Stephen Gray - Electrical Conduction on the wrong track

1. Title and Key Words
Stephen Gray – Electrical Conduction on the Wrong Track

(Episode 4 of the series: Historical Introduction to Electricity)

static electricity, electrical repulsion, electrical attraction, electrical conduction, Stephen Gray, Isaac Newton, experimental systems

2. Autor(en) und Institution(en)
Andreas Henke, University of Bremen / Germany

Dietmar Höttecke, University of Hamburg / Germany

3. Abstract
This case study on Stephen Gray's Experiments on the conduction of electricity is the fourth episode in a series about the history of electricity. The main point of this stage is the discovery of and research on the ability of materials to conduct electricity, carried out by Stephen Gray. This episode is suitable for pupils in secondary school between the ages of 12 and 15 years old. Instructed by Gray's approach, pupils will experience the development of his experimental systems in the course of his research and how, despite premature conclusions and indirect paths, he nevertheless could create a division between conducting and non-conducting materials. The pupils can reconstruct this process and thereby reflect on the notion that, under such conditions, scientific knowledge should be taken as hypothetical and provisional. The pupils can reconstruct Gray's process of developing experimental systems themselves through experimentation or on the base of the materials provided. Thus, they should gain a realistic sense of the role experimental systems play in the research process. Further foundational ideas of electricity, which can be dealt with in this stage using the examples of Gray's research, are electrical induction as well as the overlap between electrical and magnetic forces.

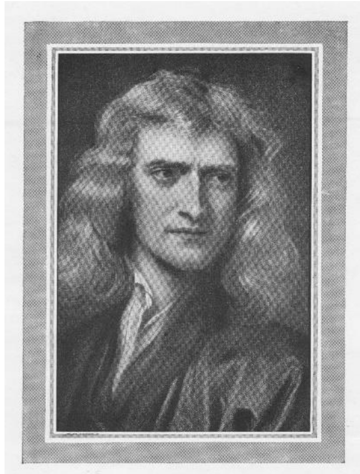
4. Description of Case Study (and Suggested Plan of Action)

In this stage the pupils can reconstruct the origin of the idea that electricity can spread or move itself within materials They will take part in Gray’s research and will also experience the wrong turns he took on his path. At the beginning, we suggest a short introductory phase about the life and research of Stephen Gray. Details are in **Sections 5.1.1 and 5.1.2**. Pupils can also inform themselves, for example during group work, about the points mentioned below, and present their results – **Material IV** is intended for this purpose.

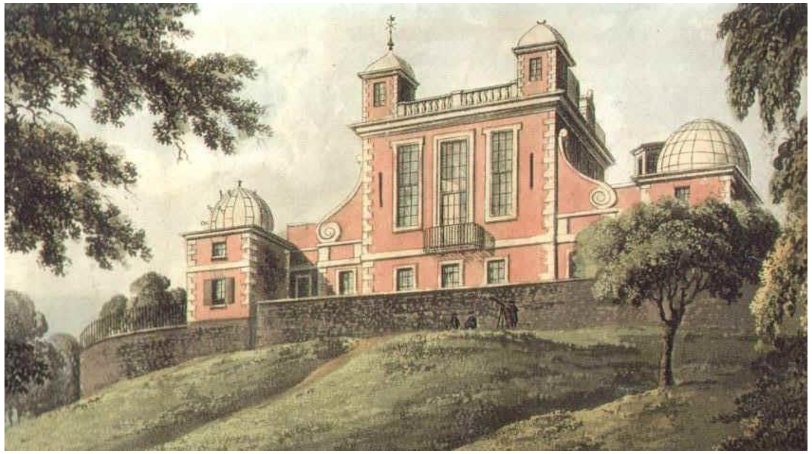
The following points are important here:

- His origins and occupation, and constantly precarious financial situation
- His interest and successful work as an astronomer
- Isaac Newton’s suppression of Gray’s results and its consequences
- Gray’s time in a London poorhouse and his initial experiments there
- Gray’s close work with other scientists of his day such as Granville Wheeler or Charles dú Fay (connection to the third stage of this series)
- His need to conduct spectacular demonstrations on electricity throughout London („Flying Boy“, „Conducting over Great Distances“) in order to earn money for his research.
- The unexpected beginning of Gray’s research on conductivity through his first setup with a glass tube.

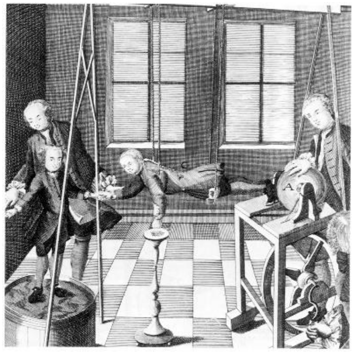
There is no known existing portrait of Stephen Gray.

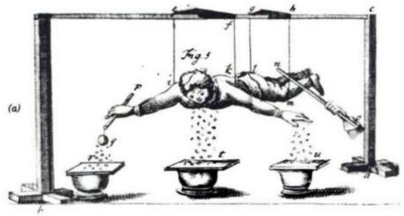


Sir Isaac Newton



This last point can be supported either with an **original text** from Stephen Gray (see Source I) or by **Demonstration Experiments** on setup 1, 2, and 3 (see Section 5.1.2). In a brief reflection on the nature of the natural sciences, pupils can comment on to what extent Gray's life and research contain typical elements of the natural sciences. (see Section 5.2) Possible questions for reflection could be:



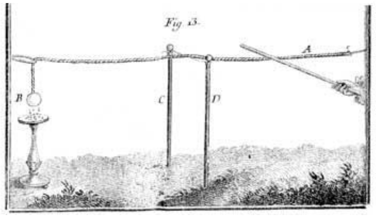


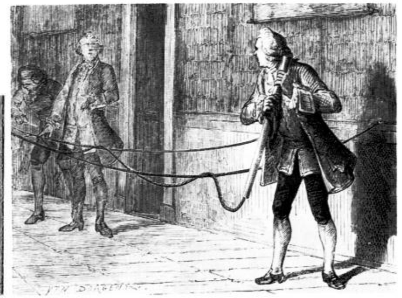
- What reasons caused Stephen Gray to present his experiments to the public? Where does something like this happen nowadays, and why?
- Until his death, Isaac Newton attempted to suppress Stephen Gray's research results. Because of this, Gray could not publish them for a long time. Do similar things happen often in the natural sciences, or is this an exceptional case?

In the following experimental phase pupils can follow Gray's path in exploring conduction as a property of a material. Gray's experimental setups are described in section 5.1.2 and the experiments in section 7.

An important feature of the development of Gray's research is the **random confirmation of hypotheses which are wrong from today's perspective**, that is, that electrical conductivity is solely influenced from the thickness of the material being used. He and his colleague first noticed their mistake as they were forced –through mechanical difficulties – to change their setup while they were already in the middle of the next problem. In addition, the reconstruction of this process for instruction aims at practicing the use and meaning of the terms **speculation, observation, experiment, and experimental setup.**

Before the actual experimental phase begins:An important feature of the development of Gray's research is the **random confirmation of hypotheses which are wrong from today's perspective**, that is, that electrical conductivity is solely influenced from the thickness of the material being used. He and his colleague first noticed their mistake as they were forced – through mechanical difficulties – to change their setup while they were already in the middle of the next problem. In addition, the reconstruction of this process for instruction aims at practicing the use and meaning of the terms **speculation, observation, experiment, and experimental setup.** Before the actual experimental phase begins:





- pupils should be informed about Gray's original research intention (testing a hollow glass tube to see if it can be electrified), for example using demonstration experiments with setups 1, 2 and 3 (see Section 5.1.2)
- the technical requirements should be explained (electrification through rubbing, loss of electrification through grounding)
- a concrete research question should be posed which is valid for the entire research phase (for example**„What influences whether a material conducts electricity or not?"**)

Information about possible experiments in the experimental phase as well as the corresponding experimental setups can be found in Section 7.1.

One possibility for guiding the students during their experiments is to use **Material for Pupils I & II**. Here, through a fictional correspondence with Gray, they are informed about his experimental setup, lines of questioning, suppositions, and observations. Through the accompanying tasks, they will be motivated to **do their own research** or **to reflect** on scientific endeavours**.** At the end of a step in the research, the pupils can present or discuss their results, or ask for help from their teacher, Some suggestions for reflective questions on learning about the nature of the natural sciences can also be found in **Material for Pupils I & II** The correspondence following each can serve as a reinforcement of the previous research task, or can also, as needed, provide extra assistance for the pupils during the experiments.

5. Historical and philosophical background including nature of science

5.1 Historical background

5.1.1 Stephen Gray's rocky career

Stephen Gray (born December 1666 in Canterbury; died 7 or 15 February 1736 in London) and Charles dú Fay were the key figures in electricity research between 1729 and 1740. Both progressed from examining static phenomena of charged bodies to experimenting on the movement of electricity. However, for dú Fay the transmission of electricity was still only possible through a ‚transport body', for Gray electricity itself was brought into motion and transmitted *itself* over great distances.

After a **rudimentary school education** Stephen Gray soon began working as his father's assistant in the **dyers' trade**. (This was one reason why he later held the hypothesis that the color of a substance has something to do with its ability to be electrified). There was not much money to be made in this trade and he could only pursue his interests in the natural sciences, especially **astronomy,** through consistent private study and the help of affluent friends who allowed him the use of their libraries and scientific instruments. Gray began to grind his own telescope lenses and quickly became known for his exceptionally good work and his exact **astronomical observations**, including new knowledge about **sunspots** and the **moons of other planets** in the solar system.

A bitter setback for Gray was the **bankruptcy of an observatory** where he worked (Isaac Newton was not altogether innocent in the matter of this bankruptcy, see below). This forced him to return to the dye works for some time. Because of health problems, he obtained an unpaid position as an **assistant** to John Desaguliers (Gray did get room and board). Desaguliers worked for the Royal Society (a society of British intellectuals committed to promoting science, for example through publishing physics journals) seeking to demonstrate the newest scientific knowledge throughout England.

Poverty continued to trap Gray and it was only with the help of his friends in getting accomodation in a **home for the needy** and a small pension in recognition of his discoveries in astronomy, that he was able to begin his **experiments on electricity**, mostly either in his room or in the hallways. (see Fig 8).

