**William Gilbert - Separating Electric from Magnetic Effects**

1. Title and Keywords

„William Gilbert – Separating electric from magnetic effects“

(Episode 1 of the series: Historic-Genetic Introduction to Electricity)

static electricity, electrical attraction, magnetism, magnetic attraction, lab diary, categorizing, sorting, experimental method, William Gilbert

2. Authors and Institutions

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3. Abstract

The episode about Wilhelm Gilbert is the first in a series about the history of electricity. Its objective is to raise an understanding for his experiments, which aimed at distinguishing magnetic from electrical attractions. The episode can be used for teaching secondary school students (age 12 to 15) about the nature of magnetic and electrical attractions and how they differ. An analysis of the phenomena will be encouraged based on specific characteristics of both phenomena. Hence, the students develop the idea that there are different kinds of natural forces and learn in close accordance with Gilbert's work how structured experimental procedures lead to knowledge about structures in nature. Explicit epistemological reflections are concerned with the question of how physical knowledge develops in science. Emphasis is placed on the process of researching the characteristics of phenomena, followed by their organisation and differentiation in terms of substances and experimental procedures. This episode is meant to serve as an example for the aspects of scientific practice like aligning and categorizing the phenomenal world.

The students are asked for putting themselves into the position of somebody who has found Gilbert's lab diary, which actually is a fictitious scenario. Unfortunately parts of the diary have been destroyed during the past centuries. Then the students are prompted to reconstructing the missing diary entries of Gilbert. For doing this they have to perform experiments similar to Gilbert's. Their own open-ended activities are guided and structured by the historical context of early research about natural forces. Helping cards with additional information are offered to the students as a means for supporting them individually.

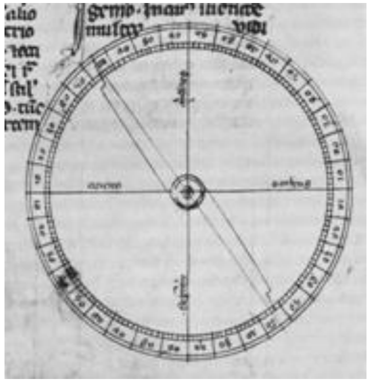
The person of William Gilbert furthermore serves as an example of scientific research being inspired by personal interests as well as economic and technical circumstances.

4. Description of Case Study

This episode starts with a brief **outline of the history of electricity and magnetism** until the beginning of the 17th century. Main aspects could be the previous phenomenological knowledge of electricity (forces of rubbed amber) and effects of attractions in nature like gravity. The role of socio-historic contexts for inspiring research about magnetism are highlighted by the important role of magnetic compasses enabling navigation on the sea as well as for coal mining.

After that, the person of William Gilbert will be introduced paying special attention to his interests in seafaring and coal mining (paragr. 5.2 and 5.4.2). The students can make use of this information fruitfully later for their reflections on the nature of science.

The following **experimental phase** is guided by Gilbert's fictitious **research diary,** which "has survived for many centuries with grave damages" (see material I and V). Gilberts' instructions are generally preserved. They are meant to guide and structure the students' activities. By means of two activities (see material II and material IV) small groups of students are supposed to **retrace** Gilbert's studies and **reconstruct his lab diary**. Firstly, they examine **what materials can be electrified by friction** and then they look at the **differences in electrical and magnetic attractions** (see paragr. 6.1). An evaluation of the results should be carried out after each activity. At this stage a short, general **reflection** according to the method of "Reflection Corner"- should follow (see page "Reflection Corner"). **Questions for addressing the nature of science explicitly** could be:



**Introduction**

**Reconstructing Lab Diary - Part 1**

**Reconstructing Lab Diary - Part 2**

**Reflection Corner**

**Interviewing Gilbert**

- “What’s influencing the scientists’ choices of research topics and the way they do research?”
- “Why do scientists write about their work?”
- “What is the role of inference in science?"
- "Did Gilbert (do scientists) need to do EXPERIMENTS or are there other ways to do research?"
- "Why do most scientists use such things like lab-diaries?"

More detailed information on the aspects of the **nature of sciences** and what learning opportunities this case study offers can be obtained in paragraph 5.4.
For scaffolding the students’ activities helping cards have been designed (see materials III and material IV). They support students with little experiences in planning experiments, setting up hypotheses or documenting observations. Helpful inspirations are offered to them for all activities in case the students are asking for them. The use of the helping cards is under the self-control of the students.
Next to the Reflection Corner another activity has been designed for addressing the nature of science: This episode may close with a creative writing activity. The students put themselves into the situation of interviewing William Gilbert about the following question:

- “How does one achieve new knowledge in science?"
- "In what ways is your research typical for the way science generates new knowledge?"

