Magnetism

- do some magic, iron nail moves on the table, without touching it (magnet underneath the table)
- *New subject: magnetism*
- Show different magnets: bar magnet, round magnet, compass, white board magnet, electromagnet, dc-motor
- Explain this text:

Introduction

The term magnetism comes from the region of Magnesia, a province of Greece, where magnetic stones, that means stones that attract iron, have been found 2000 years ago.

- Question: who is stronger, the earth or this magnet (take a small one, then lift a nail) ----similar to electrical forces. There are many more links to electricity to come.

We will see that magnetism is strongly related to electricity. And like electric forces, magnetic forces are much stronger than gravitational forces, since a magnet can lift up pieces of metal from the floor, easily overcoming the attraction of the earth. E.g. the magnets that are sticking to your teachers board, magnetic needle in a compass.

Magnetism is a very important phenomenon these days, since it makes possible to convert mechanical energy into electrical energy (generators, power plants) and vice versa (motors).

Where else do we find magnets in our everyday life? Write it down:

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Loudspeakers, white board magnets, Headphones, motors...

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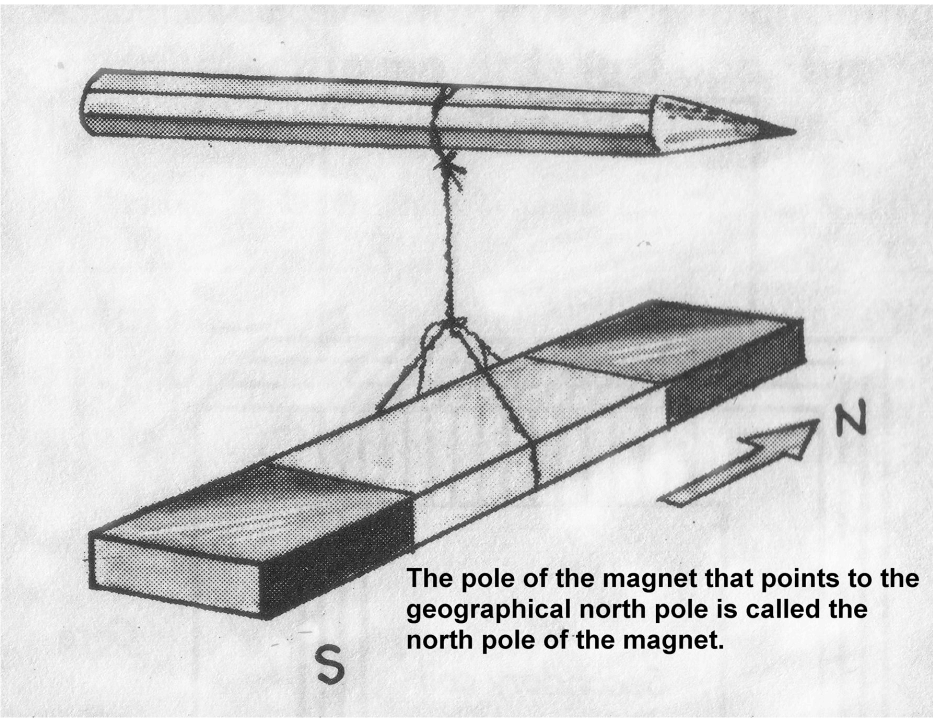
But first simply talk about magnets and the magnetic force.

Magnetic poles

- Magnet and nail suspended on a string, turn around, hold one in each hand. *Do you see a different behavior?*

- Explain text:

If you suspend a bar magnet (a magnet in shape of a bar) at its center by a piece of string, you'll have a compass. One end will point northward, we will call it the north pole of the magnet, the other end will point southward, and this end will be called south pole.



- show compass,
- give magnets to students, tell them to put them together in different ways, then:

Investigating how two magnets interact, we will find out that the south pole of one magnet is always attracted by the north pole of the other. But if we try to put two south poles together, we will feel a repellent force. The same for two north poles. That means

Like poles repel each other, opposite poles attract each other.

- show broken magnet, ask what they think, is there a purely north/south pole now? Let them try it out, then:

A magnet is always built up of two poles, you cannot find or create a magnet with only a south pole and without north pole or vice versa. So magnets are said to be bipolar ("bi" means two in Latin).

Single magnetic poles do not exist, magnets are always bipolar.

Can you see any similarity to the behavior of electric charges? Write it down:

