

Maxwell's Equations and the Lorentz Force

Nearly all effects of electricity and magnetism can be described by the very few fundamental statements: Maxwell's equations and the Lorentz force. These equations show the connections between electric field, magnetic field, electric charges, and electric currents.

a) Maxwell's equations:

- 1) An increasing magnetic field is surrounded by an electric field.
- 2) An increasing electric field is surrounded by a magnetic field.
- 3) An electric current is surrounded by a magnetic field.
- 4) Electric field lines go out from positive electric charges and end in negative electric charges.
There are electric field lines that have no beginning and no end, because they are closed or infinite.
- 5) Magnetic field lines are always closed or infinite. There are no single magnetic poles.

b) Lorentz force

- 6) A positive electric charge is drawn with the electric field.
- 7) A moving electric charge is deflected sideways at a right angle to the velocity and the magnetic field.
- 8) Electric field lines go out from positive electric charges and end in negative electric charges.
There are electric field lines that have no beginning and no end, because they are closed or infinite.
- 9) Magnetic field lines are always closed or infinite. There are no single magnetic poles.

Hand gestures to illustrate these equations

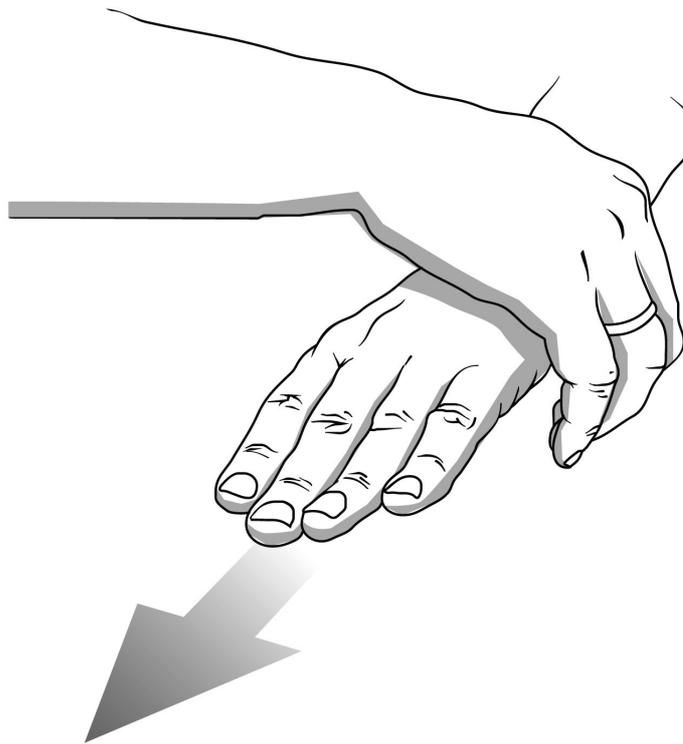
Gestures with the hands symbolize these equations. They help to memorize them, and they give the correct directions.

The following conventions are used:

electric field:	flat right hand, direction towards the fingertips
magnetic field:	flat left hand, direction towards the fingertips
increasing field:	the hand moves forward
positive electric charge:	the fingers of the right hand pointed and closed
negative electric charge:	the fingers of the right hand turned inwards but closed
electric current:	the extended index finger of the right hand, direction towards the fingertip

The drawings of these hand gestures were made by Mr. Olaf Zwätz (former address: Abtsgäßchen 14, 60594 Frankfurt am Main, present address: Kiesstraße 5, 60486 Frankfurt am Main, Germany), Tel. Nr. 069/96741380

1) An increasing magnetic field is surrounded by an electric field.