They write down or optionally stage the interview situation using the ideas elaborated throughout the reflection . Again the can ask for optional guidance from an information card for supporting this activity.

# 5. Historical and philosophical background including nature of science

## 5.1 Electrical and magnetic forces in the history of physics

The phenomena of magnetism and electricity have been known at least since ancient Greece. We already know that Thales of Milet (624 – 546 B.C.) had discovered that lodestones (see figure I) could attract iron and other lodestones. Until the early years of the 17th century, these lodestones were regarded as the only source of magnetic forces. Also, the early knowledge about amber (see figure II and figure II) trace back to Thales. After strong rubbing, amber was able to attract light objects. The ancient Greek term "elektron", amber in English and Bernstein in German, reminds us until today of the connection between findings about electricity and this particular stone. Furthermore it was known that in general, lodestones kept their special properties whereas the attracting properties of amber usually wore off after a short period of time. Amber had to be rubbed anew time and time again in order to unfold its powers.

Until the early modern era, the properties of attraction and north-south alignment of lodestones and later on of magnetic needles had become highly important when compasses were constructed. Innovations accrued from this area of phenomena determined the maritime navigation, the orientation in underground mining (see figure VII and figure VIII), geodesy, the measuring of time by sundials and in military use or the adjustment of cannons as exact as possible. Still, a clear phenomenological distinction of the forces of amber and magnet stone developed only rather late.

Girolamo Cardano (1501 – 1576) was one of the first scholars to point out that there were not only similarities, but also differences in the attracting effects of these two kinds of stones. The London physician William Gilbert made around 1600 a first detailed experimental elaboration of similarities and differences was made by. His work was published in a Latin publication called "De Magnete" (see figure IX). It was established quickly as the standard work on electrical and magnetic phenomena. Likewise, the development of natural research based on experiments dates back to this period. So, unsurprisingly, Gilbert was able to refute the centuries old idea that lodestones would lose their essential properties under the influence of diamonds or even garlic.

## 5.2 About William Gilbert

William Gilbert (see figure X), also Gilberd or Gylberde, was born on May 24th, 1544 in Colchester, Essex, England and died on December 10th, 1603 in London or Colchester. He was an English physician and natural scientist coming from a wealthy middle class family. After finishing his medical studies in Cambridge, Gilbert established himself around 1573 as a doctor in London and became a member of the Royal College of Physicians, an association of London doctors. In

1600 he was even elected president of the College. The following year he was appointed personal physician of Queen Elisabeth I and, after her death, of King James I. Gilbert never married.
He showed great interest in the mining activities in his home country (see figure XI) and had a deep knowledge in metal processing. Being in regular contact with miners, he carried out experiments on the magnetic alignment of iron ore he could not have accomplished without their help. He took home into his laboratory the suggestions and ideas he received from his conversations with the miners and turned them into experiments.
Furthermore he admired the sailors and circumnavigators, Sir Francis Drake and Thomas Cavendish, with whom he talked about their experiences with the nautical instruments they had used. Accordingly, the importance of seafaring for the society of that time had a guiding effect on Gilbert's research.

## 5.3 Gilbert's research

William Gilbert successfully separated the phenomena of attraction of lodestones from those of electrified matter. Starting with experiments on the electrification of substances, he divided them into electrifiable and not electrifiable substances through friction. (These tests were carried out with light objects such as straw and husk.) He also invented the term "electricity", using it to describe what the rubbed object had received in case it could be electrified. Electrifiable materials can therefore be called "electrica" and those not electrifiable "non-electrica". Having secured the electrifiability of wood and metal, he used both as a kind of early electroscope, his so-called "versorium" (Latin for "turning around", see figure XII). Two versions are known: Metal or wooden bars put up on a silk threat or placed on top of a needle. These instruments were extremely sensitive to electrostatic attractions.
Gilbert now carried out a great number of experiments with these methods. He was able to distinguish magnetic from electrical attraction through the following characteristics (see original text I):

- Characteristic 1: "(Variety of) Attracted Objects“
- Characteristic 2: "Permanence of Attraction“
- Characteristic 3: "Removal of Attraction“
- Characteristic 4: "Shielding of Attraction“

This clear distinction, derived from experiences made during experiments, did not exist before.
The necessary materials and information on Gilbert's experiments are located in paragraph 7.1.

