Otto Guericke - Analogies, Forces & Quality of Scientific Instruments

1 Title and Keywords

„Otto von Guericke and the sulphur sphere – electrical repulsion and the role of scientific instruments" (Episode 1 of the series: Historic-Genetic Introduction to Electricity)

Keywords: static electricity, electrical repulsion, Otto von Guericke, sulphur ball, scientific instruments, analogies, Royal Society, Robert Boyle

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3 Abstract

Relation to the curriculum, range of use, target group, historical and philosophical contents

The episode about Otto von Guericke's experiments on the electrical repulsion is the second in a series about the history of electricity. Its objective is to introduce students to his experimental course of action which led to the description of the electrostatic repulsion. This episode is suitable for secondary school students aged 12 to 15. Otto von Guericke's own approach offers an insight into the role analogical thinking played in early science as he constructed his instrument as a model of the Earth. They may reflect on how and why these lines of argumentation can be both helpful (generating hypotheses) or deceitful (interpretation bias).

The main point of this episode is to reconstruct the experiments on electrical phenomena with the sulphur sphere or a replica that can be built easily. The students will gain an insight into the role and function of scientific instruments and will also design some themselves, acting as Guericke's engineers.

They will look into the subject of quality criteria for scientific instruments and learn how (and why) Guericke's instruments have been met with great scepticism. Within this context it becomes clear that scientists are rather critical among themselves in the assessment of their results and therefore towards scientific instruments, which play an important role in this process. Having constructed their own instruments, the students can apply their knowledge immediately by writing an advertising text for the instruments.

4 Description of Case Study and suggestion course of action

This case study should start with a brief information on Otto von Guericke.
The following aspects might be of importance (see paragr. 5.1):

his manifold roles as a scientist, politician and constructor of fortresses as well as
his various fields of work and research (drawing up detailed city maps, research on meteorology and weather forecast, air pressure and vacuum, electricity, astronomy and comets).
his motivation for research (this provides the realistic context to results on repulsion): to find and categorise all forces effective in nature.

Therefore, Guericke did not soleley aim at researching electrical repulsion, only nowadays he has been credited with this issue. His achievement lies in the presentation of this effect as unambiguously electrical, and to convince others of this. Also, the effect of repulsion is integrated in a wider research framework (see below). As to his research instrument - the sulphur sphere or ball: Students should not yet be informed about Guericke's exact set-up (pictures III and V).

Since, with the help of material I (an fictive assignment by Guericke), the students may now design a scientific instrument apt to investigate the forces of electricity. They should first

1

Background information

Research Intent

2

Design of a scientific instrument

Reflection: character and quality criteria of instruments

3

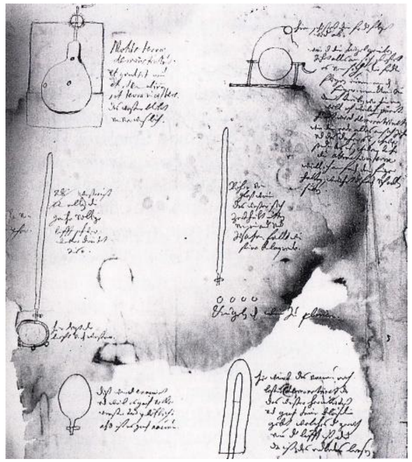
Guericke's sulphur globe as a model of the earth

4

Investigation: "The floating feather"

5

Boyle,



consider characteristics of a good scientific instrument. The students' outlines can be compared with each other regarding how well they conform to the demands proposed by Guericke, namely to produce electrical phenomene in the lab easily, reliably and strong enough to be analysed (see paragr. 5.2.1 and 5.2.2).

Questions to reflect on this activity in the following could be:

What characterizes your instrument as a good scientific one?
What do scientists need scientific instruments for?

Not before now, Guericke's drawing from his lab diary (see picture I) should be presented, followed by a picture withdrawn from his publication (see picture III) and a picture of the replica (see picture V). Students may speculate briefly on why Guericke chose this kind of set-up.

To Guericke the globe serves as an example of nature - everything being possible in nature should be researchable via this globe. This is why he constructed his instrument for creating electrical effects in the shape of a ball or globe, pivot-mounted as an analogy of the rotating Earth. This purposeful analogical construction is worth mentioning as it was quite usual at that time. Statements referring to the whole of the Earth (or universe) were made by inferring them from similar effects in analogous situations (see pragr. 5.2.3). Besides, the topic of the "construction of good scientific instruments" will play a central role in this case study as the most important element of

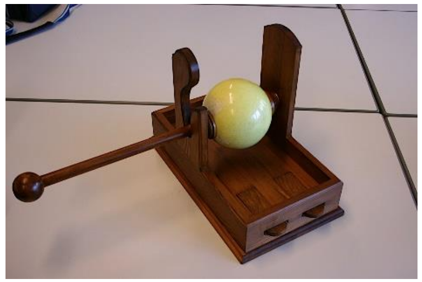
the sulphur globe,
rebuffed by the Royal Society

6

Reflection:
Why so sceptical?