During his life and even today, Gray's recognition as a scientist has suffered, **firstly** from the consequences of his **poverty**, which caused him to have to publish his results through other people, and **secondly** from his status as an **amateur scientist**, who only followed his vocation late in life, but the **third**, and most profound hindrance to his recognition was the influence of **Isaac Newton** (see picture under the Members of the Royal Society.) Newton found himself in a long and heated dispute with a good friend and supporter of Gray, John Flamsteed, and the result of this was that he did not permit many of their articles to be published. For Gray, who was dependent on his personal connections and their support, this had fatal consequences: the majority of his articles could only be first published after **Newton's death** in 1727, whereupon in 1731 and 1732 Gray received the first two Copely Medals in recognition of his discoveries – only four years before his death. Even on his deathbed, Gray told his doctor about all the experiments and discoveries he was still planning to undertake.

Even today Stephen Gray is much less honored than, for example, Benjamin Franklin or many other researchers in the area of electricity, although he carried out many more experiments than can be covered here. It is assumed that he is buried in a mass grave for the residents of the poorhouse where he lived.

5.1.2 Stephen Gray's Experiments on the Transmission of Electricity: Electricty as a Property of Form or as a Property of Material

Background and Details

Originally, Gray wanted to study whether the electrifiabiliy of a hollow glass tube is dependent on whether or not its ends were open or closed during and after rubbing. Starting from the discovery of the transmission of electrification (see Material A) he expanded his experiments by constantly varying his setups, and thereby discovered that the conductivity of materials is less dependent on their form (thickness) than on the material itself.

It was thus possible to differentiate between conductors and insulators of different. In point 8 a reconstruction of Gray's research for teaching purposes is depicted.

The term **insulator** was influenced by **Charles dú Fay,** (see Stage 4), but arose from good communication between Gray and dú Fay. Because dú Fay claimed that Gray's transmitting cords always lost some of their electricity to the air, he recommended that they should be protected from the air with an i**nsulating** casing.

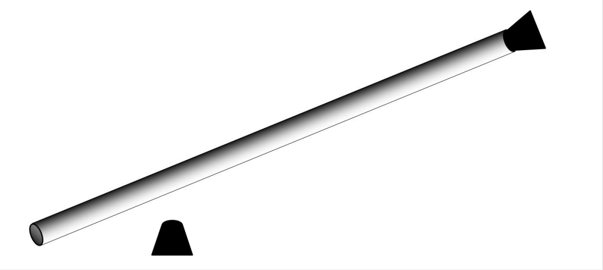
Development of Gray's Experimental Setups

In the course of his resarch he continually varied his experimental setups. Only thus was it possible – mostly through **coincidence** - for him to conclude that the transmission of electricity is indeed dependent on the material and not on its form. The most important six stations of this process and Gray's approach are outlined here:

1. Glass Tube with Cork Stoppers
Electricity is transmitted 1 – Fig 2

The glass tube is corked from one or both sides and then rubbed. One can see that not only the tube, but also the corks seemed to be electrified.

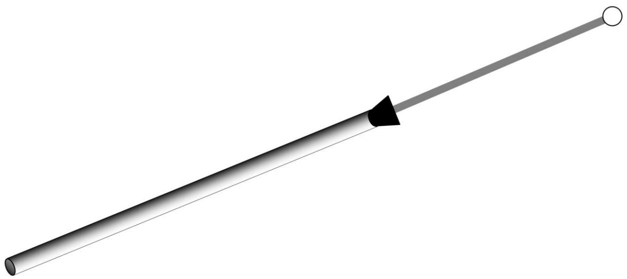
([2], p. 20 center, [1], p.18 bottom)



2. Glass Tube with Cork Stoppers & Rod with Ball
Electricity is transmitted 2 – Fig 3

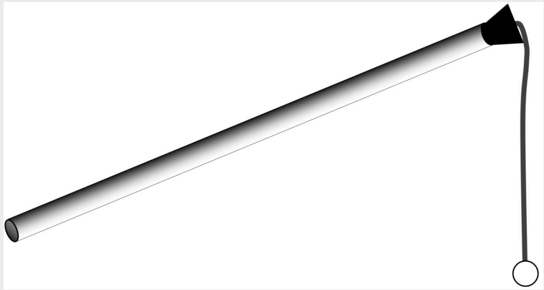
A rod is stuck into a cork, and an ivory ball is attached to the end of the rod. If the cork is then stuck into the glass tube, the ball also becomes electrified.

([2], p. 20 bottom, [1], S 19 top)



3. Glass Tube with Cork Stoppers & Cord with Ball
Electricity is transmitted 3 – Fig 4

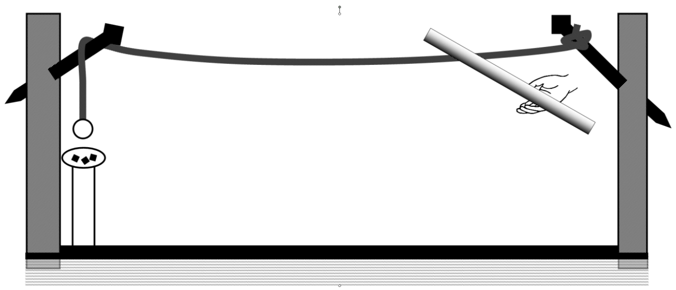
This setup demonstrates the transition to the hemp cord experiments. Here, a piece of hemp cord, ca. 1m long, is attached to the cork, and the aforementioned ivory ball is attached to the end of the cord. If the cord is suspended and the glass tube rubbed, the ball is also electrified. In the second variation, Gray made the cord



longer and suspended it from a balcony. Even then, the ball appears to be attracting.

([2], p. 21 center, [1], p. 19 bottom)

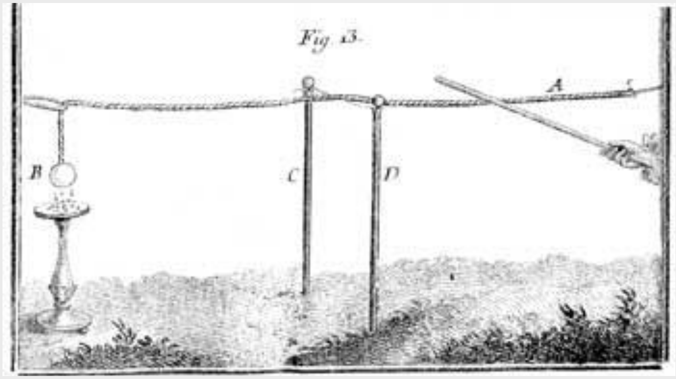
4. Horizontal hemp cord, electrified by the glass rod
Thicker bodies transmit – Fig 5



Here a hemp cord is stretched out horizontally, similarly as can be seen in Material C. *Gray admits that the transmission failed.* The reason: he used thick nails in wooden beams to support the cord. He himself recognized that the electrical current was transmitted through the nails and beams into the earth and changed his setup.

([2], p. 25 center)

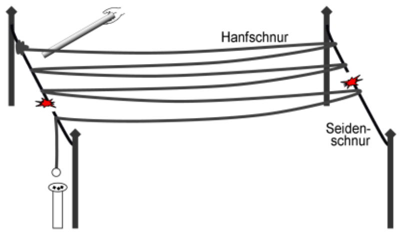
5. Horizonal hemp cord, attached to silk threads
Thinner bodies do not transmit – Fig. 6

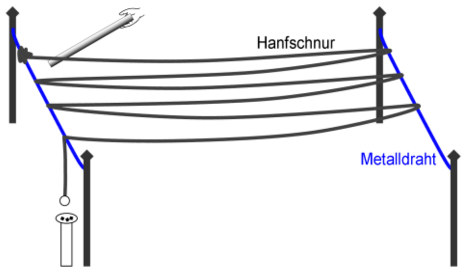


Gray's Hypothesis: the thickness of the cord determines whether it transmits or not. (the beams were thick) Therefore, he laid the hemp cords on thin silk threads and had success. **Thus the wrong hypothesis was confirmed** (only thin bodies do not transmit), because silk is an insulator, and whether it is thick or thin is not at all important! Only with a further variation in the setup and a new line of questioning could this idea be corrected.

([2], p. 26 center)

6. Long hemp cord – transmission over great distances
Thin bodies do transmit! Transmitters and non-transmitters.
With his friend Granville Wheeler, Gray made the hemp cord longer and longer, in order to test **how far electricity allowed itself to be transmitted**.
In Variation 6A the hemp cord was attached in a zig-zag fashion over lines of cord. (Fig 7, Fig 13) Through the weight of the hemp cord, the silk cord ripped. Wheeler suggested using **thin metal wire instead,** which, according to the hypothesis posed previously, should **not conduct**. Both Gray and Wheeler were of the opinion that electricity could not flow through thin materials. However, when they used a thinner but more sturdy metal wire instead of silk this **wire conducted electricity, contrary to their expectations.**
([1], p.21 bottom – p.22 top).





They concluded that it is not the thickness that is decisive in electrical conduction, but rather the material itself. Just as one can differentiate between electrifiable and non electrifiable materials, one can make a distinction, too, between **conductors and non-conductors.**

They used this information in **Variation 6B**, and used a great number of parallel silk cords to support the zig-zagged hemp cord. (Fig 8, Fig 9)

5.2 Learning about the Nature of Science

5.2.1 Detours in Research – Provisional Knowledge

Gray’s experimental approach, and the knowledge he gained through it, make the core components of the scientific learning process clear. The example of Gray’s work further demonstrates that scientists may even then come to the (later proven) wrong conclusions when their observations fit their hypotheses. After his first discovery, Gray began to research more stringently.

He **observed** and **measured**, and proposed a **hypotheses** based on his observations. He designed a range of new experiments to test his hypotheses. All these are important elements of scientific research. This case shows that such research is not a perfect method, inevitably leading to hard facts, but can, as shown here, through chance and misinterpretation, lead to false evidencial support for a hypothesis.

The „ignorant old-fashioned researcher“ is naturally guilty of these false conclusions, as pupils often imagine; however, such things continually happen in modern research processes as well. The direct result is that knowledge in physics which is seen as ‚proven’ nowadays (for example that the universe is not infinitely large) is also provisional, because it can be changed or even conclusively disproved in the near future. At the end of the day, this knowledge is also "nothing more" than a complex body of hypotheses fitting each other and supported by observations.

5.2.2 Development of Experimental Setups

In the course of research on a particular object or phenomenon, constant gradual changes in the setup of the experimental process are almost always taking place (when the setup is not being fully built anew.) The amount of change is guided by the original line of questioning, new observations and guesses, mistakes, and the creativity of the researcher. A good experiment does not suddenly arise complete and ready to go either on the drawing table or in the mind of the scientist, but rather continues to develop through questioning and the problems that occur as things go along. At the end, the experimental setup can be completely different from what it was at the beginning.

