Lars Jaeger

The Stumbling Progress of 20th Century Science

How Crises and Great Minds Have Shaped Our Modern World

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Dedicated to my daughter Anika Mai Jaeger

Prologue

"Science doesn't always go forwards. It's a bit like doing a Rubik's cube. You sometimes have to make more of a mess with a Rubik's cube before you can get it to go right."
Jocelyn Bell Burnell, *Radio Astronomer*[1]

By the end of the nineteenth century, almost all scientists were convinced that they had thoroughly understood the laws of nature and thus everything about the very essence and depth of the world. Newton's laws were regarded as an eternally valid world formula, and the recent findings in the fields of magnetism and electrodynamics seemed to round the picture off beautifully. With this attitude, it happened that, when the young Max Planck asked one of his teachers in the 1870s whether he should study physics, he was given the answer that there was not much more to discover in the field. Fortunately, Planck did not listen to this advice.

Werner Heisenberg, who revolutionised physics two generations later in the 1920s, was already one step ahead:

"Few know how much you need to know to know how little you know."[2]

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[1] Jocelyn Bell Burnell discovered the class of stars known as pulsars, but the Nobel Prize for this discovery was awarded to her male colleagues.

[2] *Source: Fliegende Blätter, humorous weekly German paper, 1845–1944. Heisenberg was probably inspired here by Socrates, whose sentence "I know as a non-knowing person" or "I know that I do not know" is often misquoted as "I know that I know nothing".*

Even knowledge that had been so painstakingly gained and was believed to be certain proved in the end to be unexpectedly volatile. What earlier generations of researchers believed to be absolutely true is, in the vast majority of cases, no longer true for us today. Scientists have learned this lesson. Today, they explicitly assume that knowledge can only ever be temporarily correct. What is valid today can turn out to be wrong at any time.

This turn away from eternal claims to truth began at the end of the nineteenth century and triggered a comprehensive crisis in the sciences. In the eighty years from 1870 to 1950, a period that is a blink of an eye in the history of humankind and covers not much more than a human lifetime, there was what is probably the greatest revolution in thinking of all time. It was far more significant than the paradigm shifts of the Renaissance and the Enlightenment (even if one hears little about it in school history books). This crisis in the sciences was accompanied by two world wars, the downfall of traditional social orders, and a reorganisation of the world.

Where suffering is great, salvation is not far away. From the end of the nineteenth century and in the first half of the twentieth century, a number of scientific geniuses of breathtaking creativity were at work, ultimately leading the sciences out of this crisis. This book describes their contributions and follows science on its exciting and bizarre journey into the modern age. Along the way, we shall meet, among others, the mathematical and physical genius of James Clerk Maxwell, the intellectual giants Georg Cantor and Ludwig Boltzmann, engaged in serious psychological struggles, Charles Darwin, who was so moved by questions of faith as well as science, the reluctant revolutionary Max Planck, the Swiss revolutionary Albert Einstein, numerous ingenious and youthful physicists gathered around Niels Bohr, who overturned the world of physics for good at the age of not much more than 20, and last but not least the mathematical geniuses John von Neumann, Kurt Gödel, Alan Turing, and Emmy Noether, whose revolutionary thinking would not even stop at the basic principles of logic.

This book is divided into two parts. Chapters 1–5 describe a first phase that can be roughly associated with the period between 1870 and 1925, in which developments took place almost simultaneously in physics, mathematics, biology, and even psychology that led to the deepest crises in those disciplines. Chapters 6–12 discuss those same sciences in the subsequent years up to 1950, which brought about the transition to modernity. This period also marks the decisive turn from a science oriented towards theory and philosophy to its present more practical and application-oriented approach.

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Contents

Part I

The Great Confusion

With Newton's mechanics, the physicists of the 18th century had at their disposal for the first time a fundamental theory of nature based on natural laws. They no longer had to use their faith or metaphysical speculation to explain the objects of their experience of nature. They only had to solve mathematical equations. Newton's laws provided them with the necessary world formula to do so. The resulting explosion of scientific knowledge had its due effect on the mindset of European societies in the 18th century: the Enlightenment was the intellectual offspring of Newton's physics. And with the technological possibilities arising from the new knowledge of nature, an ever stronger optimism for the future developed in the course of the 19th century.

