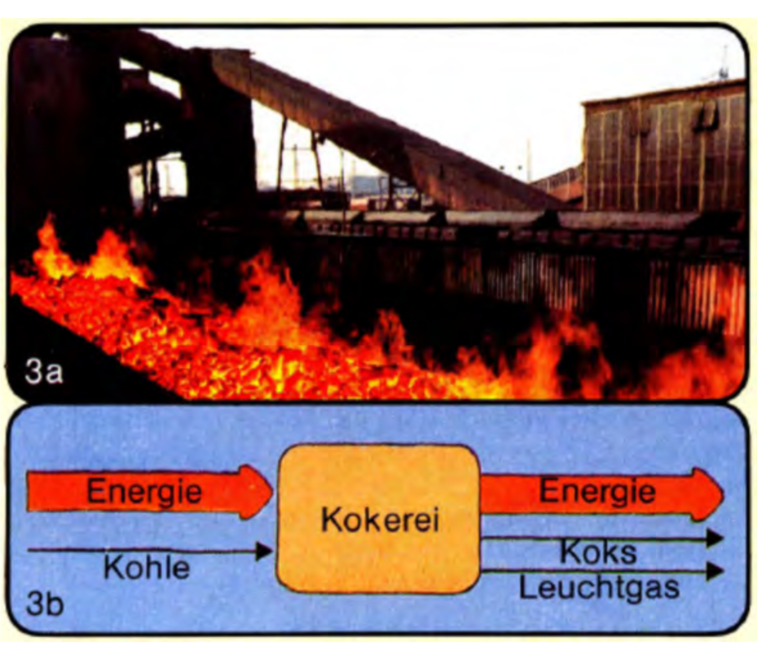


energy
electricity
transformer
energy
electricity

Figure 1 a shows a device into which the energy flows with the carrier electricity and out of which it flows again with the carrier electricity: a transformer. Figure 2 a shows a device into which the energy enters with the carrier angular momentum and which it leaves again with the same carrier: A gearbox. Fig. 3 a, shows a plant into which the energy goes with the carrier fuel and out of which it comes with the carrier fuel: a coking plant.



energy
angular momentum
18 revolutions/min
gear box
energy
angular momentum
2 revolutions/min



energy
coal
coking plant
energy
coke and city gas

Although the energy carrier is the same at the entrance and at the exit of these transloaders, there is still a difference between entrance and exit: The energy carrier is loaded with energy to different degrees.

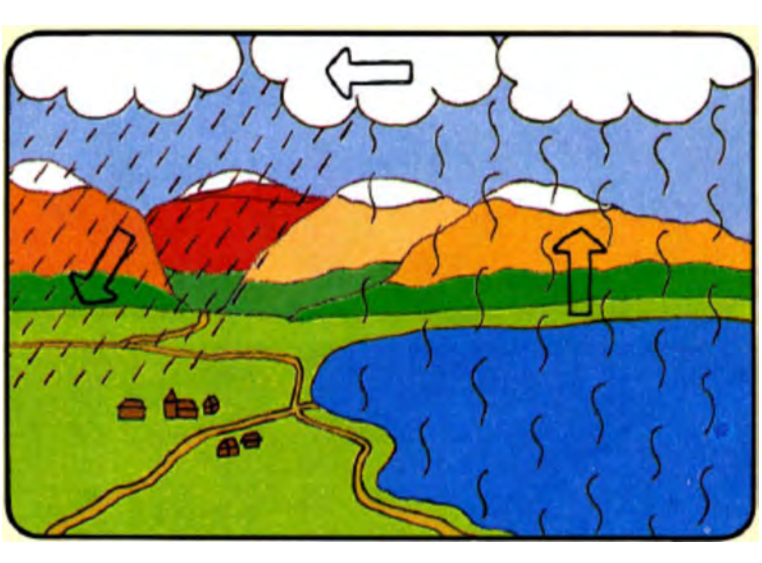
With the transformer, the voltage at the input is not the same as at the output Fig. 1 b. The input and output shafts of the gear unit rotate at different speeds, Fig. 2 b. In the coking plant, the fuel at the entrance is not the same as at the exit Fig. 3 b.

Enter transformer, gearbox and coking plant in the table in section 10.4. Have you read the section on the gravel movers? Can you imagine a gravel transloader transferring gravel from a carrier to the same carrier? What's the point of such a transloader?

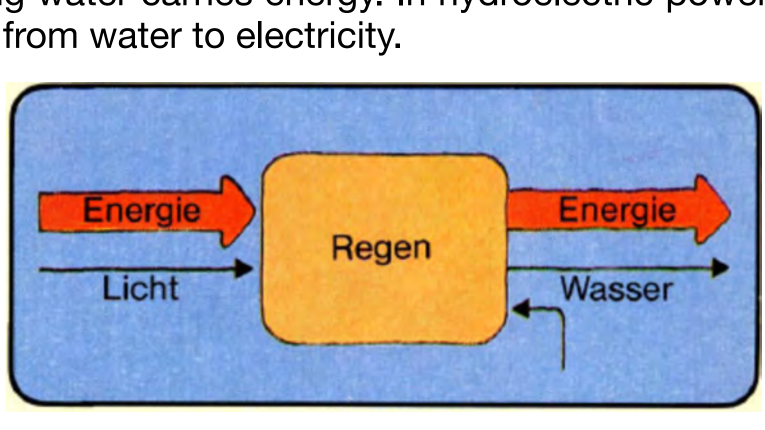
What are the transformer, the gearbox and the coking plant used for?

S 10.6 The "rain" as an energy transloader

Water constantly evaporates on the surface of seas, lakes and rivers: the water becomes gaseous and mixes with the air. The energy used for evaporation is supplied by the sun. The evaporated water rises. Energy is needed for this too, and it also comes from the sun. It's getting colder and colder to the top. At some point it is so cold that the water vapor becomes liquid water in the form of many small droplets. A cloud is forming. At some point, the droplets become so big that they fall down. It's raining. Since the wind carries away the evaporated water, the water does not rain down again at the same place where it evaporated.



Rainwater flows on earth from the mountains down into the valleys and into the sea. Running water carries energy. In hydroelectric power stations, it can be transloaded from water to electricity.



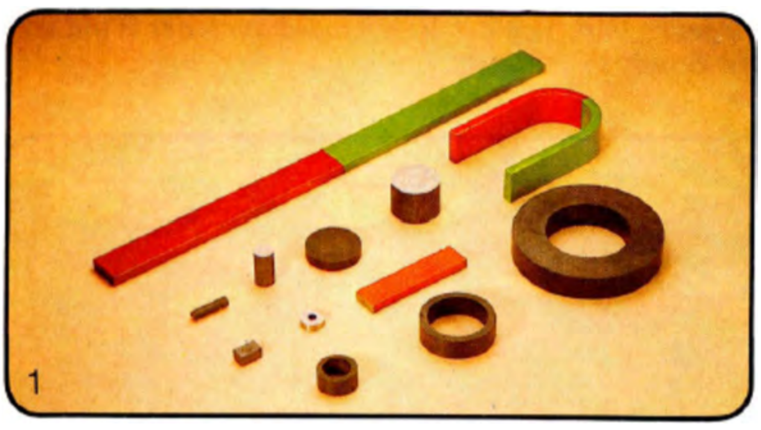
energy
light
rain
energy
water

The energy carried by the water of the rivers was thus charged on the water by the sunlight. Here, the transloader is not a technical device, but a natural phenomenon. For simplicity's sake, we write the word "rain" into the symbol, although there is actually more to the transloader than just the rain. Like the rain, the wind is also driven by the sun.

11. Electromagnet and electric motor

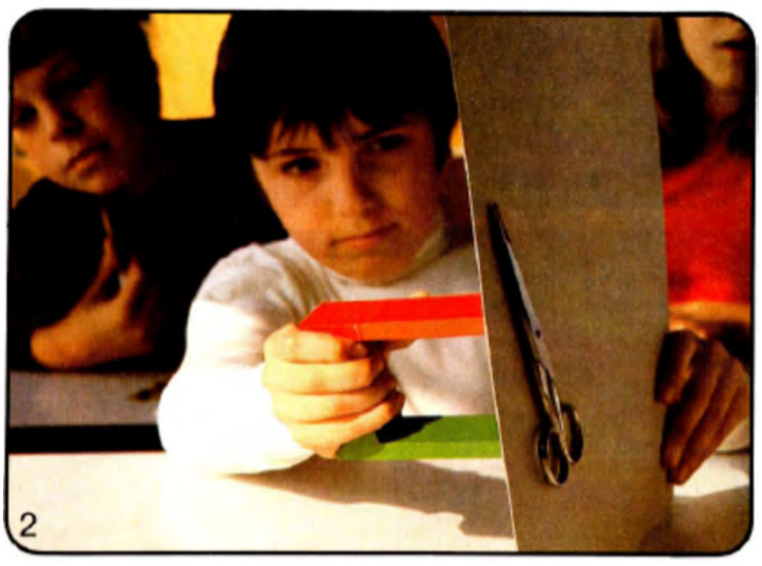
11.1 Permanent magnets

Magnets, as shown in Fig. 1 and as they are in the lock of the refrigerator door, are called permanent magnets. They remain magnetic all the time. Electromagnets, on the other hand, are only magnetic as long as an electric current flows through them.



1

Magnets attract objects made of iron. They do not need to touch the object. The attraction works through other objects that are not made of iron. When the magnet behind the cardboard in Fig. 2 is moved, the scissors move with it.



2

A magnet has two places where the attraction is particularly strong. These places are called the poles of the magnet. The poles can be seen particularly clearly when the magnet is held in iron filings, Fig. 3.

3

In a rod magnet, the poles are at the ends of the rod. In the case of the disc-shaped magnet in Fig. 1, the two large surfaces are the poles. If you hang a rod magnet on a thin thread in such a way that it can rotate, it sets itself in a north-south direction. The north pointing pole is called the north pole, the south pointing pole is called the south pole. A compass is nothing more than a freely rotatable rod magnet.

If one magnet is brought close to another, two things can happen: If two different poles face each other, the magnets attract each other. If two equal poles face each other, they repel each other.

With a compass you can check which is the north pole and which is the south pole of a magnet. The tip of the compass needle (north pole) always points to the south pole of the magnet.

Summary: Magnets have two different poles. Equal poles repel each other, unequal poles attract each other. Iron objects that are not magnets themselves are attracted to magnets.

Supplements S 11.1 and S 11.2

Exercises

1. Magnets attract iron objects. Is this always the right sentence?

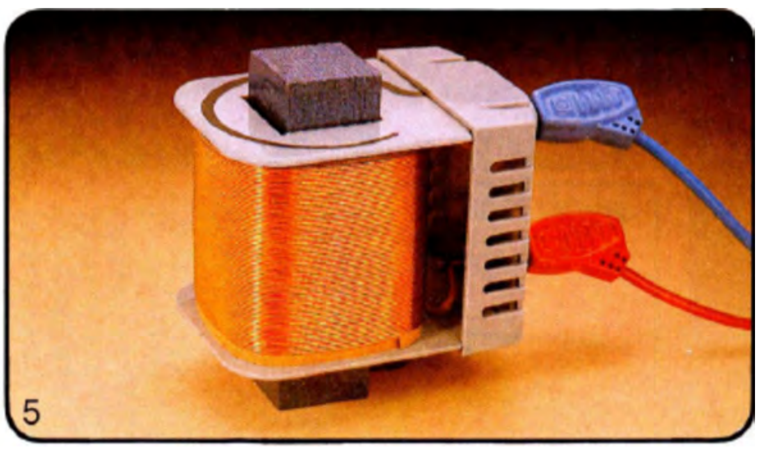
2 Why is one pole of a magnet called the north pole, the other the south pole?

3. The earth is a magnet. How can you tell? Where is the north pole of this magnet?

11.2 Electromagnets

An electromagnet is easy to create. You need a piece of iron, e.g. a nail, and insulated wire. You wind the wire, always in the same direction, around the iron piece – and the electromagnet is ready, Fig. 4. Fig. 5 shows how a purchased electromagnet looks like. The piece of iron is called the *core* of the magnet, the wound wire the *coil*.

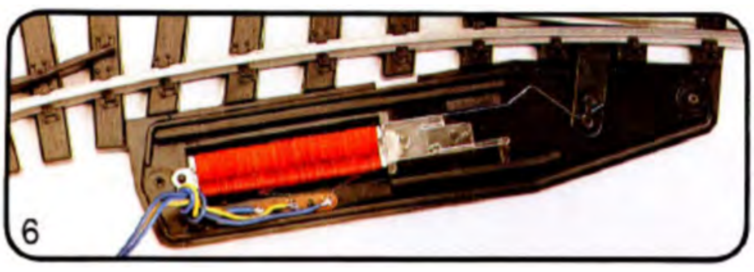
4



5

An electromagnet attracts iron particles as long as an electric current flows through it. The greater the current, the stronger the pull. As soon as the current stops flowing, the magnet ceases to attract.

The electromagnet has, just like a permanent magnet, a north and a south pole. On Fig. 5 one pole is at the upper end of the iron piece, the other at the lower end. Whether the north or south pole is up depends on the direction of the electric current in the wire. If the direction of the current in the wire is reversed by interchanging the connections on the battery, the polarity of the magnet is reversed.



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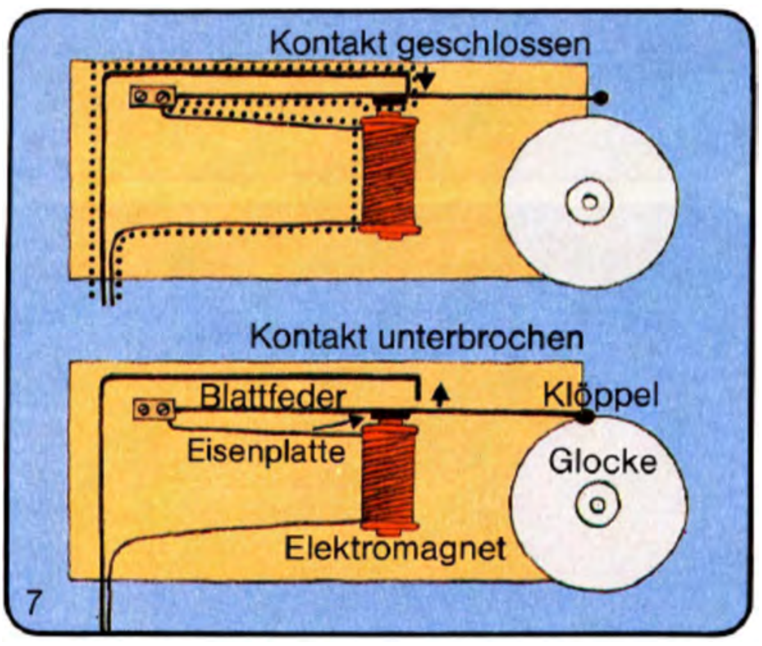
Electromagnets have many applications. The turnouts of the tram are set by an electromagnet, just like the turnouts of model trains, Fig. 6. In the washing machine, taps are magnetically operated. In the electric door opener, a bolt is pulled out with the aid of an electromagnet.

Fig. 7 shows an electric bell. When the electromagnet is switched on, it attracts an iron plate attached to a leaf spring. The clapper strikes against the bell. At the same time, the circuit is interrupted at the breaker contact. Therefore, the electromagnet releases the iron plate. This closes the contact and the game starts again.



7

contact closed

contact interrupted

leaf spring clapper
iron plate

bell

electromagnet

Summary: An electromagnet has, like a permanent magnet, a north and south pole. The position of the poles depends on the direction of the electric current in the coil of the magnet.

Supplement S 11.3

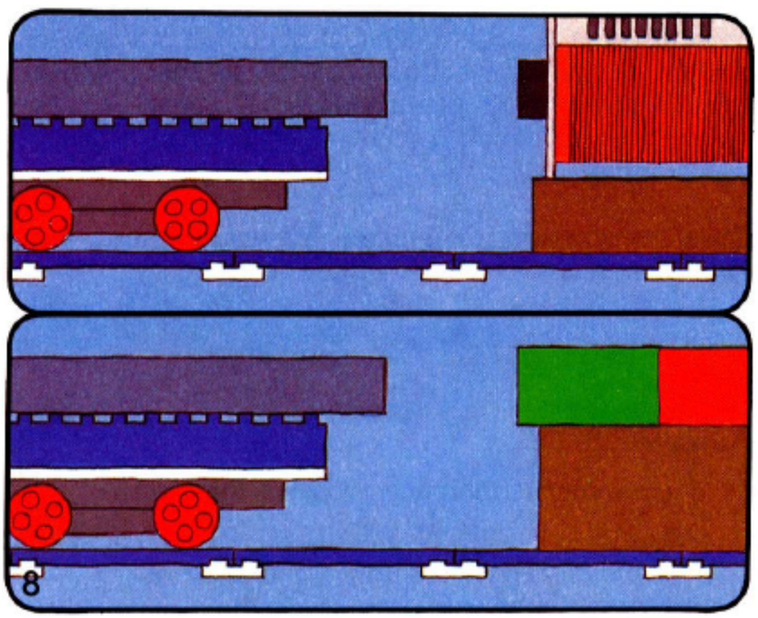
Exercises

1. Why must the copper wire of an electromagnet coil be insulated?
2. How can the strength of an electromagnet be changed?
3. How do you reverse the polarity of an electromagnet?
4. Name technical devices using electromagnets and describe how they work.

11.3 Where magnets get their energy from

Fig. 8 above shows a railway car with a piece of iron on top and an electromagnet. When the electromagnet is switched on, the railway car starts moving, it approaches the magnet. Normally a railway car is moved by a locomotive. Then the locomotive supplies the energy for the movement. When the car is attracted by the magnet, the magnet provides the energy. The electromagnet itself gets its energy from the battery to which it is connected.

We could also have set the car in motion with a permanent magnet, Fig. 8 below. Where does the energy come from? The permanent magnet does not have a cable to supply it with energy. The energy must have been in the magnet before. It got the energy at the magnet factory.



If a permanent magnet attracts a piece of iron, part of the energy of the magnet is consumed. If the piece of iron is removed from the permanent magnet, this energy is given back to the magnet.

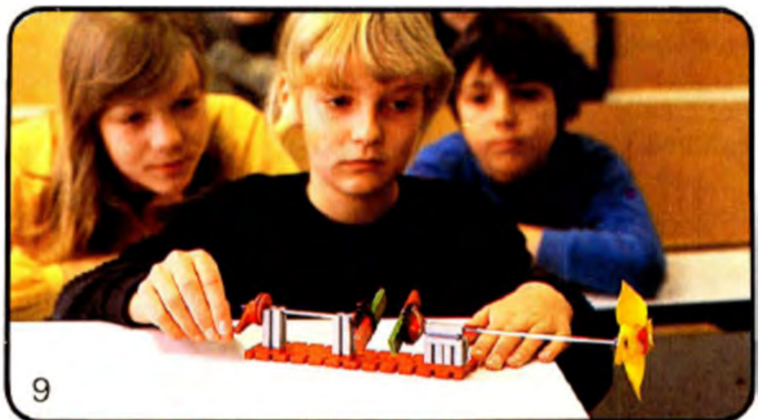
The railway car and the magnet in Fig. 8 below behave similarly to some toy cars: when you push such a car back, you pull up the spring of the car and energy is stored in it. If you let the car go, it moves forward again on its own. It uses the energy that was stored in the spring as it was pushed backwards.

Summary: Magnets have energy. When they attract something, they give off energy. An electromagnet gets its energy with the electricity from the source to which it is connected. A permanent magnet gets it during its production.

Supplement S 11.4

11.4 Magnetic coupling

Magnets can be used to transfer energy without contact. Fig. 9 shows how the energy arriving through one shaft can be transmitted to another shaft without the shafts being connected. Such a device is called a magnetic coupling. In Fig. 10, energy is transmitted through a board with the magnetic coupling.



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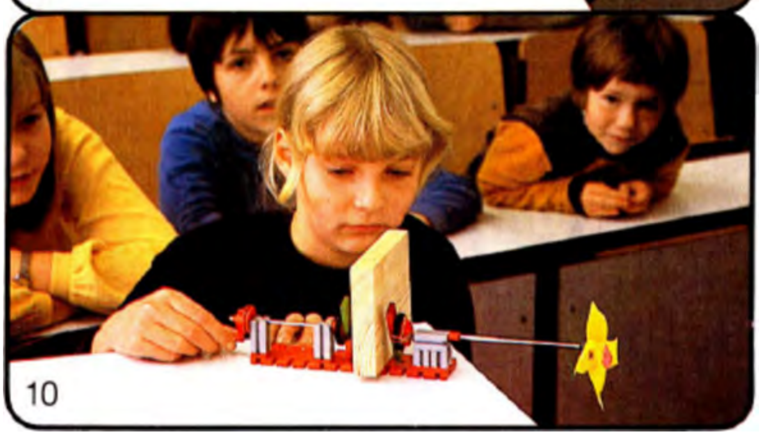
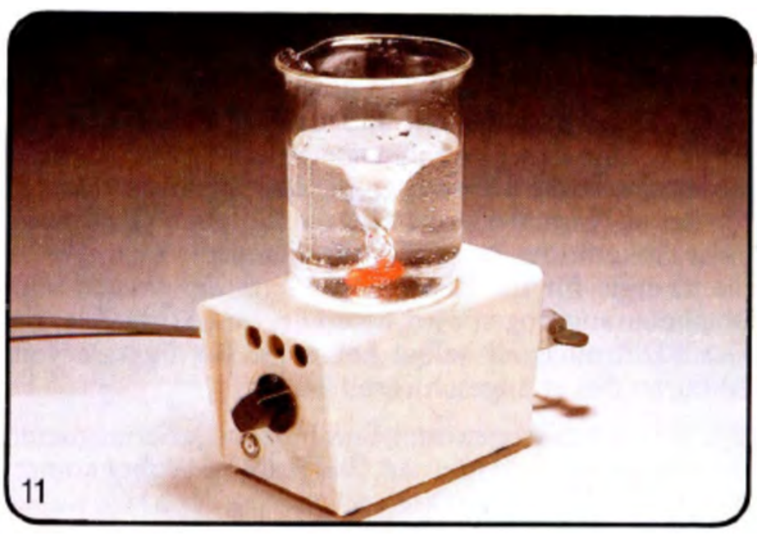


10

In chemical experiments, sometimes a liquid has to be stirred in a closed container. A magnetic stirrer is used, Fig. 11, and a small permanent magnet is located in the liquid. There is a second permanent magnet in the box on which the container with the liquid is placed. This is rotated by a motor. The magnet in the liquid rotates with it, stirring the liquid.



11

Magnetic stirrer

Summary: With a magnetic coupling, energy can be transmitted through walls.