Gray’s experimental setup developed from the original **glass tube with stoppers** to one containing hundreds of meters of silk cords. However, the area he was researching (the transmission of electricity) remained roughly the same.

5.2.3 The Material Culture of the Natural Sciences

The materials Gray used in his experiments are very different from those which are used for similar experiments nowadays. Many of the materials he used, such as silk or hemp cords, are materials with which we simply do not come into contact nowadays. Contrasting the use of different materials in experimentation in Gray's time and today can help the pupils grasp how science, and scientists, are influenced by the culture in which they live. This kind of influence exists even today and can also be the target of the pupils' reflection. The material culture of a time is defined as the totality of natural and artificial materials, machines, tools, buildings, clothing, jewelry, and similar products which were used at that time. In addition, the role these things play in humans' lives is part of this culture.

The material culture of research on electricity was strongly influenced by Gray's discoveries and the materials and devices he used: glass tubes quickly became standard objects in other researchers' inventory, and the use of silk cords for electrical insulation of objects remained the method of choice for quite some time.

5.2.4 Technology, Experiments and Theory

In scientific research, three things play a fundamental role and are also continuously influencing and affecting each others' development:

1. **Technology** – for example, the typical kinds of **craftmanship** and **available materials** of a particular time and place, which are used to realize the idea of an experimental setup. This experimental setup is then suitable for example for testing a particular assumption.
2. **Experiments** – this means the necessary **materials** for a particular setup and their particular arrangement as well as the **practical experience** of the researcher who is dealing with the setup – this is the core of research, but it is worthless without technology and theory.
3. **Theory** – the **previous knowledge** and **theoretical background** of the researcher, his or her presumptions about the existance of and relationship between **variables**, the reasons that he or she comes up with to order his or her assumptions and to **explain** his or her observations, and the reseachers ideas - influence what she or he changes in the experiment and what he or she understands about it.

No *real*, *existing* experiment in a *real*, *existing* research process can be carried out meaningful without practice. This means not only *understanding* what disturbances can occur and how to prevent them, but also the real *capability* to do so. Science is often enough just as much craftmanship as it is mental work! The pupils should understand that real experiments are not created instantaneously, ready to go at the push of a button and quickly test hypotheses or provide clear measured results. Rather, constant development and fine tuning is always part of the process. This constant tinkering is just as important for scientific work as the development of theories, the acquisition of knowledge, or the presentation of results.

5.2.5 Conflicts, Intrigues, and Fortunes in Science

The influence that the famous Isaac Newton had on Gray's life through Newton's **lifelong obstinacy towards Gray's publishing of his results** makes it clear how important the human element is in the sciences. These conditions meant that Gray's results remained long unknown, and that his financial situation became ever more precarious.

The meaning of fame and recognition emerges as well as that of human weakness, against which even brilliant scientists like Newton are not immune. (for more, see 5.1.1 and the attached students' information material).

5.2.6 Subjectivity and Error as Part of Scientific Endeavor (see Experiment 5)

Experiment 5 and especially Gray's statements about it clearly shows the influence of the personality of the researcher and his or her life experience on the interpretation of observations, and in this case, even the unconscious creation of results to verify his ideas.

Gray's longstanding work as an astronomer, his strong interest in and previous knowledge of the positions and movements of stars and planets, and his wish for more recognition after the long period of suppression through Newton may, in this case, have led to the unconscious creation of an aligned circular/elliptical motion of the pendulum, based on the direction of motion of planets which was already known to him. Perhaps Gray initially observed some cases of circular motion in the "wrong" direction, but because of his deep belief in his assumption, he a) unconsciously surpressed this results, as is possible in this kind of pendulum experiment or b) attributed these cases to experimental flaws.
Two other points may have amplified his prepossession towards one type of circuar motion:

1. The certainty that he could use the effect to construct an electrical-mechanical model of the solar system, through which he could gain greater recognition
2. The hope that he could devise from this effect **an (electrical) theory that explains planetary motion in the entire universe.**

This kind of subjectivity exists everywhere in the sciences and is dangerous; it is the unconscious influence of the scientist's hard-held beliefs in his or her own ideas that influences the process of measurement.

5.2.7 Science in the Public

Gray and Wheeler went public quickly with **their large-scale experiments** – for example, they planned to hang a hemp cord from the top of a church tower, in order to get more length in their experiment. They perform the experiment with the **hanging boy (see Material)**, who was electrified, and then attracted small objects which flew onto his hands and face. Whenever Gray conducted it publicly in London, this experiment was a huge hit.

Here it is plain to see that scientists are always dependent on the acceptance and support of the general public. This was especially so for Gray. (see 5.2.5 Conflicts, Intrigues, and Fortunes in Science).

When scientists want to impress with huge experimental setups or spectatular results they often are doing so on purpose. This connection between society and science continues to be reflected, even today, in the promotion of research, for example, or the politics surrounding research, where sponsorship is dependent on results being published.

Large scale experiments and experimental setups still have a representative character today; good examples here are the Drop Tower at Bremen's University, or the parts of the Cern Laboratories in Geneva which are visible above ground. Progress on the construction of the billion-dollar Large Hadron Collider continues to be reported on worldwide, the Hubble Telescope now has multiple fan sites on the Internet. Examples from history include Foucault's Pendulum experiment in the largest planetarium in Paris to which he invited the whole Parisian scientific community. A further demonstration for all citizens in the Panthéon, the tallest building in Paris, was even mandated by the King of France, in order to demonstrate his support for the sciences.

6. Target group, curricular relevance and didactical benefit

6.1 Learning objectives and competencies

6.1.1 Nature of science

Pupils should...

- Experience that scientific knowledge is often determined through the gradual and continuous development and changing of experiments
- Experience that scientific knowledge is not necessarily gained through a completed experimental setup but that rather often changing setups leads to new phenomena.
- Understand that scientific knowledge can only ever be provisional but that it is none the less reliable because it is supported by observation.
- Recognize that research in the natural sciences is not an exclusive process of proving, but instead a never-ending process of reinforcing or breaking down of hypotheses.

- and understand that research is always underlaid with subjective influences, which can be helpful as well as dangerous to the research process.
- Comprehend that scientists never obtain hypotheses ‚off the top of their heads' but that these hypotheses are influenced by previous experiments.
- Understand that the process of research in the natural sciences is strongly influenced by improvisation, creativity, and constant practice.

6.1.2 Scientific Inquiry

Students are supposed to …

- solve their tasks in groups
- control their results by comparing them with other groups
- assess the influence of possible sources of errors on the validity of their results
- draw up simple sketches
- argue in a comparative way using "the (more) … the (less)" structures
- express with our without any assistance assumptions on the correlations or reasons
- develop with or without any assistance approaches to verify their assumptions
- plan and carry out simple experiments with different degrees of autonomy
- record their observations with or without any assistance and establish measuring charts
- use their observations for the assisted verification of their assumptions
- deal independently with the experimenting materials

6.1.3 Content Knowledge

- Electricity can spread itself within materials
- Conductivity is dependent on the material itself – there are conductors and non-conductors.
- Non-conductors are called insulators.
- Electrostatic Induction (latin „Influence"): redistribution of electrical charge in conductive objects, caused by the attraction and repulsion by nearby charges
- Electrical and magnetic forces overlap each other without disturbance.
- Electricity discharges into the ground. The earth is a very large reservoir for electrical charge.

6.1.4 Communication

The pupils should…

- get to know the interaction between science and public life, for example by recognizing the role and function of Gray's public demonstrations aside from financial conciderations.

6.1.5 Critical Judgement

The pupils should...

- assess the influence of external and non-rational factors on the process of scientific research, using the example of Newton's suppression of Gray's work.
- grasp the meaning of scientists' ‚worldly' motives by analysing Gray's actions with his precarious financial situation in mind.
- understand the meaning of material culture for science in a particular era and thus comprehend that science had other materials at hand at different points in history. This does not mean that such research is limited or of lesser value.

7. Activities, methods and media for learning

7.1 Experiments

7.1.1 Required Material

Most of these materials can be purchased at a hardware or arts and crafts supply store or in the materials for chemistry lessons.

- (Flint)Glass tube, with a diameter of ca. 3cm, and length of ca. 1m, and the appropriate cork stoppers for both ends.
- Silk cord, hemp cord of different thicknesses, metal wire
- Small balls with eyelets or holes (cork, ivory, brass, etc.)
- Objects for securing the silk and hemp cords (such as wooden rods)
- Metal plate or other conducting surface
- Pendulum electroscope (optional)
- Objects for rubbing: wool, cotton, and silk cloths, cat fur
- Magnets/magnetic iron ore
- lightweight bodies: chaff, small pieces of wood or wood chips, dry earth, small stones, salt, smoke (for example the smoke of an extinguished candle), cotton threads, scraps of paper, brass or iron shavings, powdered iron.

Experiment 1: Electric Attraction and Repulsion Continues to Function after Transmission

Gray conducted this experiment **with almost all of his experimental setups** (see 7.1.2) in order to test if conduction through different materials or over differing distances had any effect on electrical phenomena which are **already known**. For this purpose, a small pile of lightweight bodies on a plate were positioned under the end of the tube or thread which was to conduct electricity. When conduction accured the small objects would be attracted

Advice:
Because it is difficult to show the repulsion affect in this experiment, it is good to use Guericke's experiments on repulsion. One can then let a piece of down feather float at the end of the tube (cork, ball or stick, see below.) Repulsion can also be clearly demonstrated by a pendulum electroscope because of its high degree of sensitivity, or ,following dú Fay's method, one could even use a simple silk thread.

Experiment 2: Conductivity as a Property of Material Instead of a Property of Form
When the weight of the hemp cord in experiments on long-distance conduction became too heavy, **the silk cord broke** and Gray had to look for an alternative. After **Setups 4 and 5**, he was of the opinion that electricity could not flow through **thin materials**, but when he used a thinner, but more sturdy **metal wire in Setup 6**, he found, contrary to his expectations, that it indeed did conduct. ([1], page 21 bottom – p.22 top). He concluded that **it is not the thickness, but the material itself** that is critical for conduction of "the electrical fluid". Similarly to how electrifiable and non-electrifiable materials could already be classified, one could now make a distinction between conductors and non-conductors. In Setups 5 and 6 the ability of various materials to conduct could be tested. For example, Gray tied a piece of silk cord to the middle of the hemp cord. Longer rods of wood, glass, or metal could also be laid over two silk cords and tested for their conductivity. These experiments show that materials which do not conduct are the same which are easiest to electrify, and that those which are good conductors are harder to electrify. The term „conductor", and therefore the present-day conceptualisation of **conductors** and **non-conductors** was introduced by Gray's colleague John Desaguliers.