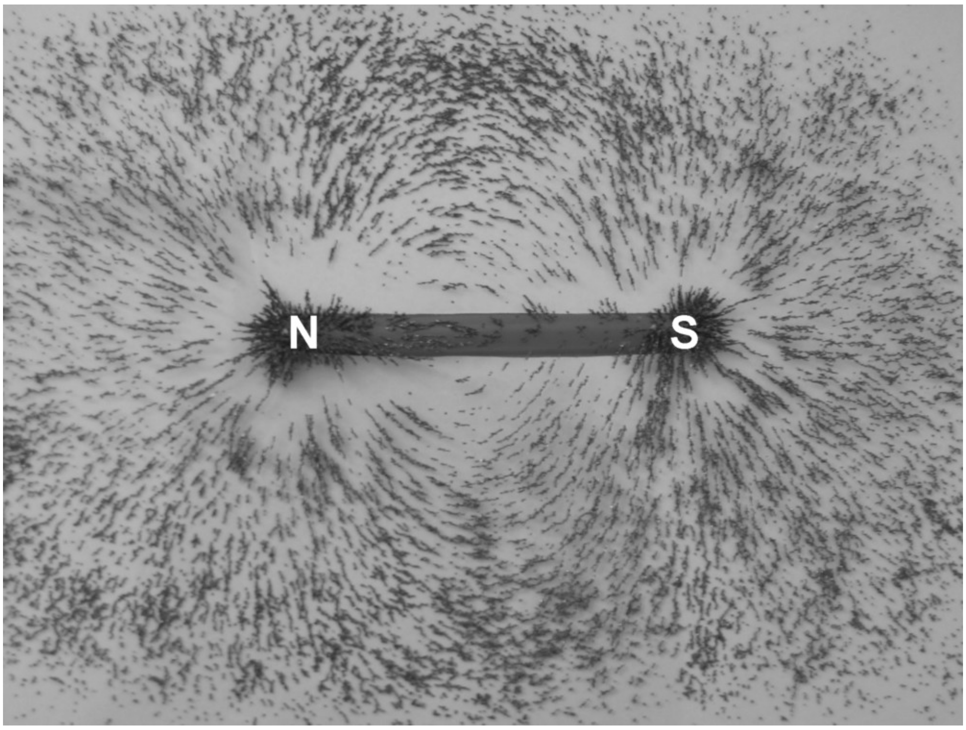
Unlike charges repel, like attract

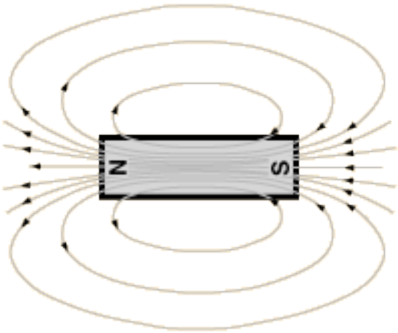
What is different?

There are single electrical charges, positive or negative ones

Magnetic fields

We know that magnetic force acts in distance. We can lift some iron piece from the floor without touching it and unlike poles of two magnets do repel each other without touching. Now it would be interesting to know where exactly magnetic forces are acting in space and how strong they are. So we put some iron filings on a sheet of paper which is placed on a magnet.





The shape which is revealed by the filings is called the **magnetic field**. Where the lines are closer together, the magnetic field is stronger. This means that some iron will be attracted with a bigger force than at places where the lines are wider apart. If we place a small compass anywhere in the field, its poles will line up with the lines of the magnetic field.

Here you see the example of the magnetic field of two magnets, put once with attracting poles next to each other, once with repelling poles.

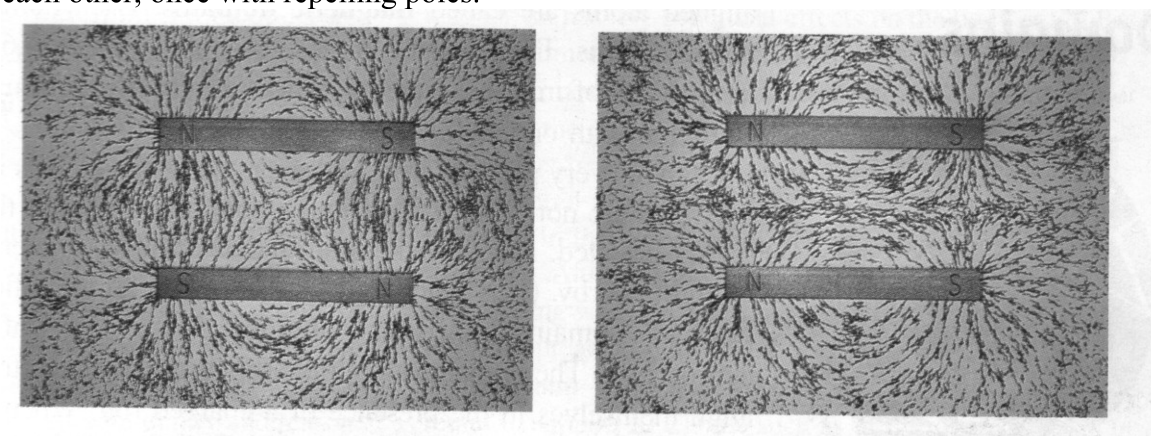


Figure 1

Which very popular magnetic field do you already know? And what do we use it for?

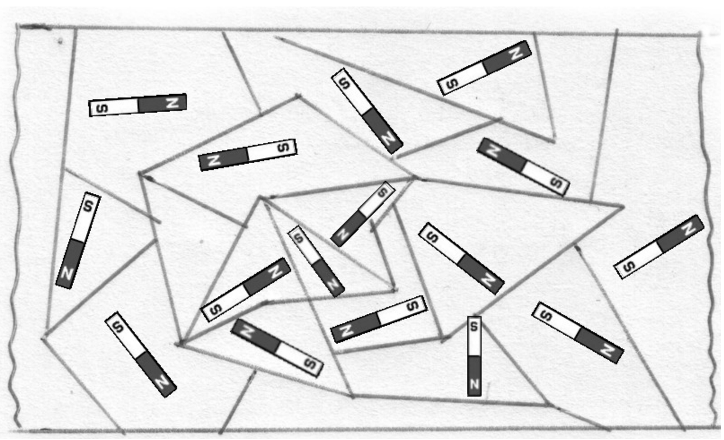
Earth magnetic field, used for orientation by means of a compass.