Supplement S 11.5

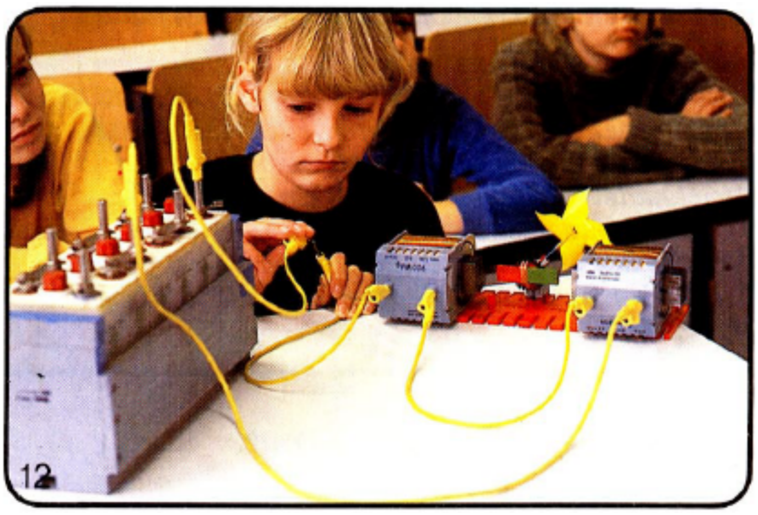
Exercises

1. How does a magnetic stirrer work?

2. Which carrier is used to transfer the energy from one side of a magnetic coupling to the other? Justify your answer.

11.5 The electric motor

The energy for rotating the propeller in Fig. 9 is supplied by the girl turning the crank. She no longer wanted to turn and thought about what she could do to make the propeller turn without making an effort herself. Fig. 12 shows the solution. It has replaced one of the two permanent magnets with electromagnets. This no longer needs to be turned. It is enough to switch the electromagnets on and off regularly. The poles of the permanent magnet are then always attracted for a short time. While they are not attracted, the permanent magnet continues to rotate due to its inertia until its poles are attracted again at the right moment.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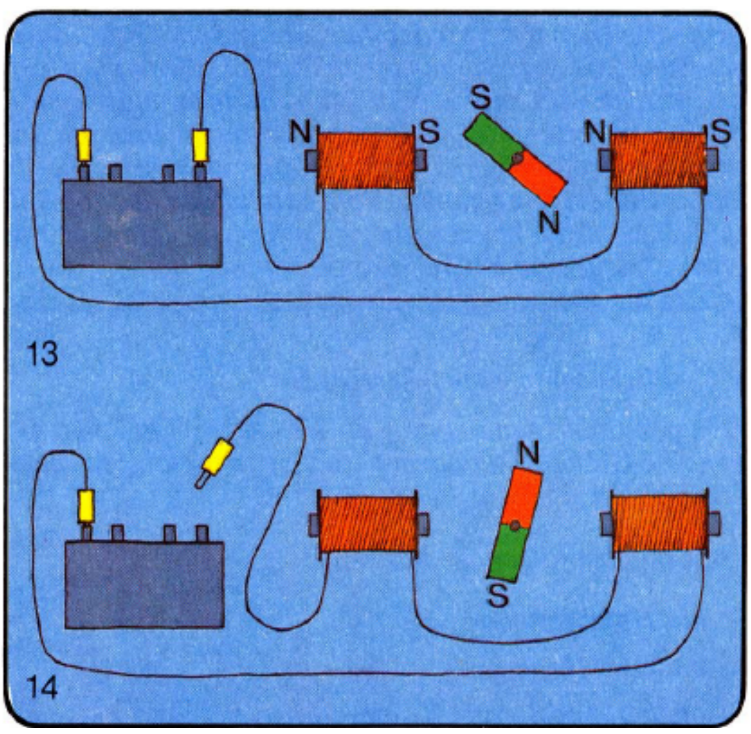
In Fig. 13 the north pole of the permanent magnet is pulled to the left and the south pole to the right. In Fig. 14 the permanent magnet continues to rotate because of its inertia. Switching the electromagnet on and off is not easy. If it does not happen at the right moment, the permanent magnet gets out of sync.



13

14

The energy that flows through the shaft to the propeller no longer comes from a crank, but from the battery.

This strange device is almost an electric motor. There is yet a small disadvantage: You have to switch the power on and off manually all the time. A real electric motor does this automatically.

Supplement S 11.6

S 11.1 How to make your own permanent magnets

Any steel object, i.e. hardened iron, can be magnetized. Take a steel knitting needle, for example, and stroke one pole of a magnet several times in the same direction over the knitting needle, from one end to the other: The knitting needle becomes a magnet, a real magnet with a north pole at one end and a south pole at the other. You can check this with a compass.

S 11.2 Magnets with a single pole?

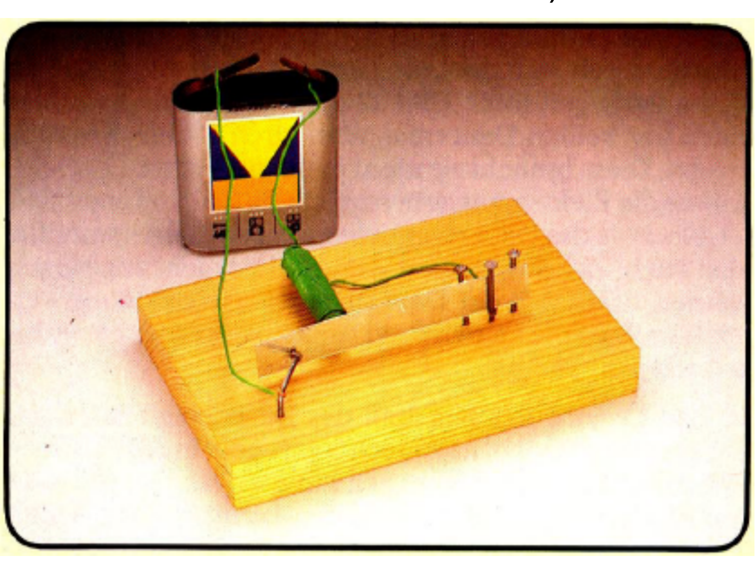
Such magnets have not yet been found. You can try to make one yourself. A magnetized knitting needle has a north pole at one end and a south pole at the other. If you now break through the knitting needle in the middle, you should get two knitting needle halves, each with a single pole. Try it, you'll be surprised: Two new poles have been emerged at the fracture point, each half of the knitting needle is again a complete magnet with a north and a south pole.

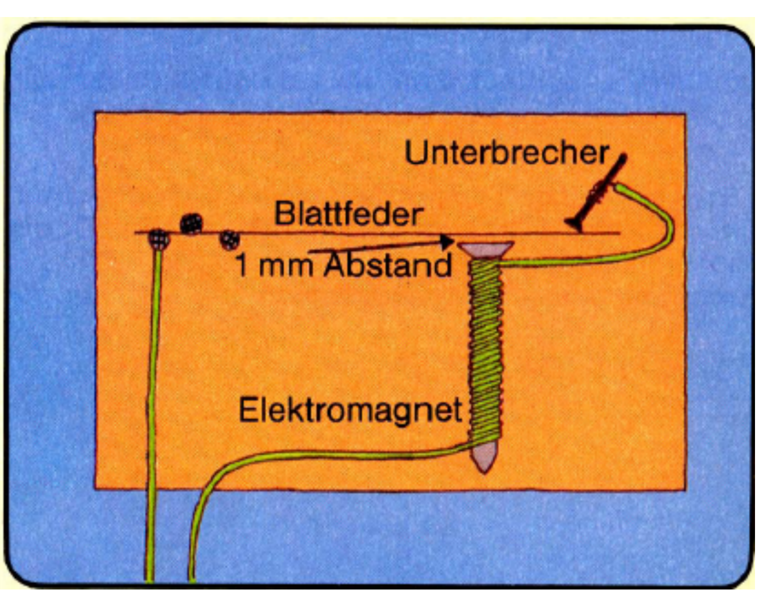
S 11.3 A buzzer to build yourself

It works exactly like the bell in picture 7, but it has no bell. The noise is made by the moving leaf spring alone.

You need the following material:

- a little wooden board,
- a couple of nails,
- about 3 m insulated copper wire,
- a leaf spring (metal strips of a folder - scrape off paint -, a piece of watch spring or a piece of sheet metal of a milk can).





circuit breaker

leaf spring
1 mm distance

electromagnet

The drawing shows how to set up the buzzer. The coil should have about 200 turns. The leaf spring must press against the interrupter nail. The interrupter nail can be rotated in its hole in the wooden board. It is adjusted so that the distance between spring and electromagnet nail is about 1 mm. With a buzzer you can transmit messages through a cable. You use the morse alphabet.

a	·–	o	–––	ü	··––
b	–···	p	·––·	Punkt	·–·–·–
c	–·–·	q	––·–	Komma	––··––
d	–··	r	·–·	?	··––··
e	·	s	···	0	–––––
f	··–·	t	–	1	·––––
g	––·	u	··–	2	··–––
h	····	v	···–	3	···––
i	··	w	·––	4	····–
j	·–––	x	–··–	5	·····
k	–·–	y	–·––	6	–····
l	·–··	z	––··	7	––···
m	––	ä	·–·–	8	–––··
n	–·	ö	–––·	9	––––·

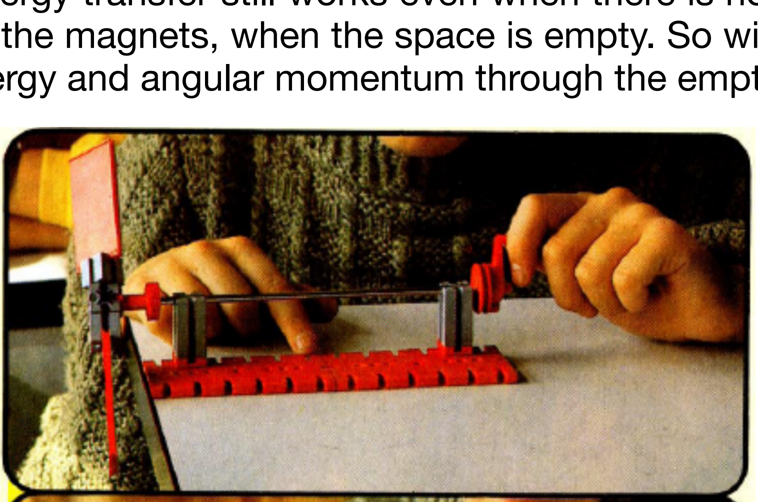
dot
comma

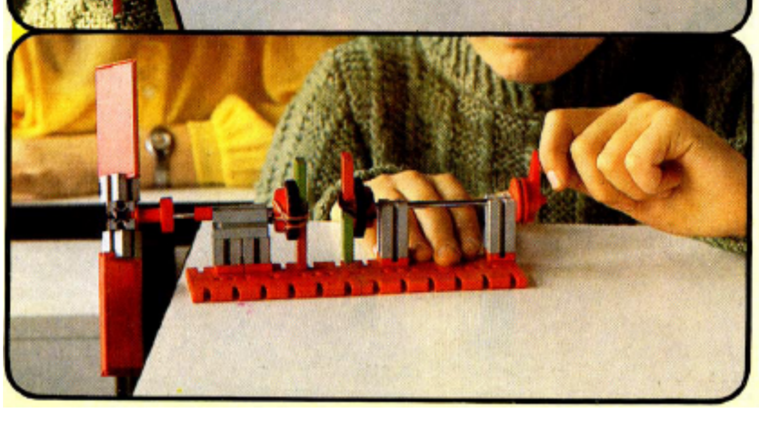
S 11.4 The energy reserve of a magnet

A horseshoe magnet that hasn't attracted anything yet has energy. It can use it to pull an iron block towards itself. If it has done so, its energy supply is exhausted. It can't attract a second iron block anymore, it doesn't even have enough energy left to attract a nail.

S 11.5 Angular momentum flows through the empty space

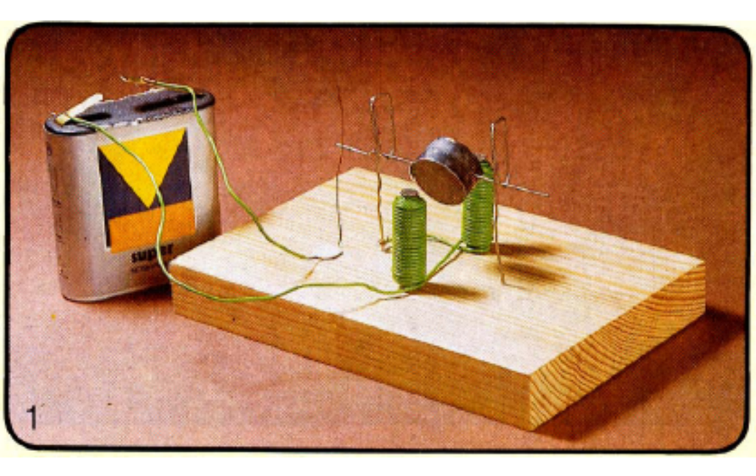
The upper picture shows a fan in which energy flows with the carrier angular momentum from the crank to the propeller. The picture below shows almost the same fan, only here is a gap in the way between crank and propeller. Also in this case, the energy starts on the right side at the crank with its carrier angular momentum, and on the left side at the propeller it arrives with angular momentum. So both energy and angular momentum flowed through the gap. The energy transfer still works even when there is no more air in the space between the magnets, when the space is empty. So with magnets one can transfer energy and angular momentum through the empty space.





S 11.6 A self-built electric motor

The finished motor is shown in figures 1 and 2. Look closely at Fig. 2 to understand how it works.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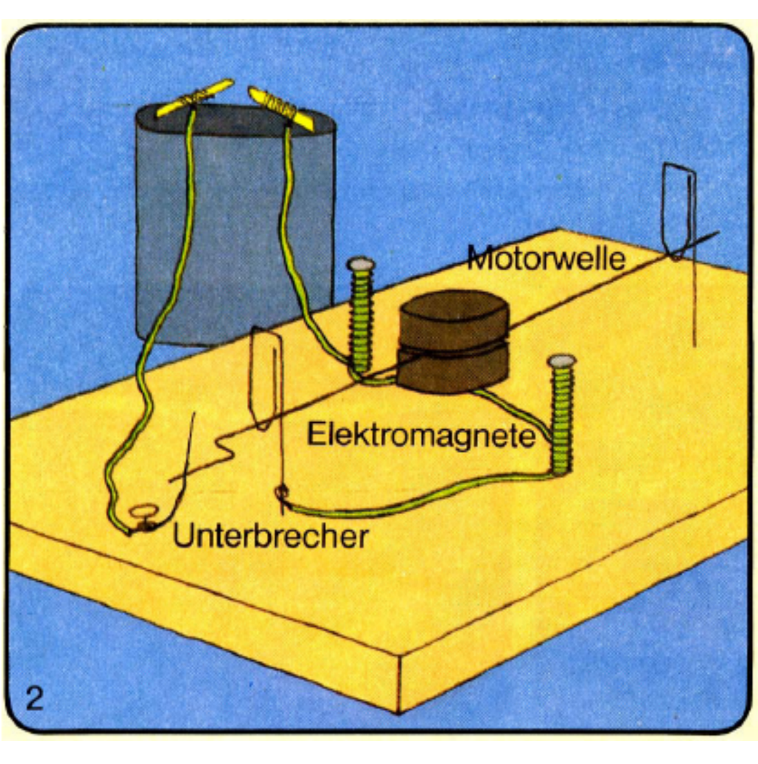


2

motor shaft

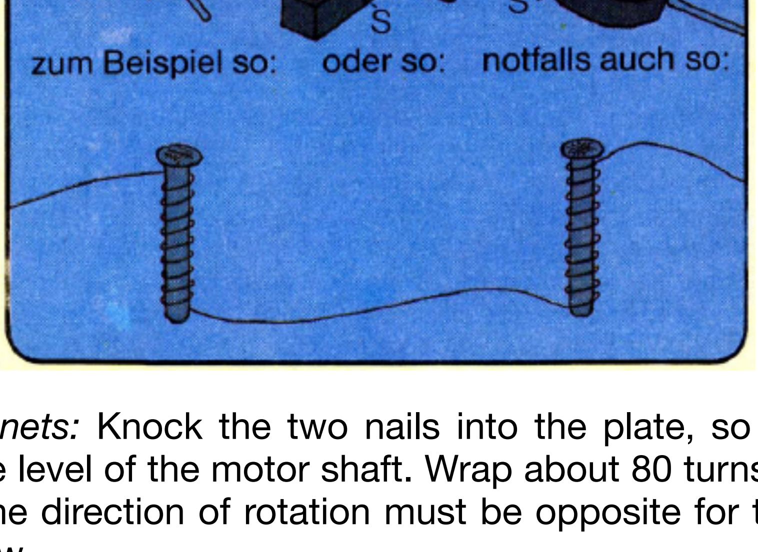
electromagnets

circuit breaker

You need the following material:

- a little wooden board,
- 2 small permanent magnets,
- 2 iron nails or screws (about 4 cm long),
- approx. 3 m insulated copper wire,
- 3 paper clips,
- adhesive tape or quick-drying adhesive,
- a tack,
- a battery.

The motor shaft: Bend a paper clip so that a piece of straight wire is formed. Attach the permanent magnets to this wire with adhesive tape or glue. The two north poles must point in the same direction, and the two south poles in the opposite direction, Fig. 3 above. The suspension for the motor shaft consists of two bent up paper clips which are attached to your wooden board. Bend one end of the motor shaft to create a small crank. The crank may only protrude a few mm from the shaft. It must be at right angles to the north-south direction of the magnet.



for instance this way:

or that:

or eventually so:

The electromagnets: Knock the two nails into the plate, so deep that their heads are at the level of the motor shaft. Wrap about 80 turns of copper wire on each nail. The direction of rotation must be opposite for the two nails, in the picture below.

The breaker: Remove the insulation from a short piece of wire. Attach one end to the wooden board with the tack. Bend the other end so that it is touched by the crank just during half a turn of the motor shaft, and not during the other half. Connect one of the electromagnet leads to the motor shaft suspension. Connect the battery to the second lead of the magnet and to the drawing pins.

Important: balancing the motor shaft, adjusting the breaker.

What does not really matter: wire thickness, number of turns of the electromagnets.

12. Energy stores

12.1 What energy stores are needed for

We often have to deal with energy sources that can run out, e.g. the car battery, the torch battery, the fuel tank, the propane bottle. So the energy coming out of them was stored in them. That's why we call them energy storage systems, or energy stores for short. Let us consider two examples to illustrate what they are needed for.

A car needs energy to drive. That's why most cars have an energy store, the fuel tank. There are also vehicles where the energy is stored in batteries, Fig. 1, but some cars have no energy storage, Figures 2 and 3, which do not have as much freedom of movement as the cars with storage. A car that has an energy store can drive to places where no power line, i.e. no electrical cable or no fuel hose, leads. So when you use a storage tank, you have energy in a place to which there is no line.

If you want to use solar energy to heat water, there is a problem: You need warm water every day, but the sun does not shine every day.

So you have to be able to store energy for a while, so that in bad weather you still have energy, and thus warm water. A large water tank serves this purpose. This is heated up in sunshine, i.e. energy is put into it. At bad weather or at night this energy can be taken out again, see the Figure in S 8.2.

Summary: With an energy store, energy can be brought to a place to which there is no line.

With an energy store you can store energy for a time when you need it.

Supplement S 12.1

Exercises

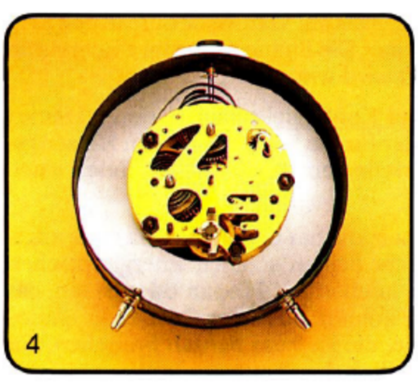
1. What are the reasons for using energy storage devices?
2. Name some energy stores. What are they needed for?

12.2 Examples of energy stores

The sun: The sun is an energy source that does not receive its energy from elsewhere. It is therefore an energy store and will become empty at some point. Although it emits enormous amounts of energy (S 8.1), it is assumed that this will not happen for another 4 billion years. So we have nothing to worry about.

Luminous paint: Some alarm clocks and wristwatches have luminous numerals. The luminous paint is an energy store. When it's light, it absorbs the energy it gets from the light. In the darkness it emits the energy again with the light.

The wind-up motor: Some toy cars have a wind-up motor. When winding, energy is put into the spring of the motor. The energy is stored in the spring until it is needed. In older watches and pocket watches, a spring is used to store the energy needed to drive the movement. An alarm clock has a second spring for the energy it needs to ring, Figure 4.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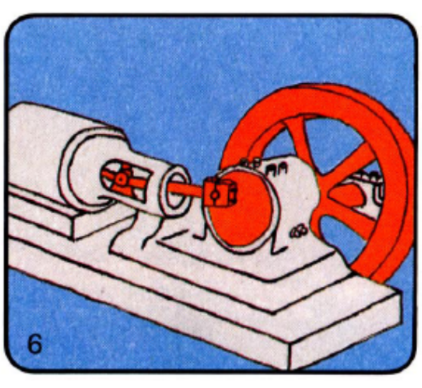

6

The flywheel: Some toy cars are driven by a flywheel, Fig. 5. Such a car must first be quickly pushed over the ground. The flywheel is set in rotation. It absorbs energy. The faster it rotates, the more energy it contains. If you now put the car on the table, it will drive itself. The flywheel releases the stored energy.

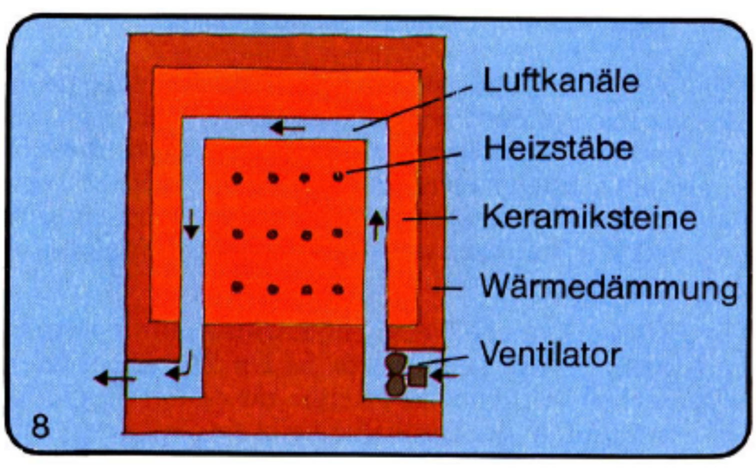
Steam engines also have a flywheel, Fig. 6. The crank is driven by the piston of the engine via piston rod and connecting rod. If the crank is at the far right or far left, i.e. in one of the "dead centers", it cannot be moved either by pressing or pulling the piston. That is why a flywheel has been placed on the crankshaft. It is charged with energy when the crank is up or down, and it releases energy to the crankshaft when the crank runs through the dead centers.