7

Advertising scientific instruments

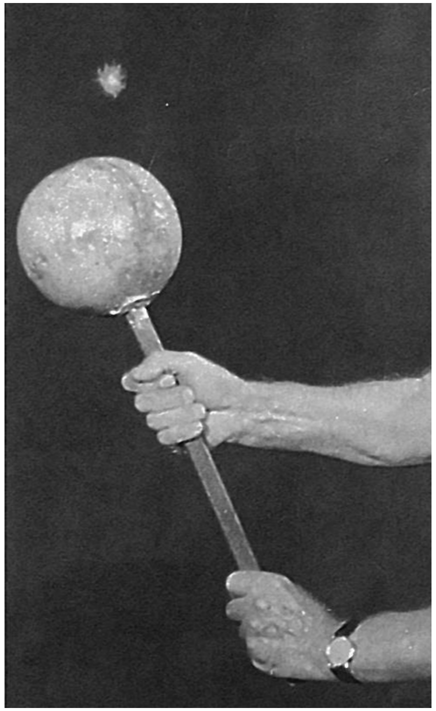


the nature of science (see paragr. 5.2.1). For Guericke, one quality criterion was the resemblance of his instrument to the Earth in all important aspects.

An experimental phase with the students retracing Guericke's actions may follow this initial introduction. Paragraph 7.1 describes the experiments which can be enacted as inquiry activities in the classroom:

"Reproducing the known phenomena of electrical attraction",

"Electrical repulsion demonstrated with down feathers and other light bodies",
"Floating feather"
"Discharging the feather"
"Quiet electrical discharge/electro-luminescence"



There are various options of how to enact the case study:
Aiming for a more <u>structured investigation</u>, the students could be presented with questions like "Do the known effects act as expected regarding this instrument?" or "What forces does the electrified globe exert on other bodies?" (Guericke's description of the effect of repulsion can be found in the Original Text I.) Another research question could be, "Guericke assumed that electricity can also be repulsive. Please design an investigation of Guericke's instrument to test this assumption."
More <u>open-ended investigations</u> in mind, the students *themselves put* questions, develop hypotheses and investigations starting from Guericke's general aim to discover all forces of nature. Questions concerning mechanics and kinematics can be

picked up as well.
After the experimental stage, the students should be encouraged to discuss various aspects of the nature of science (see paragr. 5.2) by an open reflection in the Reflection Corner (as described in the page "Reflection Corner").

After that, the credibility and quality of Guericke's research will be the centre of attention. As demonstrated in material II, fellow scientists initially were not convinced of the quality of his instrument and likewise of the results he obtained with it. This material should prompt students to contemplate what defines good scientific instruments against the background that these results have to be justified. Information on this topic can be found in paragraph 5b. Material III provide the students with a short summary.

Possible questions to reflect:

Why do scientists present their results and instruments to each other?
Why were other scientists sceptical when Guericke demonstrated his instrument?
What should scientists observe when presenting their results to others?
What are scientific instruments used for in science?

In the aftermath of Guericke, "real" electrifying machines played an important role in the research of electricity. Real in the sense that they differed in their intended use - their sole purpose was the production of electricity while Guericke used his instrument with the intentions mentioned above. Pictures VI, VII, VIII and X show some of the construction methods for electrifying machines using friction. This is meant to illustrate a typical function of scientific instruments, namely the reproduction of stronger, but controlled natural effects in a laboratory so that they can be analysed. These instruments are subject to further technical developments roughly based on Guerickes principles.

The students may then return to their own outlined designs and check whether they meet the quality standards defined ealier. If necessary plans have to be adjusted. Lateron students write a short advertising text describing the special qualities of their instruments . This can be initiated via material IV.

5. Historical and philosophical background including nature of science

5.1 Historical background

5.1.1 Electrical repulsion from Gilbert to Guericke

Even after Gilbert's separation of electrical and magnetic phenomena of attraction, the question of what exactly was the reason for attraction could not be sufficiently answered. It was still assumed that the electric state of a body was due to the warming of objects caused by friction. Furthermore, *attraction* would happen generally by means of "effluvia", which means something like "delicate outflows", used time and again in various forms as an explanation in the aftermath. However, it was at a loss to explain electric repulsion, which, by the way, was not seen as an electrical phenomenenon by Gilbert. Nicolaus Cabeus noticed in 1629 – and Otto von Guericke later as well – a repulsive effect along with the known attraction which he explained as a mechanical phenomenon: The previously attracted, light objects (swept along by the air that had been "thinned" by outflows) bounced off the electrified objects. Until Guericke's findings, attraction remained the outstanding electrical phenomenon whereas repulsion was regarded as a purely mechanical one.