## 5.4 Nature of Science Issues

### 5.4.1 Categorising, arranging, distinguishing

In "young" scientific disciplines, which are characterized by a lack of a theoretical framework for deducing explanations or making predictions, it may be preferential to apply an exploratory strategy [5]. Natural phenomena are explored, arranged, varied and classified in order to divide phenomenal areas from each other and to establish stable empirical rules. (In this case: "There are two different kinds of attraction."). The character of this kind of experimental research is basically inductive.

The associated procedure is the gradual, planned alteration of the examined object, represented in Gilbert's experiments through the controlled exchange and examination of just one new substance at a time. This results in a lot of experiments being conducted and a lot of observations being made. Gilbert's approach is characteristic of a scientific discipline on an early stage: Developing experiments to explore new phenomena by arranging, distinguishing and classifying their properties. The ability to admit attractive forces by friction was considered for a long time to be a typical property of amber. Gilbert was able to extend the list of substances, which could also be electrified by friction. Among them were diamonds, sapphires and opals as well as glass, sulphur and sealing wax. The list of substances that could be attracted without being attractive when rubbed was much longer. According to Gilbert a huge amount of substances even wood and water were among them. Gases however were not supposed to show this property. It was an almost established fact among Gilbert's contemporaries that in order to be attractive, substances had to be rubbed.

Gilbert's categories, „Attracted Objects", „Strength of Attraction", „Permanence of Attraction", and "Removal of Attraction" should be open for extensions made by the students (e.g. shielding of attraction, north-south alignment etc.). (see original text I).

It should be pointed out that categorizing, classifying and distinguishing are common methods of science. Chemistry is characterized by the idea to classify substances. Its most important and well know classification system is the periodic table, which aligns chemical elements according to empirical and theoretical aspects. In biology living organisms are classified in genealogical trees and species, which both are important tools for understanding the natural world.

### 5.4.2 Personalities and peculiarities of scientists (see "About William Gilbert")

Gilbert's interest in and knowledge of mining and seafaring reflects how the sciences are culturally and socially influenced. Very often, scientists prove to be "children of their time" whose cultural context would inspires interests and actions. Therefore, Gilbert's "versorium" (see figure XII, see suggestions for experiments) was based on the construction method of compasses.

As science and scientists are socially and culturally integrated into the society of their time, their actions, interests, and motives have to be presented within the conditional framework of their historical context.

5.4.3 Documentation of the research process and justification of the results

In addition to the official publication, there are various, primarily non-public methods of documentation in scientific research, of which we would like to point out the laboratory diary.

Lab diaries exist not for their own sake but play important roles in science. Among them are:

- Justification of the results before colleagues
- Documentation of ownership of experimental results, theoretical ideas or instrumental developments (e.g. if someone wants to apply for a patent)
- Accounting the honesty of your research and safeguarding that there are no falsified results
- Chance to carry on researching after an interruption or setback
- Chance for colleagues to carry on the research
- Exposing unfounded conclusions
- Compare and analyze experimental data
- Keeping thoughts and insights
- Develop theoretical ideas
- Preparing publications

Students may guess the importance of the documentation for the reconstruction of research by the suggested activities (see material II and material VI). However, the impression that a lab diary would give a perfectly objective image of the research process must be avoided. As well as the conducted experiments and used instruments, all observations and data mirror the theoretical background of the respective observer. These observations have already been gained with a certain theory in mind, and will be interpreted again when published. Moreover, some aspects of experimental activity are even not documentable. This dimension of science has been called tacit even though it is a necessary condition of research.

5.4.4 Goal-orientation of research – involvement of science and technology

It is possible to go one step further and spot the beginning of the 17th century as the early bloom of capitalism and its accompanying economising measures of work processes. Hence, Gilbert’s research can be called goal-oriented: Researching and explaining the phenomena of attraction and the resulting separation of natural phenomena can contribute to a better understanding of forces in nature and how to use them. Thus, it can lead to an increased productivity of industrial processes (mining, metallurgy) as well as increased safety and efficiency of trade routes (nautical instruments). The relation of science and technology is not obvious in this case, but given by the different fields of Gilbert's enterprise. 6. Target group, curricular relevance and didactical benefit This episode is a part of a larger case study about the history of electricity. It is directed to secondary school students aged 12-15. In most of the physics curricular teaching about electricity has an important role.

## 6.1 Learning objectives and competencies

### 6.1.1 Nature of science

Students should be able to ...

- demonstrate that **documentations of results**, **instruments and processes** of scientific research characterize common scientific practice.
- name the **lab diary** as a method of documentation.
- identify (and practise) the **separation and classification of phenomena** along certain characteristics as a scientific approach
- state that **scientist are motivated** by interests, curiosity, but also by purposeful objectives
- state that the current **technical necessities** influence the direction of scientific research.

### 6.1.2 Competencies referring to scientific inquiry

Students are supposed to ...