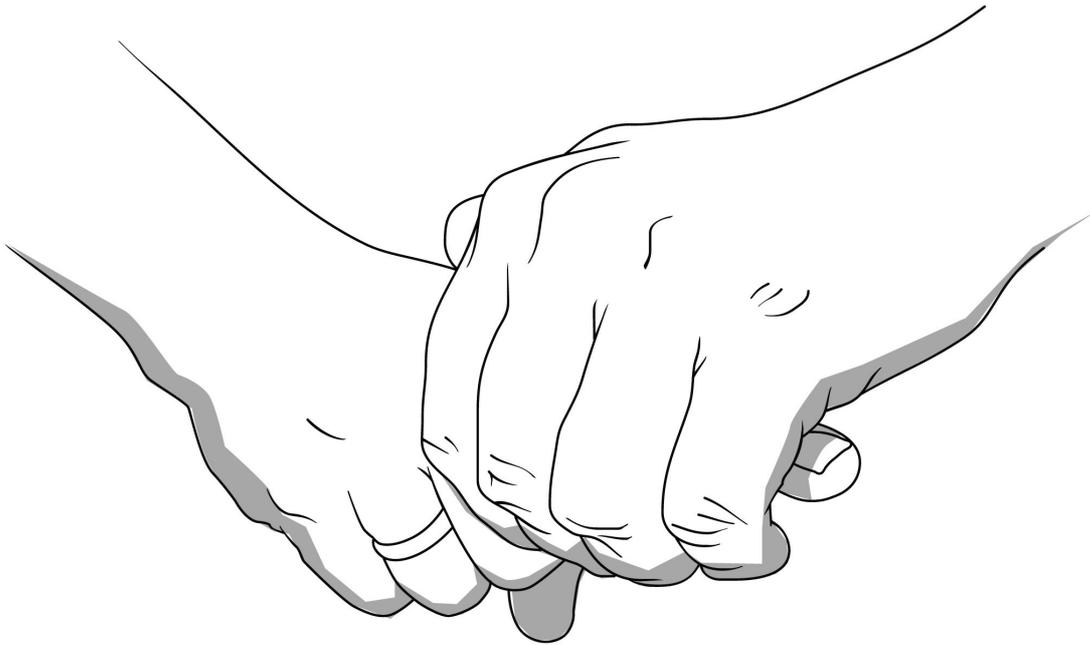
The extended flat left hand (*magnetic field*) goes forward (*increases*), while the right hand (*electric field*) goes around it with its palm towards the left hand.

2) An increasing electric field is surrounded by a magnetic field.



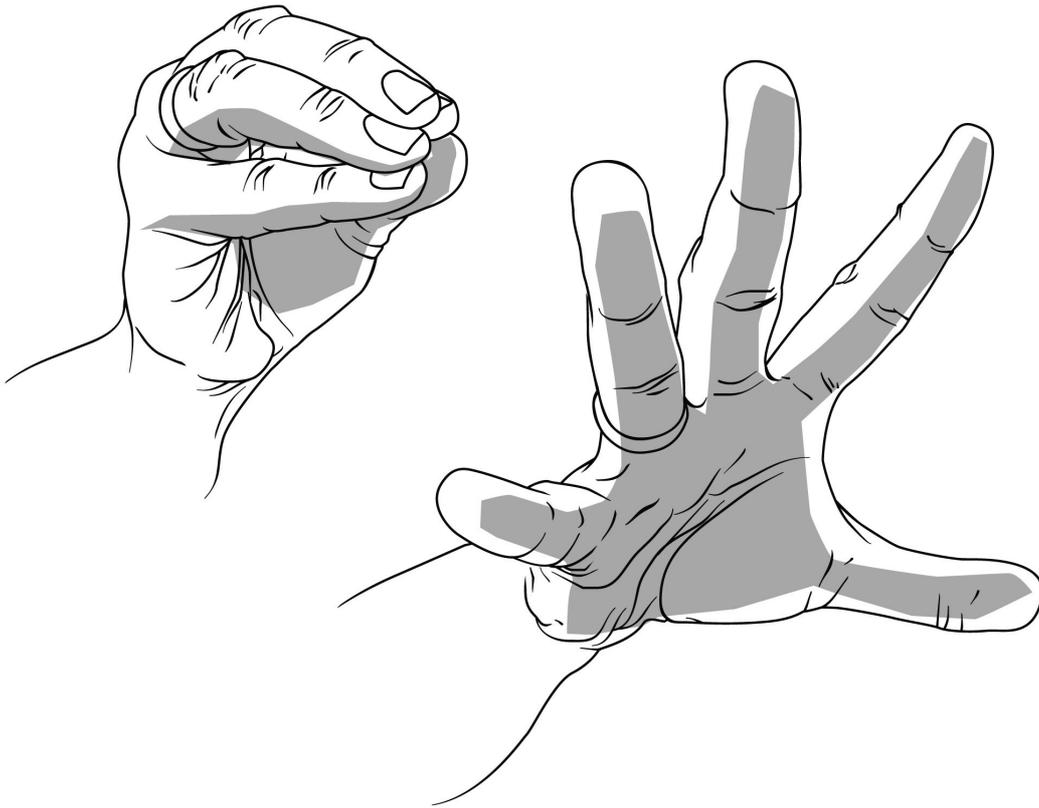
The extended flat right hand (*electric field*) goes forward (*increases*), while the left hand (*magnetic field*) goes around it with its palm towards the right hand.