Magnetism on atomic level

But what is the cause of magnetism, where does it originate from? Scientists found out the following:
Magnetic fields are created by charges in motion, either positive or negative ones.
- explain text:

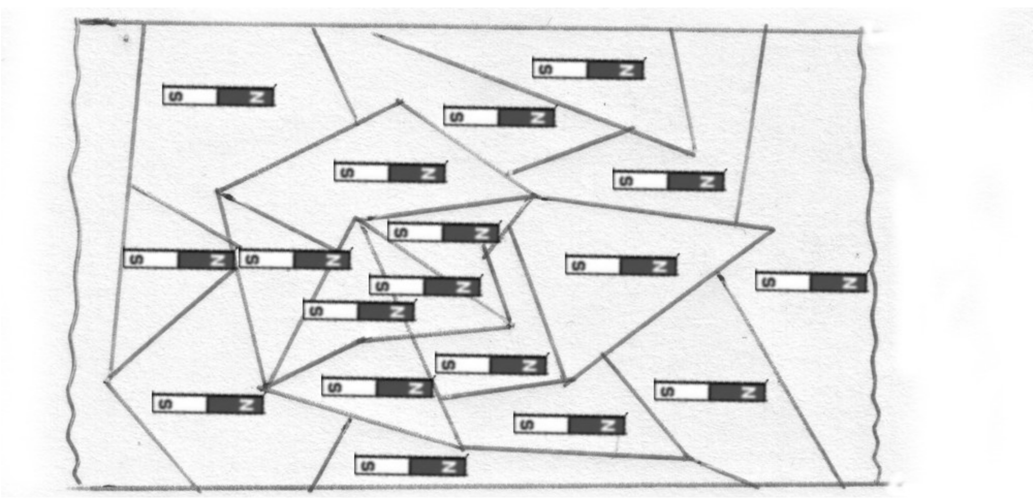
We know that electric current is defined by moving charges. But what about bar magnets for example? They are magnetic without being connected to an electric circuit, so where are the moving charges? The answer lies in the atomic level. Electrons are spinning about their own axes and do also revolve about the atomic nucleus. In most common magnets, magnetism is mainly caused by electron spin. Every spinning electron is a tiny magnet. The more electrons are spinning in the same direction, the stronger will be the resulting magnet. But since in most materials the spin directions of the electrons aren't the same, only a few materials can be magnets (iron, nickel, cobalt and some alloys).

In magnetic materials, billions of atoms will line up with one another. Even if it's billions of atoms, these domains are very small, even microscopic. These domains of aligned atoms are just like microscopic magnets, that's why they're called **magnetic domains**.



If a magnetic material is put into a magnetic field, the magnetic domains will align themselves according to this magnetic field. It's like little compass needles in the earth's magnetic field. If taken out of the field again, they will normally lose this alignment. But if placed into strong magnetic fields they can keep this alignment for a long time, like a bar magnet. Also by a stroking movement of a magnet on an iron piece, the iron piece can be made magnetic for some time. Pieces of iron that keep their magnetic properties are called **permanent magnets**. Dropped or heated, magnets become weaker.

- Presentation magnetised staples on paper in water, approach bar magnet



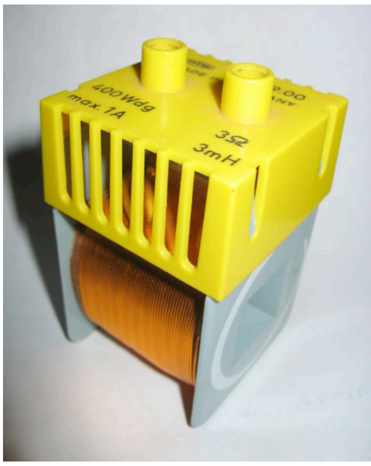
Electric current and magnetic fields

Since a moving charge produces a magnetic field, it follows that a current of charges also produces a magnetic field. We can demonstrate this by placing a compass near to a current-carrying wire. When current is flowing, the compass needle will change its position, it lines up with the magnetic field of the current. We can also show it with iron fillings, that the magnetic field produced by a current-carrying wire has the shape of concentric circles around the wire. When we change the direction of the current, the compass-needle will also turn around and be in opposite position than before. The direction of the magnetic field is changing with the direction of the current in the wire.
This effect was first observed by chance in 1820. Then a Danish science professor named Hans Christian Oersted was doing some demonstration on the electric current in his classroom and he noticed that the needle of a magnetic compass, lying by accident near the current carrying wire, was affected by the current. You see, scientific discoveries and technical inventions sometimes happen by accident!

- presentation four light bulbs on DC Power supply, compass needle near the wire, switch on and off the power supply, change polarity

If you bent a current carrying wire to a loop, the magnetic field lines become bunched up inside the loop. If you bent the wire to another loop, overlapping the first, the concentration of magnetic field lines inside the loops is doubled. It follows that the magnetic field intensity in this region is increased as the number of loops is increased. These loops of wire we will call a coil.

Electromagnet



A current carrying coil of wire is an electromagnet. Its strength can be increased by increasing the current through the coil or also by adding more loops to the coil. Another possibility is to put a piece of iron within the coil. Magnetic domains in the iron then will align to the magnetic field of the coil and their field will add to the field of the coil.

- Presentation electromagnet, with power supply

Magnetic force on moving charged particles

Imagine electric charges in a static magnetic field, first charged particles at rest, then charged particles in motion (beam of electrons, like inside a TV-set). What will happen in those two cases? Is there any difference?

The charges at rest won’t be affected. The moving charges, because of their magnetic properties, will be interacting with the field.