During this time, natural scientists also set their sights on phenomena that had remained unexplained since antiquity: chemical transformations, heat, electricity, and magnetism. In doing so, they recognised that they had to grasp the behaviour of the smallest particles and made an important assumption: the laws of physics should also apply to the microcosm, i.e., to processes beyond direct observation, just as they apply to the macrocosm. In particular, the same determinism should apply here as in Newton's laws and those of electricity and magnetism. But this assumption contained philosophical explosives: the closer the physicists tried to grasp the properties of the smallest particles, the clearer it became that their behaviour did not follow the known laws of physics. They discovered something here for which there was no place at all in Newton's physics, but which seemed to play a fundamental role in events in the microcosm: chance.

With Charles Darwin's theory, biologists also found themselves exposed to a revolutionary new paradigm: suddenly, man was no longer a creature of God, but a product of nature. And Darwin also had to make a decisive assumption in his theory of evolution: as in physics, tiny particles had to act in biology, behaving according to the rules of chance. Thus, at the end of the 19th century, the ancient enigma of the smallest particles entered the stage of scientific thought with full force. At the end of the 19th century, physicists had only just got used to the idea that their theories would soon enable them to understand the world completely and in all its details, and that they would only have to worry about a few remaining minor problems, when their mental edifice collapsed.

However, it was not only the sciences that were hit by crisis. Mathematics also fell into a deep one at the end of the 19th century due to its now emerging inner contradictions and it had to fight a no less difficult battle for its integrity in the first decades of the 20th century. Revolutionary discoveries were no less prevalent in the scientific investigation of our own minds: psychology now described our mind as an uncontrollable beast. After it had shown its ugliest grimace yet in the First World War, a new age was already looming on the horizon that would make science the plaything of political interests: totalitarianism.

1

Newton's World Formula that Wasn't One—How the Speed of Light Shook Up Classical Physics

Throughout almost all of human history, there was little doubt that God alone—or an ensemble of gods—determined what happened on earth. In everything that humans observed or encountered, his will was revealed. If an arrow hit its target, it was only because God had willed it to do so. The laws of planetary motion discovered by Copernicus and Kepler were also regarded as proof of divine omnipotence. Galileo Galilei had already suspected that the "book of nature was written in the language of mathematics", but until 1687 no one had really tried to open this book and take a look at what would be a completely different way of explaining the world. In that year, Isaac Newton published his work "The Mathematical Principles of Natural Philosophy" (Latin original: Philosophiae Naturalis Principia Mathematica). He was not the first person to link his observations with mathematical calculations, but never before had there been a self-contained scientific theory that provided a rational and causal explanation for almost all of the natural phenomena known at the time. In order to cope with this gargantuan task, Newton had had to develop completely new ways of calculating. It was only with the integral and differential calculus that it became possible to calculate with mathematical precision the motions of the objects around us and the forces to which they are subject. Just as Galileo had predicted, mathematics actually proved to be the decisive tool for describing nature.

Philosophy of nature: The attempt to explain the processes in nature and to form a unified view of the world.

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Newton had achieved this breakthrough not least because he had discovered gravity as a force. All other forces known at the time acted *directly* from body to body. For example, a cart could only be pulled by a horse if both were connected by a drawbar. But gravity also works when the bodies do not touch each other at all. When Newton understood that the force that keeps the planets in their orbits is the same as the force of gravity that makes an apple fall to Earth, he was able to formulate his universal law of gravitation. With this law and the three basic laws of mechanics, almost all phenomena known at the time could be rationally explained and even predicted. The trajectory of a stone thrown through the air, the way a pulley makes work easier, the tides, even planetary orbits and the recurrence of comets had now become comprehensible. Now it was only a small step to an explanation of the world from the ground up that no longer had to resort to the will of a god or other transcendent causes.

The Last Magician

Newton did not adopt this approach throughout his whole life. His mathematical laws were purely rational, but he himself was not a very rational person. Deeply religious and with a strong inclination towards the occult, he spent a lot of time searching the Bible for hidden clues and secrets. When in 1650 the Irish archbishop James Ussher thought he had proved through the most exact and careful study of the Bible that the day of creation was 23 October 4004 BC, Newton checked this date against the astronomical constellations and came to the conclusion that the world had to be 534 years younger than Ussher had calculated.