Cabeus had declared impossible what Gilbert never mentioned, namely the transfer of attraction by touching. However, Guericke was soon to present clear evidence for a transfer occuring. Having been in contact with the sulphur sphere, the down feather he used for many of his experiments *gladly attracted everything close to it or, if that was not possible, nestled up against it* (see [1], p.167). Dú Fay (see the corresponding episode in this unit) would later formulate this as a general principle.

Guericke's sulphur sphere represented something of an innovation in experimental electrostatics. Previously natural pieces of "elektrika" or other objects not directly manufactured for electric research had been used for experiments. Planing and designing a suitable instrument is a novel approach. However, the fact that sulphur can be electrified has been known before (see l. [2], p. 36).

Guericke's attempts to explain the effect of repulsion are based on conclusions by analogy and a somewhat animist world-view. The globe, constructed thoughtfully as a model of the Earth, would strive just like planet Earth to keep together all things belonging to it. Following, a rejection of all things detrimental should also be possible. **Based on his view of how to come to knowledge about nature, the sulphur sphere mainly served as a model for all those forces he thought to be effective in the universe.** In order to be historically correct, it has to be mentioned that **the sulphur sphere therefore did not represent an electrifying machine in the way it was used by later researchers.**

Also, the early stages of the discovery of the electrical conduction and electrostatic induction can be found, but Guericke did not mention them specifically. It was left to Stephen Gray who much later did a systematic investigation of these effects.
Most of Guericke's findings on electricity fell into oblivion, probably because he claimed them to be confirmations of his ideas on the forces of the universe. He did not even bother to present his findings to the Royal Society. When his colleague, Boyle, finally did this on 27 November 1672, he was met with great scepticism (see Students' Material II).

5.1.2 About Otto von Guericke

Otto von Guericke (born 30th of November 1602 in Magdeburg; died 21st of May 1686 in Hamburg) was a German politician, lawyer, scientist/natural scientist, veterinary surgeon and inventor.
From 1617 to 1619, Otto von Guericke studied arts at the University of Leipzig and, due to the expansion of the Thirty Years' War, also a few weeks in Helmstedt. He then studied law at the University of Jena from 1621 to 1623 before he went to the Dutch University of Leiden in the same year to study law and fortress construction. In 1631 Guericke became the patron of the Magdeburg while the city was sieged by the imperial Catholic Army. However, he and his family were captured so he had to buy them out and moved to Braunschweig afterwards.As from 1632 onwards, he was significantly involved in rebuilding the cities of Leiden and Magdeburg, which both had been destroyed during the war. In 1646 he was appointed mayor of Magedeburg because he had diplomatically been very successful as an envoy of the city when negotiating with Saxon occupying forces, securing a lot of advantages for Magdeburg. In his spare time and particularly in his old age, Guericke dedicated himself to scientific research. He is known for his invention of the vacuum air pump about 1650 and especially for the spectacular experiments he carried out with the so-called "Magdeburg Hemispheres" that were based on his invention (see pictures II and XI). Guericke enjoyed demonstrating the citizens of Magdeburg not only these experiments but also a lot of his other ones.
Towards the completion of his research he turned to the aforementioned experiments on electricity. He finally published them along with his other conclusions in 1663, giving in to the pressure of his fellow scientists and friends, Gottfried Wilhelm Leibniz and Caspar Schott.

5.2 Learning about the nature of sciences

5.2.1 Justification of the results and demands for the experimental set-up

Oftentimes, a special (new) phenomenon becomes the focus of scientific research. In Guericke's case, this is the repulsion of electrified objects. Aspiring to **examine**

this effect and its properties closer, it is to be **purposefully produced** and **easily and safely reproduced**. For this purpose, a **special set of instruments** must be **developed**. Also, the **experimental proficiency to deal with it** needs to be established.
If the effect is to be examined with these instruments (e.g. the range of the repulsion, its effect on various substances etc.), the quality of the results will depend critically on this equipment (and of course on the actions of the examining person).
It is crucial that findings obtained with these instruments are **recognised by other scientists**. This will be more likely, if a device meets high quality standards.

Some quality criteria are:

1. **Traceability by others** through **simple handling**
2. **Safe and repeatable** production of the desired effect
3. **Excluding disturbing side effects** – only the effect in question is examined
4. They are **effective** regarding the creation of the effect, i.e.
    - the effect **is generated freely** and
    - the effect is **strong enough** to be examined
5. They are constructed in such a way that the enable a sound understanding of the **cause of the effect**. Therefore, there is a core area of the set-up that may not be modified without the effect disappearing.