So only the charged particles in motion will be interacting with the field. Actually, these particles will experience a deflecting force. This force is growing with bigger charges, bigger magnetic field and bigger velocity of the moving charges. It will be maximal, for a given set of parameters (charge, magnetic field, velocity), if the velocity of the charges and the magnetic field lines are perpendicular (

= right angle = 90º) one to the other. If they make an angle of 0º, that is when they are parallel, the resulting force will be zero. The direction of the force will be perpendicular to both velocity of the charge and magnetic field!
Thus, for the case where the moving charges and the magnetic field lines are perpendicular to each other, the magnetic force F_M is:

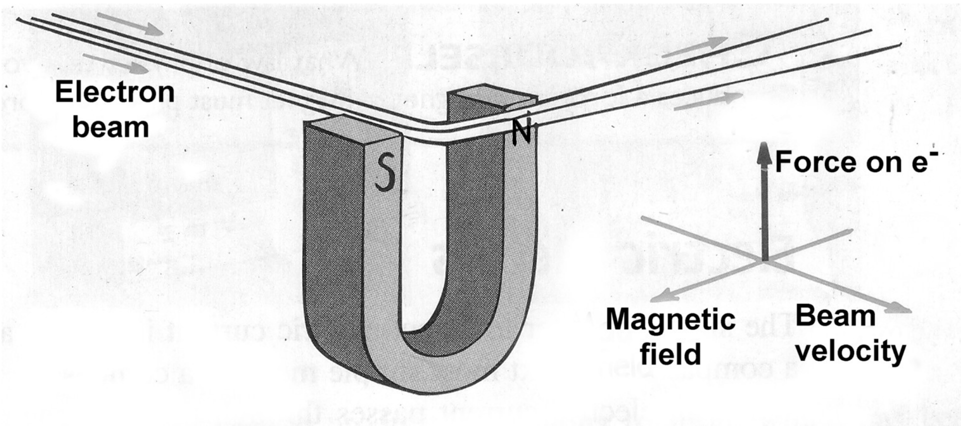


Figure 2

$F_M=q*v*B$

Where q = electric charge [C]
v = velocity of the charge [m/s]
B = magnetic field strength [T]

The unit of the magnetic field strength is [T],which is standing for Tesla. It is named after a famous scientist and engineer of Croatia, Nikola Tesla. He was inventing or improoving lots of things in the field of generation, transportation and use of electricity around the year 1900. Following you find some examples of magnetic field strengths:

Object /	magnetic field strenght /
Space /	10^{-10}T - 10^{3}T
earth /	$3*10^{-5}$T
Horseshoe magnet /	0.001T
Magnet resonance imaging /	7.2T
Strongest magnetic field created in a laboratory /	45T
Some stars /	10^{6}T - 10^{13}T

An example for deflected electron beams can be found in space: Our earth's magnetic field protecting us of cosmic radiation.

Magnetic field of the earth

The earth itself is a huge magnet. That's why people can orientate themselves geographically with the help of a compass. In fact, the geographical pole and the magnetic pole are not located at the exact same place, but in most geographical latitudes, precision is sufficient. Generally spoken, the nearer to the earth equator you are, the smaller the difference of the north (south) direction shown by a compass to the geographical north (south) will be. This difference is known as the magnetic declination.

But how and why is the earth behaving in such magnetic manner? Think about and write down how this phenomenon could be explained, using the knowledge of magnetism you have acquired so far:

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Maybe you just explained yourself how it really is. Because even scientists are not sure about it, they cannot prove the theories they have about the earth magnetic field. Fact is, that the earth's magnetic field has the same shape like if there would be a huge bar magnet at the center of the earth. It is interesting, but logical that the geographical North pole corresponds with the magnetical south pole and vice versa. This is because the magnetic pole of the bar magnet that is pointing North was called north pole of the magnet. But we know, that unlike poles attract, that means that the northpole of the barmagnet must be attracted by the magnetic southpole of the earth!
What most earth scientists think is that moving charges looping around within the molten part of the earth create the magnetic field. Some speculate that the electric currents are the result of convection currents (molten rocks that flow like a very very viscous fluid) inside the earth generated by the heat rising from its central core. Combined with the rotational effects of the earth there would be a lot of charges in motion to produce the earth magnetic field.