For the same reason, every car engine has a flywheel. It sits on the crankshaft of the engine. Crankshaft and flywheel are in the engine housing and therefore not visible from the outside.

The pump storage plant: The energy consumption of a city with electricity as its carrier varies during the course of a day, but also from one day to the next. If you want to know why, read supplement S 12.1. To keep the large power plants running as evenly as possible, pump storage plants are constructed. A pump storage plant absorbs energy from the electrical grid when it is left over and releases it when it is needed: When there is an excess of energy, an electric pump pumps water from a low-lying lake into a high-lying lake, Fig. 7. When energy is needed, the water flows back into the lower lake via a turbine. The turbine drives a generator. This passes the energy through the grid to the consumers.


7

The night storage heater: At night, when most people sleep, less energy is needed. The power plants therefore sell the energy cheaper at night. To use this cheap energy, some households have night storage heaters. A night storage heater consists mainly of ceramic bricks, Fig. 8, which are heated to over 600 °C at night using an electric heater. So energy is put into the bricks and stored in the bricks. During the day, when you want it warm, a fan blows air past the bricks into the room. The bricks release their energy into the air, the air gets warm.



8

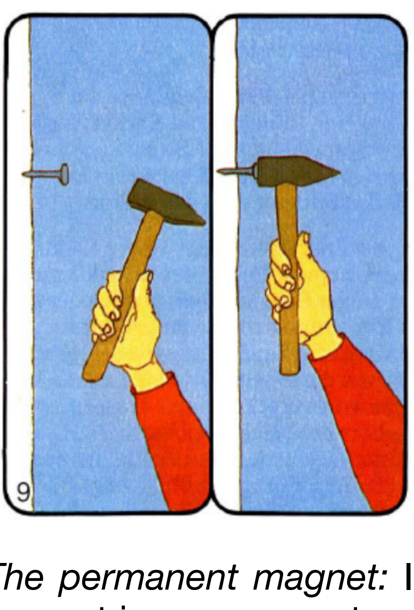
air channels
hating rods
ceramic stones
heat insulation
blower

Fuel tanks and coal cellars: Most houses have a storage for the energy needed for heating: either a fuel oil tank or a coal cellar.

A house that has gas heating and is connected to the gas network does not need such an energy store. Some households cook with propane or butane from a storage tank: a gas bottle. Cars take the energy they need to drive from a storage tank, namely the fuel tank.

Food: The energy that humans consume is always stored for some time. A bag of sugar is just as much an energy store as a full potato cellar.

The hammer: A hammer is also an energy store. As you accelerate it, Fig. 9, you put energy into it. When hitting the nail, it releases all its energy in a very short time. The faster a hammer moves, the more energy it contains.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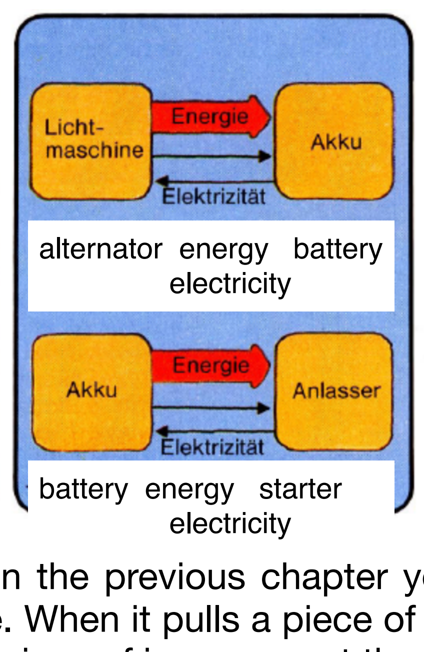
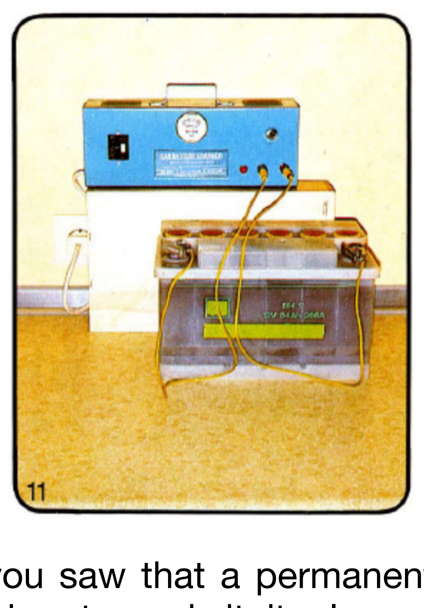



11

The permanent magnet: In the previous chapter you saw that a permanent magnet is an energy store. When it pulls a piece of iron towards it, it releases energy. If you remove the piece of iron, you put the energy back in.

The car battery: In a car, energy is needed even before the car engine is running: to start the engine. This is done with a small electric motor, the starter motor. This gets its energy from the battery, Fig. 10 below. Once the engine is running, the battery and starter are no longer needed. The battery is recharged with energy. The battery gets this energy from the alternator, Fig. 10 above, and the alternator gets it from the engine. If you let the starter run often and for a long time and only drive a little, the alternator does not keep up with the charging. Then the battery must be charged with a charger. The charger takes the energy for the battery out of the socket, Fig. 11.

Small batteries: You know what small batteries are used for. The energy is put into all these sources during production.

Supplements S 12.2 to S 12.4

Exercises

1. What energy stores do you have at home? What are they used for?

2. In section 12.2 three different energy stores in the car were mentioned. What are these? What are they for?

3. What energy stores are used in watches? Are there watches without energy storage?

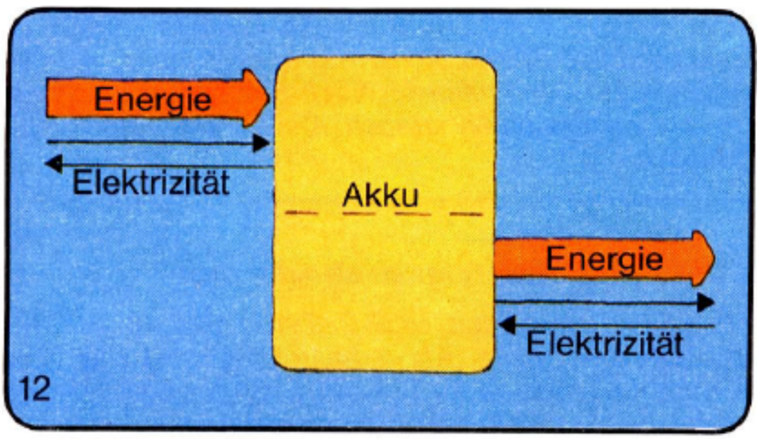
4. What energy stores are used in toy cars?

12.3 The symbol of an energy store

An empty battery can be recharged, Fig. 10 above. When charging, the positive terminal of the battery is connected to the positive terminal of the alternator and the negative terminal to the negative terminal. As long as the battery is being charged, it is an energy receiver.

Do you remember that the battery is charged only with energy, but not with electricity? The electricity flows into the battery, discharges its energy and flows out again. Correspondingly, in Fig. 10 below, energy is taken out of the battery, but no electricity. Also when discharging, as much electricity flows into the battery through one connection as it flows out through the other.

We combine the symbols of the battery in Fig. 10 above and below into a single one, Fig. 12. The offset between input and output indicates that a certain time has elapsed between filling and emptying.

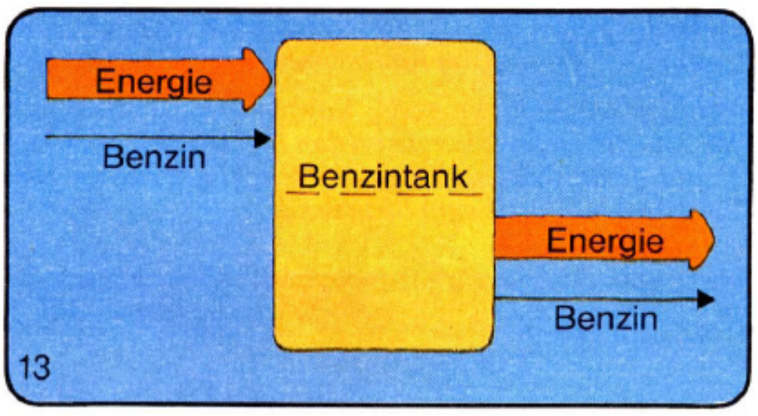


energy
electricity

battery

energy
electricity

In a battery energy is stored, but not the energy carrier. There are stores in which the energy is stored together with its carrier. Such a storage is, for example, the fuel tank of the car. Fig. 13 shows its energy flow diagram. Compare the image with that of the battery.

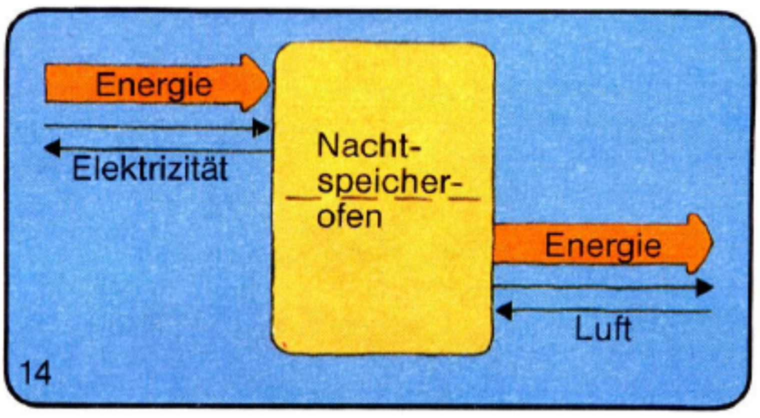


energy
gasoline

gasoline tank

energy
gasoline

Regarding the battery, the energy comes in and out with the carrier electricity. In the gasoline tank, the energy comes in and out with the carrier gasoline. For the battery and the gasoline tank, the carrier of the energy flowing in and out is the same. There are stores in which the energy flowing in and out is carried by different carriers. This includes the night storage heater. The energy is brought in with the electricity, it comes out with air. Fig. 14 shows its energy flow diagram.It shows that such a storage is also an energy transloader.



energy
electricity

night storage heater

energy
air

Exercises

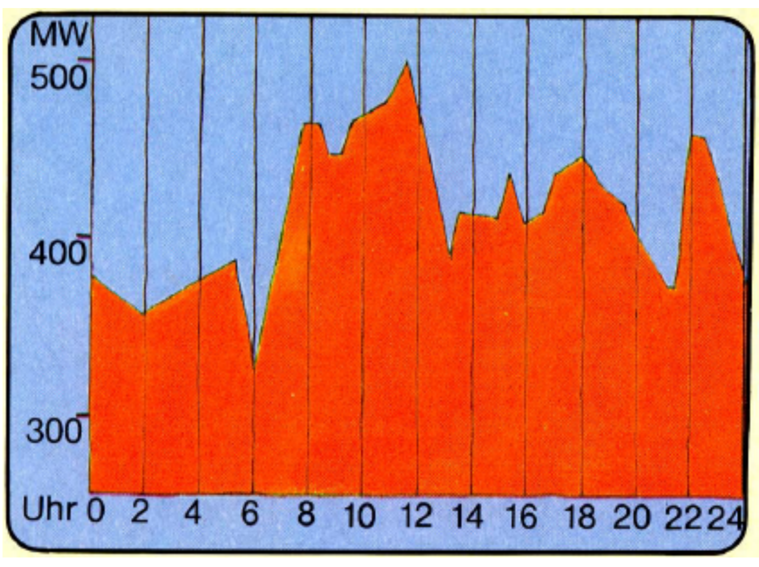
1. Draw the symbol for the store “propane gas bottle”. Is the energy stored together with its carrier?

2. The wind-up motor is an energy store that receives and emits its energy with angular momentum. However, the angular momentum itself is not stored. Draw the flow diagram.

Supplements to chapter 12

S 12.1 The energy consumption of a city in the course of a day

The picture shows the consumption of energy carried by electricity in a large city over the course of a day. The time is plotted to the right and the energy current, or “wattage”, is plotted upwards. The curve shows that the energy current at 10 o’clock is 470 MW. (So at 10 o’clock every second 470 MJ or 470,000,000 J are consumed.)



Look at the curve from left to right. From midnight to 6 a.m. the energy current is small because people are asleep. Then people get up, turn on the lights and radios and make coffee. The factories start to work. All this leads to the first consumption peak at 8 o’clock. At 9 o’clock there is a breakfast break in many companies, the machines are switched off and energy consumption goes down. Then it rises again. Between 11 a.m. and 12 noon, the “cooking peak” is caused by the energy consumption of the electric cooker. I’m sure you can explain the afternoon yourself. From 9 p.m. the power station starts charging the night storage heaters. This again causes a strong increase in energy consumption.

S 12.2 The wheel of a bicycle as a flywheel

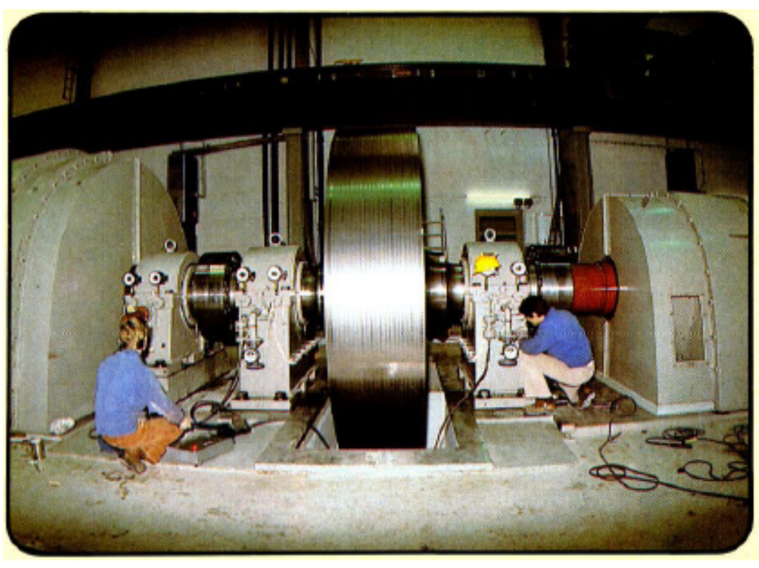
Turn your bike over so that it stands on the ground with saddle and handlebars. The wheel on which the dynamo is located is used as the flywheel. The dynamo does not run at first, it is disengaged.

Charging the flywheel: Turn the wheel quickly by hand. Energy is now stored in the wheel.

Discharging the flywheel: Engage the dynamo. The wheel gives its energy to the dynamo, which passes it on to the bicycle lamp and tail light. The wheel comes to a quick stop.

S 12.3 How a flywheel turns a small energy current into a large one

A research institute near Munich (the Max Planck Institute for Plasma Physics) has the world’s largest flywheel to date. It has a diameter of 2.9 m and weighs over 200 tons. It is used to generate very large energy flows for a short time. It is charged by a “small” electric motor. The electric motor (right in the picture) supplies an energy current of 5.7 MW. The charging time is 20 minutes, i.e. during 20 minutes the flywheel is set into ever faster rotation.



For discharge it is connected to a generator (left). It gives all its energy to the generator in a few seconds. This results in an energy current of 150 MW for a short time. So the flywheel is used to turn a small energy current that flows for a long time into a large energy current that flows only for a short time.

What this flywheel does with the energy is the same thing your savings account does with the money. Your savings account is a money store. If you save on some larger purchase, e.g. a bicycle, you fill the account – unfortunately only very slowly. The money flow is small. If there’s enough money in the store, you’ll let it out all of a sudden. The money flow is big.

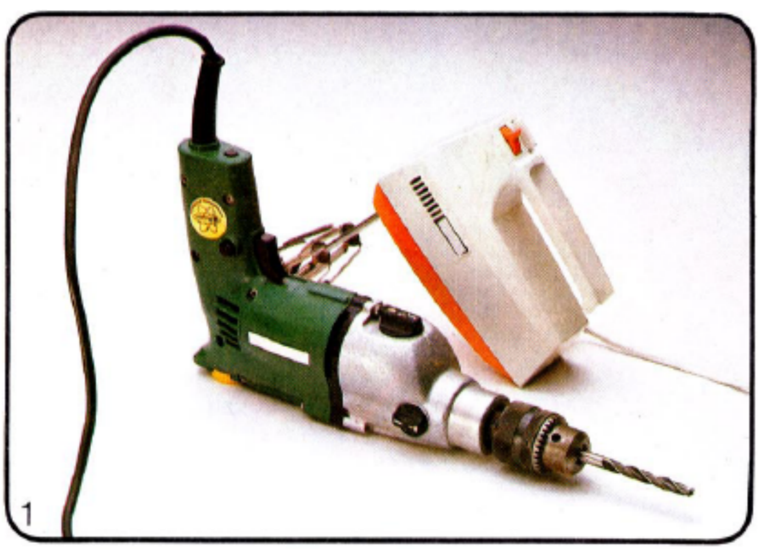
S 12.4 Compressed air tank

A tank containing compressed air is an energy store. When the air is pressed in, it is charged, when the air is released, it is discharged. An inflated car tire contains compressed air, so a car tire is an energy store. Normally, the stored energy is not released. But you can do it. This energy can be used, for example, to power a toy steam engine.

13. The cooling exit

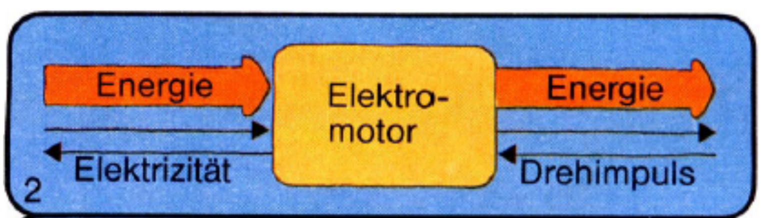
13.1 The cooling exit

Fig. 1 shows two very similar devices. Each of them is simply an electric motor to which a wide variety of tools can be attached. One of them is for the kitchen. You can mount an agitator or a dough hook on it. The other one is for the workshop. You can attach a drill or a grindstone to it, for example. Both electric motors transfer energy from electricity to angular momentum. We want to take a closer look at both devices.

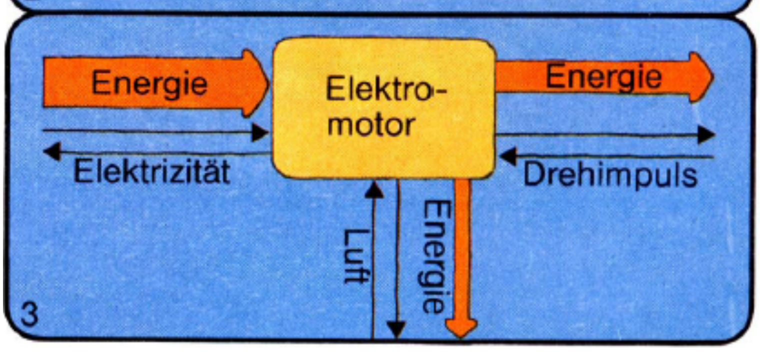


Both have openings on the side of the housing. If you let the devices run, air comes out to one of the openings, air flows in to another. Probably you can imagine what this air is for. The electric motor must be cooled. If you close the air vents, the motor gets warm and it can burn out. The air flowing out is slightly warmer than the air flowing in. The air carries energy out of the device.

The energy flow diagram of the electric motor as we have drawn it so far, Fig. 2, is therefore incomplete. A second output for the energy is still missing. We call it the cooling exit. Fig. 3 shows the completed energy flow diagram of the motor. The width of the energy arrows indicates the strength of the energy current. The energy entering the input is distributed to both outputs.

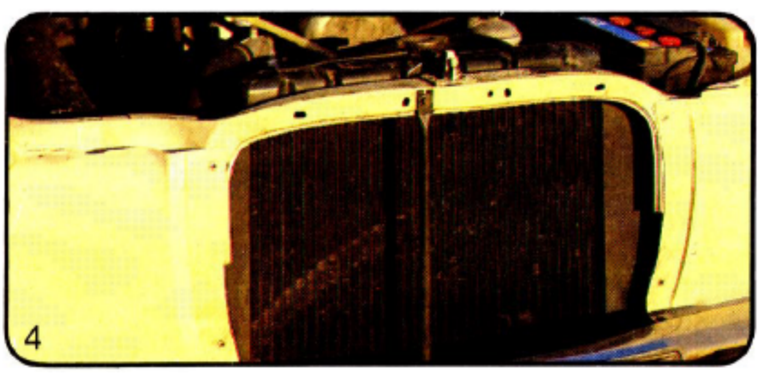


energy
electricity
electric motor
energy
angular momentum



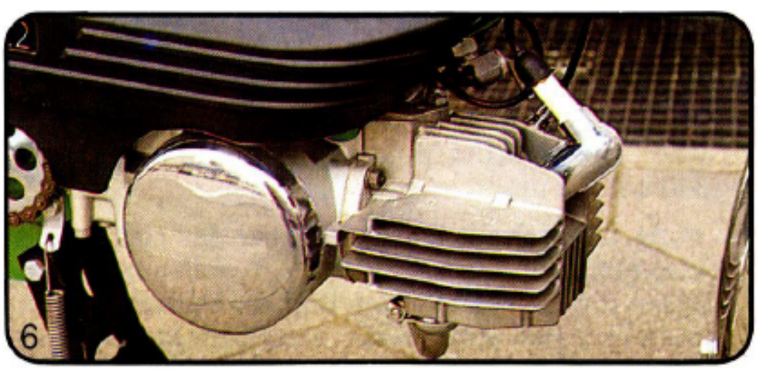
energy
electricity
electric motor
energy
angular momentum
energy
air

The cooling exit is a necessary evil. The energy that comes out of here is not being used, it is lost to us. Nevertheless, we cannot do without the cooling exit.



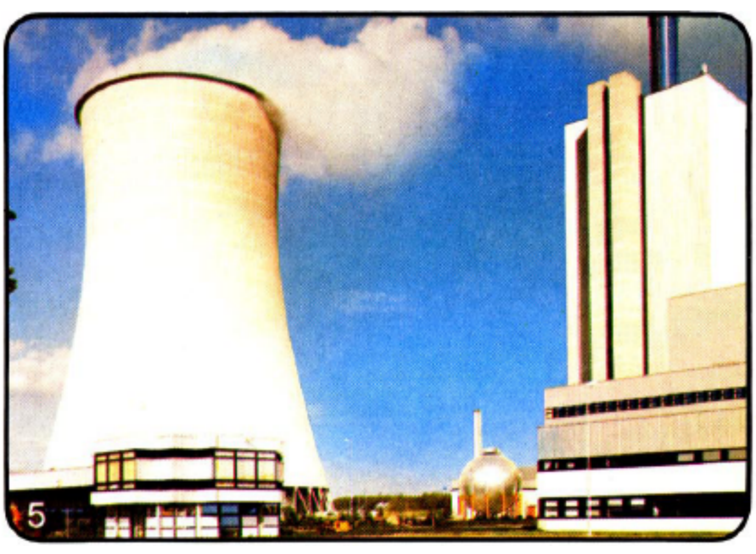
The cooling exit of the car engine

Not only the electric motor, but also many other energy transloaders have a cooling exit. The car engine has a cooling exit that is clearly visible: warm water flows through a hose from the engine to the radiator, Fig. 4, and from there the water flows cooled back to the engine. Motorcycle and moped engines release energy directly into the air that passes them. The cooling fins facilitate the transfer of energy to the air, Fig. 6.