As an ardent follower of alchemy, Newton believed in a spiritually active substance called aether which permeates every solid substance and also circulates between the centre of the earth and the celestial bodies. In his manuscripts, he repeatedly referred to the aether, which in his view, as the originator of gravity, should push all matter towards the centre of the Earth or Sun. It is paradoxical that Newton's deep belief in alchemy and in the all-encompassing work of divine, alchemical, and astral forces in nature led him to develop the idea of an invisible force of gravity, which pulls things to the Earth's surface and also keeps the other planets in their orbits. The fact that it was Newton, a convinced secret ally and occultist, who helped modern, strictly rational science to make its decisive breakthrough is one of the strangest twists in the history of science.

Occultism: Worldview in which only a few people are given access to hidden, mystical powers. The occult sciences include alchemy and astrology.

On 17 July 1946, a commemorative speech was read out that at Trinity College, Cambridge, Newton's former place of study, on the occasion of the tercentenary of Newton's death. It had been written by the famous British economist John Maynard Keynes, who had died only a few weeks earlier:

> In the 18th century and ever since, Newton was thought to be the first and greatest representative of the modern scientific age (...) But Newton was not the first of the Age of Enlightenment. He was the last of the magicians, the last of the Babylonians and Sumerians, the last great mind to look upon the visible and intellectual world with the same eyes as those who began to build our intellectual heritage scarcely less than a thousand years earlier.

Newton's religious faith had been unshakeable, but his laws were now out and about in the world and weakening the power of religions everywhere. With the explanations they gave, the world was no longer a place where the inexplicable will of God made incomprehensible things happen. People began to understand nature—including man himself—as a machine that follows universally valid and comprehensible laws and that can be mathematically calculated and predicted with the help of Newton's equations. Newton became the hero and idol of his age.

The influence of the new thinking on European societies was enormous. For many centuries, countless scholars had struggled to describe and understand what was happening in nature. Especially since the Renaissance, they had increasingly found the courage to question religious dogmas. However, since they had had to fear persecution, they had corresponded only amongst themselves. People outside these scholarly circles—from aristocrats to peasants—had been excluded from such ways of thinking, and their lives and experience had remained the same. But this changed with Isaac Newton. The great philosopher Voltaire had played an important role in this. He had wanted Newton's works to be translated into French (but he could not do it himself, so instead his long term lover, the brilliant female mathematician, Émilie du Châtelet, did it between 1745 and 1749) and spread his enthusiasm for Newton's laws in his native France. From there, the new thinking conquered the whole of Europe. There were heated discussions in the coffee houses and private salons of Paris, Berlin, and London, but also around the table in country villages. Freed from the religious stranglehold on interpretation, people now began to question the nature of political power. If it was not God, who or what would really determine the position and rights of every human being? Who or what would confer political power? Newton and his laws opened the door to the Age of Enlightenment, in which the new rationality also revolutionised social and political thought. The American Declaration of Independence of 1776 and the French Revolution of 1789 would probably not have happened without the Enlightenment, fuelled as it had been by Newton.

Enlightenment: From the end of the seventeenth century, a new way of thinking spread across Europe that relied on human intellect and reason and sought to overcome ideology, superstition, and prejudice.

Newton's edifice of natural laws was not perfect, however. Some phenomena that scholars dealt with in the ensuing period could not be explained by his mathematics:

1. Chemical conversions
2. Heat and cold
3. Electricity and magnetism.

But the optimism for the future was great. The natural scientists were convinced that they only had to supplement Newton's laws with a few more formulae. It seemed to be only a matter of time before humans would be able to understand and calculate everything without exception.

Blank Spots on the Map of Science

The mystical activities of the alchemists had already amassed some knowledge about chemical transformations, but the nature of even the most everyday substances such as water and air was still completely unknown to Newton's contemporaries. For the naturalists, the gateway to understanding chemical reactions was combustion. It was obvious that air had to play an important role in this process, because without a supply of air, combustion never gets under way.

- A significant step was taken in 1781 by the Englishman Henry Cavendish. From sulphuric acid, iron, and zinc, he obtained a gas he called "combustible air", known today as hydrogen. His discovery that this gas produced pure water when burned was a shock, because ancient doctrine had classified water as one of the four basic substances. But if water consists of "combustible air" and oxygen, which was also isolated shortly afterwards, then there had to be more elements than just air, water, fire, and earth. A millennia-old certainty had turned out to be impossible.