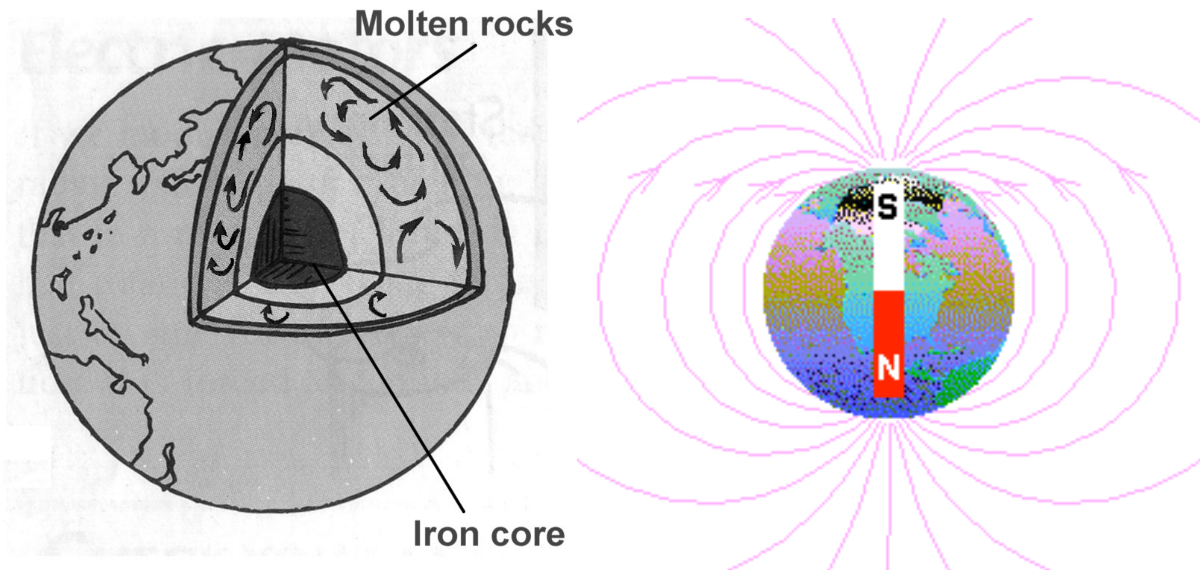


Figure 3

Another interesting fact is the instability of the earth's magnetic field. Of course we're not talking of changes that occur from one day to another, but 700'000 years ago, there was even a reversal of the north and the south pole, after the magnetic field had become more and more weak. So where now is north, was south before and vice versa. Such reversals occur irregularly about every 500'000 years. How do we know this? Have there already been any scientists at that time? Of course not! But in solidificated sediments in the sea or stones build by solidificated lava of volcanoes on land, there are some little amounts of iron. When the lava is hot, there is no magnetic alignment of the iron particles. But while the lava is cooling down, there is some of this iron which will align with the momentary magnetic field of the earth. Now if scientists can determine the age of the stones or sediments, means how long ago they solidified, they will know about the direction and strength of the earth's magnetic field at that time.
But fortunately the earth's magnetic field is stable at the moment. Because it deflects most of cosmic rays (charged particles, which are harmful to any living) coming from outer space or from the sun. Explain why cosmic rays are deflected by the earth's magnetic field.

Because of the magnetic force that is acting on moving charged particles.

Is the deflection the same on any place on earth? If not, explain why!

On the magnetic poles, particles which come parallel to the magnetic field lines will not be deflected.

Biomagnetism

There are even organisms which are making use of the earth's magnetic field. Certain bacteria biologically produce grains of magnetite (iron containing mineral, Fe_3O_4) that they string together to form internal compasses. With the help of this sense of direction the bacteria are able to locate food supplies.
Also pigeons have been found to have magnetite magnets in their skulls what are connected with a large number of nerves to the pigeon brain. Like this, they can discern longitudinal directions and also latitude.
Magnetic material has also been found in some bees, wasps, butterflies, sea turtles and fish.

Magnetic force on current-carrying wires

We know now that moving electrical charges are influenced by magnetic fields. If we consider an electric wire with an electric current we also have moving electrical charges inside that wire. So, put in a magnetic field, there will be a force acting on the electric current and because this current, means these moving charges are bound to the electric wire, the force will be applied on the wire. There again, this force will be perpendicular to both the magnetic field lines and the direction of the velocity of the moving charged particles, the electric current. Changing the direction of the current will change the direction of the resulting force.

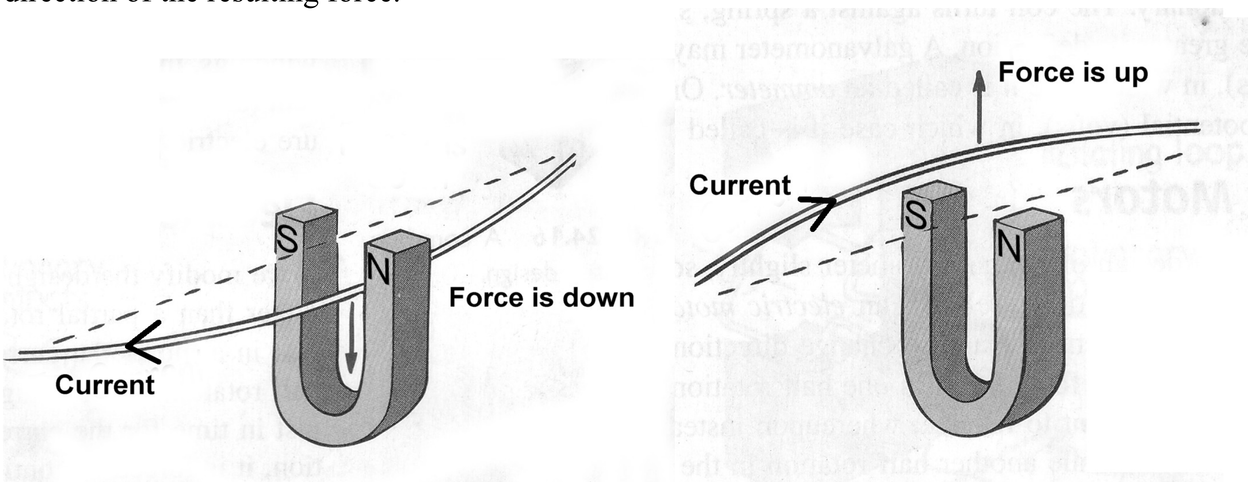


Figure 4

Why is this change of the direction happening?

We have seen before, the magnetic field lines change with the direction of the current in the wire. In fact, the magnetic field will change its polarity.