Of course, very **pragmatic considerations** are also included: Which materials are available, how expensive are the single parts, could old compositions of experiments be modified instead of designing completely new ones? Guericke mentions some of these criteria in the fictitious letter in Material I. Most of the other criteria are also presented there and can be learned with the help of a creative writing task (Students' Material II).

5.2.2 Generating phenomena

Guericke's experiments represent a lucid example for the **conscious and controlled generation of a phenomenon in the laboratory for closer examination** (e.g. generating sound with loudspeakers in order to research the propagation of soundwaves or breeding of the Drosophila flies in a lab environment to study questions of inheritance).
This, however, is not always possible. As seen in marine and environmental sciences, it is often the other way round: as long as e.g. sea currents cannot be reproduced in the laboratory, the instruments must be transported to the phenomenon. A distinction must be made between the **phenomenon as such** (unaffected natural appearance) and its **laboratory equivalent** (purposeful generation using special instruments). As a matter of principle, scientists aim at

propositions about the phenomena as such, their properties, and the factors in their development. However, research is mainly carried out in the lab. It would be a finicky question to ask whether the findings obtained with the help of the laboratory phenomenon do apply to the phenomenon as such. A solution for this apparent problem is to imagine the experiment as a planned process of **stabilizing a phenomenon**. Experiments therefore are often guided by theoretical expectations. If theoretical expectations are of minor importance, because the research field is rather new and not sufficiently structured, explorative strategies of experimentations might be applied. Nevertheless, at the laboratory bench an experimenter transforms a natural phenomenon into **a purified, more regular and easier manipulable object**. If during such a process an unexpected quality (like repulsive forces) appears that has not been deliberately observed before, this aspect will be regarded as a **realisation of something potentially possible in nature** (after all, the laboratory and the instruments are parts of nature as well).

5.2.3 Useful and dangerous irrationality in science (argumentation by similarity/analogy and by completeness)

It would be a fallacy to assume that scientists are always guided by purely rational views while doing research. A lot of scientists are led for example by the idea that scientific theories should be "beautiful", i.e. particularly simple or elegant. Others for instance appreciate the role of analogies and structural similarities in science: As long as objects or phenomena are similar to others in some respect, they assume them to be consistent in further asects as well. This has also guided Guericke's course of action:

<u>Guericke's example 1: The sulphur sphere is an analogy to the terrestrial globe. Reseachr therefore reveals principles of the earth itself</u>.

Guericke did not construct the sulphur sphere according to the aim to examine electrostatic phenomena, even though such a historical reconstruction is quite tempting from a moder perspective. He focused instead on an examination of the forces being effective in the universe. He was especially eager to find all forces on and around the Earth so that he could develop a sound understanding of the world. For this reason **he constructed the sulphur sphere in analogy to planet Earth**:

- A *rubbed sulphur sphere attracts light objects which adhere to its surface and rotate with it.*
  IT FOLLOWS: The Earth attracts everything on its surface. Attached objects are carried with the earth during its daily rotation.

- A *feather is repelled by the rubbed sphere, stays for a while at the same distance, but points always with the same side to the sphere, and the sphere can be positioned well in a distance below the feather.* IT FOLLOWS: The moon relates to the Earth exactly like a repelled and electrified feather relates to the sphere.

<u>Guericke's example 2: Electricity should be explainable by the same (already known) principles as magnetism since they are analogous</u>.

Guericke's world view was strongly influenced by the idea of wholeness and completeness. It would have been rather astonishing to him if the pair of opposite forces, attraction and repulsion, that occurred with magnetism had not likewise appeared in electricity. Guericke's discovery of the effect of repulsion has surely broadened the phenomenal field of electricity, but also **completed** it in a certain sense since magnetism was used as a guiding phenomenal realm. What are, thus, the dangers and what are the benefits of scientists letting themselves being guided by rather „emotional" or esthetic considerations or even intuition. Is there a role for analogies, similarities, symmetries, contrariness or simplicities in science?
Consideraions like that can be used as powerful heuristic devices in science. They can be **useful** since they are inspiring a scientist's creativity and helping him or her creating new ideas, experimental apparatus and measuring devices, hypotheses or explanations, which have to be carefully analysed afterwards.

On the other hand it might be **dangerous** if scientists are influenced by them in a way that they ignore their own observations or the results of fellow scientists if evidence contradicts their preconceived ideas.
The Guericke episode might help to correct the distorted image of the ever so rational, objective, and empiricist scientist who is lacking any subjectivity. Quite contrary to that, scientists are at times guided by ill-founded principles, but should retain a critical attitude towards their own guiding principles and ideas.

6. Target group, curricular relevance and didactical benefit

This case study about Otto von Guericke's experiments on the electrical repulsion contributes to a series of episodes about the history of electricity. This episode is suitable for secondary school students aged 12 to 15. The teaching on electricity plays an important role in physics and physics teaching.