3) An electric current is surrounded by a magnetic field.



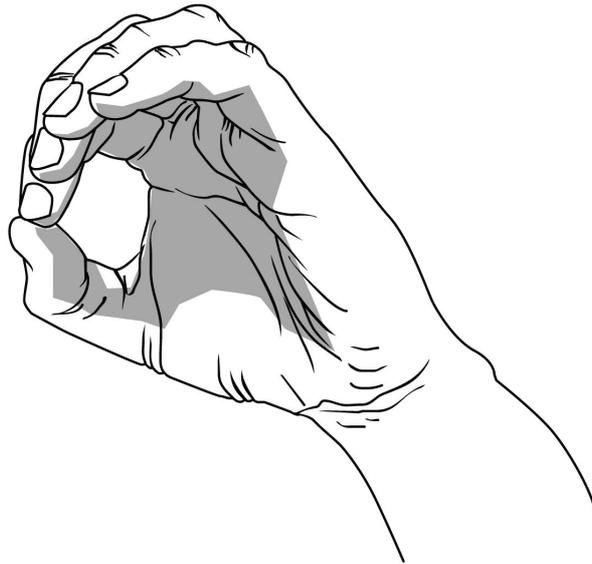
The left hand (*magnetic field*) goes around the extended index finger of the right hand (*electric current*) with its palm towards the finger.

4) Electric field lines go out from positive electric charges and end in negative electric charges. There are electric field lines that have no beginning and no end, because they are closed or infinite.



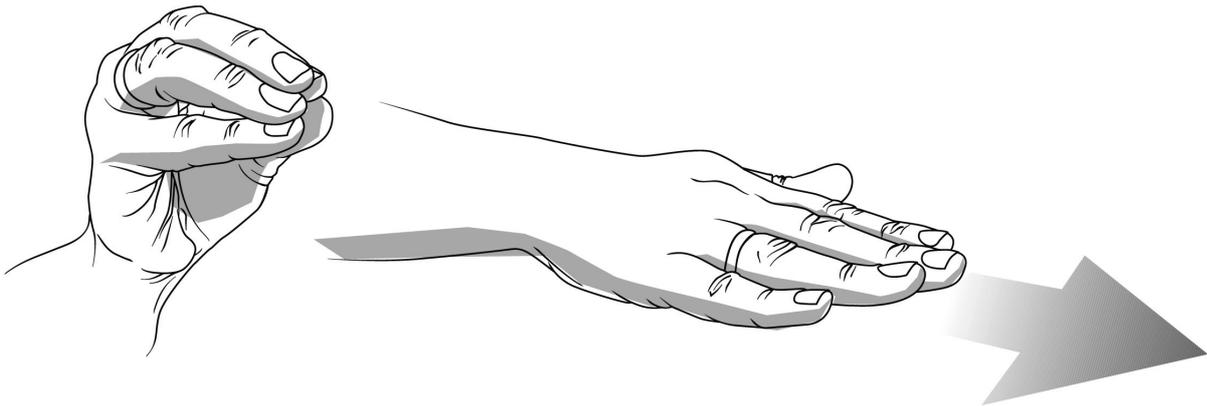
The pointed and closed right hand (*positive charge*) opens and spreads (*indicating the electric field lines going out from the charge.*). Then the fingers come together again, but this time the fingertips are curved inwards (*The electric field lines go towards negative electric charges*). Then the thumb and the index finger of the right hand form a circle (*electric field lines may be closed*) and both arms are stretched out sideways (*electric field lines may be infinite*).