Cooling exit of the moped

The more energy an energy transloader transfers, the greater the cooling exit. Power plants that operate with steam turbines have a cooling exit that is sometimes so large that only a large river is sufficient to bring the energy out. If a river is not available or is not sufficient for cooling, cooling towers are built, Fig. 5, where the energy comes out either with air or with steam.



Summary: Energy transloaders have not only one output for the energy, but two. However, the energy coming out to the second exit is not used.

Supplements S 13.1, S 13.2

Exercises

1.Name some devices that have a cooling exit. Where is the cooling exit located?

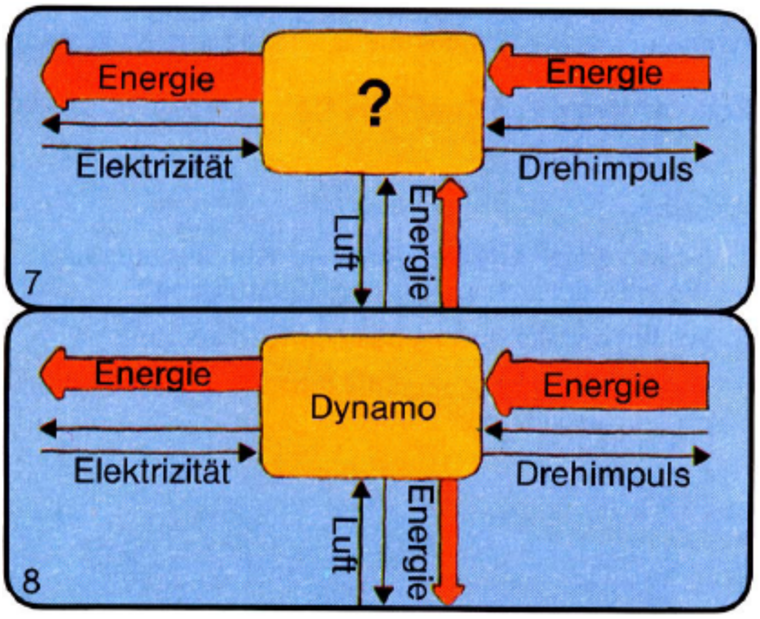
2. Where does the vacuum cleaner have its cooling exit?

3 What happens if the air opening of the overhead projector is blocked?

13.2 The inverted electric motor

Some electric motors can be run as dynamos. The energy flow diagram of the dynamo can therefore easily be obtained from that of the motor: You simply reverse all the arrows.

In the previous section, however, we have improved the flow diagram of the electric motor, Fig. 3, and we will now try to create the dynamo symbol from this improved diagram using the same method as before: we reverse all the arrows in Fig. 3 and obtain Fig. 7.



energy
electricity
?
energy
angular momentum
energy
air

energy
electricity
dynamo
energy
angular momentum
energy
air

Wrong and correct energy flow diagram of the dynamo

Take a good look at that picture. This “dynamo” would give off more energy with the electricity than it absorbs with the angular momentum. Let us assume that it emits 3 J per second with electricity, but absorbs only 2 J per second with angular momentum. Then it should take up 1 J per second with the air through the cooling openings. The air would therefore have to leave it cooled. Of course there is no such dynamo. With a real dynamo, heated air comes out of the cooling openings, just like with the motor. Fig. 8 shows the correct energy flow diagram of the dynamo, so again energy is lost during transferring energy from one carrier to another.

Summary: Part of the energy is always lost in both the electric motor and the dynamo. It flows out through the cooling exit.

Supplement S 13.3

Exercise

Draw the energy flow diagrams of solar cell and incandescent lamp with a cooling exit.

13.3 The loss in an energy transloader

Some of the energy is lost during transloading it. Of course you want to keep this energy loss as small as possible.

If 4 kW flows into an electric motor with the electricity and 1 kW flows out to the cooling output, only 3 kW remain for the angular momentum. A quarter of the incoming energy comes out to the cooling exit and is no longer used. We say the energy loss of the motor is 1/4.

If 100 W flow into a motor and 50 W flow out to the cooling exit, its loss is 1/2.

The loss is therefore that fraction of the energy flowing in, which comes out to the cooling exit.

The table shows the energy loss of some typical transloaders:

Transloader	Energy loss
big water turbine	less than 1/10
big electric motor	1/10
generator	1/10
gas engine	7/10
Diesel engine	6/10
coal-fired power plant	6/10
nuclear power plant	7/10
solar cell	9/10
incandescent lamp	19/20

Maybe you're wondering why energy transloaders lose so much energy. But it gets even worse if you connect several transloaders in series to form a chain. Then it can happen that only a very small fraction of the energy sent off at the beginning arrives at the end of the chain. The largest part flows out to the cooling exits of the transloaders. If the transport routes are long, there are also "line losses": energy flows out on the way between the transloaders.

Summary: The energy loss of a transloader is the fraction of the incoming energy that flows out to the cooling exit.

Supplements S 13.4 and S 13.5

Exercises

1. List some devices that have particularly low losses.

2. List some devices that have particularly large losses.

3. What is the energy loss of a car whose engine is stationary?

4. What is the energy loss of the cyclist from S 13.2?

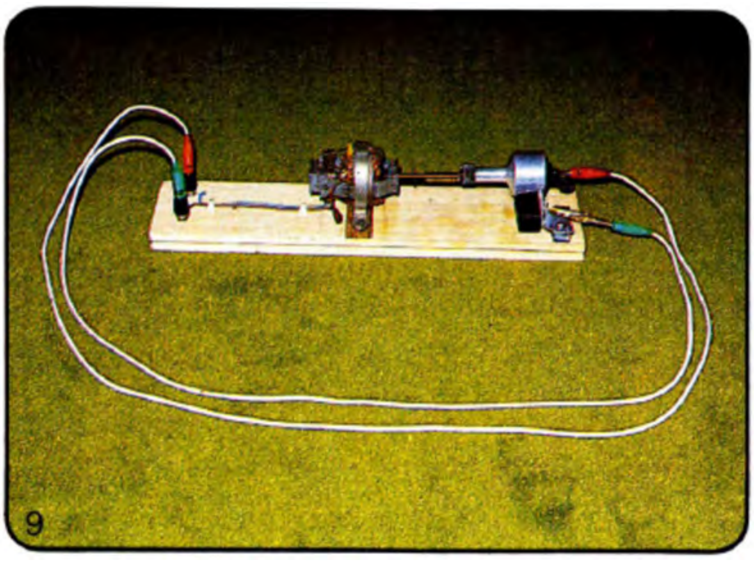
5. An incandescent lamp has an energy loss of 19/20, a neon tube of only 16/20. How many 40 W bulbs emit as much light as a 40 W neon tube?

13.4 The perpetual motion machine

Perpetual motion means eternal movement. A perpetual motion machine is a machine that supplies energy but does not consume energy. Countless inventors have thought about how to build such a machine, and there are interesting suggestions for such machines. All these machines have one thing in common: they do not work. The explanation is simple. If no energy flows in, no energy can come out.

Often perpetual motion machines are proposed that simply consist of several energy transloaders coupled to each other in such a way that they form a closed circuit.

Consider the suggestion in Fig. 9: An electric motor drives a dynamo. The motor itself gets the energy it needs from the dynamo. Let us try to understand why this machine does not work. If the motor and the dynamo are at a standstill, nothing happens, of course, the machine (consisting of the motor and the dynamo) cannot supply any energy. We now try to start the machine by setting the common shaft of the motor and the dynamo in motion.



Does this machine supply energy?

This means that we first give the machine some energy in the hope that we will later get more energy out than we have put into it. Imagine if we put 10 J into it when we started it. The dynamo now transfers these 10 J to electricity. Part of the energy flows out to the dynamo's cooling exit. Let's assume this is 1 J. The electric motor gets the remaining 9 J. It transfers it back onto the angular momentum. If 1 J flows out to the cooling output of the motor, 8 J are left. These go to the dynamo again. Let's assume it passes 7 J to the motor, which returns 6 J to the dynamo, etc. The energy flows around in a circle, and on each tour some of it is lost through the cooling exits. Finally the machine stops. It therefore does not supply any energy. On the contrary, in the end even the 10 J we put in at the beginning are lost.

Summary: There is no machine that constantly emits energy without receiving this energy from elsewhere. There is no perpetual motion machine.

Supplement S 13.6

Exercises

1. One could come up with the idea of building a perpetual motion machine from a solar cell and an incandescent lamp. Can you imagine how?

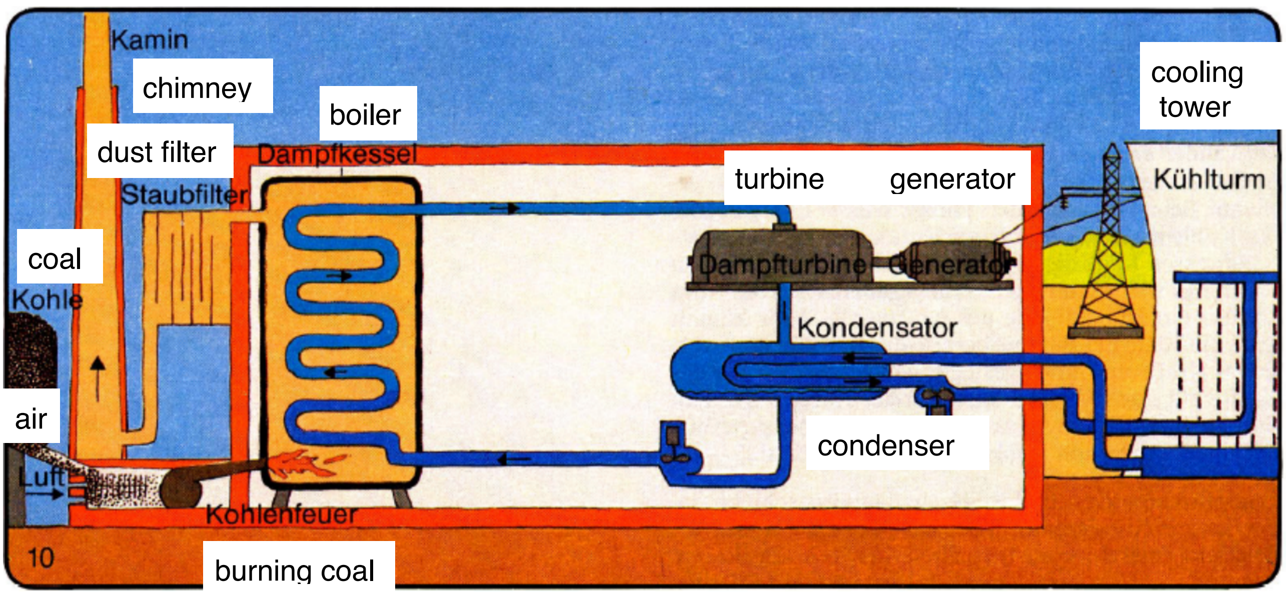
2. Try to invent a perpetual motion machine. Describe it.

13.5 The coal-fired power plant

Many of the power plants are coal-fired. The carrier with which the energy is brought into these power plants is black coal or lignite. The picture in S 2.4 shows a large coal-fired power plant.

The energy supplied to the customers by this power plant amounts to 2100 MW. That is enough to cover the needs of 3,600,000 people.

How does a coal-fired power plant work? It's quite simple in principle. A toy steam engine that drives a small dynamo works almost in the same way. Fig. 10 shows a coal-fired power plant schematically.



1. The boiler: Water is evaporated in the boiler with the energy of the coal fire. The steam has a high pressure, about 150 bar, and a high temperature, about 500 °C. The steam boiler takes up most of the power plant building.

2. Steam turbine and generator: The steam coming from the boiler drives a steam turbine (S 3.8). It works like a water turbine: the steam flows from the side against the blades of a turbine wheel and sets it in motion. The pressure and temperature of the steam decrease. Since pressure and temperature have decreased only slightly after a single turbine blade, the steam can still be used. It flows against a second blade wheel, then against a third, fourth, etc. A large steam turbine can have 70 blade wheels. As the steam expands with each blade wheel, they must become ever larger: the first is the smallest, the last the largest. In a large turbine, the last blade wheel has a diameter of 5 m.

At the outlet of the last turbine wheel the pressure of the steam is almost 0 bar and the temperature is about that of our environment. You can't do anything with this steam anymore.

The turbine drives a large generator. Or in other words: From the turbine the energy flows with the carrier angular momentum to the generator.

3. The condenser: The steam coming from the steam turbine still has a lot of energy, although it is no longer hot and no longer has any pressure. Water vapor has more energy than liquid water. Nevertheless you can't do anything with it anymore, its temperature is too low. It is fed into the condenser. Here it turns into liquid water. This is pumped back into the boiler by the feed water pump. When the water becomes liquid, it releases energy to the cooling water flowing through the condenser. The cooling water carries the energy to a cooling tower. It is released into the air in the cooling tower. The cooling tower is therefore a cooling exit of the power plant. This is where about half of the energy that was put into the power plant with the coal comes out. The power plant also has losses through other exits, such as the chimney. The total energy loss in a modern coal-fired power plant is about 6/10.

Steam locomotives and toy steam engines have no condenser. Here, the steam exiting the steam engine is discharged directly into the atmosphere. This steam outlet is the cooling exit. The energy loss with such machines without a condenser is greater than with machines with a condenser. Steam locomotives have an energy loss of about 8/10.

Supplement S 13.7

Exercises

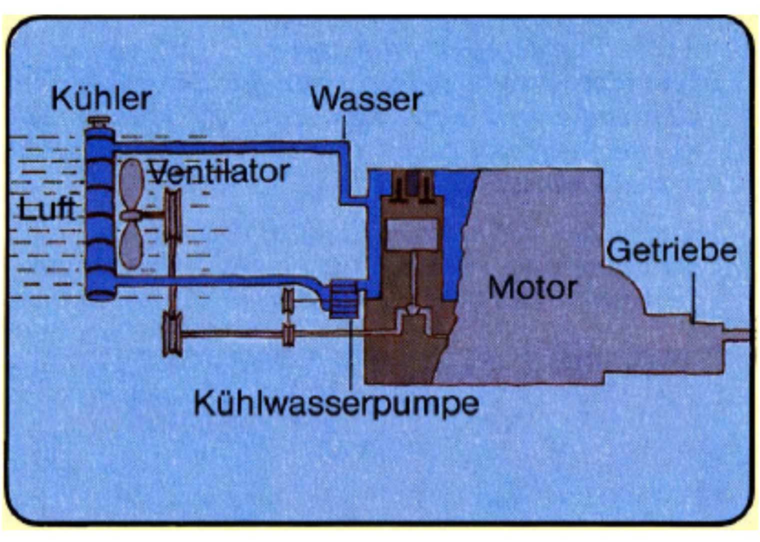
1. Describe the design of a steam power plant.

2 Why does a steam turbine have several blade wheels of different sizes?

3. The steam boiler of a power plant together with the furnace is an energy transloader. Draw its flow diagram.

S 13.1 The cooling system of the car engine

A gasoline engine must be cooled. If it is not cooled, the engine becomes hot and the lubricating oil becomes so thin that it no longer lubricates. The pistons of the engine would jam: There would be a "piston seizure". That means the engine is broken. To prevent piston seizure, cars have a thermometer or a red light on the dashboard that lights up when the engine temperature gets too high.



radiator water
fan
air
gear box
engine
cooling water pump

The picture shows the structure of the cooling system of a car engine. In the engine, energy is charged onto water so that the water gets warm. The cooling water pump pumps it to the radiator. Here it transfers its energy to the air. As long as the car is stationary or driving slowly, there is not enough air flowing past the radiator. Therefore there is a fan behind the cooler.

Cooling can fail in several ways:

- there's a leak in the cooling system causing the cooling water to flow out,
- the cooling water pump does not work, perhaps because the V-belt with which it is driven has broken.

In any case, the engine must be switched off immediately.

S 13.2 The cooling exit of humans

A person riding a bicycle gives off energy with the carrier angular momentum. With a racing driver this can be up to 200 joules per second, i.e. 200 W. At the same time, however, the racing driver sweats; he releases energy through the skin, namely about 600 W. The skin is the cooling exit of the person.

S 13.3 The cooling exit of conduits

We have seen that energy transloaders have losses. Part of the energy flowing in comes out to the cooling exit and is no longer used.

Unfortunately, these "transloading losses" are not the only losses that exist. Energy is also lost on the way from one transloader to the next. The conduit through which the energy carrier flows also has a cooling exit: More energy flows into a conduit at its beginning than comes out at the end. Conduits become warm when something flows through them. They heat the air that surrounds them.

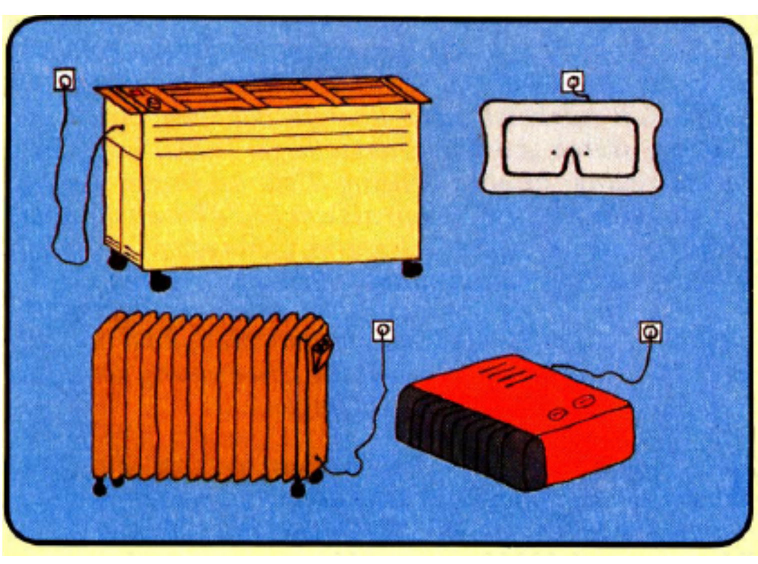
You may have already experienced the warming of electrical cables yourself. To keep the warming low, thick cables are used.

When transporting energy with shafts, the bearings become warm. To keep energy losses low, ball bearings are used.

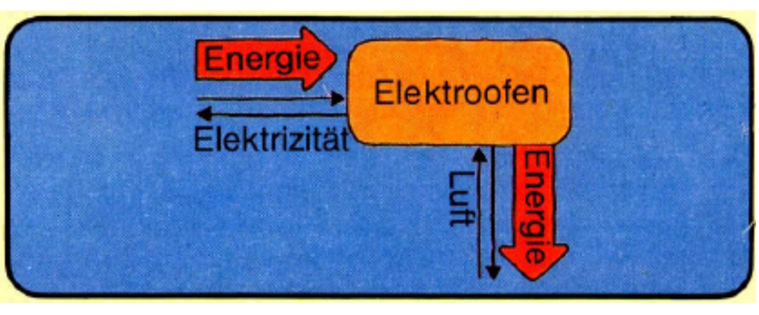
You know that heating pipes lose energy, too. To keep these losses as low as possible, the pipes are insulated.

S 13.4 Energy wasted by electric heaters

The picture below shows four different electric heaters. All these heaters have no loss. All the energy that the electricity carries into the heaters comes out with warm air. You could put it this way: these heaters have only a cooling exit. For once, we are interested in the energy that comes out to the cooling exit. So, one could conclude, electric heaters are the ideal heaters. With other heaters, some of the energy goes out to the chimney.



However, this conclusion is wrong, because we have only looked at the last link in a chain of transloaders. The energy for the electric heater comes from a power plant, which discharges it from the coal with a loss of at least 6/10. If you burn the coal through an oven that heats the room, you have a smaller loss: about 3/10.



energy
electricity
electric stove
energy
air

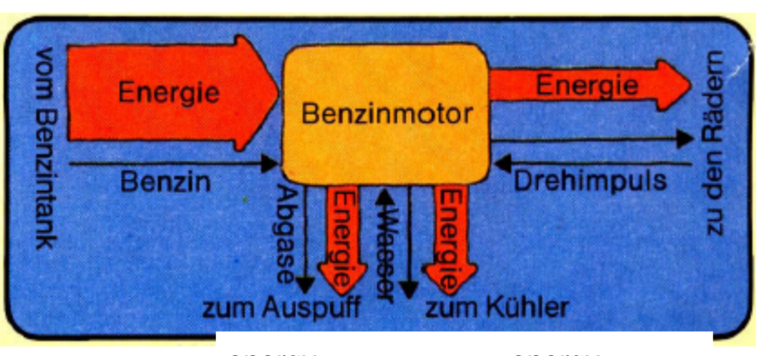
S 13.5 The losses of a gasoline engine

The car radiator is a cooling exit of the car engine. But it is not the only one. Unused energy also comes out to the exhaust: The exhaust gases are hot and still carry a lot of energy. As a rough rule of thumb, you can remember:

1/3 of the energy of the gasoline flows to the wheels.

1/3 of the energy of the gasoline flows out to the radiator.

1/3 of the energy of the gasoline flows out to the exhaust.



from gasoline tank
energy
gasoline
engine
energy
angular momentum
to the wheels

energy
exhaust gases
to exhaust pipe

energy
water
to radiator

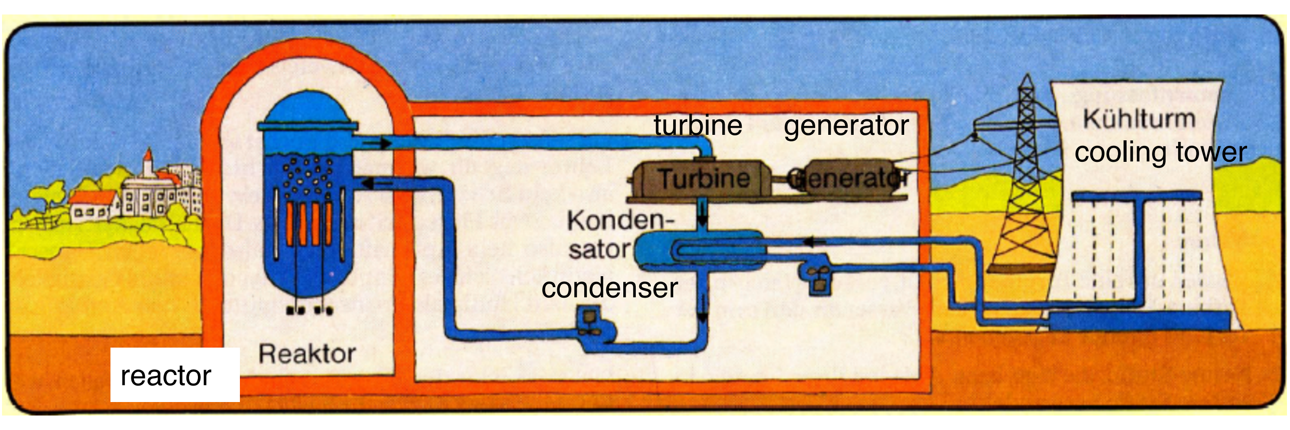
S 13.6 Perpetual motion

A flywheel that is set in rotation stops turning after some time. That is due to friction. If friction is reduced, e.g. by ball bearings, the rotation lasts longer. If one could completely eliminate friction, the wheel would turn forever. One would not call such a wheel a "perpetual motion machine". Because a perpetual motion machine is expected to give off energy and still keep running. And our wheel wouldn't do that.