- solve their tasks in **teamwork**
- **control their results** by comparing them to those of others
- assess the influence of possible **sources of errors** on the validity of their results
- draw up **simple sketches**
- **draw general conclusions** based on experimental evidence
- develop with our without assistance **explanations** to check their suppositions
- **plan and carry out simple experiments** with different degrees of autonomy
- **record their observations** carefully and establish measuring charts with or without assistance
- use their observations for the assisted **verification** of their suppositions
- **monitor the progress of their work** and use helping systems if needed

6.1.3 Content related competencies

Students should be able to …

- **distinguish the phenomena** of electrical and magnetic attraction on the basis of their characteristics
- name different **substances that can be electrified** by friction
- **name attraction** as the action of force between charged (electrified) objects
- name the attraction of **light objects as a way to prove electrical charge** (electrified objects)
- name a simple **device to prove electrical charge** (electrified objects) (versorium)
- describe qualitatively the **action of force in the vicinity of electrically charged objects**
- **classify magnetic bodies** in terms of attractions they exert of various substances
- describe permanent magnets with **north and south pole**
- describe the **construction and use of a compass** and interpret its mode of operation phenomenologicaly
- name the consequences of the **compass in the historical and social context**
- carry out simple **experiments for demagnetisation**

6.2 Students' (Mis-)Conceptions and Learning Obstacles

Students tend to confound the phenomenological areas of electricity and magnetism. It often happens that they are confused about the use of a proper terminology. Confusion becomes evident, if they talk about the north- and south pole of an electric battery or the positive and negative pole of a magnet. Additionally humanising analogies such as like/dislike and attract/reject are often used for describing electric and magnetic phenomena.

Teachers should be aware of this problem since the separation of electrical and magnetic phenomena is supported by an exact use of the related terminology. A clear-cut idea about this separation is actually enhanced, if the students re-enact Gilbert's experiments. In doing so, it should be possible to reduce a future blending of phenomena as the students not only can accept the differences but also name them. Furthermore, it is of great importance to separate electricity from magnetism clearly, before teaching about electro-magnetic phenomena. Otherwise the relation of both phenomenological areas will not become evident to the students.

7. Activities, methods and media for learning

7.1 Experiments for separating magnetic and electrical forces of attraction according to Gilbert

Required materials

**Substances to electrify:**

- Amber
- quartz/rock crystal
- soapstone
- alum crystal
- salt (as a rock like e.g. in salt lamps)
- sealing wax bars
- colophony (resin)
- glass bars (PE bars as backup)
- Things to rub with: cloth made of wool, cotton wool, silk, and cat fur

**Magnetic substances:**

- various magnets/lodestones/magnetic iron ore

**Test objects 1:**

- husk
- wood (chips and thin bars)
- dry earth, small stones
- salt (grains)
- smoke (e.g. from blown out candle)
- cotton wool threads
- paper scrap (confetti)
- brass splinters (waste from metal working places)
- iron cuttings or powder, silk thread

**Test object 2:**
Gilbert's versorium (see figure XII): thin wooden or metal bars, e.g. wires without coating
<u>Instructions:</u>
The bars or wires can either be placed on a needle stuck in a piece of cork or suspended on a silk thread.
In Gilbert's sense, the electrified material should not touch the bar as otherwise there would be a charge transfer followed by repulsion.

**Instructions**
In order to distinguish the phenomena of attraction by electrifiable substances, the students are trying to purposely electrify the given materials by rubbing them. Then, they are testing the generated attraction on light objects or the versorium.

The results will be the basis for content learning and an explicit reflection on the underlying scientific method (distinction by means of characteristics, see chapter 5.4, see also the related learning objectives).
Gilbert's fictitious lab diary (see students' material I and material V) and the tasks referring to it (see students' material II and material VI) guide the experimenting. They can also be used to contemplate the meaning of the scientific research process's documentation.

**Gilbert's course of action**

1. Electrifiability and attractability
   In order to electrify the substances, Gilbert rubs them with the mentioned "things to rub" and uses magnetic iron ore as magnets. Regarding wood and metal, he tests for their attraction by suspending thin bars of either horizontally on a piece of freely pivoting string before bringing the electrified substances or magnets close to one end. If the bar starts turning, the substance is obviously attractable. Here the similarities to the construction of a simple suspended compass are visible.
   He initially ascertains the electrifiability of the very first tested materials by rubbing them. Then he checks whether they are able to attract the light objects that have already reacted on rubbed amber as these ones were known for sure to be attracted electrically. Thus, by using the substance now known to be electrifiable as the starting point for further tests, he can gradually extend the list of electrifiable substances as well as those attractable by electrified objects.
2. Distinction of electrical from magnetic attraction
   Gilbert goes on to compare the substances identified as electrifiable to lodestones with regard to their effect of attraction. He can expose at least four differentiating criteria of the two kinds of attraction.