6.1 Learning objectives and competencies

Students regard the phenomenon of electric repulsion as another basic property of electrified (electrostatically charged) objects and can relate it to electrical attraction

Students learn that the deliberate production and reproduction of physical phenomena with instruments is a significant practise of scientific activity. Students learn that scientists have to vindicate and defend their results before their colleagues, leading to certain requirements for the instruments they are using.

6.1.1 Nature of science

Students should be able to ...

- argue that the design, production and use of scientific instruments represent a facet of scientific practise
- name the criteria used to judge the quality of scientific instruments
- name the properties of scientific instruments that affect the quality of the results
- explain the role and importance of vindicating and defending results before other scientists (in the context of scientific instruments or more general)
- name the controlled production of natural phenomena as one of the uses of scientific instruments
- state that the findings some scientists are known for today do not necessarily represent their original motivation towards research.

6.1.2 Competencies referring to 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 or 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 suppositions
- deal independently with the experimenting materials

6.1.3 Competencies relating to Content Knowledge

Students should be able to …

- name various substances that can be electrified by rubbing
- regard repulsion as the action of force between charged (electrified) objects
- regard repulsion of light objects as a way of proving the electrified state of a body
- describe qualitatively the action of forces in the vicinity of charged (electrified) objects

7. Activities, methods and media for learning

Methods, Experiments, work sheets, task suggestions, media / materials

7.1 Experiments

7.1.1 Required material

- Replica / experimental set-ups
  One or more copies of Guericke's electrifying set-ups
  Alternatively: glue two cardboard rolls onto the opposite sides of a round balloon (see picture IX)
- Materials for further comparing electrifying experiments
  Amber, sealing wax bars, glass bars
- Stuff to rub with
  Cloths of wool, cotton wool and silk, cat skin
- Light objects'
  Down feathers (unprocessed but without the hard pinfeather)
  Cotton threads, scraps of paper, brass foil, iron cutting or powder

7.1.2 Possible investigations

<u>Experiment 1: Reconstruction of the known phenomena of attraction</u>

Rubbing the dry sulphur sphere – attached to the set-up or not – with dry hands or even better, with a fur or a cloth, means electrifying it so as it quickly attracts light objects electrostatically. In order to obtain this effect, the objects are placed below the sulphur sphere or on another base (like a petri-dish or a saucer).
Water drops are also attracted when approached by the sulphur sphere. Then the drop becomes visibly deformed in the direction of the sphere.

Experiment 2: Effect of repulsion with a down feather and other light objects
Guericke describes this experiment using a down feather. If the feather is falling down onto the sulphur sphere rubbed beforehand, it briefly clings to it before being repelled again by a slight shake of the sphere. This is the new effect Guericke investigated extensively.
Scraps of paper or confetti thrown below the sphere still attached to the set-up are constantly attracted and repelled, a game that can last for hours. Repulsion can also be observed when a small piece of cork on a thin string is being used as an electroscope: having been attracted and touched, it is repelled in succession.
This experiment can also be carried out with bars of glass. At this point it makes sense to draw attention to the subsequent development of electrifying machines where mainly glass has been used as the material to be rubbed by a cushions of leather (see pictures VI,VII,VIII,X,XII).

Experiment 3: Letting a down feather levitate and being discharged

Holding the sphere in the hand, a feather electrified by the sphere beforehand can freely levitate and be directed through the space. If it touches a grounded object, in succession it will be attracted anew by the sulphur sphere until it touches the sphere and be repelled again. This effect has also been described by Guericke. A feather levitating in this way ca be "handed over" to another pupil, who for instance holds an electrified PVC-rod or another electrified sulphur sphere in his hands.

Experiment 4: Silent electrical discharge / electroluminescence

Guericke describes a superficial glowing occurrence on the sulphur sphere, if it has been rubbed well before. The effect occurs only in absolute darkness and under ideal (i.e. dry) conditions. It was only nine years after his first experiments with the sphere that he was sufficiently confident about this peculiar observation that he dared to publish this effect.

Some technical recommendations

1) If the sulphur spehre is charged too strongly by rubbing the effect of electrostatic induction will prevail and the feather will be prevented from being repelled by the sphere. Repulsion therefore will be achieved with more ease by

rubbing the sphere cautiously beforehand.

2) The down feather should not be too voluminous. Otherwise electrostatic induction entails sustained attraction of the feather's "arms" as Guericke called them. These have to be trimmed if necessary.

3) All experiments should be carried out with a sulphur sphere quite dry and in a dry and warm atmosphere (room temperatur). Therefore it should be avoided to touch the spehre with damp hands or bring it outdoors. For keeping it in a dry box the use of a drying agent is recommendable.

7.2 Material for students

Material I: Task for designing a scientific instrument

Imagine being a mechanic and scientific instrument maker in Otto von Guericke's hometown Magdeburg. You design and construct scientific instruments together with scientists.