- For a long time, natural scientists were convinced that every combustible material contains an invisible substance called phlogiston (from the Greek *phlogistós*: "burnt"). It seemed logical: as soon as the phlogiston escaped from burning wood, for example, ash remained. The chemist Antoine-Laurent Lavoisier made a decisive breakthrough in 1772. In a series of experiments, he burned substances such as phosphorus and lead, even diamonds, and thanks to his elaborate laboratory equipment and the use of precision scales, he was able to measure the initial and final products of these reactions very precisely. He found that the total weight of all products remained constant before and after a combustion. So no material was lost, and nothing was added. But where was the phlogiston? After this discovery, the phlogiston theory would not be able to hold on for long.
- Soon afterwards, Joseph-Louis Proust discovered that the chemical compounds he studied contained integer ratios of the elements involved in the reaction processes, e.g., 3:2 or 2:1. Another Frenchman, Joseph Louis Gay-Lussac, showed in 1808 that this principle also applied to gases. These were the first indications that tiny, indivisible particles were involved in chemical processes.

1. **Chemical conversions**
2. Heat and cold
3. Electricity and magnetism.

Lavoisier did not live to see the successes of his compatriots. He became a victim of the French Revolution. Having previously held important offices in the service of the king, he was arrested, but his fate was sealed by a completely different circumstance. A few years earlier, he had denied the revolutionary leader Marat access to the French scientific elite. Marat now saw a welcome opportunity for revenge. Lavoisier was executed by guillotine in 1794. Even today, the great scientific nation of France still grieves that one of its most brilliant minds was executed in this way.

Steam Flasks and Stills

Like the specific chemical conversion of substances, the mastery of the phenomena of **heat and cold was** also of great practical importance. In particular, the development of steam engines in the late eighteenth century required a deeper understanding of the conversion of heat into mechanical energy that was lacking. Even then, this knowledge could have decisively advanced technical processes and old crafts, such as the distilling of whisky. But Newton's laws did not allow a mathematical approach here either. For a long time, it was believed that, rather as in the phlogiston theory, heat was also a substance contained in all materials. Even Lavoisier, who had brought down the phlogiston theory in chemistry, was an ardent advocate of the view that heat was a substance. He referred to it as "calorique".

- The American Benjamin Thompson studied the relationship between friction and heat. In 1798, he observed how the barrels were drilled into cast bronze cannons in the royal gun foundry in Munich. This was hard work that had to be laboriously carried out using metal drills. He noticed that the bronze heated up again and again with each work step, suggesting that friction was an inexhaustible source of heat. However, a "heat material" would have had to run out at some point after dozens of repetitions. It was thus clear that Lavoisier's caloric theory had to be wrong. Thompson described heat as a form of energy. However, he was too little versed in the sciences to make connections with other areas of physics, especially mechanics.
- Physicists had realised in the eighteenth century that gases could be compressed in a sealed container. This suggested that a gas might consist of particles that whirl around wildly like little balls. External pressure could then reduce the space available to them. In 1811, the Italian Amadeo Avogadro drew the conclusion from his measurements that equal volumes of gas at constant temperature and pressure contain the same number of particles. This resulted in a universal law relating volume, pressure, and temperature, i.e., a law that was the same for all gases. Newton would have been delighted—everything was still in accordance with his laws.
- About 50 years after Thompson, the British physicist James Joule succeeded in developing a mathematical theory for the conversion of mechanical energy into heat energy. In it, he established that heat is related to the motions of the smallest particles.

1. Chemical conversions
2. **Heat and cold**
3. Electricity and magnetism.

In both fields—chemical transformations and the phenomenon of heat and cold—the natural scientists had reached a similar point. There was still nothing to say that Newton's laws were not also valid in these areas. Indeed, they had already found some connections that showed analogies to Newton's laws. But if they wanted to understand chemical transformations and also heat and cold from the bottom up, they realised they would have to deal with the smallest particles.

Ancient thinkers like Democritus and Aristotle had already thought about the building blocks of the world. At the beginning of the nineteenth century, the smallest, indivisible things left the field of philosophy and became the subject of concrete scientific considerations and experiments. However, atoms could not be observed directly; their existence and the laws of their behaviour could only be deduced indirectly with the help of models and hypotheses. For the English naturalist John Dalton, the integer ratios of the initial and final substances of chemical reactions were concrete indications that all matter is actually composed of the smallest, no longer divisible particles. In honour of Democritus, Dalton called them atoms.