**Criterion 1: "(Variety of) Attracted Objects"**
While electrified materials attract all light objects, magnetic properties are limited to metallic objects with magnets.

The following, further differences can easily be tested experimentally:

**Criterion "Strength of Attraction"**
Even weak magnets are capable of lifting objects of comparatively high weight, whereas the electrical attraction seems to be limited to small and light objects.

**Criterion 2: "Permanence of Attraction"**
While the electrification disappears after a certain amount of time and must be renewed through rubbing, the magnetic attraction is a permanent phenomenon.

Even breathing on a magnet does not provoke a loss of its attractive force. Here it would be possible to talk about the loss of magnetisation through jolting or heating if students ask these kinds of questions. On the other hand the accidental jolting of electrified objects by dropping them also leads to a loss of the ability to attract (earthing), this could pose a problem. It becomes even more clear that Gilbert's criteria are far from being selfevident.

**Criterion 3: "Removal of Attraction"**
The electrification is lost if the electrified object is breathed upon. Contrary magnets, which can even be dipped into water without losing their attraction, humidity leads to the loss of their attraction.

**Criterion 4: "Shielding of Attraction"**
Almost every material can shield the electrical effect of attraction whereas a magnet remains unaffected.

**Further obvious criteria**
An electrified object has no north- and south pole and does not align itself with a cardinal direction.

7.2 Materials for students

Material I:

*London, 11th February AD 1600*

*Continuation of my experiments on the ability of different materials to attract others, something on which not more seems to be known than that handed down to us from ancient Greece. However, I can build on this knowledge – for example, that a certain material can be electrified if after strong rubbing with fur or cloth it attracts small pieces of paper or straw. Also I can use the electrifiability of amber for my research.*
*Today I am trying to research whether there are two different kinds of attraction – the attraction of electrified objects and the one of lodestones – or whether it is the same in both cases.*

***From my previous experiments I have arrived at the following hypothesis that I want to test today:***
*Maybe the kinds of attraction differ from each other regarding the sort (or amount) of materials attracted. If that is the case, the magnet should attract other substances than the electrified object does.*

*First, I must verify what materials can be electrified through rubbing and write them down.*
*Then I will compare the objects attracted by the electrified substances to those attracted by a magnet.*

*For my experiments I am going to use the following materials:*
*[…]*
*Materials to be tested on their electrifiability:*
*[…]*
*The objects exposed to the effect of attraction are the following:*
*[…]*
*All my observations and ideas:*
*[…]*

*An idea for an apparatus: The way a compass works has given me a good idea – I am going to suspend a wooden bar in such a way* *that it can pivot freely. Electrifiable material will then be able to turn it around.*

*Are my observations speaking for or against my hypothesis?*

*During these experiments, some more characteristics have come to my mind that could possibly distinguish the kinds of attraction: […]*

Damaged extract from Gilbert's (fictitious) lab diary – experiments on the force of attraction of magnets and electrified objects.

Material II

Activity for students related to Material I

Task 1

Now you know a part of Gilbert's lab diary or what's left of it. Please try to do your own research in order to replace the destroyed part.

Document everything you do, every observation and idea.

1) First examine which objects can be electrified by rubbing and which ones cannot. Gilbert wrote how this can be done.

2a) Determine which materials do get attracted by electrified objects, by magnets and which do not.

2b) Arrange your results on electrified and magnetic objects **clearly** and think about how to do this best **beforehand**. If you are unsure you can get advice from **Instruction Card 1a**.

3) Complete now the destroyed parts of the lab diary.

4) Speculate further about how else the two kinds of attraction could differ. State how you arrived at that assumption and how it could be tested experimentally. If you do not have any idea, **Instruction Card 1b** might help you.

Material III
Optional instructional material for supporting students doing task 1.

**Instruction Card 1a**

William Gilbert was one of the first scientists of his time who gained extensive knowledge through experiments. In order to keep track of the many materials, experiments and observations, he might have used a **chart** or a **list**.
He probably wrote down which magnet or electrified material he had used and what he was able to attract with it or not. This allowed him to decide if magnets and electrified objects differ regarding the materials they attract. His chart could have looked like this:

| Various materials to be attracted | attracting material:<br>Either **only by the lodestone** or **only by the electrified material** or **by both** or **by none.** |
|---|---|
| sawdust | Only by lodestone |
| … | … |
| … | … |
| … | … |
| … | … |

Material IV
Further optional instructional material for supporting students doing task 1.