You receive the following letter from Guericke:

„Dear colleague,

We have been working together for quite some time now and you have always been very helpful and imaginative regarding my various instruments. As you may know I am currently investigating the forces affecting our planet Earth, and I feel the urge to investigate those forces created by the phenomenon of the electrification of objects. Others have already done a good job in this area. These electrical phenomena occur only rarely in nature or else they are too weak to be investigated closely. Unfortunately, all known natural occurrences of these phenomena are not reliable and powerful enough – I need to produce the same phenomena myself. Therefore I need your expertise and creativity to construct a machine enabling me to do this in a controlled way in the laboratory. At the time and I a strength that I can determine for myself."

You received Guericke's assignment to develop an instrument that allows the electrification through rubbing in the lab. Please pay attention to the fact that it should be possible to carry out scientific experiments with your instrument. Use your knowledge from the previous electrifying experiments.

Draw a rough sketch of such a machine.

Note briefly: What makes your machine a good scientific instrument?

Remember that we are in the year 1660 – there are not, for example, any motors, electrical or otherwise.

Material II: Information on the skeptical attitude towards Guericke's instrument

The following event happened when a friend of Guericke presented the results Guericke received with his instruments. You can see, that there are strict criteria for what makes a scientific instrument a good one and for the trustworthiness of its results:

On 27 November 1672, Robert Boyle (1627-1691), working like Guericke also in the field of air pressure, presented the sulphur sphere and the results Guericke obtained with it to the London Royal Society. This important and renowned community of scientists whose members critically examined each other's research results had been particularly skeptical regarding the sulphur sphere and provisionally rejected its results until they had the chance to check the quality of the instrument themselves before recognising and publishing the results received with it.

Material III: Information on the quality criteria for scientific instruments

Scientific results obtained with instruments regarded as unreliable are usually met with doubt. Scientists usually agree on some properties good instruments should possess:

- It must be possible to establish exactly how the effect to be examined (e.g. repulsion) is created by the instrument
- Other scientists should *in principle* be able to handle/operate the instrument
- The instrument should be operationally reliable and produce the effect whenever needed.
- The effect must be clearly observable, undisturbed by further occurrences.
- An experiment carried out with the instrument and producing a certain result should produce the exact same result when repeated.

Practical things to keep in mind:

- it should not be too expensive

- it should be usable more than once
- ...

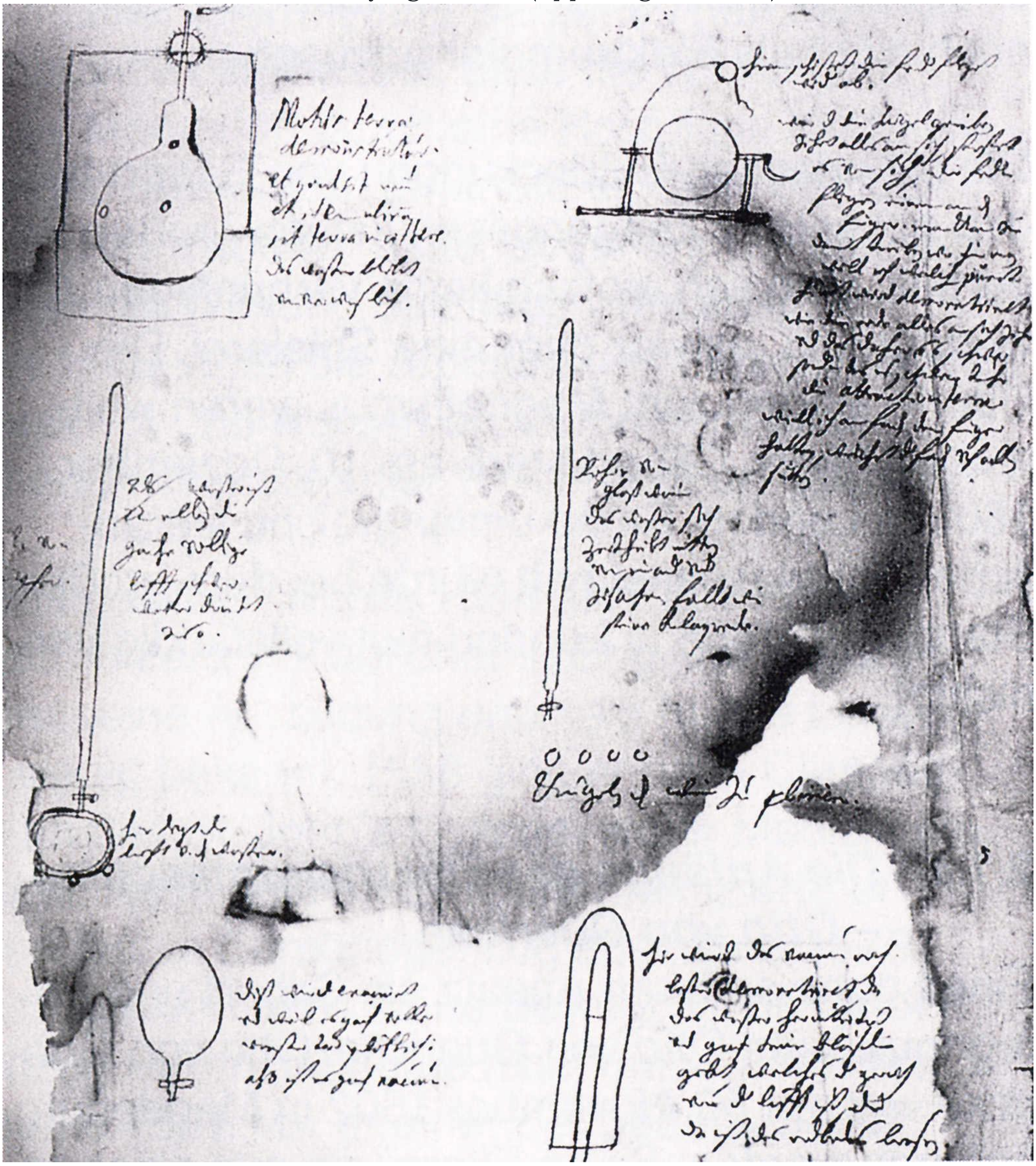
Some aspects can be taken into account only while the instrument is being constructed.