Do you know any other phenomenon comparable to this?

Like poles repel, unlike attract each other. Two bar magnets held together also change the direction of the force if you change the polarity of one of them

Electric motors

So a current carrying wire experiences a force in a magnetic field. This force is used in a technical application: the electric motor.

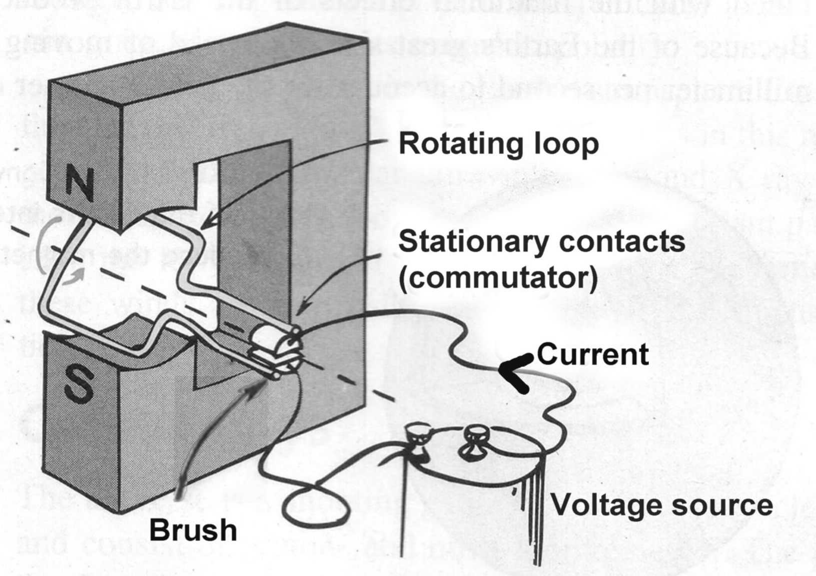


Figure 5

On the picture you see the simplified principle of an electric motor. The permanent magnet produces a magnetic field. A rectangular loop is turning about the axis which is drawn with a dashed line. The wire is connected to a voltage source (e.g. a battery), so a current will flow through the wire. This current has one direction in the upper part of the wire, and the opposite direction in the lower part of the wire (compared to the magnetic field). This means we have current carrying wires in a magnetic field. In the previous chapter we have seen that there will be a force attacking the wire. If the upper side of the wire is forced to the left, the lower side will be forced to the other direction, the right. This is because the current is flowing in the opposite direction (compared to the magnetic field) in the lower part of the wire. The result of these forces is a turning motion of the rectangular wire loop. This motion would last until the loop would reach a horizontal position. There the forces on the wire would give no more contribution on the rotational motion. The force on the part of the loop which was up before would act in one direction, the force on the part which was down would act in the other direction. The loop would stop its movement.
That's why we will not supply the loop with current when it's near its horizontal position! You see that the stationary contact on the picture is interrupted at its horizontal position. Because of the inertia of the loop, it will continue turning until there will be contact to the power supply again. But, compared to the loop, we switched the polarity of the voltage source. That's why, again compared to the loop, the current will flow in the other direction. But compared to the magnet, the current in the part of the wire which is up now, has the same direction. According to the forces experienced by a current carrying wire, the force will act in the same direction as before. Thus, the rotation continues in the same direction as well. The same for the part of the wire which is down now. And the electric motor keeps on turning.

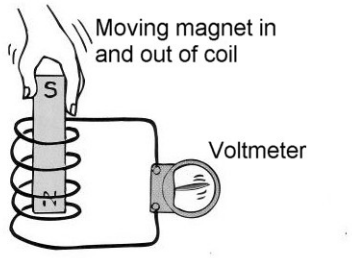
Which are the four reasons that keep this motor turning?

A voltage source, a magnetic field, a current carrying wire and the switching of polarity of the current of the wire.

- presentation and group work with simple electric motor - "Freihandexperimente" CD

Electromagnetic induction

In the previous chapters, we have seen how electric current and other moving electric charges are influenced by magnetic fields. Thanks to these discoveries, it was possible to transform electric energy back into mechanical energy by means of motors. Around 1830, Michael Faraday in England and Joseph Henry in the USA both found out, that an electric current even could be produced by a magnetic field. This was a big discovery which changed the world in the following years. Because this discovery made it possible to convert energy of windmills, water turbines, Steam-electric plants and so on into electric energy, which is quite easy to transport to places far away from the production places of those energies.
Faraday and Henry both discovered that electric current can be produced in a wire simply by moving a magnet in or out of a coiled part of the wire. No battery or other voltage source is needed.



They discovered that voltage is caused, or induced by the relative motion between a wire and a magnetic field. And we know, that if there's voltage and you close the electric circuit, with a bulb or other resistance for example, there will be a current. The term relative motion simply means that either the magnetic field or the wire or both can be in motion. In fact, the change of the magnetic field will induce the voltage.

- Show bar magnet moving through coil of electromagnet, which is connected to a voltmeter. Voltmeter (analogue, black one, on sensitive scale) will show the induced tension. Leave magnet in rest inside the coil, and no tension will be any more.

The greater the number of loops of wire, the greater will be the induced voltage. Pushing a magnet into twice as many loops will induce twice as much voltage. Three times as many loops induce three times as much voltage and so on. This phenomenon of inducing voltage by changing the magnetic field in a coil of wire is called **electromagnetic induction**.
These points are summarized in Faraday's law, which states:

The induced voltage in a coil is proportional to the product of the number of loops and the rate at which the magnetic field changes within those loops.