**Instruction Card 1b**

At first, Gilbert tried to distinguish the magnets' and electrified objects' forces of attraction by how many materials and which ones have been attracted (and which ones have not). Maybe they also differ in the following criteria:

- **Strength** (What weight can the forces lift?)
- **Permanence** (How long does the attraction last? How can it be removed?)

Can you think of other criteria of distinction?

Material V
Damaged extract from Gilbert's (fictitious) lab diary – observations and experiments to weaken the attraction of lodestones and electrified objects with humidity.

London, 12th February AD 1600

Having been so successful yesterday in finding out the differences in the attraction of magnetic and electrified objects, I am today going to carry out further experiments on how else these two kinds of attraction might differ.
Already yesterday it seemed to me as if the electrified objects' strength of attraction would gradually … Particularly when I …
Also at the start of the week, when we had … weather, I noticed that …
This would be an additional criterion to differentiate the two kinds of attraction!
My assumption thus is: …
I can even think of an easy experiment to test my assumption: …

I will use a simple device with which I can test for electric attraction just like a compass tests the magnetic attraction. I have called it *versorium*. Whenever an electrified substance or a lodestone is approaching, it will turn to them.

My experiments will become much easier and more reliable with it.

My observations and if they confirm or refute my assumption:

[...]

Material VI

Task 2

Now you know the second preserved page of Gilbert's lab diary. He obviously noticed some more differences in the forces of attraction during his experiments.
*Surely you can also complete this page.*
Write down your observations accurately.
Only if you really do not have any idea, use **Instruction Card 2**.

Material VII
Further optional instructional material for supporting students working on task 2

Instruction Card 2

William Gilbert found out that after a while, electrified objects lose their ability to attract light objects. This happens the faster the more humid the ambient air is – so he certainly wrote about the attraction getting weaker and weaker when there was rainy weather. Already at his time it was known that there was a high amount of water (vapour) in exhaled breath. Maybe the attraction becomes **weaker** when the **breath is exhaled in the direction of the electrified substances.**
In his experiments he might have breathed at various electrified objects and lodestones and examined if they were still able to exert their forces of attraction afterwards.
His assumption must suit his question of how to distinguish two kinds of attraction. It could have been this:

**I assume that the magnetic and the electrical attraction differ in their reaction to humidity. Maybe the electrical force of attraction disappears with humidity whereas the magnetic force of attraction does not.**

Try to **think of an experiment** suitable to test the assumption. You probably need magnets, electrifiably substances and light objects again.

**Carry out the experiment** and **write down your observations**.
**Now use your observations:** Come to a conclusion by either **confirming** or **refuting** your assumption and mark the obervations you consider the most important.

Material VIII

Task 3

Put yourself into the year 1600 and try to image you would interview William Gilbert on the topic: **“How does science produce new knowledge?“**

Compose the interview in dialogue form. Here is an example for the beginning:

*Interviewer*: How do you do, Mr Gilbert? Thank you very much for agreeing to the interview.

*Gilbert*: You’re welcome. I like talking about my work.

*Interviewer*: Mr. Gilbert, only recently you have established clearly the differences between electrified and magnetic objects, and your books on the topic have become very popular. What do you have actually done and please tell me how your research work is typical for the way science works.

*Gilbert*: ....

Material IX
Further instructional material supporting students working on task 3
Instruction card focussing on comparing/differentiating as one of several methods and on the function of lab diaries in science.

## Instruction Card 3

Gilbert may have answered:

*Oh, I'd love to do that! In order to answer my* ***question*** *about the differences in magnetic and electrical attraction I've used the* ***experimental method****. At first, my* ***previous knowledge*** *and* ***creativity*** *helped me to come up with an* ***assumption*** *that might help answer my* ***question*** *if I could test it.*
*Then I thought up various* ***experiments with which to test the assumption****.*
*I carried them out and carefully wrote down my* ***observations****.*
*Then I* ***analysed my observations****, which means that I thought about whether they were* ***arguing for or against my assumption.***

Now ask William Gilbert the following – he can certainly say something about this:

1. *I would like to ask you:*
   *Could you explain why nearly all scientists should keep a lab diary?*
2. *As a final question:*
   *So your method is testing assumptions by experiments. How about other methods? Do scientists really need experiments?*