Material IV: Creative Writing - Composing an advertising text for the own instrument

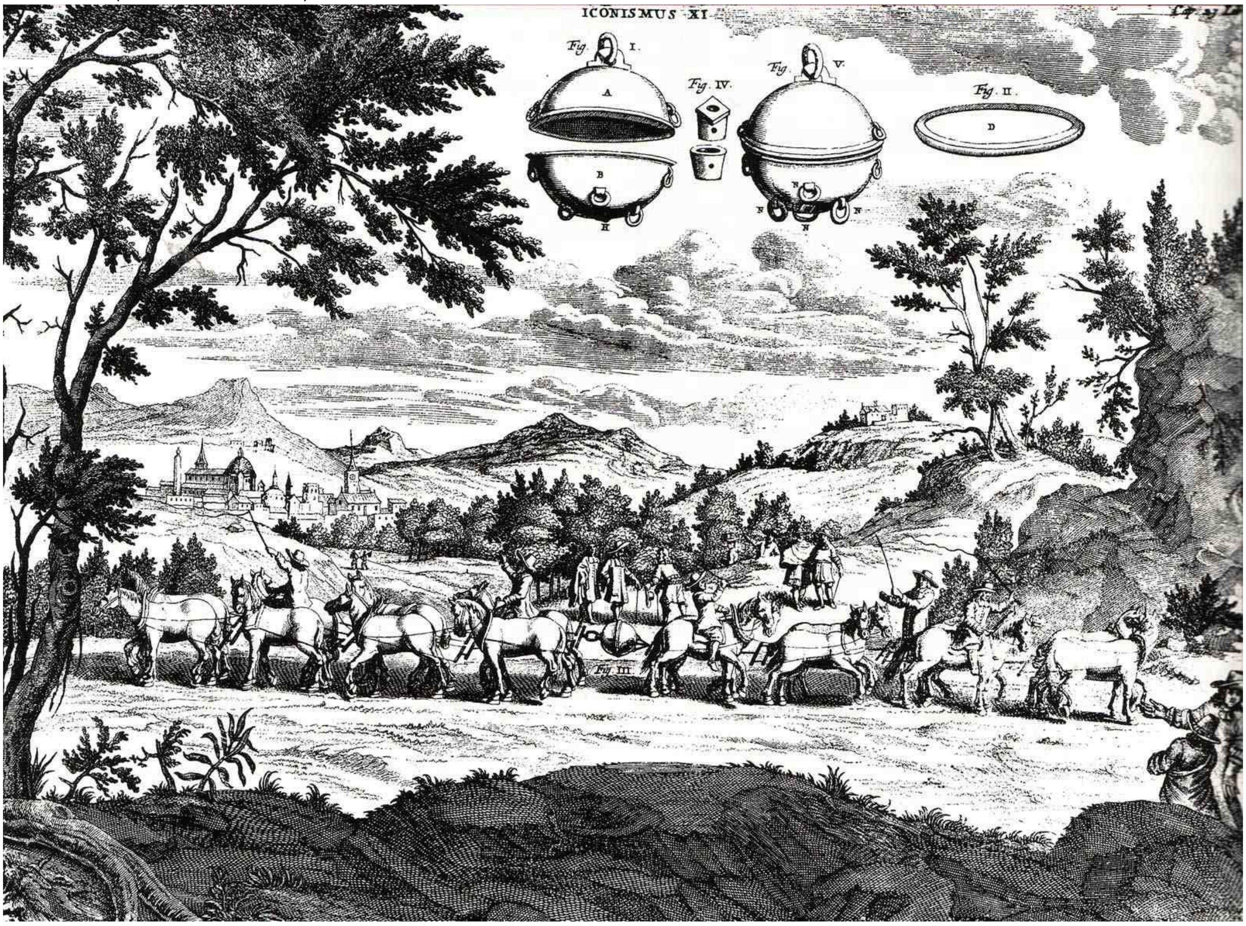
Please write a short advertising text explaining why the electrifying machine you have constructed is a good scientific instrument. Your advertisement could start like this: *Revolution in the field of electrical research! With regard to its quality as a proper scientific instrument, the Royal Society rightly expressed their doubts concerning Guericke's sulphur ball because it was difficult to operate and produced only weak electrical effects. However, my newly developed scientific instrument ...*