An example of a "wheel" with very little friction is the earth. It has been revolving around its axis for billions of years and will continue to do so for a very long time, but not forever. Within a year, the time it takes for one revolution becomes 0.00002 seconds longer. So the days are getting longer and longer. We can also put it this way: the earth is a flywheel, an energy store from which some energy constantly flows out.

S 13.7 The nuclear power plant

In principle, a nuclear power plant differs from a coal-fired power plant only in the steam boiler and its firing system. The boilers of coal-fired and nuclear power plants are designed for different "fuels".



The "fuel" of the nuclear power plant is uranium. The "furnace" of the boiler is called the nuclear reactor. Radioactive waste is generated from uranium during the release of energy. The fuel from the nuclear power plant is not constantly fed into the boiler, as is the coal from the coal-fired power plant, but the boiler is "loaded" once a year with the uranium requirements for the whole year. Likewise, most of the "ashes", i.e. radioactive waste, are removed from the boiler only once a year. The radioactive waste is extremely hazardous. Therefore, every nuclear reactor has complex safety systems designed to prevent radioactive substances from escaping. Only a very small part of the gaseous radioactive substances is constantly discharged through the chimney (not shown in the picture).

14. Substances and their properties

14.1 Substance conversions in energy transloaders

When an energy carrier flows through a receiver and discharges its energy there, it changes in some way.

Water flowing into a central heating radiator is warm. The water flowing out has less energy, it is colder. The air that flows into a jackhammer has a high pressure. The air flowing out has a low pressure, it has less energy.

There are transloaders in which the energy carrier changes much more.

One such exchanger is the car engine. The energy-loaded carrier “gasoline” flows into the engine. In the engine, the gasoline releases its energy and transforms into exhaust gases. The empty energy carrier “exhaust gas” leaves the engine through the exhaust. It is very similar with the oil stove.

What takes place in these transloader facilities is called a conversion of the substance, or also reaction.

We will now learn more about substances and substance conversions. We will do chemistry.

Summary: In transloaders that require a fuel, new substances are produced when the energy is unloaded.

Exercises

1. Water that drives a turbine changes in the turbine. How do you recognize that it has released energy into the turbine?

2. Name substances that turn into other substances when their energy is discharged.

14.2 How to recognize a substance

How do you recognize a substance? You can recognize it by its characteristics. Normally you will have no trouble determining whether a substance is water or not. But how many properties do you need to find out to make sure it's water?

Imagine a brown glass bottle on a table, sealed with a cork. You can see there's a transparent liquid in it. Can you tell from the outside whether this liquid is water? No, absolutely not. But you can exclude a lot of substances: Surely it is no solid substance, so no iron or no rubber. It is also certainly not an opaque liquid, i.e. no milk, no tar and no mercury (the liquid in the clinical thermometer). But there are many, many other liquids that come into consideration.

So you will take the bottle and shake it. The liquid is thin, so it's not motor oil or dishwashing liquid. By the way: You're still alive, so it wasn't nitroglycerin, a liquid explosive. So what could it be? Water or alcohol or petrol or apple juice or sulphuric acid (the liquid in the car battery) or...?

You open the bottle and you smell it carefully. (The teacher shows you how to do it.) Ah, it doesn't smell, so no gasoline, no alcohol, no heating oil, no vinegar... You pour the liquid into a glass. The liquid is colorless, so no apple juice. So all that's left is water? Of course not, it could be glycol, for example, the liquid that is often poured into the car radiator as antifreeze.

See how difficult it is to clearly determine what kind of material you have in front of you?

Today, several million different substances are known. It is certainly clear to you that these cannot be distinguished simply by looking, shaking and smelling. The chemists have therefore invented countless test procedures to differentiate between substances with very many identical properties.

However, it is often not so difficult to identify a substance, namely when you already know which substances are possible.

Imagine a driver who has two plastic canisters in the trunk: one with gasoline in case he forgets to refuel, and one with water in case he needs cooling water for the engine. The canisters look the same and the stickers affixed by the driver have come off. Of course it is easy to decide what is in the canisters: Only 2 substances are possible. It is therefore only necessary to investigate one property in which petrol and water differ, for example the smell. If the driver snuffs and smells nothing, he will pour out a few drops. If the liquid evaporates quickly, it is gasoline, if it evaporates slowly, it is water. He could also soak it in a piece of paper and try to light it. If it burns, the liquid is gasoline.

Supplement S 14.1

Exercises

1. Name different materials. How do you recognize each of these substances?

2. Name differences between water and alcohol.

14.3 Mixtures of substances

As we have seen, it is difficult to identify an unknown substance. It is particularly difficult when it is not a pure substance but a mixture of other substances.

On the table is a container with small white crystals. Is it salt or is it sugar? You try it and find it tastes salty and sweet at the same time. So someone made a mixture out of the pure substances sugar and salt. Many substances that surround us are mixtures of pure substances, such as brass, gasoline, liqueur or air.

Liqueur, for example, is a mixture consisting essentially of the pure substances water, alcohol and sugar.

Air consists mainly of the pure substances oxygen and nitrogen. 1 l air contains about 1/5 l oxygen and 4/5 l nitrogen. Air also contains small amounts of other gases. Among these, carbon dioxide is particularly important, although 10,000 litres of air contain only 3 litres of it. Without carbon dioxide, plants could not live, and without plants, animals and humans could not live. Air also always contains some gaseous water.

Summary: Many substances are mixtures of substances, e.g. brass, petrol, liqueur and air.

Supplement S 14.2

Exercises

1. Specify substances which are mixtures of pure substances.

2. Sea water is a mixture of pure water and various salts. How can you separate the water from the salt?

14.4 Test procedures for the properties of materials

You know a lot of substances and are able to distinguish them from each other. You ask, mostly unconsciously, different questions:

Is the substance visible, such as iron, water and oil, or is it invisible, such as air and natural gas?

Is it solid, liquid or gaseous?

Is it transparent, like glass. or opaque, like iron?

What color is it?

Is it made of crystals, like salt and sugar?

Is it viscous, like tar, slightly less viscous, like car oil, or thin, like gasoline? (In other words, how well does it conduct the angular momentum?)

Is the substance elastic, like rubber?

Does it feel cold, like marble, or warm, like wood?

Does it have a smell?

Does it have any taste?

Is it heavy or light?

Each time you answer one of these questions, you apply a "test procedure" for a particular substance property. You're investigating color, toughness, smell, etc. These tests are so simple that you don't need any tools, you get along with your sensory organs alone.

To answer the following questions, one needs somewhat more complex test procedures:

Is the substance soluble in water, such as sugar or salt, or not, such as sand or fat?

Is the material flammable?

Is it magnetic?

How well does it conduct electricity?

Some of the chemists' test procedures are very complicated. There are also devices that perform such tests automatically.

Summary: In order to distinguish between substances, many test procedures are used.

Exercises

1. List as many properties as possible for any three substances.

2. Name as many properties as possible in which

a) Iron and air,

b) Gold and Silver

differ.

3. How can you find out whether a substance

a) conducts electricity,

b) is magnetic?

14.5 Properties of some gases

Most people know very little about gaseous substances. That's probably because you can't see most of the gases. However, some gases are very important for life on earth, such as oxygen and carbon dioxide, while others play a major role in technology, such as hydrogen and methane. Others you meet in many households: Propane and butane.

We therefore want to take a closer look at some gases and look for properties in which they differ. We deal with the five gases oxygen, hydrogen, propane, carbon dioxide and nitrogen (in Fig. 1 from left to right). These gases can be bought in steel cylinders with standardized color.

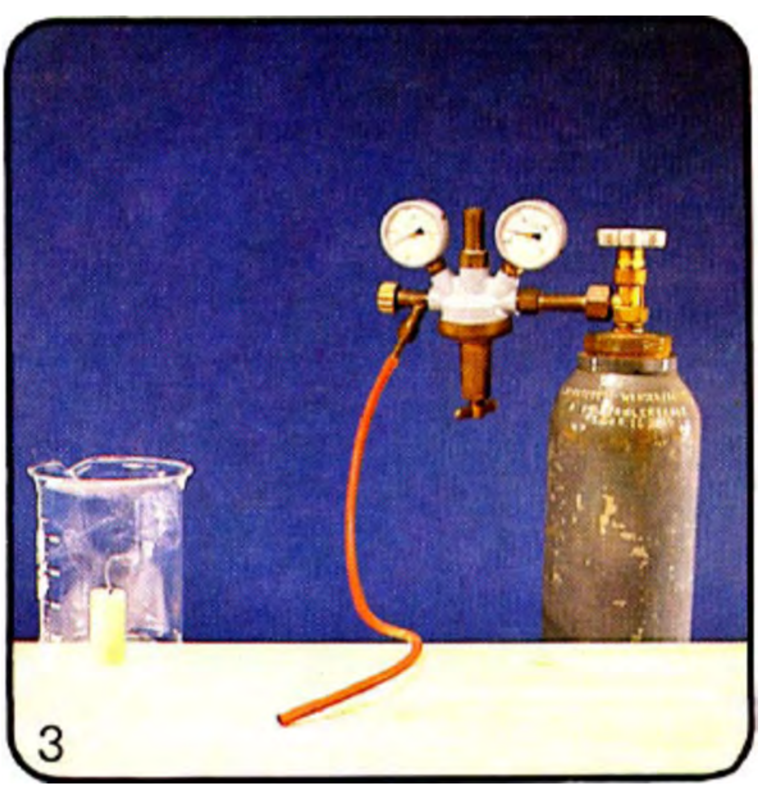
Many gases can be bought in steel cylinders.

Odor: The easiest to check is the smell. Bottle propane contains an additive that smells unpleasant. Oxygen, nitrogen and hydrogen are odorless. Carbon dioxide smells slightly acidic.

Flammability: The gas to be tested flows through a metal tube into the atmosphere. The gas flow must be very small so that the flame does not become too large if the gas burns. Now you hold a burning match into the stream. The result: hydrogen burns with a barely visible flame, propane burns with a flame that is yellow at the bottom and blue at the top. If you hold a burning match in the oxygen stream, it flames brightly. The oxygen itself does not burn, but the wood burns brighter and faster than without oxygen, Fig. 2.

Oxygen boosts combustion.

Nitrogen and carbon dioxide do not burn. If you fill a cup with carbon dioxide or nitrogen and dip a burning candle into it, the candle goes out, Figure 3.



The candle extinguishes in carbon dioxide.

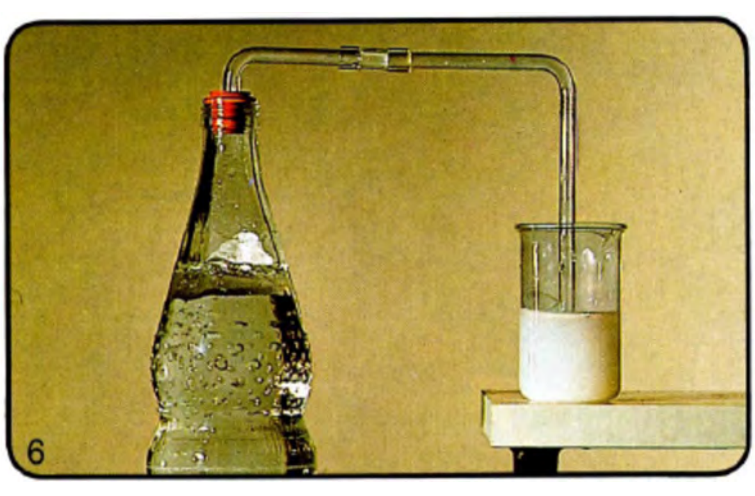
Weight: Only two of the five gases are not yet distinguishable: Nitrogen and carbon dioxide. We are therefore still investigating the weight of the gases. We fill a balloon with each of the gases, Fig. 4 The hydrogen balloon rises. Hydrogen is therefore lighter than air. All other balloons sink to Earth, the carbon dioxide balloon and the propane balloon especially fast, Figure 4. We can use it to distinguish carbon dioxide from nitrogen: Carbon dioxide is heavier than nitrogen.

Hydrogen is lighter than air. Carbon dioxide and propane are heavier than nitrogen.

The lime water test: We will later have to answer the question of whether a gas mixture contains carbon dioxide, possibly a very small amount. We can't decide that by filling it into a balloon. We therefore want to get to know a test procedure with which small amounts of carbon dioxide can be detected. Fill some lime water into a glass (lime water is obtained by dissolving a very small amount of ordinary building lime in water). Lime water is a water-clear liquid. Fill the rest of the glass with carbon dioxide and shake. The lime water becomes cloudy. All other gases do not cloud the lime water.

Carbon dioxide, which was in the upper half of the bottle, has dissolved in the water.

Solubility: Fill a bottle half with water and the rest with carbon dioxide. Close the bottle with your thumb and shake vigorously several times. There is a vacuum in the bottle, you can let it hang on your thumb, Fig. 5. Part of the carbon dioxide has disappeared from the upper half, it has dissolved in the water. Carbon dioxide dissolves very well in water. The other gases don't dissolve so well. However, so much oxygen is dissolved in the water of lakes, rivers and seas that the fish can live. Fish need oxygen to live, just like land animals.



The gas that escapes from a bubble bottle is carbon dioxide. It clouds lime water.

Carbon dioxide dissolved in water, is already familiar to you. Guide the gas that escapes from a bottle with sparkling mineral water through lime water, Fig. 6. The lime water becomes cloudy. The gas in the mineral water bottle is therefore carbon dioxide. It was pressed into the mineral water during production and had dissolved in the water. So mineral water is simply water in which carbon dioxide is dissolved.

Summary: Oxygen does not burn but boosts combustion. Nitrogen suffocates flames. Carbon dioxide suffocates flames, is heavier than air, makes lime water cloudy and is easily soluble in water. Hydrogen burns and is lighter than air. Propane burns with a yellow flame and is heavier than air.

Supplement S 14.3

Exercises

1. List some gases. What do they have in common?

2. How can nitrogen be distinguished from carbon dioxide?

3. How can you determine whether a gas mixture contains carbon dioxide?

4. Fermentation of grape juice produces carbon dioxide. Before the winegrower enters his cellar, he sometimes lights a candle, although the cellar is electrically lit. Why?

14.6 Solid, liquid, gaseous

We had said that one of the things you recognize about water is that it's liquid. However, water is not always liquid, there is also gaseous, and there is solid water. Everybody knows solid water: ice. If liquid water is cooled, it turns to ice at 0 °C, i.e. to the solid state. If ice is heated, it becomes liquid again at 0 °C. The transition temperature is called the melting temperature. Solidification takes place at the same temperature as melting.

To obtain gaseous water you don't have to do anything. The air always contains some gaseous water. One speaks e.g. of damp or dry air and means that the air contains more or less water in the gaseous state. It is obvious that the air must contain gaseous water, since you know that liquid water evaporates.

If you hang damp laundry on the line, some of the water first drips off, the rest evaporates, it becomes gaseous. After a rain the earth becomes dry again. Part of the water drains off, the rest evaporates.

What we have said here about water also applies to other substances. Substances that you only know as gases, such as air, can become liquid and solid. Likewise, substances you know only in the solid state, such as iron, can be liquid and gaseous.

The table shows some melting temperatures.

Substance	Melting temperaature in °C
Hydrogen	–259
Oxygen	–219
Nitrogen	–210
Alcohol	–114
Water	0
Lead	327
Iron	1528

As the table shows, if the temperature were lower than –219 °C, the air would cover the earth's surface like a layer of ice.

Evaporation is easier to see with some substances other than water, namely with substances that have an odor. “A substance smells” means that it gets into our nostrils in gaseous form. That we smell gasoline, heating oil, wax polish or perfume is therefore only possible because these substances evaporate.

Summary: At melting temperature, a substance changes from solid to liquid or from liquid to solid. During evaporation, a substance changes to the gaseous state. Air usually contains some gaseous water.

Supplements S 14.4 and S 14.5

Exercises

1. When lead is heated, it becomes liquid at 327 °C. At what temperature does the liquid lead solidify again when it is cooled?

2. How can you tell that air contains gaseous water?

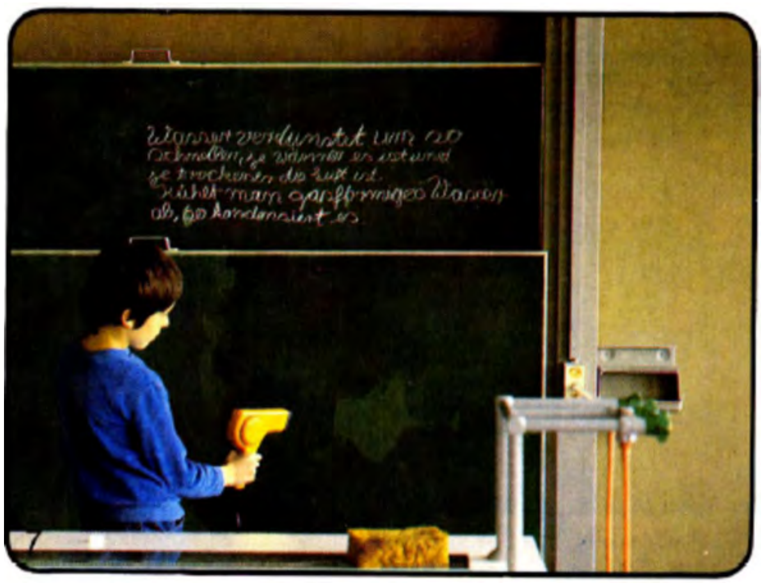
3. Name some substances whose melting temperatures a) are lower, b) higher than the melting temperature of water.

14.7 Evaporation – Condensation

Laundry dries particularly well when you hang it in the wind. Why is that so?

- The less gaseous water the air already contains (the drier it is), the faster water evaporates. Therefore the evaporation can be accelerated by the wind. It blows water that has just evaporated away from the water surface so that dry air constantly flows in.
- Laundry dries well even without wind when the sun is shining. The warmer the water, the faster it evaporates.

Water evaporates particularly quickly when both heated and blown. The laundry on the clothesline dries fastest when the sun is shining and the wind is blowing at the same time. The hair dryer, Fig. 7, also blows and heats up at the same time.



But what happens when air containing water is cooled? This often happens at night, and you can see the result in the morning in a meadow: Dew has settled on the grass. The dew is water that was previously in the air as gas and is now liquid. One says the water is condensed. Condensation and evaporation are inverse processes. When liquid water becomes gaseous, we speak of evaporation, when gaseous water becomes liquid, of condensation.

Summary: The warmer and drier the air, the faster water evaporates. If gaseous water is cooled, it condenses.

Exercises

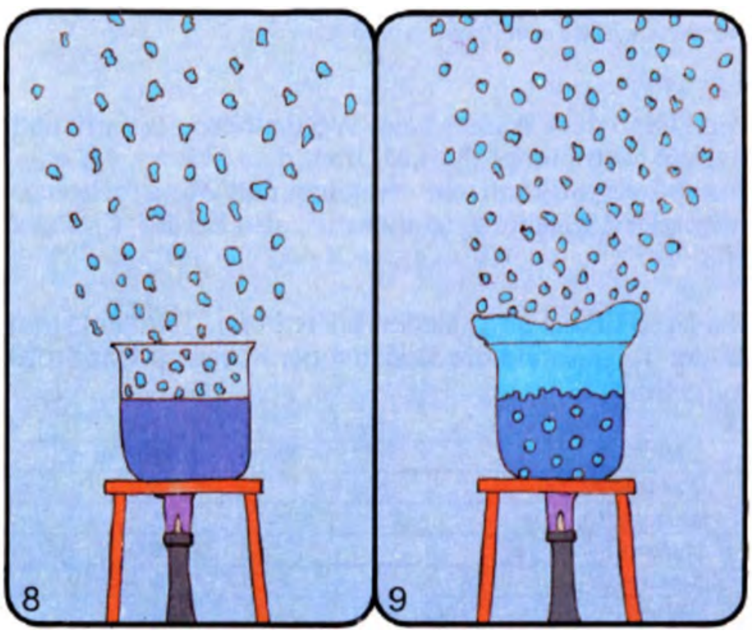
1. Why does the hair dry faster if you use a hair dryer?

2. If you take a bottle out of the fridge, it mists up, it is covered with a layer of water. Where does the water come from?

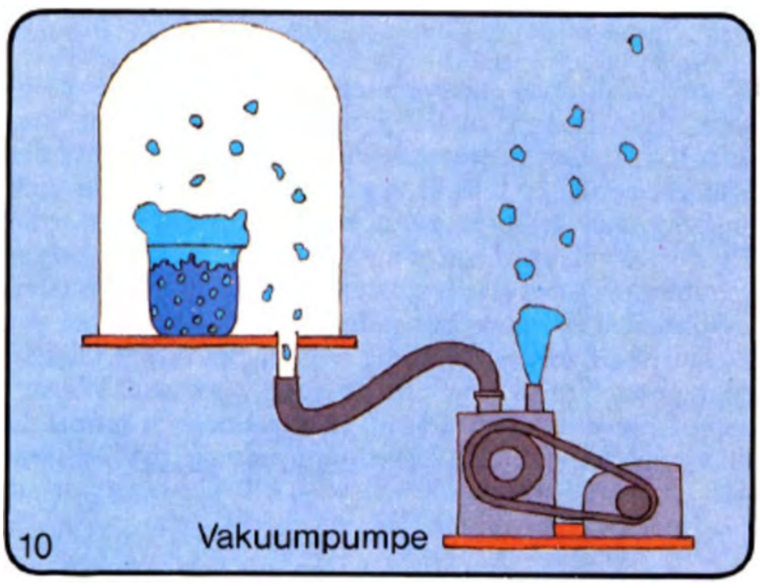
3. When you breathe against a window pane, the window pane mists up. Where does the water come from?