Experiment 3: Electrostatic Induction – Electrification Occurs over Distances ([1], p.28 center):

In good (dry) weather and with a strong electrical charge in the glass tube, one can see how **electrical attraction already starts occuring on the other end of the cord even when the tube is only placed near the one end.** The attraction only remains as long as the tube is in the vicinity of the cord, which demonstrates that there is no transmission occurring from the rod to and through the cord. Gray himself used small metal rings which enclosed the conducting cord, and onto which he again fastened a ball. He could then ascertain electrical attraction in the ball when the conducting cord had been electrified.

Experiment 4: Undisturbed Overlap of Electrical and Magnetic phenomena
Instead of the ball, a magnet is attached. First, it only attracts the materials which are known to be attracted by magnets, but when it is electrified through the rubbed glassrod and via the conducting hemp cord, it attracts all materials. When analysed all the known properties of each phenomena remain – magnetism and electricity clearly do not negatively affect one another.

„Drawing sparks“
Gray employed, almost simultaneously with dú Fay, some of the first systematic experiments on ‚electrical fire.’ With this term, they meant electrical sparkovers, known as sparks – in Gray’s day the comparison with fire was obvious and common, due to their brightness, the pain associated with sparks, their ability to leave burn marks and finally due to the famous show-exeriment of igniting ether by electrical sparks. Among other investigations, Gray studied which body parts produce the brightest sparks. (Setup as in Material E)
For teaching purposes, different forms of discharge points can be tested and the phenomena and their dependence on form can be described.

Experiment 5: Electricity and The Motion of the Planets – Gray’s False Conclusion Through Analogy (see Fig. 11)
First, Gray electrified a small ball (ca. 3 cm. diameter), placed in the middle of a round, insulating surface, through rubbing or through the electrified glass tube. Then, in the same manner, he electrified a small piece of cork with a long, thin silk thread (ca. 20 cm. long). Next this was held at about 50 cm. above the ball, as close as possible to its center, and the piece of cork is slowly brought downwards until it is almost touching the ball. The piece of cork attached to the string will slowly begin to move in a circle around the ball – as Gray put it „from the right side to the left“ – that is, in the same direction as the planets move around the sun (to the left, as seen from looking down at the plane of the ecliptic from the north celestial pole.

Hint:
The unconscious influence can be seen very dramatically when using this experiment for teaching in a special way:

Two groups of pupils get the text from Material G, where one text describes motion to the left, the other motion to the right. In an attempt to reconstruct Gray’s results, both groups arrive at positive results and will defend them before the other group!

The resulting confusion can be used to reflect on ideas of the quality of their research (e.g. why holding the silk thread **with bare hands**) and the objectivity of their observations (since they are reiterating **known results** from a **credible scientist**). This discussions may then be used to make generalizations about science and scientists.

7.2 Material for Students

Material I & II: Correspondance with Gray / Milestones in Gray's Research

The following list may help structure the experimental phase; for example, it can be used to carry out a fictitious correspondance with Stephen Gray.
Images of Grays experimental Setups can be given along with them.

These imaginary letters from Gray can initiate pupils' research:

My esteemed colleague,

I am delighted that you show so much interest in my experiments on electricity! In the coming weeks and months I will keep you informed about the progress of my research. I will demonstrate my experimental setups for you and explain why I have changed them. In addition, I will report the hypotheses my research has led me to, which experiments I will use to test these, and which observations support or weaken my hypotheses. If you should happen to discover any errors in my experiments or catch me making overly hasty conclusions, I beg of you to please inform me as soon as possible,

your most obedient humble servant,

Stephen Gray

The pupils can, in the five steps displayed here, receive pictures of the experimental setups, the corresponding letters, and the tasks for each experiment

	Setup and Material	Gray's Commentary (for example as correspondance or cards with extra information)	Suggested Tasks
1	Setups 1, 2, 3, 4 Figures 2-5	*My hypothesis is that all materials will conduct electricity if they are sufficiently thick. After all, in my first rather surprising experiment, the corks were thick. The wooden rod in my second experiment and the hemp cord in my third setup were also relatively thick. Also, in my final experiment, with the cord nailed to the wooden beams, there was no conduction: I could not observe an attraction at the end of the cord. The electricity must have been transmitted through the thick nails and the thick beams into the earth, instead of through the cord. Therefore, the conduction of electricity must be determined by the thickness of the material.*	1) Note the research questions that you and Gray want to research. 2) Which hypothesis did Gray have and which observations already support his hypothesis? 3) Plan an experiment with which you can test Gray's hypothesis. Create an appropriate setup which Gray could also have used.
	Possible Questions for Reflecting on the Nature of Science: Which materials and devices did Gray use for his research? Which would researchers nowadays employ for these purposes? How do the available materials for research influence how scientists work? Many people claim that "scientists could not do proper research" in earlier times in history, because they did not have access to good materials and devices' – what do you think of this claim?		
2	Setup 5 Figures 6 and 12	*Instead of the nail, I've now attached the hemp cord to a silk cord. Now I have observed that the hemp cord conducts electricity. The electricity is no longer grounded into the earth through the silk cord.This supports the hypothesis I have obtained from the previous setup, because the hemp*	Stephen Gray made different observations during his experimenting with different setups. These observations supported his hypothesis that all materials will conduct

			cord is thick and the silk cord thin. I am now quite certain that the thickness of a material determines whether it conducts or not. Now I can say with some certainty that thin bodies prevent the flow of electricity and thick bodies allow it to flow freely, no matter what kind of material they are made of – this is a truly a new idea!	electricity if they are just thick enough. 1) Which observations are these? 2) How certain can Gray be that his hypothesis is correct? Give reasons for your answer.
3	Setup Figure 13	6A	*Now I am working with my friend and colleague Granville Wheeler. Our further experiments should demonstrate how far electricity can be transmitted. For this purpose, we have lain the hemp cord multiple times back and forth across the silk thread. However, the great weight often unfortunately makes the silk thread rip!*	Put yourself into Gray's shoes: he is certain that only thin materials do not conduct electricity! Using this knowledge, how would he solve the problem of the silk thread tearing?
4	Setup Figure 7	6A	*We used a very thin metal wire, which is strong enough but nevertheless thin enough that it will not transmit electricity.* ***However, with the metal wire, I could not observe any further transmission.*** *I cannot explain these results, so I have consulted with my friend Wheeler and conducted the experiment again with him – with the same results!* *We were certain that the thickness of the material determines if it conduts or not. This appears now to possibly be wrong, since our thin metal wire grounded the electricity into the earth! We believe that we have already previously been wrong, because the new observations do not*	1) What does Gray do when he is surprised by the ability of the metal wire to conduct? Why do you think does he react in this way? 2) Why is Gray of the opinion that all scientific knowledge is only provisional, that is, that it might be wrong in the future?

fit our hypothesis. Perhaps our earlier observations were, in fact, only supported through ***coincidence****.*
We must accept the fact that the knowledge we hold to be certain can perhaps be proven to be wrong in the future! In our case, luckily, this happened quickly.

Possible Questions for Reflection
If Gray had not conducted the experiment with the metal wire, would we now believe that all thin materials are non-conductors – even metal?

All scientific knowledge seems to be provisional. So why do we rely on it nevertheless?

5

After some thought we could agree on a completely different hypothesis: ***perhaps the type of material itself determines whether it conducts, and not its thickness? Perhaps, then, there are types of material which conduct electricity and those which do not.***

This new hypothesis is supported by ***both*** *our new and our old observations. Before I allow myself to be completely convinced, I must carry out further research.*

1) Which observations support Gray's and Wheeler's new hypothesis?
2) Plan an experiment with which you can test Gray's hypothesis.
Create an appropriate setup which Gray could also have used.

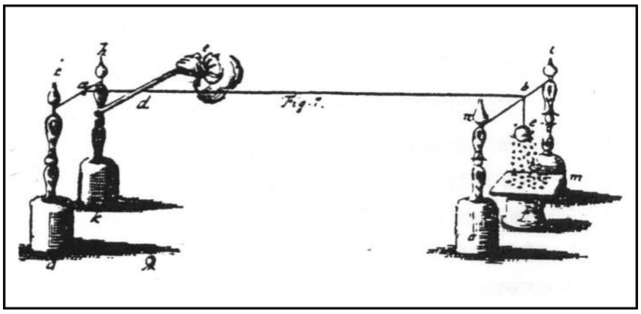
Material III: Writing Task – Critical Letters from Readers
The following material for pupils can serve as a conclusion for the case study. It consists of a fictional encyclopedia entry about Stephen Gray's research which contains some incorrect information.

The pupils should discover the errors based on the knowledge they have gained from the case study, and write a letter containing some suggestions for correction.

Encyclopedia Entry: International Online Encyclopedia

Stephen Gray *(born December 1666 in Canterbury; died 7. February 1736 in London) was an English scientist.*
… …

Stephen Gray's Research
Stephen Gray's research is a good example of research in the natural sciences. He conducted all his experiments using the setup outlined below, which he created at the very beginning of his experimenting.



In his research, Stephen Gray was always cautious not be too certain about his research results. His research was, in fact, so good, that he needed no extra help. Therefore he could demonstrate, without any detours to his conclusion, that there are two different kinds of materials – conductors and non-conductors. It is only through Gray's research that we can be certain of this once and for all.

Your Task

This encyclopedia entry on Stephen Gray's Forschung urgently needs to be fixed!
However, at least two things seem to be correct:
1. Gray's research is indeed very typical for research in the natural sciences.
2. Gray recognized that there are conducting and non-conducting materials
Unfortunately, though, much is wrong in this entry, and you definitely know better!
Find what is not correct and write an email to the editor, informing him or her about what is still not, in your opinion, correct. Suggest what she or he should write instead.

Your letter could begin like this:
"Dear Editors of the International Online Encyclopedia,

Several errors in your entry on Stephen Gray attracted my interest. It is true *that we can learn a great deal about how scientists work from Gray's research. Furthermore, it is also true that Gray discovered that certain materials conduct electricity while others do not. However, I have also noticed quite a few mistakes in the paragraph on Stephen Gray's research. For example..."*

Material IV: Informational Texts on Stephen Gray
This material can be found in the attatchment on this page.