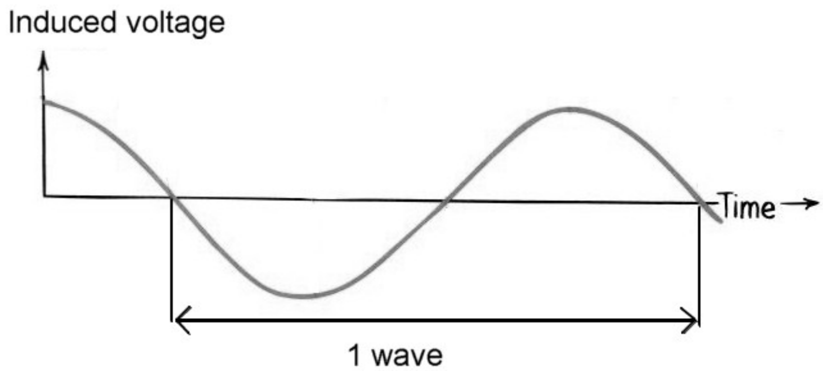
We have seen now, that a voltage is produced (induced) by moving a magnetic field near a loop of wire, or moving the loop near the magnetic field.
Can you imagine a way of inducing a voltage in a loop of wire without using a magnet?

A magnetic field can also be produced by a current.

Electromagnetic induction is used all around us. E.g. in the security system of an airport, where you are scanned if you carry any iron things. Or if you use an ATM card to draw out money from the ATM, the information of identification is stored magnetically on the card. If you listen to a tape recorder, the music on the tape is also stored magnetically.

Alternating current (AC)

When a magnet is repeatedly plunged into and back out of a coil of wire, the direction of the induced voltage is alternating. As the magnetic field strength inside the coil is increased (magnet entering), the induced voltage in the coil is directed one way. When the magnetic field strength diminishes (magnet leaving), the voltage is induced in the opposite direction. This is how an alternating voltage is created or generated. If we draw the voltage, it will be a curve that rises first from zero, and then reaches a maximum point in either positive or negative voltage. Then the curve will go back to zero and will reach a maximum in the opposite way. Then it will go back to zero again and restart the same movement.

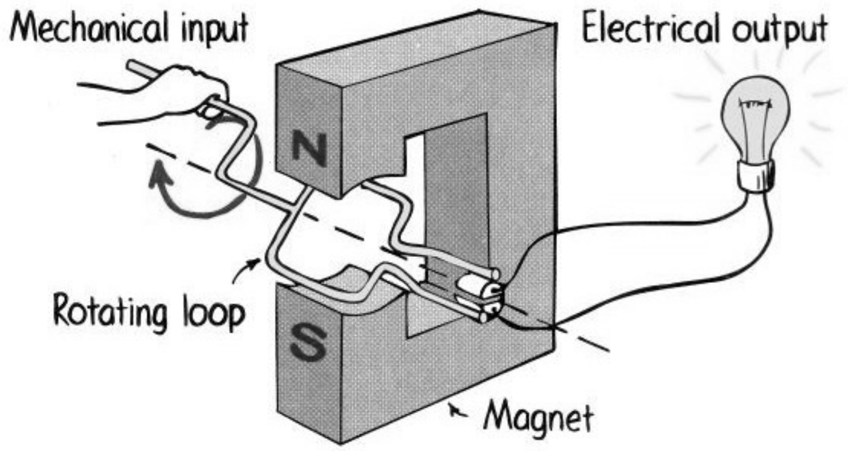


This curve of the alternating voltage will be called a wave. If the magnet is moved in the way a pendulum is swinging, then we call the curve a "sine wave". The frequency of this curve, that means the number of waves in a second, is the frequency of the alternating voltage. This frequency equals the frequency of the changing magnetic field within the loop. Frequency is measured in [Hz] which is spoken "hertz".

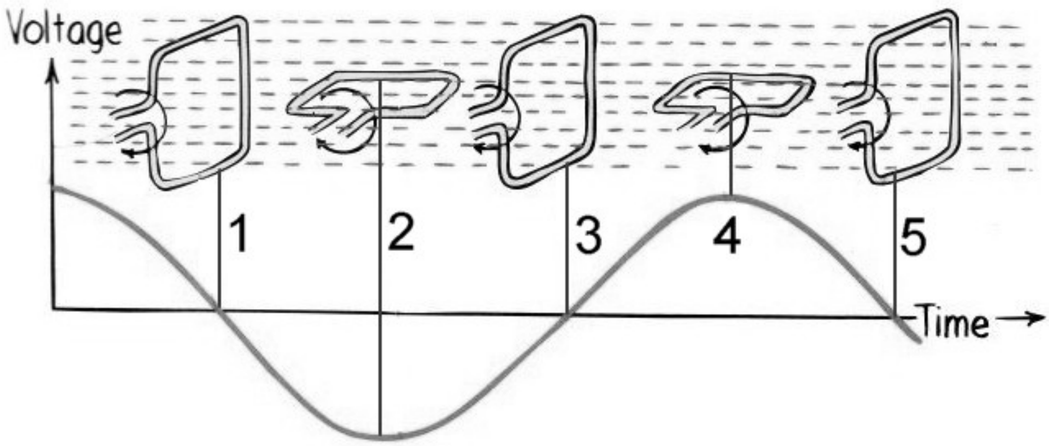
- draw some examples of sinus with time and voltage axis and ask for the frequency

Generators

Another way of induce an alternating voltage is to move a coil or a simple loop rather than to move a magnet. For example by rotating the coil or the loop in a stationary magnetic field. This arrangement is called a generator. You can see the simplified principle of a generator in the picture below:



The next picture shows you the voltage which is induced while the loop is turning. You see that there is a change of the magnetic field inside the loop without moving the magnet. This change of the magnetic field can be shown by the increase and decrease of the number of magnetic field lines inside the loop.