14.8 Boiling

The higher the temperature, the faster water evaporates. Fig. 8 shows a beaker with liquid water. Some water constantly evaporates. The air above the water surface contains gaseous water that slowly distributes outwards. If you heat the water in the pot, it evaporates faster and faster. Finally, at a certain temperature, evaporation is so rapid that the evaporated water completely pushes away the air above the water surface, Fig. 9. At the same time, bubbles of water vapor form inside the water, which rise upwards. You know this process very well: the water boils. The temperature at which this happens is 100 °C. This is called the boiling temperature of the water.



On the left, the water slowly evaporates. On the right, the water evaporates so quickly that it pushes away the air completely, it boils.



vacuum pump

On this picture, water boils at 20 °C.

You can also help the water push the air away: You pump away the air above the water with a pump. This allows water to boil at normal ambient temperature, i.e. 20 °C, Fig. 10.

Other liquids boil at different temperatures. The table lists the boiling temperatures of some substances.

Substance	Boiling temperature in °C
Hydrogen	–253
Oxigen	–183
Nitrogen	–196
Alcohol	78
Water	100
Lead	1 750
Iron	3 000

You may be surprised that metals also become gaseous, but you often encounter gaseous metals. Many street lamps are neither incandescent lamps nor fluorescent tubes (neon tubes). Rather, a gaseous metal shines in them. In lamps with “cold” light, similar to daylight, gaseous mercury shines, in lamps with “warm” yellow light it is gaseous sodium. The metal is not yet gaseous when switched on. Therefore, the lamps need a few minutes to reach their full brightness.

Summary: At the boiling temperature, so much liquid passes into the gaseous state that the air above the liquid is pushed away .

Supplement S 14.6

Exercises

1. Describe what happens when the temperature of water gradually increases to the boiling temperature.

2. How can water boil below 100 °C?

3. What must be done to boil water at a temperature higher than 100 °C?

4. A pressure cooker is a cooking pot with an airtight lid. What happens to the water in a pot like this when you heat it?

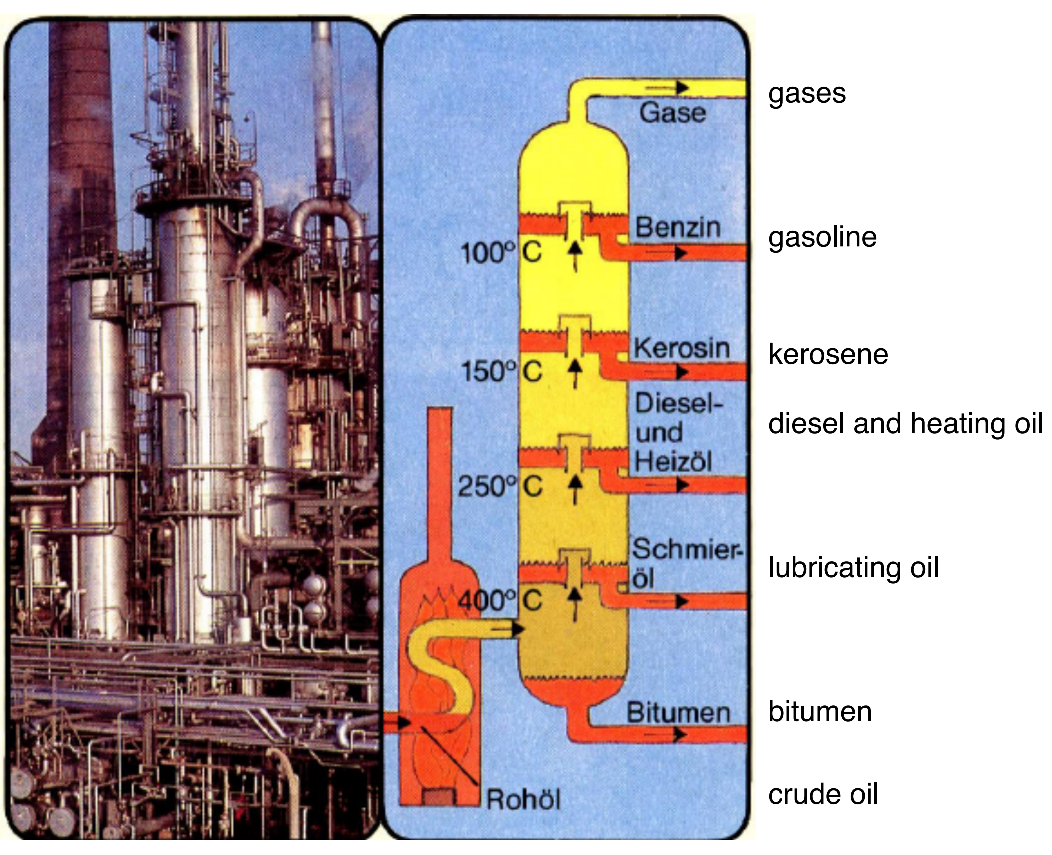
S 14.1 Caution with unknown substances!

You approach an unfamiliar dog with caution. It is best to ask the owner of the dog if the dog bites. Unknown substances are similar: they can be toxic, they can be radioactive, they can corrode, explode or suffocate. Therefore, never experiment with substances that you don't know if they are harmless or not. Above all, never examine the taste of an unknown substance.

Cyanide, for example, is a completely harmless-looking salt. 0.15 g of it is enough to kill a human being.

S 14.2 Decomposing mixtures

Sometimes it is necessary to decompose a mixture of substances, to separate the pure substances from each other. We want to describe two separation processes that are technically important.

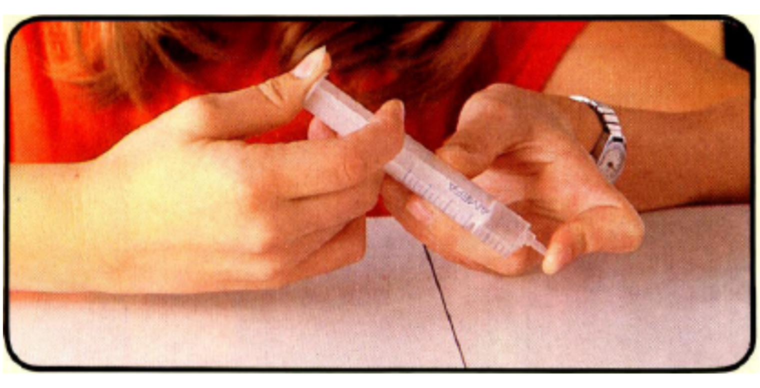


The oil refinery: Crude oil is a mixture of a large number of different fuels. You can't do much with the mixture directly. Neither a gasoline engine nor a diesel engine or oil stove would work if it were supplied with crude oil coming from the earth. The crude oil is therefore decomposed in a refinery. The process used is called "distillation". The crude oil is first evaporated, i.e. brought into the gaseous state. The gas is fed into a distillation tower. There are different temperatures in the distillation tower at different altitudes. Since the individual components of crude oil have different boiling temperatures, they condense on different levels of the tower and can be removed separately. However, not all pure substances are separated here. The components of crude oil are only separated into groups. Each group is still a mixture. One of the separate groups is gasoline, another is diesel or heating oil.

The seawater desalination plant: In many countries of the world, drinking water is a precious substance, although there is enough water. However, the available water is seawater, i.e. a mixture of water and salt. Desalination plants are being built to make drinking water from it. One process is based on the fact that only the water evaporates when salt water boils. The salt remains as a solid.

S 14.3 Gases can be compressed

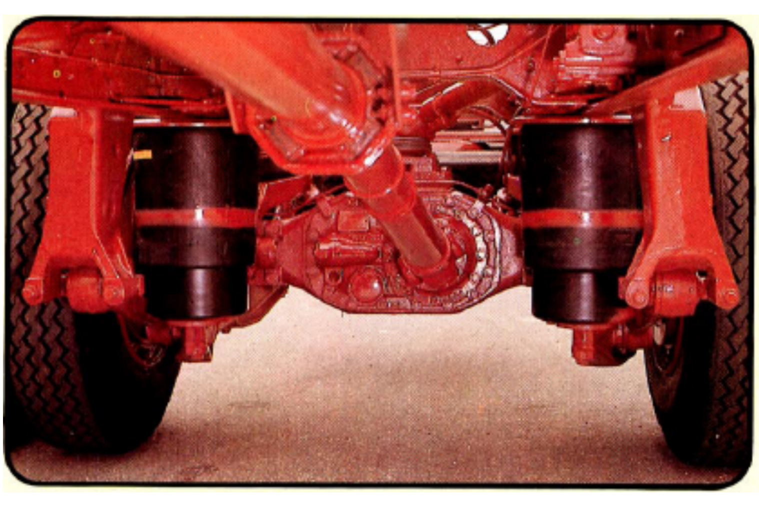
Get a syringe.



1. Pull out the piston a little, close the opening and press on the piston.
2. Fill the syringe with water, close the opening and press the piston.

Did you feel the difference? Like all gases, air is easily compressible. Water is almost impossible to compress.

The air-filled syringe behaves similar to a steel spring. There are cars that are sprung with "air springs" (bottom picture). The compressibility of the air is also used in the tires of vehicles.



When you squeeze a gas, you store energy into it. When the gas is released, the energy comes out again.

S 14.4 Liquid metals

Most metals are solid at normal temperature. If they are heated, they become liquid at the melting temperature.

To produce a metal object of a certain shape, liquid metal is often poured into a mould and then solidified.

Casting is used to produce:
Engine blocks for car engines made of iron or aluminum, church bells and bronze statues, iron stoves, zinc model toy cars.

S 14.5 Setting of concrete, hardening of eggs and hardening of adhesive

Not always when a solid is formed from a liquid substance, this change of state can be reversed.

When concrete becomes solid or, as they say, "sets", it is not a transition from the liquid to the solid state. Concrete does not solidify at a single temperature, but at almost any temperature. Moreover, it does not become liquid again simply by heating. When concrete solidifies, the substances are converted. Solid concrete is a different substance than liquid concrete.

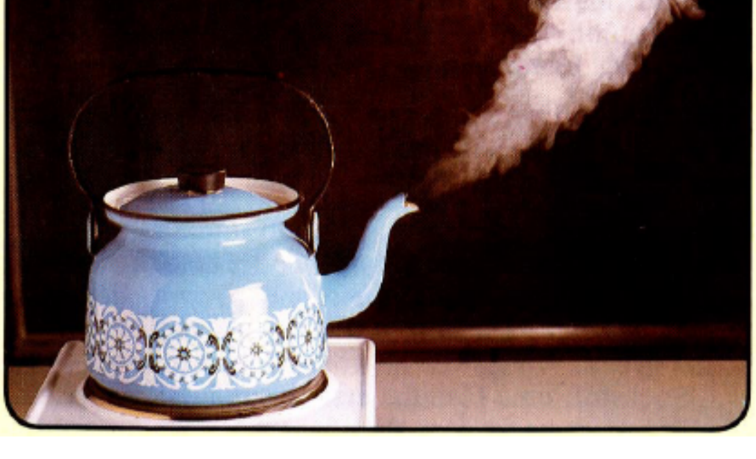
An egg you boil gets hard. This process cannot be reversed by cooling either.

Like concrete, adhesive does not only solidify at a certain temperature. Most adhesives consist of a solid material dissolved in a solvent - similar to sugar in water. When solidifying, the solvent evaporates and the solid remains.

S 14.6 Water vapor and mist

The white "clouds" that rise from a kettle on a stove are often called steam. However, the physicist and the engineer understand steam to be something else, namely gaseous water. Gaseous water is invisible.

Take a closer look at a boiler of boiling water. You can't see anything just above the spout. Do not conclude from this that there is air here, and do not hold out your finger: Invisible, hot steam is pouring out here! Only a little higher one sees a white fog cloud. This consists of tiny little drops of liquid water. The steam exiting the boiler reaches a point where it is so cold that it condenses. Then the droplets come to an area where the air is drier, they evaporate again.



Fog and clouds in the sky also consist of water droplets. Since it is very cold at great heights, the water droplets have solidified into ice particles in very high floating clouds.

15. The energy carrier „fuel + oxygen“

15.1 What is needed for combustion

If you want to discharge the energy from a fuel, you burn it. Coal is burned in the furnace, gasoline in the car engine (which is why it is also called an internal combustion engine). Wax burns in the candle flame.

Have you ever noticed that air is needed for every combustion? We’re going to look into that now.

Since air consists mainly of nitrogen and oxygen, one might wonder which of the two substances is necessary for combustion: oxygen, nitrogen or both? You can give the answer to that question already. We had seen in the previous section that nitrogen suffocates a flame and that oxygen supports combustion. What the stove needs is therefore oxygen. But what happens to the oxygen in a flame? Maybe the oxygen a coal stove needs will come out again at the chimney? The following experiment shows that this does not happen.

Place a burning candle in a glass and close the glass with a lid or cork, Fig. 1. But after a while the flame gets smaller and finally goes out. If another burning candle is placed in the glass immediately afterwards, it goes out immediately. This is because something necessary for combustion is missing in the glass: oxygen. The oxygen has been consumed by the first candle.

The following are therefore needed for combustion

- a fuel,
- oxygen.

The carrier with which the energy is brought to a flame is therefore not the fuel alone, but rather two substances together form the carrier: the fuel and the oxygen. Fuel and oxygen disappear during the combustion. They are transformed into other substances. We therefore say: combustion is a conversion of substances.

Summary: During combustion, fuel and oxygen are converted into other substances.

Supplements S 15.1 and S 15.2

Exercises

1. You can’t go by plane into outer space. Why not? (There are several reasons.)

2. How do you know that oxygen disappears during combustion?

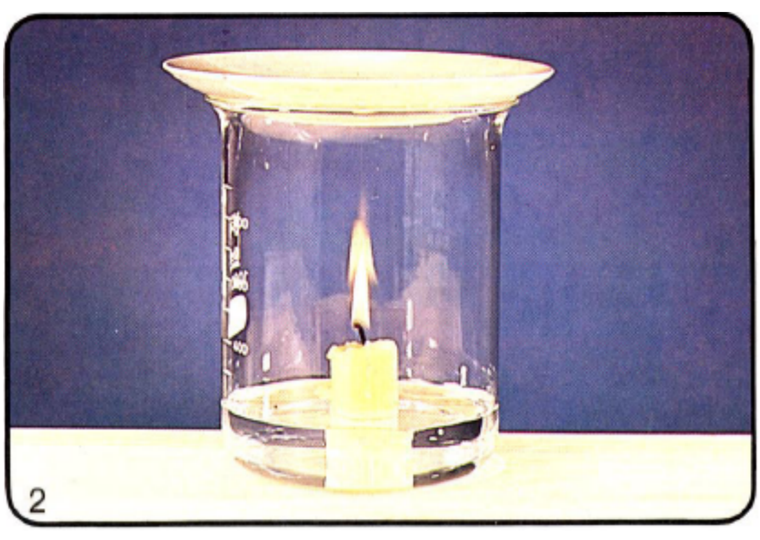
15.2 What results from combustion

What happens to the energy carrier when it has discharged its energy during combustion? Which substances are produced during combustion? “Ashes, soot and smoke”, you might say. However, all three answers are not quite correct.

When a candle burns down, when the gasoline in the car engine burns or the heating oil in the oil stove, no ashes and hardly any smoke or soot are produced. Chimneys of large coal-fired power plants have a diameter of about 5 m. However, no smoke comes out of these chimneys (picture in S 2.4). So what are these huge chimneys for? The substances produced during combustion are invisible gases. We call them exhaust gases. These gases are the actual combustion products.We want to examine them now.

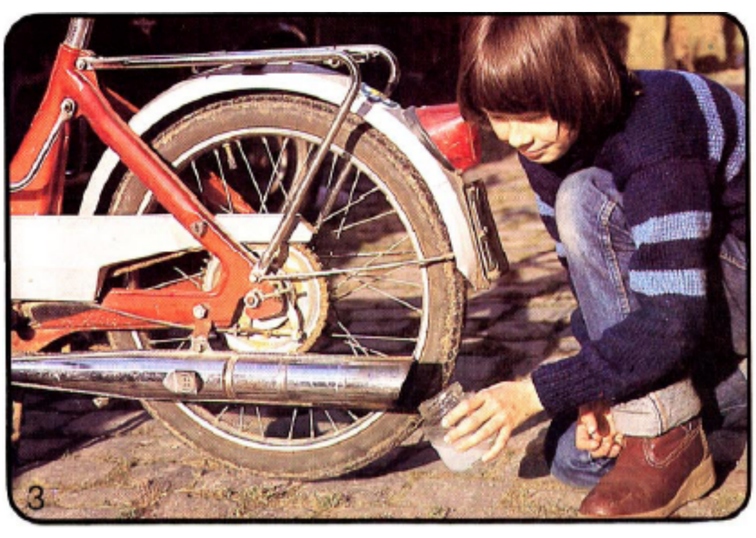
Under what circumstances and why ash, smoke and soot are produced, you will learn in sections 15.4 and 15.5.

So what substances are produced when the wax of a candle burns, when the gasoline in the car engine burns or the oil in the oil stove? We can easily identify one of these substances. We place a short candle into a beaker, pour some lime water into it, light the candle and close the glass with a plate, Fig. 2. After a short time the candle goes out. Let’s now shake the beaker a little. The lime water becomes cloudy. This means that the exhaust gases of the candle contain carbon dioxide.



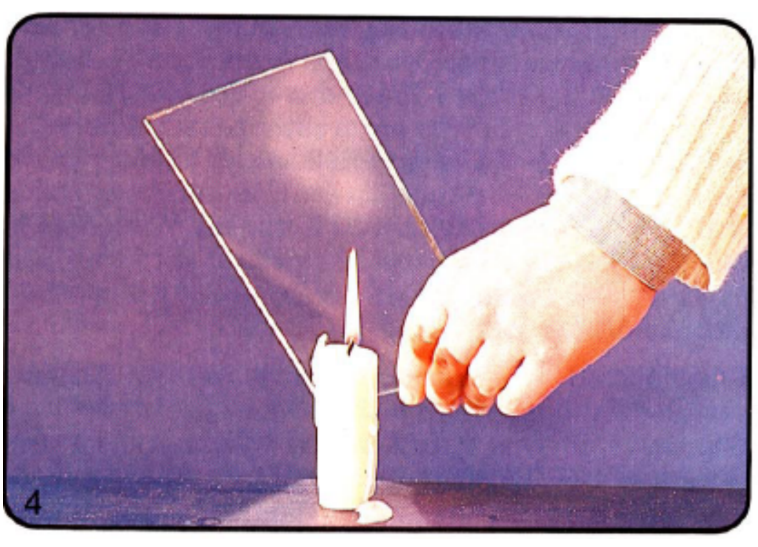
The exhaust gases of the candle contain carbon dioxide.

We also want to do the lime water test with the exhaust gases of a gasoline engine: We conduct the exhaust gases into a glass of lime water, Fig. 3, and then shake. The result is again clear: the exhaust gases contain carbon dioxide. Carbon dioxide is also produced during the combustion of heating oil.



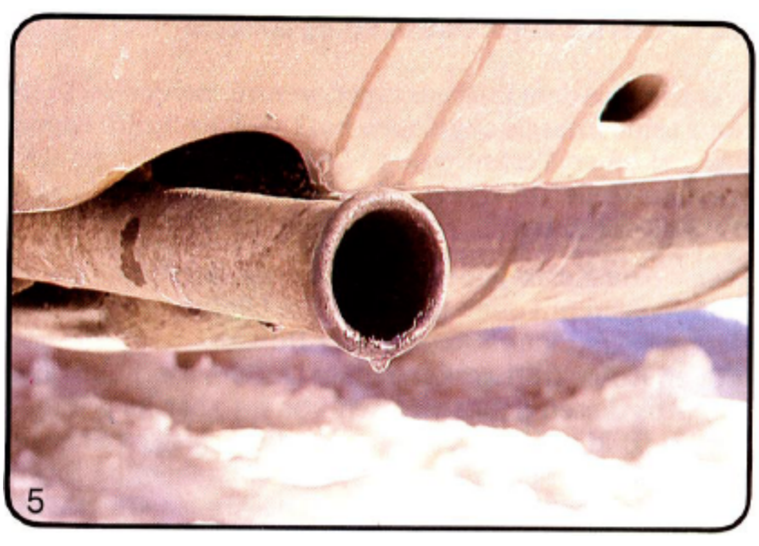
The exhaust gases of the moped contain carbon dioxide.

However, carbon dioxide is not the only combustion product of the candle, heating oil and gasoline. If a cold glass or metal plate is held for a few seconds over a candle flame, Fig. 4, it mists up, i.e. a gaseous combustion product condenses on the plate, it becomes liquid.



The cold glass plate mists over the candle

Fog clouds form behind the exhaust of a running car engine in winter. Fog, as we know, consists of small drops of liquid. If the car engine has not been running for a long time and the exhaust pipe is still cold, a large amount of this liquid collects at the exhaust opening, Fig. 5. What kind of liquid is this?



A liquid collects in the exhaust pipe.

Maybe it’s just unburned gasoline? We can easily find out whether this is the case. We pour a few drops of the liquid on a sheet of blotting paper and try to light the blotting paper. Where it is damp, it does not burn. It is a non-flammable liquid, so it is not gasoline.

In fact it is water (of course we haven’t proved that yet with our blotting paper test.)

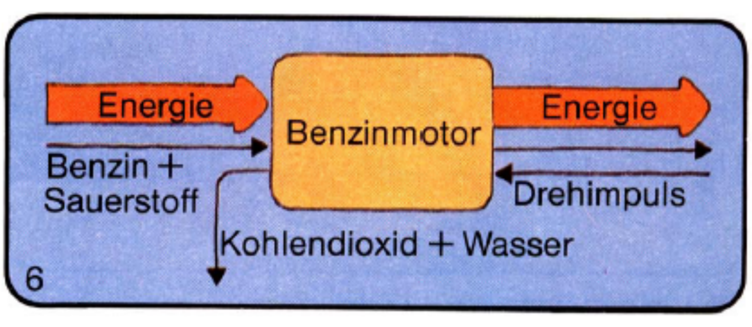
Water is also produced during the combustion of heating oil and wax. This water is initially gaseous. However, it can condense by cooling.

So we got to know two combustion products:

1. carbon dioxide, 2. water.

Both are produced during the combustion of candle wax, heating oil and gasoline. Combustion of coke produces almost only carbon dioxide, and almost no water. When hydrogen is burned, however, only water is produced, but no carbon dioxide.

We can now draw the flow diagram of the gasoline engine more precisely, Fig. 6. The loaded energy carrier is the mixture “gasoline + oxygen”. The unloaded carrier, which we had previously simply called “exhaust gases”, is the mixture “carbon dioxide + water vapor”.



energy
gasoline + oxygen
carbon dioxide + water
gasoline engine
energy
angular momentum

Summary: Carbon dioxide and water are combustion products.

Supplement S 15.3

Exercises

1. What comes out of the chimney of a house?

2. Which fuels during combustion transform into

a) carbon dioxide, b) no carbon dioxide, c) water, d) no water?