With the help of this material, pupils can inform themselves about:

1. Stephen Gray: origins, occupation, financial situation
2. Gray and astronomy – from craftsman to research
3. Gray and Newton – scientists are people too
4. Gray's collaboration with other scientists – teamwork and support
5. Spectacular Presentations – Gray's side job
6. Gray's first experiments with the glass tube

7.3 Pictures and Media
Overview

- Figure 1: Portrait of Stephen Gray
- Figure 2: Setup 1 - Glass Tube with Cork Stoppers - Electricity is Transmitted 1
- Figure 3: Setup 2 - Glass Tube with Cork Stoppers and Rod with Ball - Electricity is Transmitted 2
- Figure 4: Setup 3 - Glass Rod with Cork Stoppers and Cord with Ball - Electricity is Transmitted 3
- Figure 5: Setup 4 - Hemp Cord Hung Horizontally, Electrified Through Glass Tube
- Figure 5: Setup 5 - Hemp Cord Hung Horizontally From Silk Cords - Thin Bodies Do Not Conduct
- Figure 7: Setup 6A - Transmission over Distances - Conducting Metal Wire
- Figure 8: Setup 6B - Gray's Experiment on Transmission over Greater Distances With His Friend Wheeler in a Corridor of the Poorhouse.
- Figure 9: Setup 6B - Reconstruction of Gray's Experiment Transmitting Electricity over Great Distances (University of Oldenburg).
- Figure 10: Gray's Experiment With a Boy Hung By Silk Cords.
- Figure 11: Depiction of Stephen Gray's Experiment on Rotating Small Charged Bodies around Larger Ones.
- Figure 12: A Further Variation on Setup 5 - The hemp cord is hung horizontally from the silk thread.
- Figure 13: Setup 6A - Transmission Over Great Distances - broken silk thread.

- Figure 14: Portrait of Sir Isaac Newton

Figure 1: Portrait of Stephen Gray
There is no known existing portrait of Stephen Gray

Figure 2: Setup 1 - Glass Tube with Cork Stoppers - Electricity is Transmitted 1

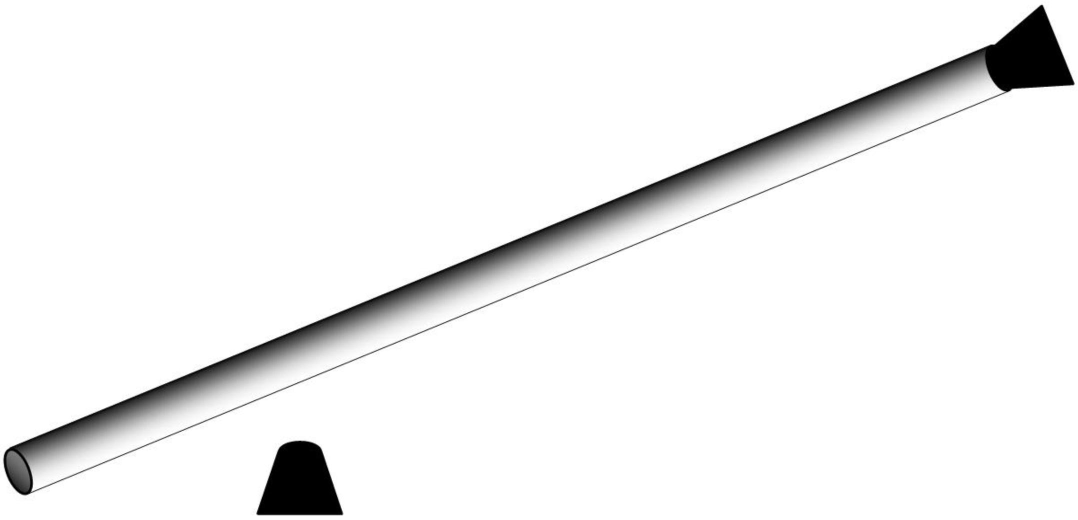


Figure 3: Setup 2 - Glass Tube with Cork Stoppers and Rod with Ball - Electricity is Transmitted 2

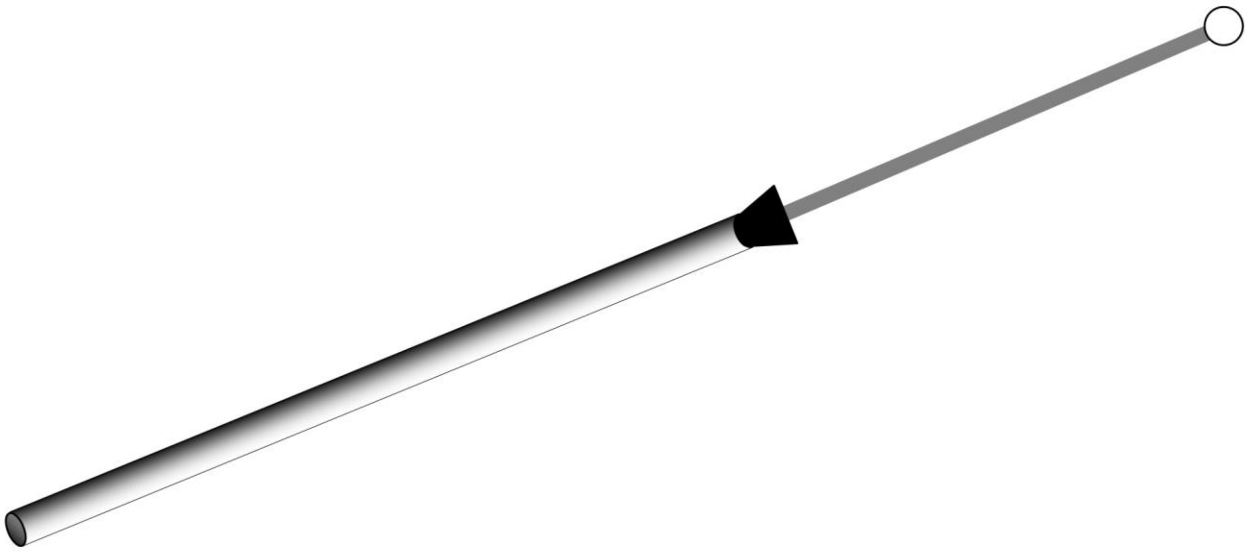


Figure 4: Setup 3 - Glass Rod with Cork Stoppers and Cord with Ball - Electricity is Transmitted 3

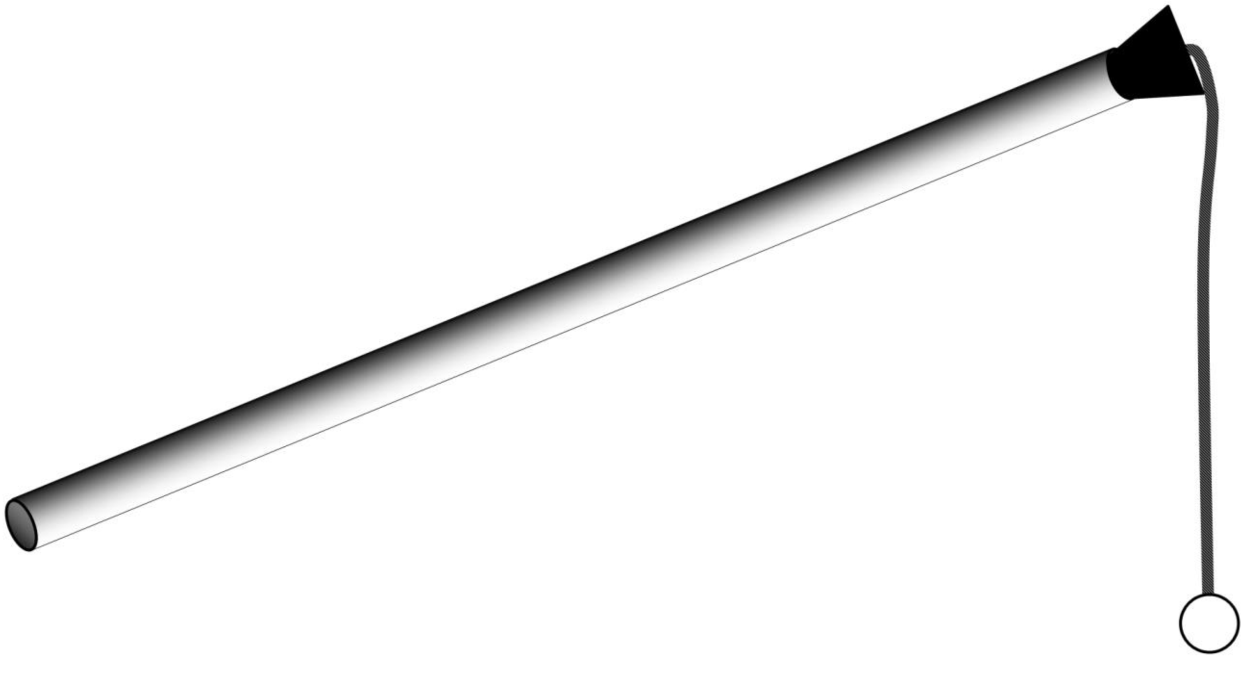


Figure 5: Setup 4 - Hemp Cord Hung Horizontally, Electrified Through Glass Tube When the hemp cord is attached to wooden beams using thick nails, no electrical charge can be observed at the other end of the hemp cord.

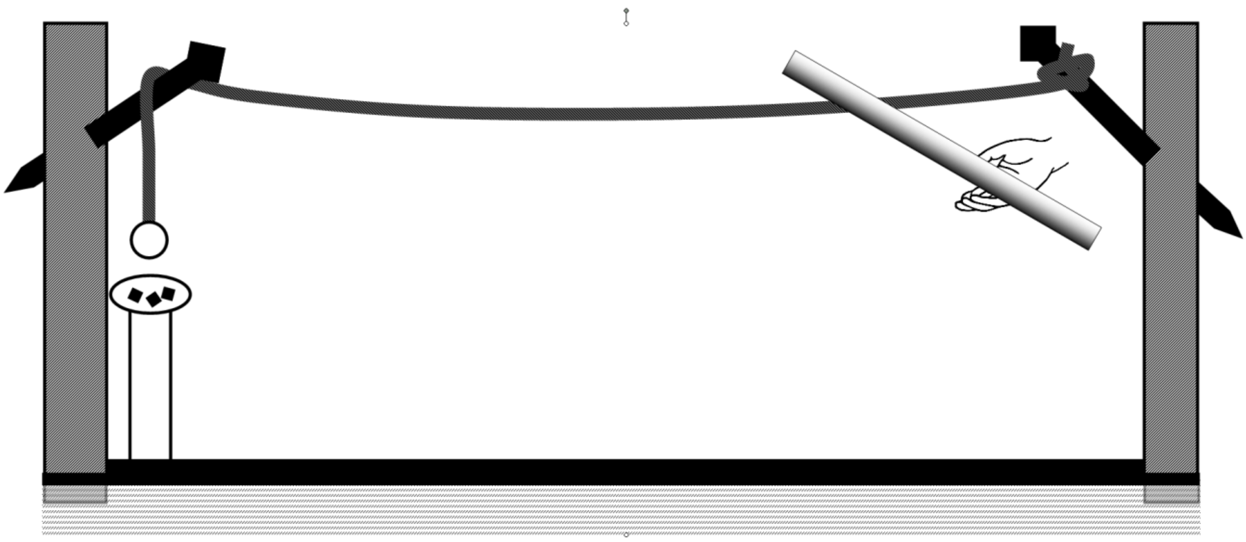


Figure 5: Setup 5 - Hemp Cord Hung Horizontally From Silk Cords - Thin Bodies Do Not Conduct
When the hemp cord is lain over thin silk thread, electrical charge can be observed at the other end of the hemp cord (paper scraps are attracted). Thus, the thin silk threads do not transmit.