5) Magnetic field lines are always closed or infinite.



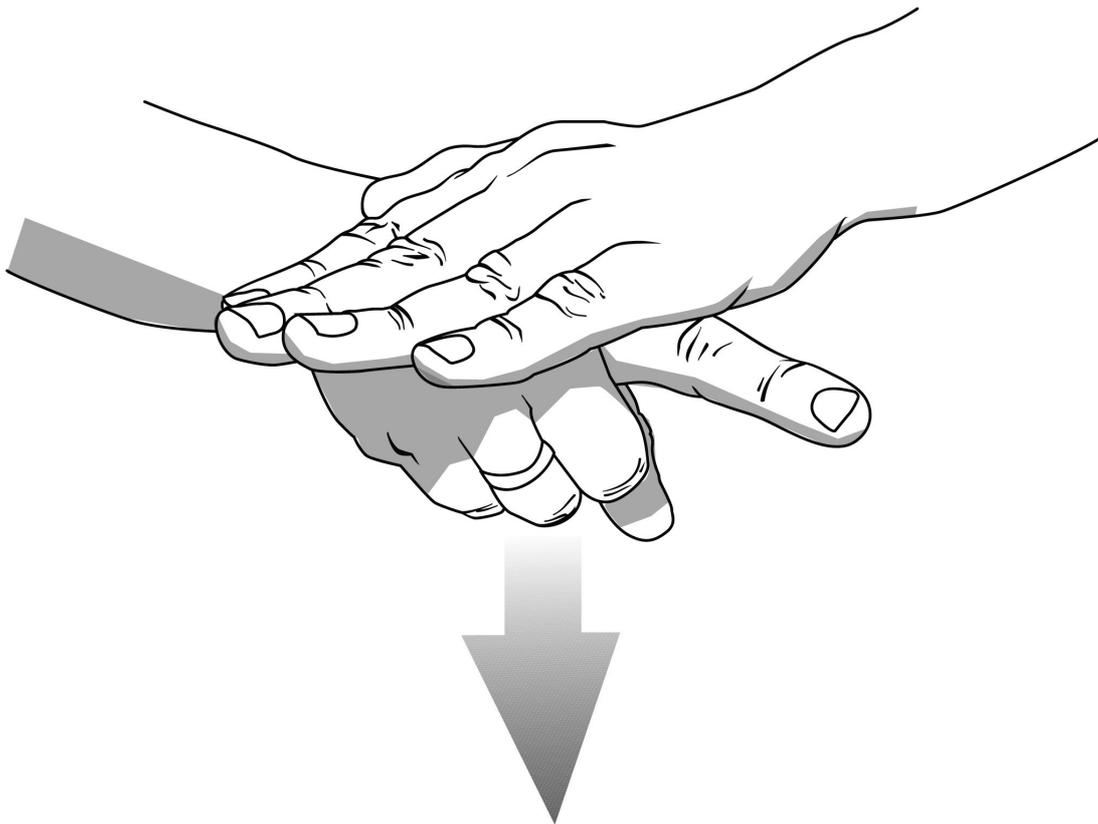
Index finger and thumb of the left hand (*magnetic field lines*) form a closed circle (*are closed*), and then both arms and hands are extended sideways (*or are infinite*).

6) A positive electric charge is drawn with the electric field.



The closed pointed right hand (*positive electric charge*) moves forward (*is drawn by*) and is turned into a flat hand (*by the electric field*). This movement should be done in front of the body sideways in order to avoid a similarity with the Nazi salute.

7) A moving electric charge is deflected sideways.



The extended index finger of the right hand (*electric current or positive electric charge moving in the direction of the finger*) is pushed downwards (*deflected downwards*) by the flat left hand (*magnetic field*) perpendicular to it.

Examples for these 7 sentences

These 7 statements are the central statements of nearly everything in electricity and magnetism.