3. Why can you see a cloud of mist behind the car exhaust only in winter? Is there no water in summer when gasoline is burned?

4. Draw the flow diagram of an oil-fired stove.

15.3 How much the combustion products weigh

We want to burn 100 grams of gasoline. This combustion requires a very specific amount of oxygen, a very specific amount of carbon dioxide and water is produced and a very specific amount of energy is discharged. All these quantities are shown in Fig. 7.

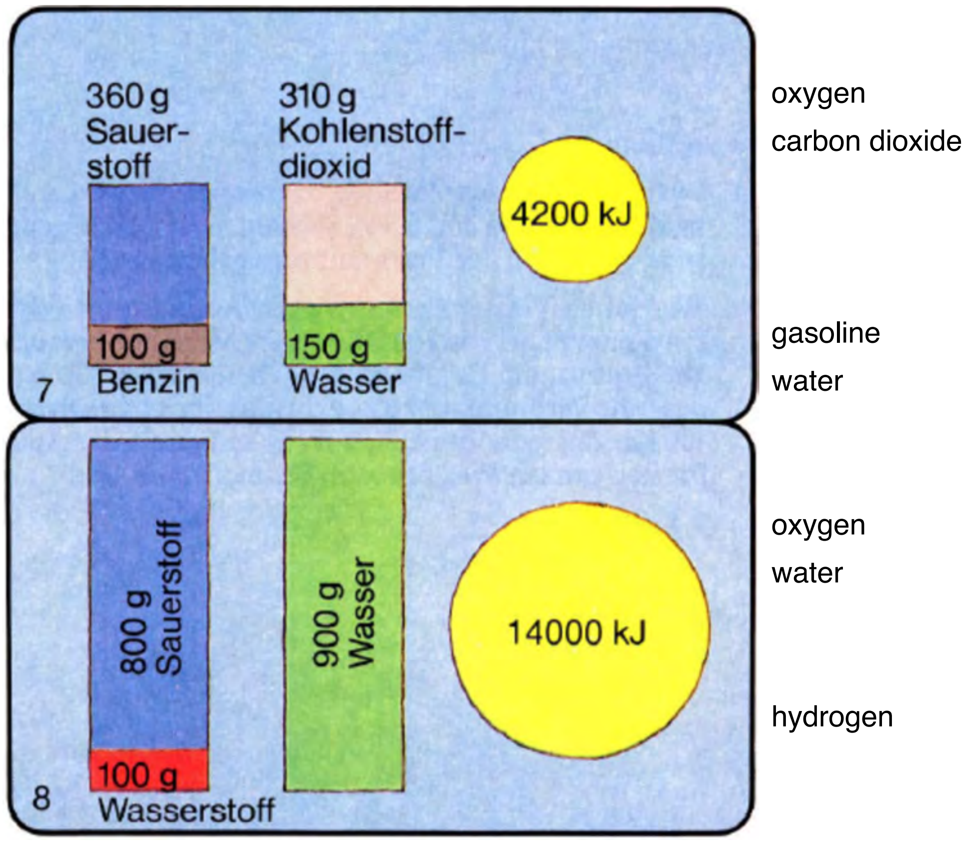


Fig. 8 shows how much oxygen is needed, how much combustion products are produced and how much energy is discharged when we burn 100 g of hydrogen.

You can immediately see on the pictures that the weight of fuel and oxygen taken together is equal to the weight of the combustion products. The carrier that is charged with energy weighs exactly as much as the empty one.

From Fig. 7 you can see that in a gasoline engine more than one tank of water is produced from one tank of gasoline. (1 liter of gasoline weighs almost as much as 1 liter of water.) Would you have thought that?

Summary: The combined weight of fuel and oxygen is equal to the weight of the combustion products.

Supplement S 15.4

Exercises

1. If 1 kg of natural gas burns completely, 2.7 kg of carbon dioxide and 2.3 kg of water are produced. How many kg of oxygen were consumed during combustion?

2 How many kg of water come out to the car exhaust during a trip from Hamburg to Munich? The distance Hamburg-Munich is 800 km; the car consumes 8 kg of gasoline (about 10 l) per 100 km. (First calculate how many kg of gasoline the car needs for the whole journey; then use Fig. 7.)

15.4 Ash and nitrogen

We have seen that carbon dioxide and water are combustion products, i.e. substances that are produced during combustion. When coal is burned, another substance remains besides the exhaust gases: the ashes. But ash is not a product of combustion. It is not a new substance that is created during combustion. This substance was already contained in coal before combustion. Coal therefore contains an incombustible part, so to speak dirt, which remains in the furnace after combustion.

Usually there is another substance that is involved in combustion but does not participate in it: nitrogen. Air flows into both the furnace and the car engine. However, only the oxygen contained in the air is used for combustion. The nitrogen comes out unchanged together with the exhaust gases, at the stove to the chimney and at the car to the exhaust. So the nitrogen is a kind of gaseous ash.

Summary: Ash is the non-combustible part of the fuel.

Supplement S 15.5

Exercises

1. Which fuels leave behind ash during combustion, which do not?

2. Explain the difference between the exhaust gases and the ashes.

3 Why is heating oil such a popular fuel?

4 What happens to the nitrogen that flows into the gasoline engine with the air?

15.5 Soot and smoke

Which substances does soot belong to? Is it a combustion product, such as water and carbon dioxide, or is it a non-flammable substance that was previously contained in the fuel, such as ash and nitrogen? Neither is right. Soot is a new substance that is created from the fuel, but can still burn itself. You may have heard of “chimney fires”. In a chimney fire, the soot that has settled inside the chimney burns.

Soot is always produced when there is not enough oxygen. An oil stove that does not get enough air produces soot, the heating oil does not burn completely. A petroleum lamp that you turn on too much won’t get enough oxygen, it produces soot. If a truck driver gives full throttle, the engine gets a lot of fuel, but not enough air. The fuel does not burn completely. Soot comes out to the exhaust.

What is the smoke made of, that is, the black “clouds” that sometimes come out of the chimney? Smoke is nothing more than a lot of tiny particles of ash and soot that the fire has stirred up and which are carried away by the exhaust gases.

Summary: Soot is semi-burned fuel. Smoke consists of small particles of ash and soot.

Supplement S 15.6

Exercises

1. Soot is produced during combustion and it is also fuel. Explain that sentence.

2. Why does the chimney need cleaning from time to time?

15.6 Humans and animals as energy transloaders

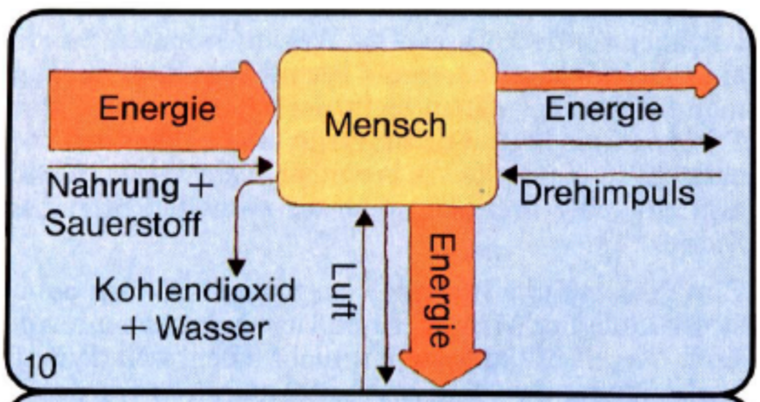
People and animals need energy to live. They ingest it with food. How is the energy discharged from the food? The same transformation of substances takes place in the body as in a flame. This is therefore also referred to as combustion. However, there is no flame, because the combustion takes place at a temperature of 37 °C. We want to investigate the transformation of substances in the body in more detail.

Burning requires a fuel. The fuel for our body is food. In fact, many foods can also be burnt with a flame, e.g. sugar and oil. Others are not flammable, but only because they contain water. They are a mixture of water and flammable substances. When the water is removed, the combustible material remains. Fresh grass doesn't burn. But when you dry it, hay is made and hay is flammable. Foodstuffs are therefore either flammable or contain flammable substances.

Combustion requires oxygen. Humans and animals get the oxygen from the air while breathing. We could not live without air, because then the combustion of the food would stop. The products of combustion are carbon dioxide and water. We absorb a lot of water while drinking, but we also get water by burning solid food. That's hard to see, though. The combustion product carbon dioxide, on the other hand, can be easily detected. Bubble through a straw of air into lime water, Fig. 9. The lime water becomes cloudy. If fresh air is passed through lime water, nothing happens. The exhaled air contains carbon dioxide. The carbon dioxide leaves the body via the lungs.

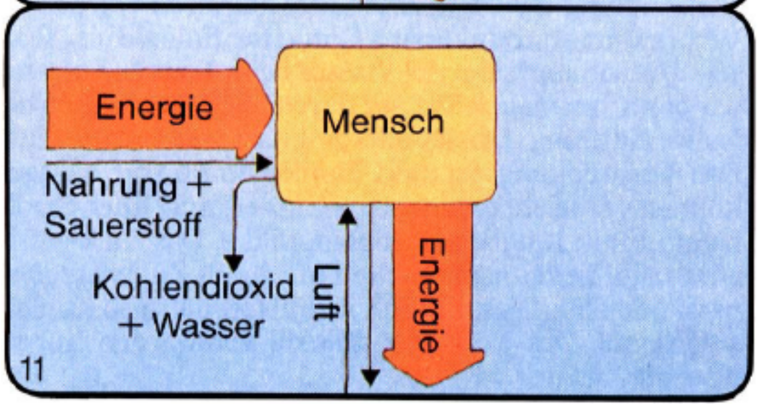
9

We want to draw a person's energy flow diagram. To do this, however, we still need to know with which energy carrier the human being releases the energy. Which this energy carrier is depends on what people are doing at the moment. For example, if the person turns a crank, it is angular momentum. However, most of the energy is always released into the air. Humans and animals are usually warmer than their environment, they warm the air that surrounds them. The energy comes out through the skin. The skin is our "cooling exit". The energy flow diagram for the cranking person is shown in Fig. 10.



10

energy
food + oxygen
carbon dioxide + water
human
energy
angular momentum
energy
air



11

energy
food + oxygen
carbon dioxide + water
human
energy
air

If a person does nothing at all or sleeps, the energy flow diagram is that in Fig. 11, even if the person is thinking, nothing changes.

Summary: Combustion takes place in humans and animals. Food and oxygen are converted into carbon dioxide and water.

Supplements S 15.7 to S 15.11

Exercises

1. Why do many foods not burn although humans can discharge energy from them?

2. How do you know that combustion takes place in humans and animals?

3. What is the difference between combustion in the human body and combustion of fuel oil in an oil stove?

4. How can we show that exhaled air contains carbon dioxide?

5. Where do fish get their oxygen from?

15.7 Meadows and forests as energy transloaders

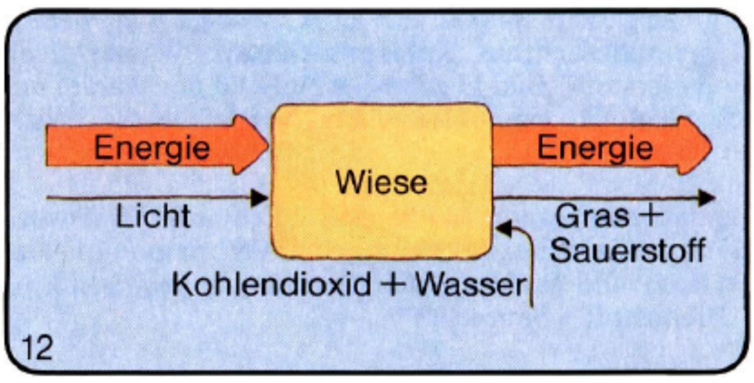
Humans and animals consume energy. They absorb energy and release it shortly afterwards. They release it when they move, but they also release energy when they rest, because they are warmer than their surroundings.

Plants also absorb energy. Plants, however, hardly move at all, and they are also not warm. They therefore give off only little energy. Unlike humans and animals, plants grow as long as they live. People and animals don't grow once they have grown up. Plants, however, constantly produce new leaves, branches, stems and fruits. The energy they absorb is contained in these leaves, branches, trunks and fruits. The energy is thus stored.

Instead of a single plant, we now want to look at a large number of plants: an entire meadow. A sheep is supposed to walk around the meadow and eat grass. The meadow is constantly absorbing energy. It gets it with the light from the sun. But it also constantly releases energy, namely to the sheep with the energy carrier grass. So the meadow is an energy transloader. The meadow produces grass, a substance that no one has put into the ground. As the meadow grows, a conversion of substances takes place.

This conversion of substances is precisely the opposite of the conversion of substances that takes place in the sheep, the opposite of combustion. The sheep turns "grass + oxygen" into "carbon dioxide + water". The meadow turns "carbon dioxide + water" into "grass + oxygen".

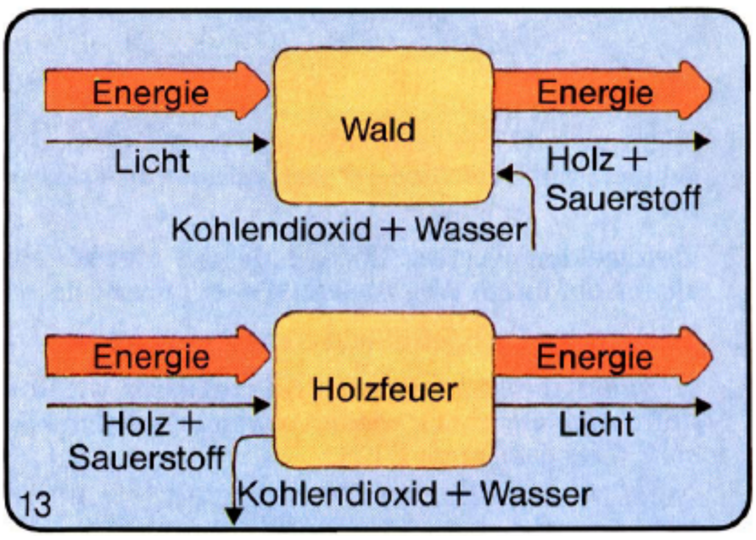
The meadow takes the carbon dioxide from the air, the water from the ground. It loads the empty carrier "carbon dioxide + water" with energy. This produces the loaded carrier "grass + oxygen". Fig. 12 shows the energy flow diagram of the meadow.



energy
light
meadow
energy
grass + oxygen
carbon dioxide + water

The meadow has received the energy it charges on "carbon dioxide + water" from the sun. The sheep gets its energy, via the meadow, also from the sun. The meadow is the "solar collector" of the sheep.

Just like a meadow, we can also consider a forest as an energy exchanger. The energy flows into the forest with the carrier light. People constantly drive felled trees, i.e. wood, out of the forest. The forest turns "carbon dioxide + water" into "wood + oxygen". Fig. 13 shows the flow diagram of the forest and the flow diagram of a wood fire. Compare the two pictures.



energy
light
forest
energy
wood + oxygen
carbon dioxide + water

energy
wood + oxygen
carbon dioxide + water
wood fire
energy
light

Summary: A conversion of substances takes place in plants. It is the opposite of a combustion. Fields, meadows and forests transfer energy from light to "fuel + oxygen".

Supplements S 15.12 and S 15.13

Exercises

1. Plants and animals use the energy they absorb in different ways. Can you explain how?

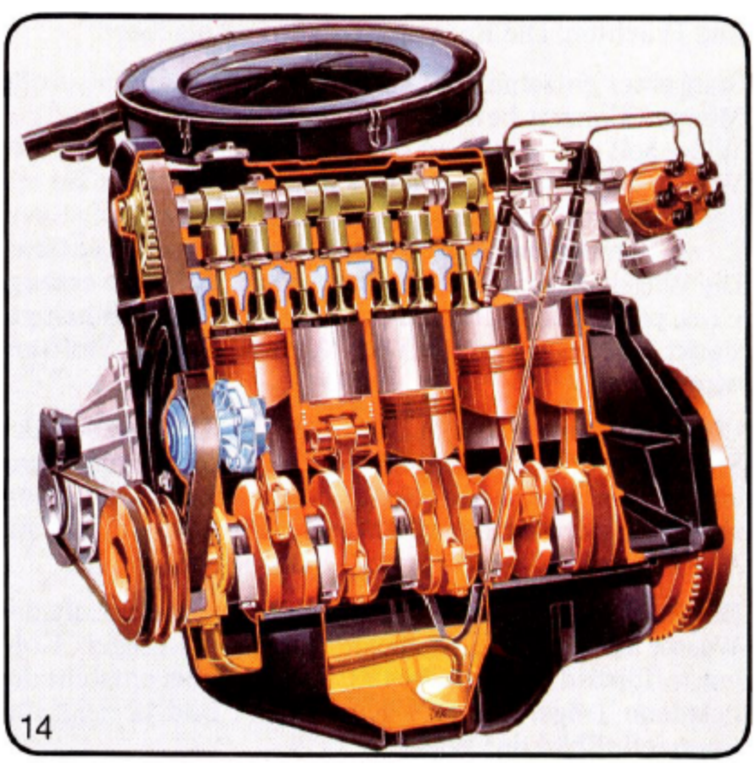
2. Trace the path of the energy that man absorbs backwards. Where does it finally come from?

3. Draw the energy flow diagram of a wheat field.

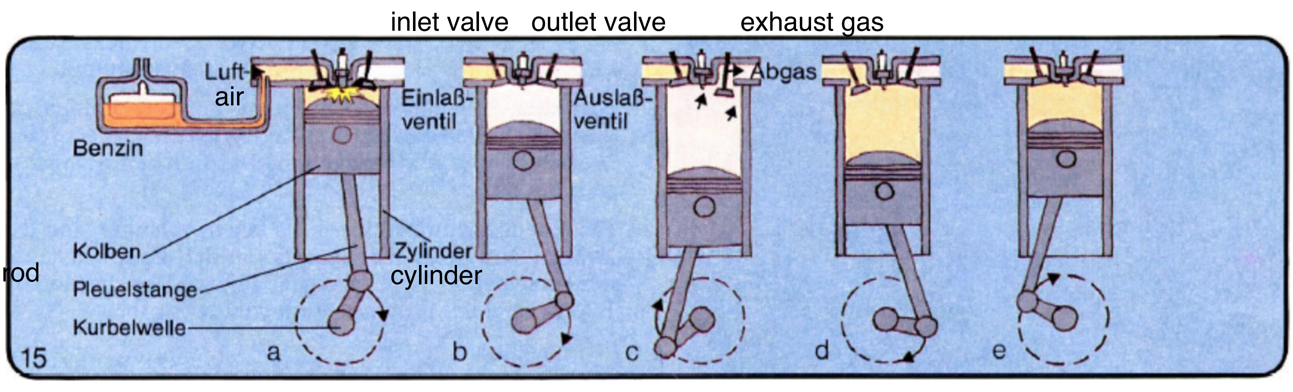
4. Why is nature a good example of how raw materials can be reused after use? (Read also S 15.12.)

15.8 The gasoline engine

Fig. 14 shows a "cut open" gasoline engine. A gasoline engine is similar to a steam engine: it has cylinders, pistons, connecting rods and a crankshaft. What is immediately noticeable about Fig. 14 is that the engine has five cylinders, five pistons, etc. That's why they call it a five-cylinder engine. You could also say there are 5 gas engines right next to each other. All cars and many motorcycles have more than one cylinder. Why build a motor consisting of several small motors instead of a single large one? The multi-cylinder engine runs more quietly. You'll soon see why.



A single cylinder of a gasoline engine is shown in Fig. 15, several times, each time in a different moment. First we want to get to know the individual parts of the gas engine. Some parts are better visible in Fig. 14, some in Fig. 15, so look at both illustrations.



The piston moves up and down in the cylinder. The crankshaft rotates because each piston is connected to the crankshaft via a connecting rod. Cylinder, piston, connecting rod and crankshaft are orange in Fig. 14. The orange wheel on the far right in Fig. 14 is the flywheel.

Each cylinder has an inlet opening at the top for the energy-loaded carrier "gasoline + air" and an outlet opening for the exhaust gases. In each of the two openings there is a valve, the inlet and the outlet valve. The valves are opened or closed by the camshaft at the right moment. Valves and camshaft are green in Fig. 14. The camshaft is driven with a drive belt. (The blue device, which is driven by the same belt, is the water pump; the alternator gets energy with the "V-belt" on the lower left.

The spark plug is located at the very top of each cylinder. It generates a spark at a very specific moment (Fig. 14 shows the spark plugs only for the two right-hand cylinders).

Liquid gasoline is finely sprayed in the carburetor and mixed with air. The fine gasoline droplets evaporate immediately, creating a gaseous mixture of gasoline and air.

To understand how the engine works, we let the engine run in slow motion, Figs. 15a to e. We start our observation at the time when the piston is at the top, in the "top dead center".

In the cylinder, above the piston, there is a large quantity of the gasoline-air mixture. A large quantity of a gas can be accommodated in a small space if the gas is strongly compressed. How the compressed gas gets into the cylinder, we will see later. Let us first examine how it gives off its energy.

The air-fuel mixture is ignited with the spark plug, Fig. 15a, and burns off very quickly. Combustion produces carbon dioxide and gaseous water. In addition, the nitrogen of the air is also located in the cylinder. As a result of the combustion, the temperature and pressure of the gas increase considerably. The hot gas pushes the piston downwards, Fig. 15 b. Energy is transferred to angular momentum. Part of this energy is stored in the flywheel.

When the piston is down, the outlet valve opens. The high-running piston pushes the exhaust gases out to the exhaust, Fig. 15 c. Energy is drawn out of the flywheel to push up the piston.

When the piston has reached the top, the exhaust valve is closed and the cycle could start again if there was already fresh gasoline-air mixture in the cylinder. You could now open the inlet opening and while the piston is at the top, quickly pump fresh gasoline-air mixture into the cylinder. However, the time available for this is very short. Besides, of course, you would need a pump.

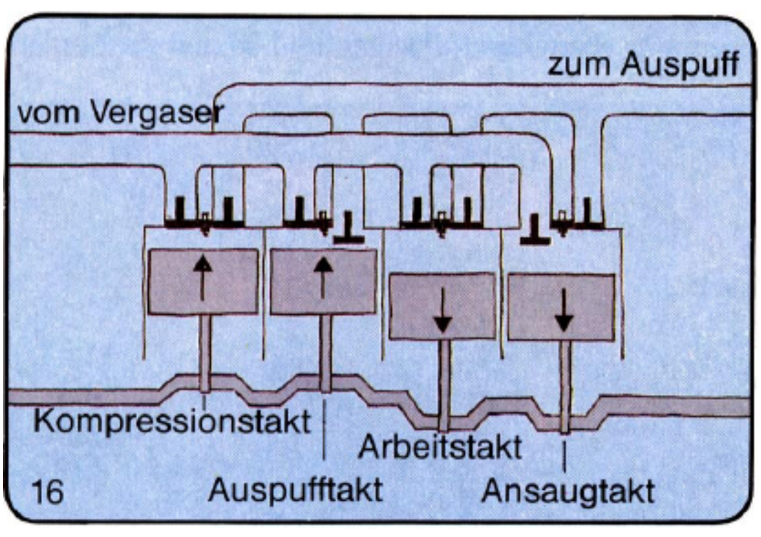
Instead, the engine itself is used as a pump. You let it make another full turn, at which it does not release any energy, but only pumps fresh gas into the cylinder: The inlet valve opens, the piston runs down and sucks in fresh gas from the carburetor, Fig. 15d. When it is down, the valve closes. The piston moves up again and compresses the gas, Fig. 15e. In the small space above the piston you have a large amount of air-fuel mixture. Energy for that pump-cycle again must come from the flywheel.