To explain the large number of basic substances found so far—among them hydrogen, oxygen, sulphur, and iron—he created the idea of chemical elements, each consisting of a certain kind of atoms. Their distinguishing feature, however, was not to be their external shape or colour, as the Greek thinkers had imagined, but their weight. Dalton gave the atom of hydrogen the weight one, and determined the weight of the atoms of all the other elements as an integer multiple of it. According to this scheme, he classified 21 different elements. Today, chemistry knows far more than a hundred.

Now the natural scientists made an understandable but fatal assumption: they assumed that Newton's laws, which in their experience perfectly described the processes in the visible and tangible macrocosm, should also apply to the microcosm. For them, it was self-evident that two atoms should behave according to Newton's laws just as two marbles do. They were convinced that they only had to find a way to apply Newtonian mechanics to the smallest particles in order to be able to calculate what happens in chemical reactions and thermal phenomena. Then they would also get to the bottom of previously unsolved mysteries, such as which forces hold the atoms together in their compounds.

There was only one catch: with the third physical phenomenon that was not covered by Newton's laws—electricity and magnetism—one quickly reached the limits of what could be explained. There was no evidence of the involvement of the smallest particles and no one had any idea whatsoever of how these phenomena came about.

The Twitching of Dead Frogs

Unlike chemical transformations and thermodynamics, **electricity and magnetism** initially played no role in industrial processes. On the contrary, an air of mystery surrounded these phenomena. At eighteenth century social events, they served to entertain the guests, making each other's hair stand on end.

- The Greeks had already recognised that amber rubbed against a cloth attracts certain objects. This fact also gave the phenomenon of electrical attraction its name: "amber" means *electron* in Greek.
- In the seventeenth century, the German natural scientist Otto von Guericke showed that electricity can be transferred from one body to another. He discovered two forms of electricity, one attractive and one repulsive.
- Like the phlogiston theory, the first theory of electricity postulated a special substance that was responsible for all electrical effects. A convinced supporter of this theory was Benjamin Franklin, who became famous in the struggle for American independence and was also the most important American researcher of the eighteenth century. He believed that too much of the "electric phlogiston" makes the body "positive", too little of it "negative". Because small flashes of lightning could be observed in the laboratory when electricity was discharged, he had the idea that the lightning that occurred during storms could also be related to electricity. He devised a dangerous experiment: according to his description, during a thunderstorm, a kite was allowed to rise into the air on a wet hemp string (which would conduct electricity), with a metallic object attached to the lower end. Franklin recounts that, when lightning flashed across the sky, he put his hand to the metal and received a shock. Presumably, Franklin was only describing a thought experiment; many naturalists who actually imitated his experimental setup lost their lives.
- In 1785, the Frenchman Charles-Augustin de Coulomb measured the force with which two balls repel or attract each other, having first applied a certain amount of electric charge to each. It turned out that this force

depended directly on the amount of charge on the balls. What's more, at three times the distance from each other, the force dropped to one ninth. This relationship, known today as "Coulomb's law", showed the same regularity as Newton's law of gravitation! Electricity was therefore not as mystical as first assumed. It also functioned according to simple, easily understandable laws, just as Newton had formulated them.

1. Chemical conversions
2. Heat and cold
3. **Electricity and magnetism**.

Until 1780, natural scientists knew electricity only in the form of stationary charges with which certain materials, especially metals, can be charged and which discharge abruptly, often sparking, when in contact or close to other bodies. That year, however, Luigi Galvani noticed muscle contractions in the legs of dead frogs when they came in close proximity to electric charges. He knew Benjamin Franklin's theory that thunderbolts were nothing more than electrical discharges. So he hung the dead frog legs in front of a metal net and waited for a thunderstorm. And indeed, when there was lightning, the frog legs twitched. In further experiments, without knowing it, he developed electric circuits from two different metals, using the salt water contained in the frog's leg as an electrolyte.

Galvani interpreted the twitching of the frog's legs as a residue of animal powers. Another Italian scientist and contemporary of Galvani, Alessandro Volta, drew quite different conclusions from the frog leg experiment. He concluded that the effect must be due to the arrangement of the different metals. To investigate the phenomenon further, he took a silver coin and a piece of tin foil, connected them with a copper wire and placed them under or over his tongue. Maybe his tongue would twitch just like the frog's legs, he thought, because after all it was a muscle too. It did not twitch, but Volta felt a tingling sensation, followed by a sour taste. He concluded that his sensations were related to flowing electricity, and that metals not only conduct electric charges but can also produce them. To enhance the effect of flowing electricity, he constructed a stack of alternating layers of metals and salt water solutions around the year 1800. With this, Volta had built the first electric battery! Such an arrangement could produce amazing things, even light, if the two metal end layers were connected with a thin wire of suitable material.