7.3 Pictures and Media

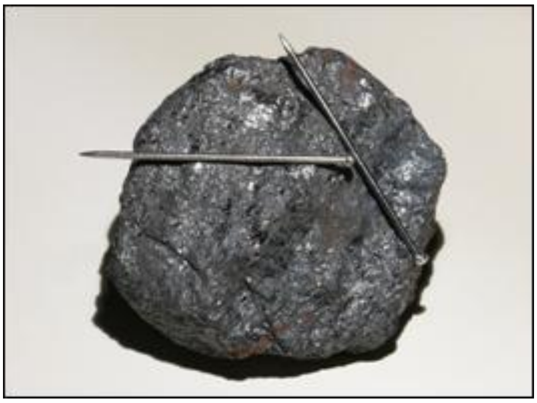


Figure I: lodestone / magnetite

Figure II and Figure III: natural amber

Figure IV: Chinese compass – the spoon lies on a plate of slate and is usually carved from lodestone

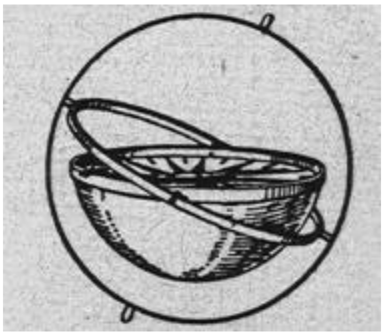


Figure V: Gimballed compass for nautical use (compensation of swell), around 1570

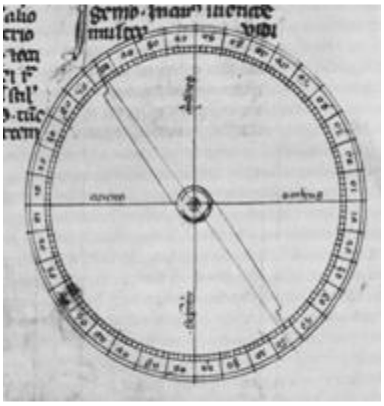


Figure VI: Depiction of a compass. Pen drawing included in a transcription of "Epistola de magnete" produced in the mid 14th century by Petrus de Maricourt

Figure VII: mining in China

Figure VIII: mining in England – various stages of tunnel digging. Orientation is very important to meet the nearest pit.


Figure IX: Cover picture of Gilbert's book "De Magnete" on magnetism, lodestones and their uses

Figure X: William Gilbert (*24 May 1544 in Colchester, Essex, England; †10

December 1603 in London or Colchester)

Figure XI: Ruins of the Poldice Mine near Gwennap in Cornwall. The Poldice Mine was in operation from the early 16th century until 1930.

Figure XII: Gilbert's Versorium – An early electroscope made of a pivot-mounted metal needle.

7.4 Further source material

**Original source text I:**
List of categories on the basis of which Gilbert has pinpointed the differences in the forces of attraction.
Source:
Die Geschichte der Physik. In Grundzügen mit synchronistischen Tabellen der Mathematik, der Chemie und beschreibenden Naturwissenschaften sowie der allgemeinen Geschichte, Teil 2: Geschichte der Physik in der Neueren Zeit, 1882, von Ferdinand Rosenberger (The History of Physics. In basic principles with synchronistic charts of mathematics, chemistry, and descriptive science as well as general history, part 2: History of Physics in Early Modern Times, 1882, by Ferdinand Rosenberger)

***He [Gilbert] states as the differences:***
***The electricity results from rubbing only, the magnet shows the force of attraction as a natural, lasting capacity***
***The electricity is neutralised by humidity, the magnet does not lose its force even when hard objects are placed in-between***
***The magnet attracts only few objects, the electricity affects almost all substances***

***The magnet moves objects of considerable weight, the electricity only light substances***

**Original source text II:**
Ferdinand Rosenberger on William Gilbert's scientific way of working (no blind belief in authority, no mere observation of nature – instead, experiments and the explanation of the observations).

Source:
Die Geschichte der Physik. In Grundzügen mit synchronistischen Tabellen der Mathematik, der Chemie und beschreibenden Naturwissenschaften sowie der allgemeinen Geschichte, Teil 2: Geschichte der Physik in der Neueren Zeit, 1882, von Ferdinand Rosenberger
(The History of Physics. In basic principles with synchronistic charts of mathematics, chemistry, and descriptive science as well as general history, part 2: History of Physics in Early Modern Times, 1882, by Ferdinand Rosenberger; page 38)

***It contains nothing of the usual Peripatetic (Aristotelian) natural philosophy, is not contemptuous of the observation of nature coupled with an overestimation of authority but is, on the contrary, founded completely on the experiment and shows evidence of some extraordinary skilfulness in the usage of the experimental method to explore unforeseen, natural phenomena.***
***Gilbert is a physician of a new style who in his closer field is competing with Galilei and is in no way inferior to him regarding his skilful experimenting, even if his ability to explain the observed does not come up to Galilei's.***

8. Obstacles to teaching an learning
The following remarks are meant to guide the teacher's proper use the material and to give advice how to support the students' reflections on the nature of science. Useful information is provided about pedagogical skills needed to teach this episode effectively.