Sentence 3) means, that we can produce a magnetic field by a wire, if an electric current flows through it. By that way we have an electric magnet or electromagnet. That is especially effective, if the wire with the current is formed into a coil.

Sentence 1) is called induction. It is used in a transformer to change the size and the voltage of an electric current, for example in a power supply, that transforms a current with 230 V to a current with 9 V.

Sentences 1) and 2) together are used in the emission and propagation of electromagnetic waves: A changing electric field produces a changing magnetic field around itself. This changing magnetic field produces a changing electric field and this changing electric field a new changing magnetic field, and so on. We get electric and magnetic fields, that race with nearly 300 000 km/s through space. These coupled fields are radio waves, TV waves, microwaves, infrared radiation, visible light in different colors, ultraviolet radiation, X rays and Gamma rays. They can be used to transport radio and TV transmissions, computer data, and they all contain a bit or a lot of energy, for example as light or microwaves.

2 parallel metallic plates that are electrically insulated against each other store energy, if the one of these plates is negatively charged and the other positively. (That is called a capacitor.) If both plates are connected by a metallic wire, that contains a coil, the surplus electrons of the one plate move to the other plate and the capacitor loses its energy. The movement of these electrons through the coil, however, creates a magnetic field through the coil, that takes up the energy. If the movement of the electron stops, the magnetic field produces a current of electrons charging again the plates.

Sentence 7) explains, why the magnetic field of the earth protects us from dangerous particles that come to the earth from the sun or elsewhere in space. The magnetic field forces these particles to run in spiral ways around the field lines of the earth's magnetic field. Thus these particles can't reach the earth.

Some thoughts, especially for physics teachers, about this use of Maxwell's equations and the Lorentz force at physics teaching:

The usual way to teach electricity and magnetism is to lead the students by experiments shown by the teacher or done by the students themselves to derive one property or law after another from measurements. The disadvantage of this way is, that the students learn a lot of seemingly unconnected details, and in many cases the lack of time and the limited accuracy of the equipment available in schools makes the proof of a theorem in many cases difficult or even an illusion. In many cases sentence 2 is not even taught. In my opinion even in physics students have simply to accept many statements by faith.

When the Nobel Prize winner Richard P. Feynman had to teach electricity and magnetism to physics students at their 2nd years of studies at the California Institute of Technology in 1962-1963 he went a new way: After a short introduction about fields electric and magnetic fields and the mathematical tools used to treat them, he started by giving Maxwell's equations in differential form and the electric force on an electric charge. These equations were the foundation for all his teachings on the subject. When I studied physics at the University Erlangen Nürnberg, Prof. Wegener followed his

example and based the whole introductory teaching of electricity and magnetism at the 2nd semester on Maxwell's equations, however in a simpler form (integral equations). This was for me a great way to really understand an essential part of physics. When I became a physics teacher myself, I asked myself, how the Maxwell equations could help high school students to understand physics. I developed an approach mainly for students in their 11th year at high school. After an introduction of electric and magnetic fields I introduced the Maxwell equations and the Lorentz force in qualitative form, as given here. We developed a ritual for the beginning of each physics lesson on electricity and magnetism afterwards: The class stands up and recites together the equations in qualitative form accompanied with the hand gestures. Afterwards the teaching continued in the traditional way by doing experiments and evaluating them. After some weeks I asked the students, whether they would like to continue it, and the students told me that they liked to go on with it.

In my opinion this way has the following advantages: The qualitative statements are quite easy understandable, as soon as the students understand, what is a field. The students have a structure, where they can put in everything they learn about electricity and magnetism. This makes it much easier to learn all the details. And it is the real structure of the subject. And the students see, that a very limited number of statements explain a gigantic field of knowledge - a central feature in physics, but often not understood by the students. In my eyes these advantages outweigh the advantages of the traditional way by far.

Literature:

Feynman, Richard P., Leighton, Robert B., Sands, Matthew: The Feynman Lectures on Physics. Vol. II. Mainly Electromagnetism and Matter. Addison-Wesley Publishing Company Reading Massachusetts, Menlo Park California, London, Sidney, Manila 1963.