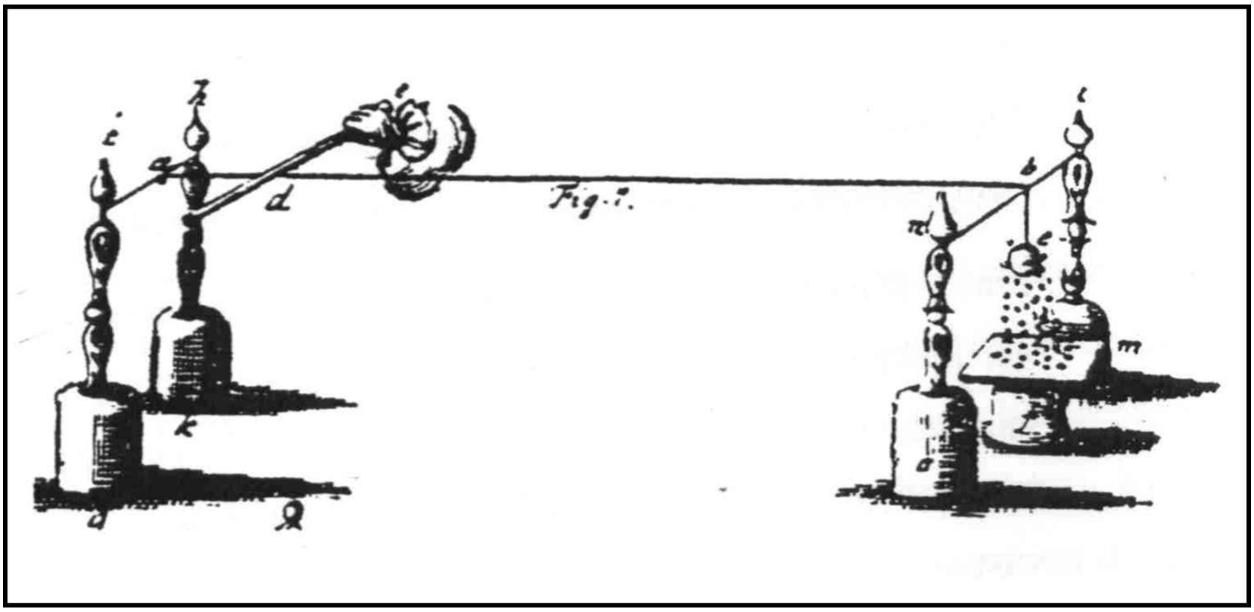


Figure 7: Setup 6A - Transmission over Distances - Conducting Metal Wire
If the hemp cord is laid over metal wire instead of silk thread, no electrical phenomena can be observed at the other end of the hemp cord.

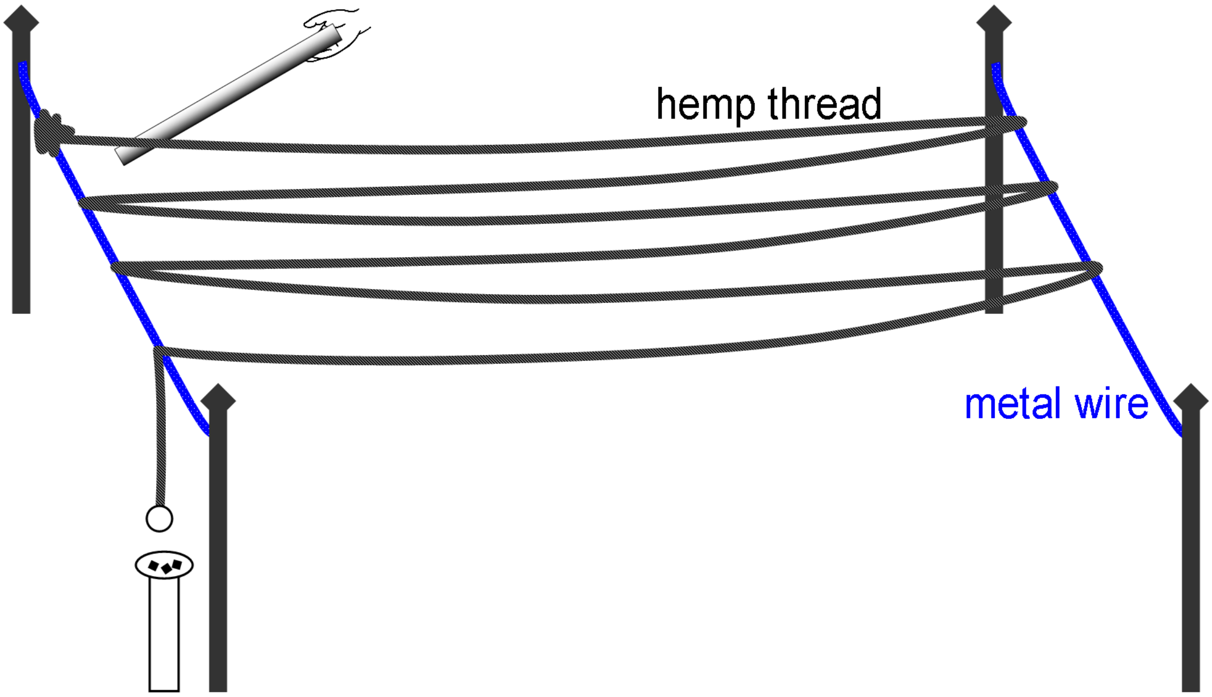


Figure 8: Setup 6B - Gray's Experiment on Transmission over Greater Distances With His Friend Wheeler in a Corridor of the Poorhouse.
Gray is in the foreground with the glass rod and a hemp cord that has been stuck into it. The hemp cord is lying on silk threads. In the background, a third person is testing the transmission of electricity using a feather.

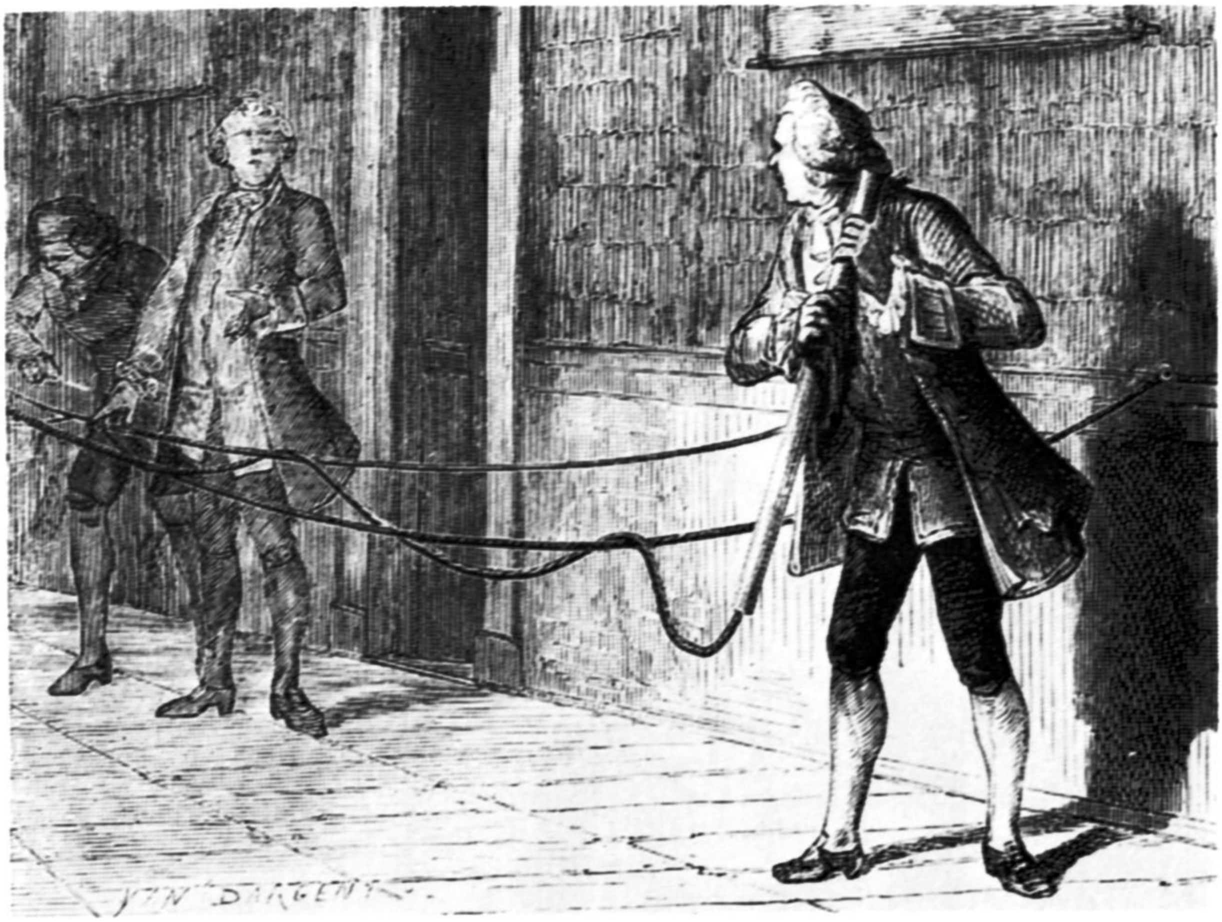


Figure 9: Setup 6B - Reconstruction of Gray's Experiment Transmitting Electricity over Great Distances (University of Oldenburg).
In the foreground is a plate with paper scraps lying on it and above the paper scraps a brass ball hangs from the end of the hemp cord. Hung diagonally are the silk threads upon which the hemp cord is lying. The silk threads are attached to wooden poles which have been stuck in the earth.