An upward or downward movement of the piston is called a stroke. The engine makes, as we have seen, four different strokes in succession and then starts again from the beginning. That is why it is also called a four-stroke engine. Let's recapitulate:

1. Intake stroke and 2. Compression stroke:	The engine is charged with fresh gasoline-air mixture.
3. Power stroke:	The hot gases (carbon dioxide, water vapour and nitrogen) push the piston down. Energy is transferred to angular momentum.
4. Exhaust stroke:	The empty energy carrier (carbon dioxide + water vapor) is pushed out of the engine together with the nitrogen.

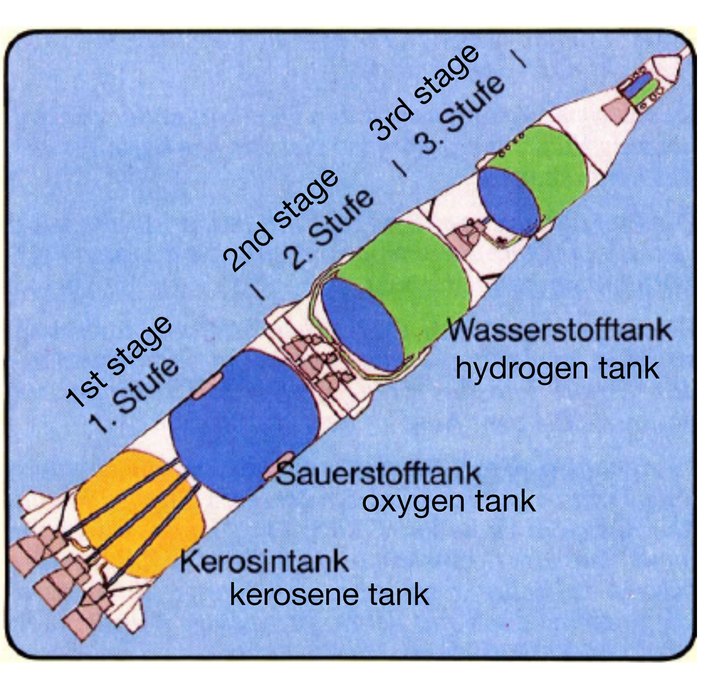
Only during the "power stroke" energy is charged onto angular momentum. In the remaining three strokes the energy is taken from the flywheel.

In an engine with more than one cylinder, the cylinders are matched to each other so that the working cycles of the individual cylinders take place in regular sequence. Fig. 16 shows this for a four-cylinder engine.



S 15.1 Rockets have two tanks for the energy carrier

A car needs gasoline and oxygen. So the energy carrier has two components. Only for one part, the gasoline, the car has a storage tank: the gasoline tank. Oxygen doesn't need a tank, there's oxygen everywhere in the air.



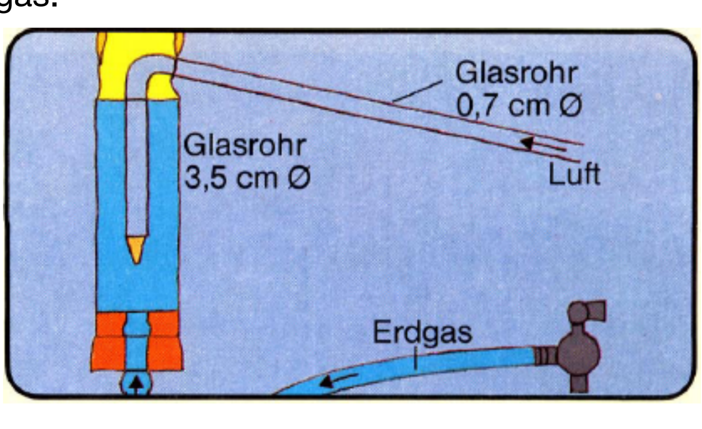
The Saturn V rocket has three rocket stages that burn one after the other. As soon as the fuel of one stage has burned down, the whole stage is rejected. The fuel for the first stage rocket engines is kerosene, the two upper stages burn hydrogen. But every rocket engine needs oxygen in addition to fuel. Since there is no air in space, and therefore no oxygen, each rocket stage has two tanks: one for the fuel and one for oxygen.

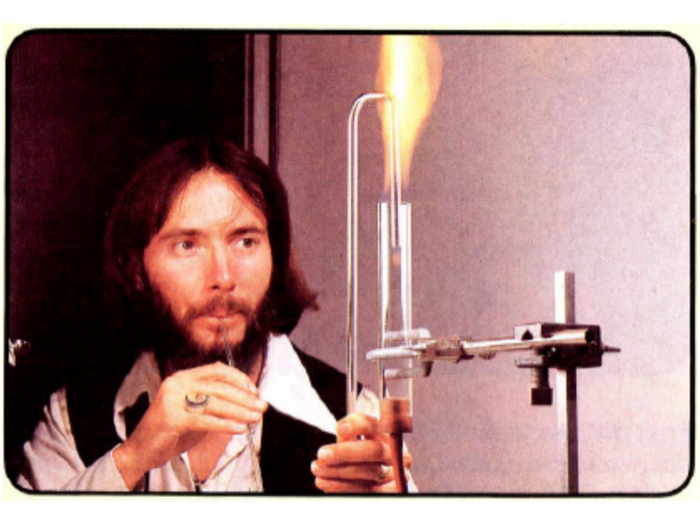
S 15.2 An inverted flame

The most important thing for a combustion is the fuel – at least that is what people on earth think. You know that oxygen is just as important, but since you don't have to pay for it, you don't usually think about it. The whole atmosphere consists of air, and one fifth of the air is oxygen.

But imagine a world in which the atmosphere, i.e. what the air in our country is, consists of natural gas. In this world, you'd have to pay dearly for air. Natural gas would be free. Gas pipelines would lead to the houses, as here, but in these no natural gas would flow, but air. In people's homes there would be gas stoves that would look exactly like our gas stoves. Only air would come out to the burners instead of natural gas. Since the whole kitchen would be filled with natural gas, the air could be lit and a flame would be created that looks exactly like our flames.

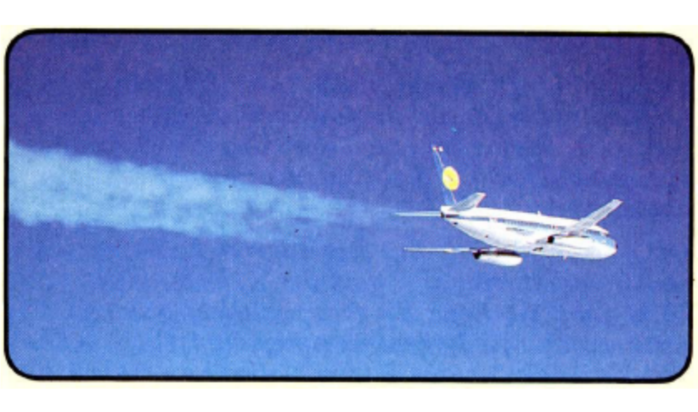
The pictures show how to build such a world in miniature. Natural gas flows through the hose into the large glass tube. At the top, where the natural gas flows out, we light it. The inside of the large pipe is filled with natural gas, it is our "perverse world". Now blow air through a small tube and lead the end of the tube from above through the natural gas flame into the interior of the large tube. You mustn't stop blowing. A "reverse flame" burns in the cylinder: air – and thus oxygen – exits from the tube into the atmosphere, which consists of natural gas.





S 15.3 Condensation trails

Jet fuel is kerosene. The combustion of kerosene produces carbon dioxide and water. The resulting water is the cause of the condensation trail that an aircraft leaves when it flies at high altitude. Because of the cold that prevails at these altitudes, the water of the exhaust gases condenses, resulting in water droplets. These evaporate again later, but only very slowly (see also S 14.6).



S 15.4 The weight of energy

We want to compare the weight of the energy carrier before it has discharged its energy with the weight after unloading.

The warm water that flows into the central heating radiator weighs as much as the cold water that comes out.

The compressed air that flows into a jackhammer weighs as much as the expanded air that comes out of the jackhammer.

Gasoline and oxygen flowing into a gasoline engine together weigh as much as the water and carbon dioxide combined come out to the exhaust.

So it looks as if the carrier loaded with energy always weighs as much as the empty one. Energy seems to have no weight. However, this is not entirely true. Since Albert Einstein established the theory of relativity in 1905, one knows that energy does weigh something, even if only very, very little: 1 Joule weighs 0.000 000 000 000 011 g.

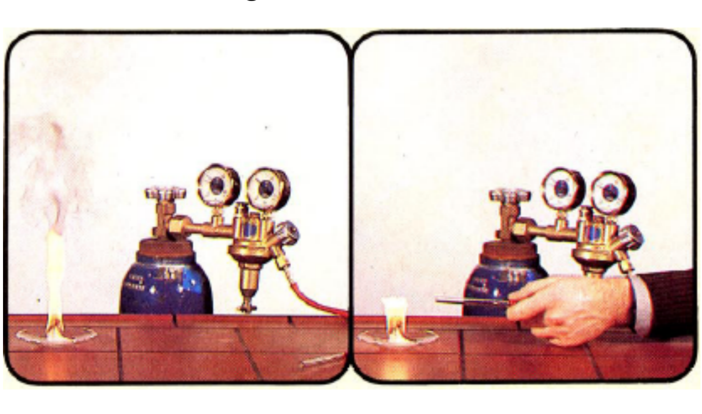
The energy that one tank of gasoline (about 50 l) discharges into the engine weighs 0.000 02 g. The energy that a large power plant delivers to the grid in one day weighs just 1 g. The energy that the sun radiates into space in one second weighs 4,000,000 tons.

S 15.5 The "ashes" of digestion

During digestion in the stomach and intestines, the substances that supply the human or animal with energy are removed from the food. These substances are called nutrients. The most important nutrients are carbohydrates and fats. However, some of the food is not digestible. Humans or animals can't do anything with it. This part is excreted as feces. The excrement is thus for humans and animals something similar to the ashes for the coal fire.

S 15.6 Oxygen supply prevents the development of soot

Pour some petroleum into a small bowl. A cotton ball is placed in the petroleum and ignited. The cotton ball acts as a wick. The result is a sooty flame. The petroleum burns incompletely. Pure oxygen is now conducted into the flame through a tube. The soot generation ceases.



S 15.7 The blood circulation

The human blood circulation serves to transfer substances from one part of the body to another. It can be compared to the railway network of a country. Just as you can take a wide variety of goods from any city to any other city by rail, the blood in the body transports a wide variety of substances from one part of the body to another. Among these substances are also nutrients and oxygen. In humans, the energy carrier is transported together with the energy by the blood.

Just like the trains of the railways, blood also needs a drive. The heart provides this drive. It pumps blood through the blood vessels.

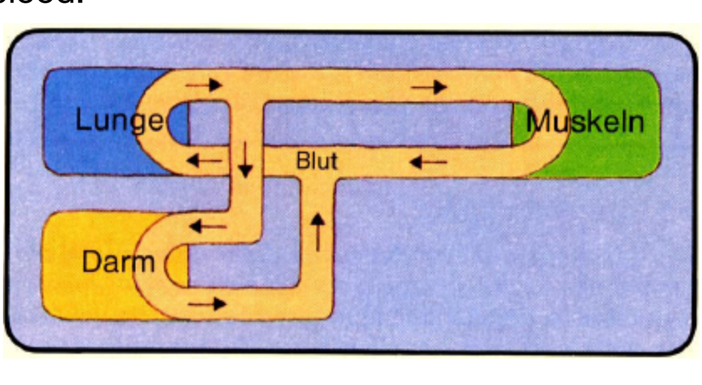
S 15.8 Intestine and lungs

To supply themselves with energy, humans take in food and air.

However, only part of both food and air can be used: From food nutrients and from air oxygen.

The intestine is there to extract nutrients from food. They are transported away with the blood.

The lung serves to extract oxygen from the air. Oxygen is also transported away from the blood.

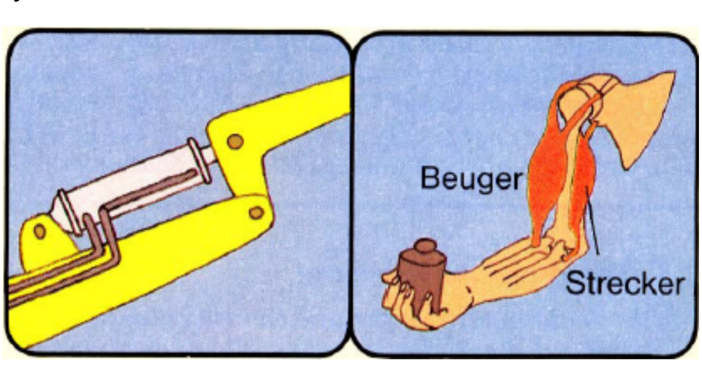


The blood brings nutrients and oxygen, both parts of the energy carrier, to the muscles.

In addition to nutrients, the intestines extract other substances that our body needs from food: proteins and vitamins.

S 15.9 The engines of man and animal

An excavator has a cylinder with a piston and two hydraulic oil supply pipes on each of its joints. This allows the arm attached to the joint to rotate in two directions depending on whether the piston is pushed by the hydraulic oil in one direction or the other. The energy for the movement comes with the hydraulic oil to the joint.



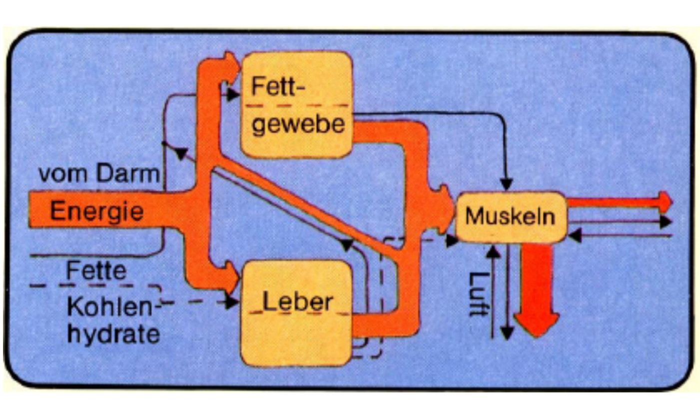
Man has two muscles on each of his joints. With the muscles, a person can turn the bone attached to the joint in two directions, depending on which of the two muscles pulls. Blood vessels lead to the muscles. The energy carrier "nutrients + oxygen" is transported from the blood to the muscle. The nutrient burns in the muscle and carbon dioxide and water are produced. Carbon dioxide and water are transported away by the blood again.

S 15.10 Human energy stores

The most important nutrients in humans are *carbohydrates* and *fats*. Both are collective names for whole groups of substances.

Carbohydrates include various sugars, such as glucose and cane sugar. Moreover, "starch" is a carbohydrate. Potatoes and flour contain a lot of starch.

You probably know different fats: the fat in butter, lard, olive oil and sunflower oil.



Both carbohydrates and fats are stored in the human body. Carbohydrates are stored in the liver and fat in the adipose tissues distributed throughout the body. If there is no more space in the liver, the carbohydrates are converted into fat and stored in the adipose tissue. That's why not only fat food makes you fat, but also sweet.

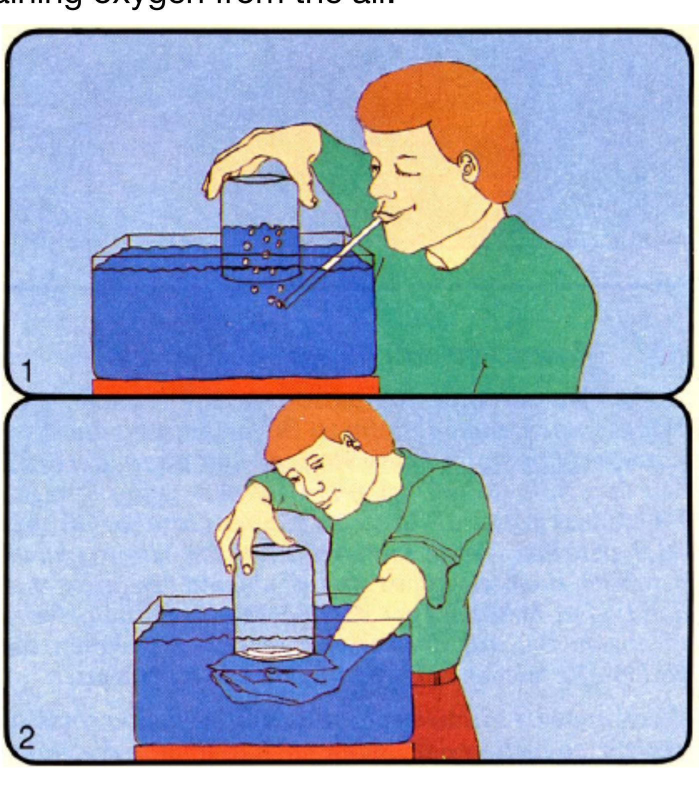
Humans do not need a storage tank for oxygen, because oxygen is everywhere. They always absorb as much oxygen as they need from the air with their lungs.

You may have noticed that it's very similar with the car. The car also has a storage tank for only one part of the energy carrier, namely gasoline. Oxygen doesn't need one. One could say that the car also "breathes". However, it does not inhale in the same place as it exhales. It inhales through the air filter and exhales through the exhaust.

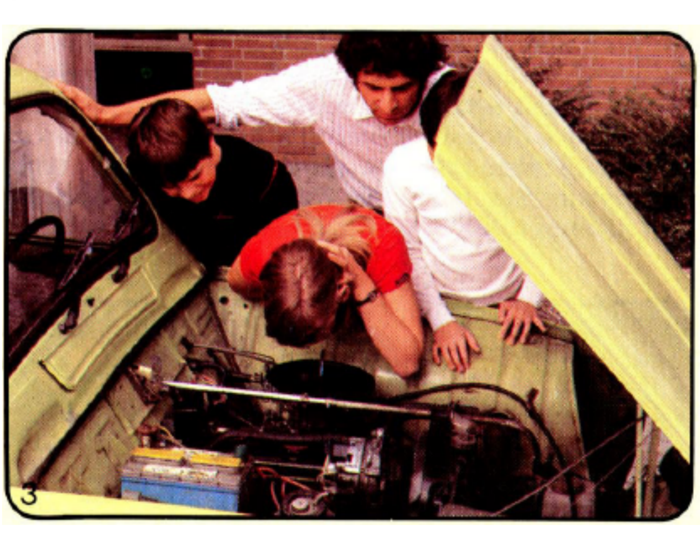
S 15.11 Candle and petrol engine cannot "live" with exhaled air

Take a deep breath and exhale right away. The air you exhaled is barely different from the air you inhaled. Your lungs haven't had enough time to absorb oxygen and release carbon dioxide. Breathe in again, but this time hold your breath as long as possible before exhaling. In the air you've now exhaled, some of the oxygen is replaced by carbon dioxide. A human being can no longer live in such air. But even a candle or a gasoline engine cannot "live" in this air.

Fill an empty glass with water and hold it upside down in a pool filled with water, Fig 1. Hold your breath for a long time and then blow the air through a straw into the glass. Close the glass with a lid, Fig. 2, and put it upright on the table. Remove the lid and hold in a burning candle. The flame goes out because the air no longer contains enough oxygen. The candle cannot extract the remaining oxygen from the air.



Remove the air filter from a gasoline engine. Exhale vigorously while the engine is running, just above the air intake opening on the carburetor. The engine goes off, Fig. 3.



S 15.12 Plants need fertilizer

Besides water and carbon dioxide, a plant needs other substances, the so-called nutrients, to build it up. They take these substances out of the ground. But with the nutrients it does not get any energy. When a plant is burned, these substances remain in the ashes. If the plants that grow somewhere are not harvested, they die and rot, and the soil gets back the nutrients. New plants that grow on the soil take up the nutrients again, and so it goes on and on.

However, when the plants are harvested, such as a wheat field, the soil gradually loses its nutrients. In order for something to grow again, one must supply the soil with nutrients again. You have to fertilize it. Do you understand why the ashes of plants are a good fertilizer? Do you understand why dung and manure are good fertilizers?

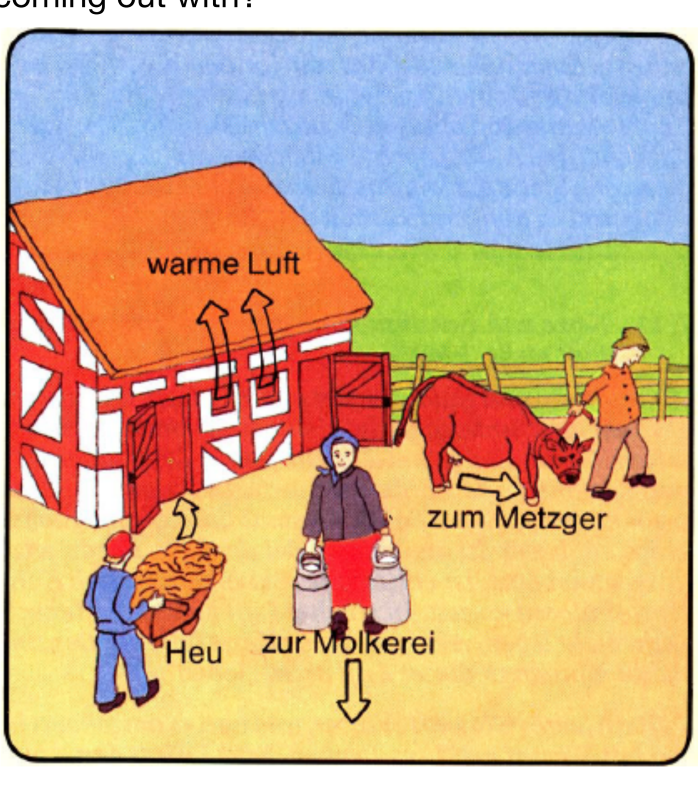
S 15.13 The cowshed as an energy transloader

We want to establish the energy balance of a cowshed:

Energy flows into the cowshed with the energy carrier "grass (or hay) + oxygen". The result is energy with three different carriers:

- Milk,
- Beef,
- warm air.

With which carriers does the energy enter a pigsty and a chicken coop? Which one is it coming out with?



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