But what exactly produced the electric current in Volta's experiments? The young English scientist Humphry Davy suspected that chemical reactions caused the electric current. Wasn't it then also possible that electric current could cause chemical reactions in reverse? In a sensational experiment, he put the two metallic ends of Volta's arrangement into a potash lye (a water solution with potassium hydroxide). A gas then formed at one end of the cell, which quickly escaped, and at the other end a metal that looked like mercury but burned quickly and explosively on contact with air. The gas was hydrogen and the hitherto unknown, highly reactive metal was potassium. It was now clear that electric current was indeed capable of separating chemical compounds into their components. Davy concluded that it is also electrical forces that hold the components of chemical compounds together. This provided only a first outline of the new force, which was still missing from Newton's explanation of the world; no uniform picture of it was yet available. But the mystery of electricity had become a calculable phenomenon. Efforts were now directed more towards the technical implementation of ideas about what electric current could be good for. In 1802, Davy had experimented with strips of charcoal to generate light by means of an electric circuit. Later, paper, bamboo, and platinum were tried out—with limited success. It would take over a hundred years before Thomas Alva Edison's incandescent lamp conquered the world.

Until well into the nineteenth century, it was possible to assume that Newton's world view only needed to be supplemented in order to solve the last riddles of nature. Regarding all the mysterious forces that the father of classical physics had not been able to explain, scientists were well on the way to integrating them into his explanation of the world. Only one last phenomenon still resisted this integration: magnetism. A student of Davy's, Michael Faraday, succeeded in connecting this force with the new electrical theory. This should have been the keystone that would complete Newton's edifice. But things turned out very differently than expected. Instead of completing and crowning the tireless work of countless natural scientists who had dedicated their lives to science, this very stone brought everything crashing down.

Magnetic Forces and Magical Thinking

Like electricity, magnetism has been known since antiquity. The first statements about its property of attracting certain things came from the pre-Socratic Thales of Miletus, who in the early sixth century BC examined magnetic stones from the area of Magnesia in Thessaly. It was also known that magnetic splinters orientate themselves in a north–south direction. In

China, floating compass needles were in use from the end of the eleventh century and in Europe, magnetic compasses with suspended needles became established from the thirteenth century. Despite these useful applications, the subject of magnetism retained its aura of mystery. The reason for this is probably that, unlike chemical reactions, heat and cold, and of course electricity, a person cannot directly experience magnetism with any of his or her senses, and so it remained shrouded in mystery to a considerable degree.

- Albertus Magnus, the great universal scholar of the thirteenth century, wrote in his book "On Minerals" that the magnet's ability to attract or repel is also useful in marriage: "The husband (may) place a magnet under his wife's head pillow. She will embrace him ardently if she is faithful to him, whereas she will be flung out of bed in the middle of her sleep if she has broken the marriage".
- The English physician and physicist William Gilbert, who described the Earth as a great magnet as early as 1600, imagined magnetism as "the soul of the Earth".
- In early modern medicine, magnets were considered a symbol for the hidden healing powers of nature, and magnetism played a central role as an occult healing instrument.
- In the eighteenth century, Franz Anton Mesmer founded the theory of "animal magnetism" (mesmerism) and described special methods of pain relief using magnets.
- From the middle of the nineteenth century, magnets played an important role in psychological suggestion therapy. "Magnetic field therapy," in which a patient is exposed to an external magnetic field, is still used as a (from a scientific point of view questionable) method of treatment in alternative medicine.

How could it be that magnetism was still seen as a magical force in the times of the Enlightenment and to some extent even up to the present day? In the nineteenth century, the so-called philosophy of life and Romanticism formed as counter-reactions to the strict rationalism that Newton's laws had carried into philosophy and science. The idea of an animal magnetism as well as an animal electricity fitted very well into this world view, which was characterised by belief in ghosts and miracles, and which had also given rise to the idea that polar opposites in constant struggle with each other give rise to a natural whole in the form of a force field.