8.1 Activities regarding the reconstruction of Gilbert's lab book
The idea of a laboratory diary, which used to be destroyed over the course of past centuries, is designed to enable more authentic and autonomous inquiry activities of the students. Students have to design experiments, collect data and evidence, keep their records and draw conclusions. This approach is challenging for a teacher since it will not be assured that all students develop similar experimental procedures and gain the same insights. Therefore guidance is needed provided by special materials the students can ask for, if needed. Moreover, different results should also be negotiated among the students. They should reflect on their experimental procedures and discuss their conclusions and insights. The teacher therefore should be aware that negotiations among students about experimental evidence and conclusions, which are supported respectively, are fruitful activities

for learning how to perform experiments on the one hand and to learn that controversies are at the heart of science itself.
Depending on the degree of their previous experience the activities can be offered to the students in different ways and combinations. Therefore, the teacher will be enabled to develop all students to their fullest potentials by considering differences among them. According to the particular student's capabilities, previous knowledge about experimentation and special interests the teacher can offer different activities or combinations of them:

1. The students will receive material I and material V together with the related tasks (material II and material VI) without any further instructional support.
2. The students will receive material I and material V together with the related tasks (material II and material VI) with further instructional support (adequate combinations of material III, IV, VII)
3. The students are free to decide, if they want to use additional instructional material (III, IV, VII) during their activities.
4. The activity for interviewing Gilbert (material VIII) can be used optional or compulsory according to the teacher's appraisal. Again, the students should be free to ask for help using material IX in order to support their autonomous and responsible learning.

In every case, the teacher should support the students in their approach in such a way that they are able to retrace Gilbert's most important stages of research on their own.
Before starting their research, it should be safeguarded that all students have fully understood the following issues:

- There is an overall research-question: "Is there a difference in the forces of attraction of magnets and electrified objects?"
- Gilbert has developed an idea as to how electrical and magnetic powers could differ. He establishes an assumption and wants to test it with experiments.

8.2 The "Reflection Corner" – a method for addressing the nature of science explicitly and reflectively

**The "reflection corner" is a method which facilitates and structures the students' reflections about role, function, conditions and properties of science, scientific knowledge, and its production towards general insights about the nature of science.**

Learn more...

9. Research Evidence
The evaluation of the case study is currently in progress.

10. Further User Professional Development
**Enclosed Literature**
[4] - Short essay of Gilbert's results containing a comment on the significance of Gilbert's differentiation of electricity and magnetism. (pg. 3, middle).

**Internet sources**
- www.iki.rssi.ru/.../stern/earthmag/DDMGRev2.htm
Summary of Gilbert's findings of "De Magnete" (German)

11. References
[1] Die Geschichte der Physik. In Grundzügen mit synchronistischen Tabellen der Mathematik, der Chemie und beschreibenden Naturwissenschaften sowie der allgemeinen Geschichte / Ferdinand Rosenberger, 2: Geschichte der Physik in der Neueren Zeit. - Reprint von 1882. - Hildesheim : Georg Olms, 19XX. - VI, 406 S.
(Rosenberger, Ferdinand: The History of Physics. In Basic Principles with Synchronistic Charts of Mathematics, Chemistry, and Descriptive Science as well as General History. Part 2: History of Physics in Early Modern Times. Reprinted in 1882. Hildesheim (19xx): Georg Olms, VI, 406 pages.)

[2] Priestley, Joseph (natural scientist, 1733 – 1804): The History and Present State of Electricity, with original experiments. London: Printed for J. Dodsley, J. Johnson and T. Cadell, 1767. (Third edition, 1775 at Google Books)

[3] Geschichte der Elektrizität / E. Hoppe – Reprint von 1884 – Liechtenstein: Sändig Reprints
(Hoppe, E. (xxxx): History of Electricity. Reprinted in 1884. Liechtenstein: Sändig Reprints)

[4] Zilsel, Edgar (1941): The Origins of William Gilbert's Scientific Method. In: Journal of the History of Ideas. January 1941, Vol. 2, Issue 1, pp. 1–32

[5] Steinle, F. (1997). Entering New Fields: Exploratory Uses of Experimentation. Philosophy of Science, 64 (Supplement), 65-S74.

[6] Kipnis, N. (2005). Scientific Analogies and Their Use in Teaching Science. Science & Education, 16: 883-920.