Figure 10: Gray's Experiment With a Boy Hung By Silk Cords.

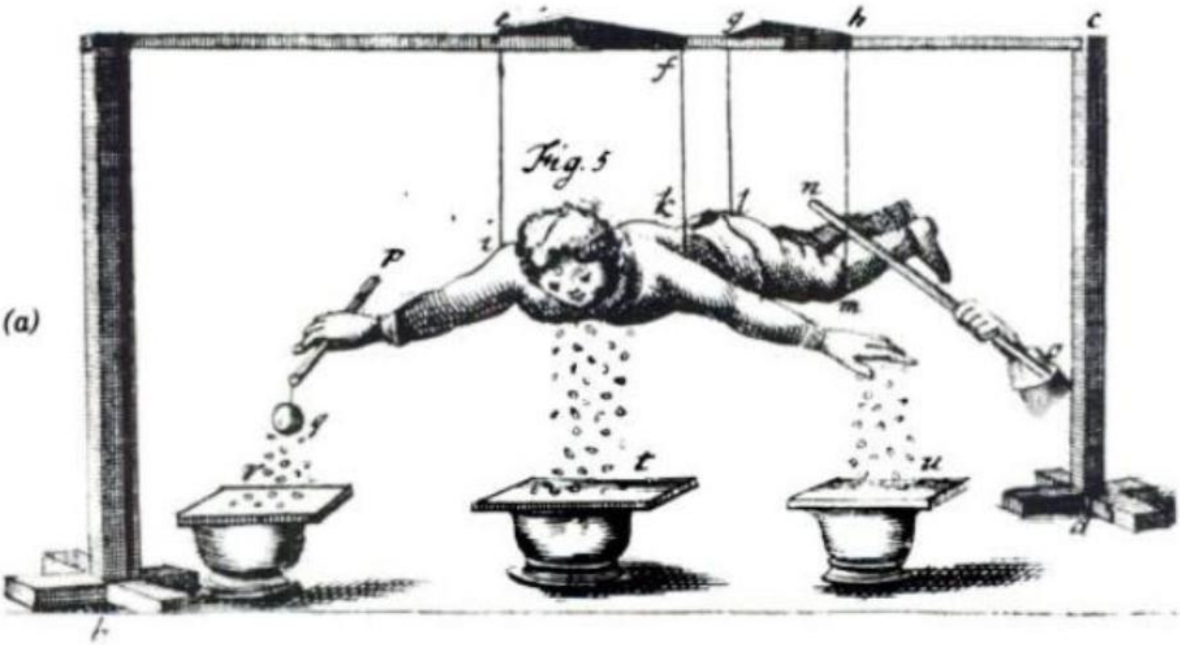


Figure 11: Depiction of Stephen Gray's Experiment on Rotating Small Charged Bodies around Larger Ones.
After the thread is slowly lowered, the rotating begins - depending on the previous expectations of the experimenter, it willl turn in one or the other direction.

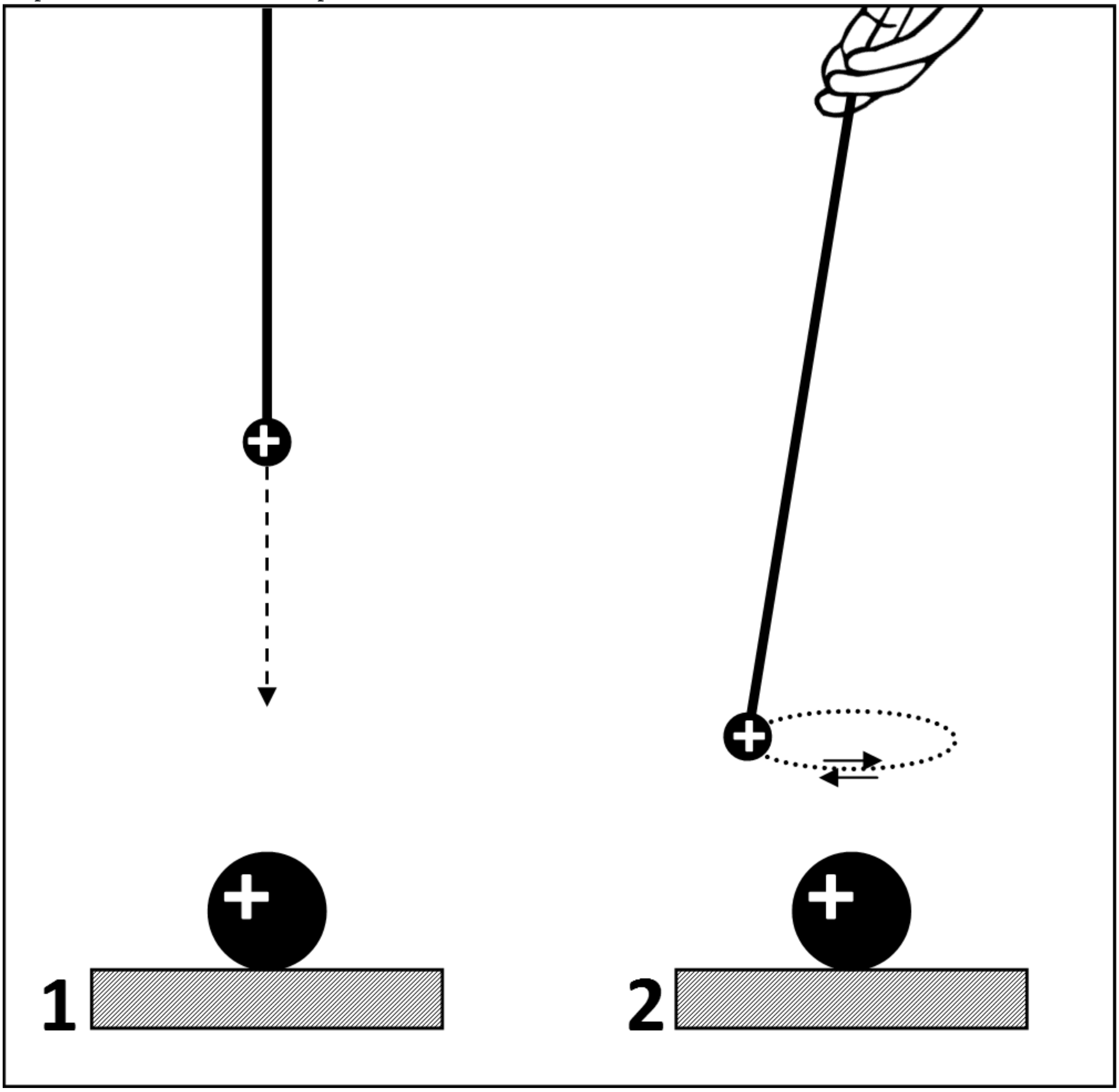


Figure 12: A Further Variation on Setup 5 - The hemp cord is hung horizontally from the silk thread. This is closer to Setup 4 than that shown in Picture 6.

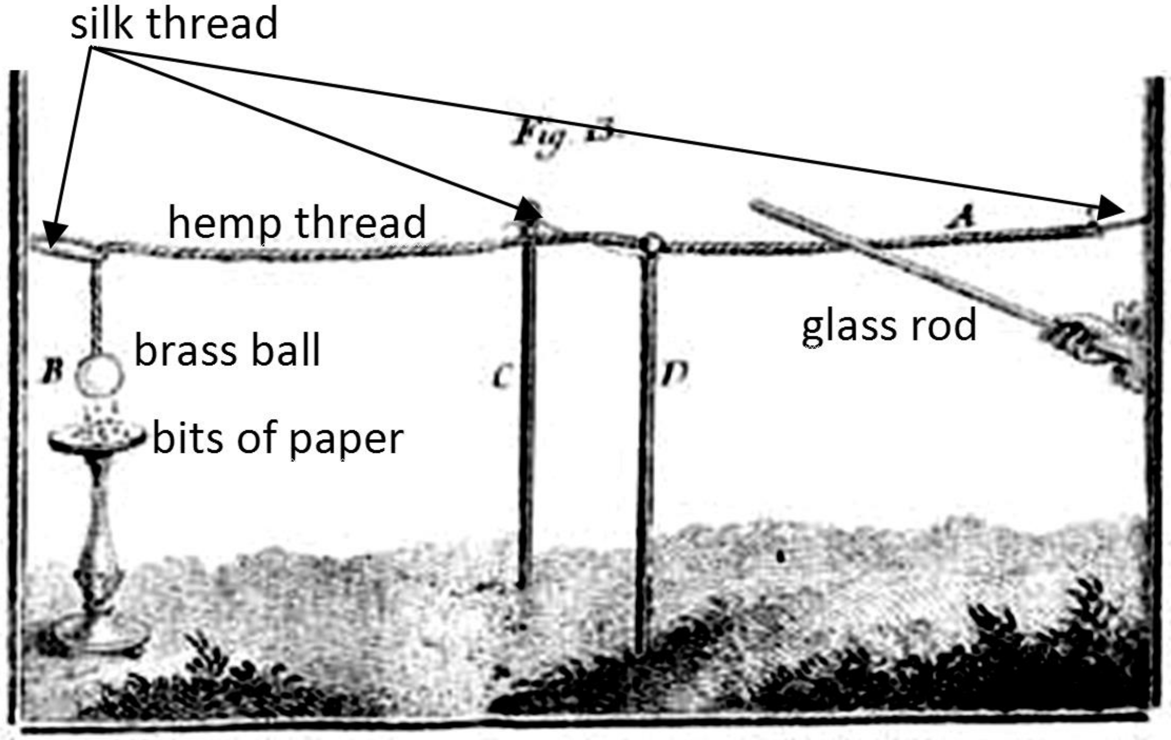


Figure 13: Setup 6A - Transmission Over Great Distances - broken silk thread. When the hemp cord is lain over the silk threads, it is not possible to endlessly increase the length of the hemp cord. The silk thread breaks under the weight of the hemp cord.