When we start at number 1 on the picture, there is the maximum of magnetic field enclosed by the loop. The loop is turning towards number 2, so the magnetic field inside the loop is getting smaller, because less magnetic field lines are enclosed. The change of the field inside the loop is slow first and is getting faster until it reaches its maximum at position number 2. Thus, according to Faradays law, the induced voltage will rise from 0 at number 1 and will reach its maximum at number 2. Then the rate of change of the magnetic field inside the loop will get smaller until it will be zero at the position number 3. The same for the voltage. Further turning will increase the rate of change of the magnetic field again, and so the increase the induced voltage in the loop. But since the loop is upside down compared to position number 1, the induced voltage will change its sign, its polarity. At position 4, the rate of change of the magnetic field will be at its maximum, and so will be the voltage again, but with inverse polarity compared to position number 2. From 4 to 5, the rate of change is getting smaller and reach zero, thus the voltage also will do so. Then the whole circle will start again.
Have a good look at the picture showing the generator. What does it look like?

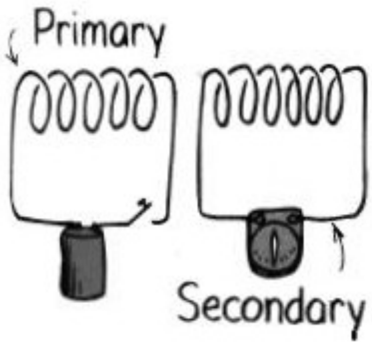
It's like an inversed motor. But this time the mechanical energy is the input, electric energy is the output.

So the generator is build up like a motor. But while a motor is used to transform electric energy to mechanical work, a generator is used to change mechanical work into electric energy. Most of the electricity that we use when plugging devices to the line has been produced by generators. They are therefore very important in our present society.

- e.g. generators in monk's restaurants.
- turn the axis of a small DC-motor connected to a voltmeter. There will be an induced voltage

Transformers

We already know that electric energy can be transported through electric wires. Know we will see that it can also be transported through empty space! In the following picture you see how this is working:



We close the switch of the circuit on the left, which consists of a coil connected to a battery. We will see that a voltage is induced on the circuit on the right side, formed of a coil connected to a voltmeter. The same when the switch is opened again.

Why this? I know, you can figure it out!

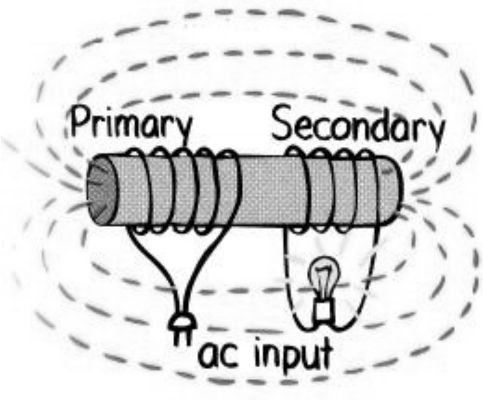
magnetic field builds up in the left coil and also around it. This field change affects the left circuit in inducing a voltage there.

When the switch opens or closes, a change of current will occur to the coil on the left side. This change of current will produce a change of magnetic field in the corresponding coil. But the field is not only in the coil, it is also around. So if the coil on the right side is close enough to the coil on the left, this change of magnetic field will also affect the coil on the right side. According to Faraday's law of induction, for a short time a voltage will be induced in the coil on the right side by this change of magnetic field.
Usually the coil connected to the power source is called the **primary** (input) and the other coil is called the **secondary** (output).

How long will this induced voltage last in the coil of the secondary?

Until the current in the primary is stable, and so will be the magnetic field.

To improve the system, an iron core is placed inside the primary and secondary coils. Like you see in the picture below. Thanks to this iron core, the magnetic field inside the primary will be intensified, and so are the changes of the magnetic field. The field is also concentrated in the core and extends into the secondary, which will get more of the field and the field change. For this reason the induced tension in the secondary will also be more intense.



Now we will change the input of the primary. Instead of opening and closing a switch, we will feed the primary with alternating current. So there will be a periodic change of the current in the primary and therefore a periodic change of the magnetic field, occurring with the same frequency like the change of the current. This also means that a voltage will be induced in the secondary, again with the same frequency of the alternating current in the primary. This arrangement, to coils linked with an iron core, is called a transformer.

Transformers are used to change the value of an alternating voltage. The induced voltage on the secondary side of the transformer is dependent on the value of the input voltage, on the number of loops on the primary side and on the number of loops on the secondary side of the transformer.
This is the relationship between primary and secondary:

$$\frac{\text{(Primary voltage)}}{\text{(Number of primary loops)}} = \frac{\text{(Secondary voltage)}}{\text{(Number of secondary loops)}}$$

The electric power (P=V*I) on the input equals the electric power on the output. You cannot gain energy with a transformer, even if the output voltage is bigger than the input voltage!

- erklaeren wofuer

- Anwendungen für transformatoren