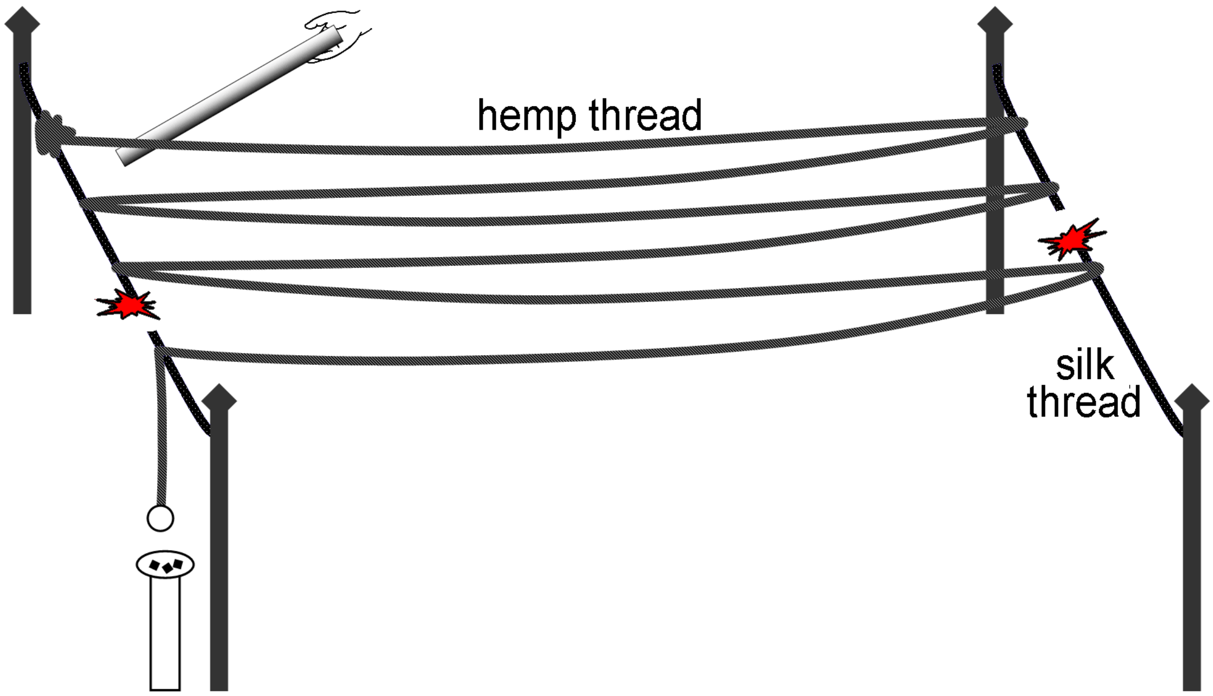
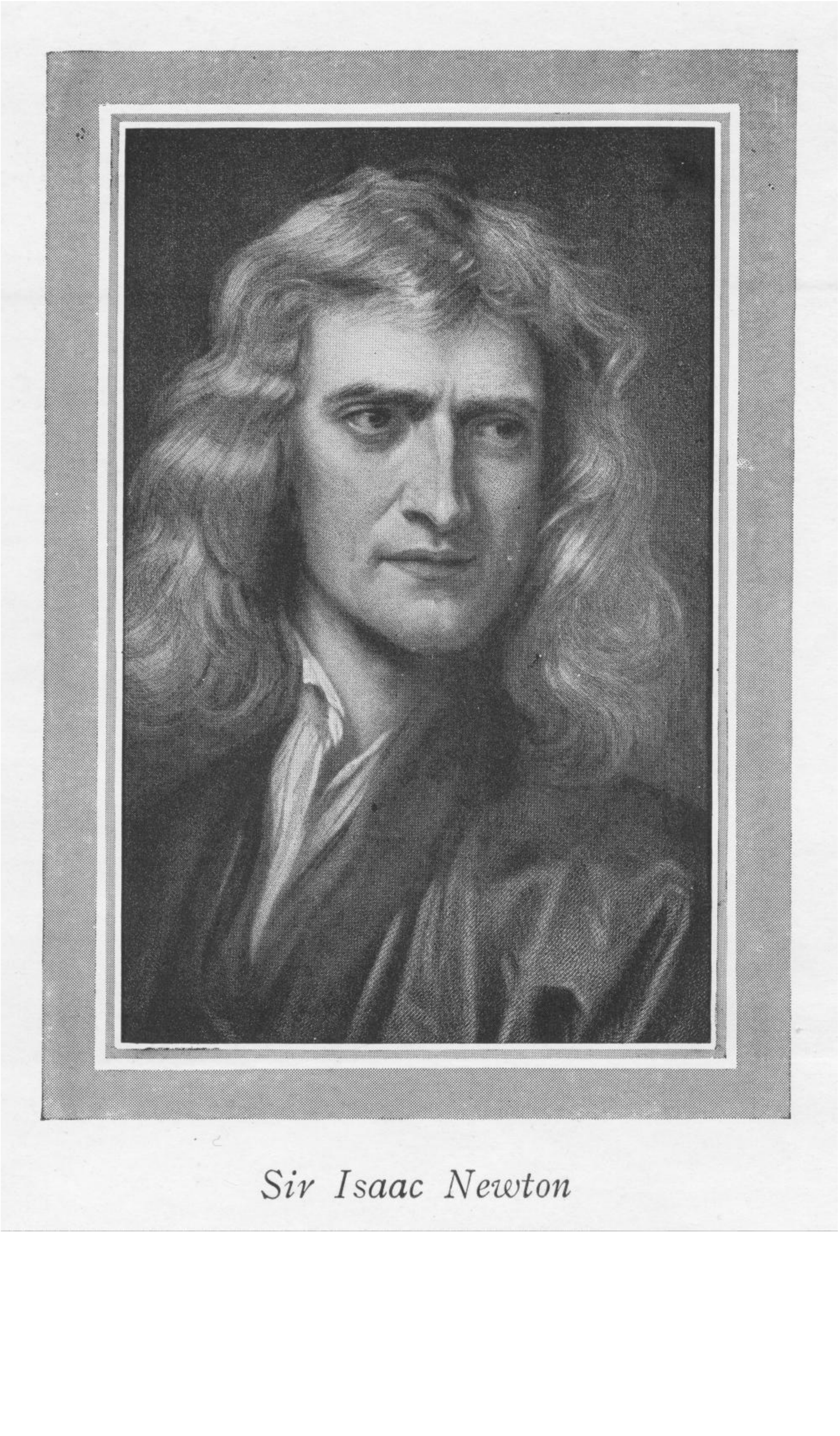


Figure 14: Portrait of Sir Isaac Newton



7.4 Further Sources

> *The first experiment I conducted sought to discover whether the tube attracts differently depending on whether or not it is closed with cork stoppers or left open. When I held a feather close to the end of the tube I saw that the feather flew towards the cork stoppers and was attracted and repulsed, exactly as it was from the electrified tube when it was left open[...] I was extremely astonished by this and decided that an attractive charge must be being transmited from the tube to the cork.*

Source I: on the surprising effect of the ‚transmission effect'– adaption of [2], p.20 center

> *Recently I have carried out different new experiments on the movement of small bodies through electricity.Small bodies can be brought into motion through larger ones, and this motion takes place in a circular or elliptical fasion, so that they circle these several times. This motion is exactly the same as the motion of the planets around the sun, that is, to the left, or from west to east; therefore I can call them small planets. I am concerned about these unexpected results, but I nevertheless observe them no matter how often I repeat the experiment. I do not doubt that within a short time the world will be able to wonder at a new kind of planetarium that no one has ever thought of before. Perhaps, too, we can obtain a clear theory about the motion of the planets from the results of this experiment.*

Source II: Stephen Gray on the rotation of small bodies around larger electrified bodies, and the analogy to the motion of the planets. Adaption of [3]

8. Obstacles to teaching and learning
8.1 Relating to Gray, accepting different interpretations of the same observations
A challenge in the course of this case study might be to ensure the students' being able to relate to Stephen Grays course of research and especially his interpretation of the experimental results. But this also openes up ways to reflect on how experimental results can be interpreted differently, regarding the differing previous knowledge of the interpreter (Gray vs. the students).

9. Pedagogical skills

9.1

In an evaluation round of this episode it proves to be very effective for student learning and teacher guidance to work on one experimental set-up which gets gradually altered along the lines of the correspondence with Gray. This way, all students can be activated, presenting their ideas on the methodological as well as the nature of science questions.

If Material I and II are chosen to structure students' inverstigations, the teacher should monitor their different approaches and results so as to be able to interrupt the investigating process to clear up some important questions. If, for example no student can identify with Grays thickness related interpretation of his observations, this point should be made a topic for explicit reflection on how and why Gray chose this intrepretation.

9.2 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...

10. Research evidence

This case study is currently being taught and evaluated..

11. Further user professional development

[A] Life and Research of Stephen Gray. By their interpretation Gray could probably have known, that the experiment with metal-wire would fail in transmission along the hemp-cord.

http://www.sparkmuseum.com/BOOK_GRAY.HTM

[1] Geschichte und gegenwärtiger Zustand der Elektricität, nebst eigenthümlichen Versuchen / Priestley, Joseph (Naturforscher) *1733-1804*. - Repr. aus dem Jahre 1772, nach der 2., vermehrten und verb. Ausg. - Hannover : Ed. "libri rari" Schäfer, 1983

(Priestley, Joseph. 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)

online, free, German:
http://echo.mpiwg-berlin.mpg.de/ECHOdocuView/ECHOzogiLib?ww=1&start=1&mode=imagepath&url=/mpiwg/online/permanent/library/T89UN1R5/pageimg&pn=7&wy=0.3034&wh=0.6068

online, free, English:
http://echo.mpiwg-berlin.mpg.de/ECHOdocuView/ECHOzogiLib?mode=imagepath&url=/mpiwg/online/permanent/library/DYSHP3NB/pageimg

[2] A Letter to Cromwell Mortimer, M. D. Secr. R. S. Containing Several Experiments concerning Electricity; By Mr. Stephen Gray, Philosophical Transactions, Vol.37 (1733), S.18-31, von Stephen Gray, Sprache: Englisch

[3] Mr. Stephen Gray, F. R. S. His Last Letter to Granville Wheler, Esq; F. R. S. concerning the Revolutions Which Small Pendulous Bodies Will, by Electricity, Make Round Larger Ones from West to East as the Planets do Round the Sun, Philosophical Transactions (1683-1775) Vol.39 (1735/1736), S.220, Sprache: Englisch

12. Written resources
Material for Students depicting various facets of life and work of Stpehen Gray.

Attachments

[2] Gray_phil_trans_37_s18-31

[3] Gray_letter planetary motions