7.3 Pictures and media

Picture I: Extract from Guericke's research diary, around 1660 – sketch to illustrate his considerations on electrifying devices (upper right corner)



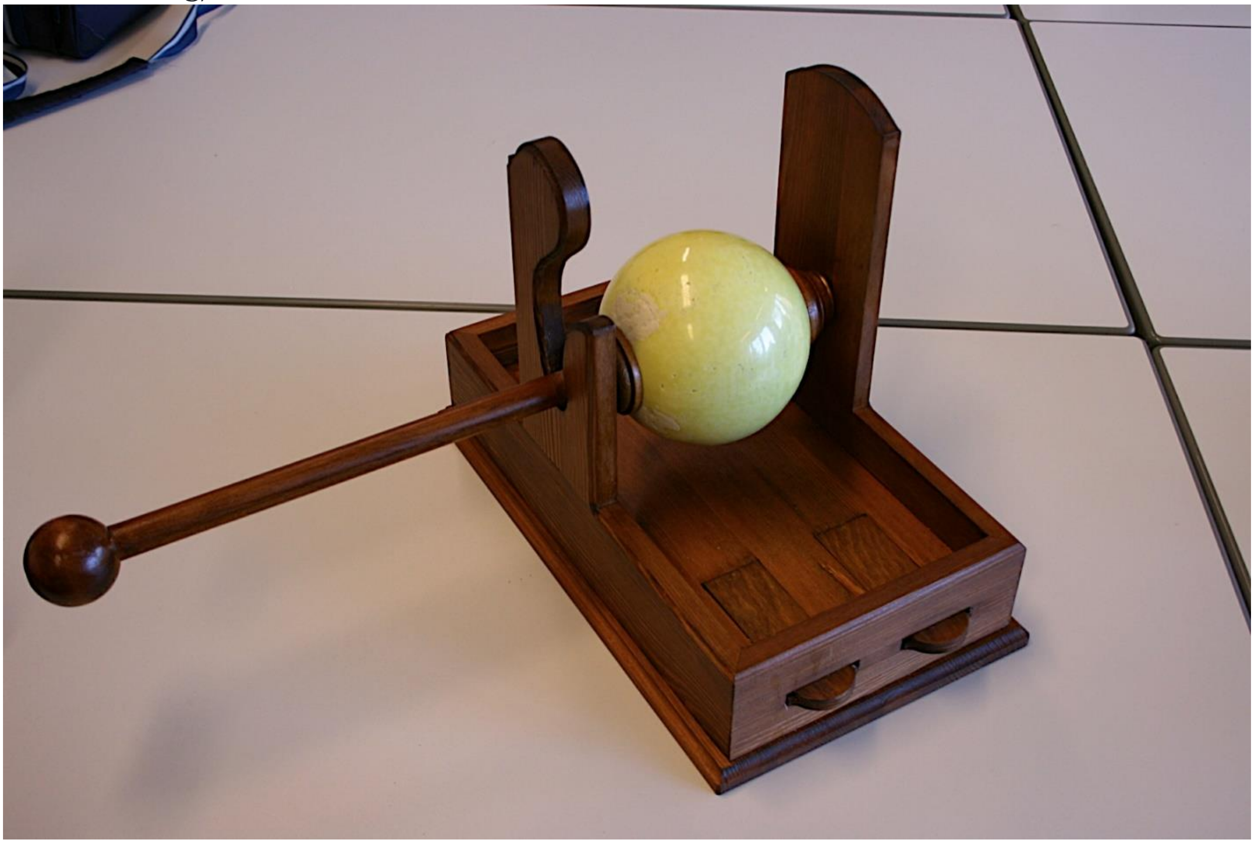
Picture II: Experiment on the "Magdeburg Hemispheres“ – Illustrated by Caspar Schott (around 1660)



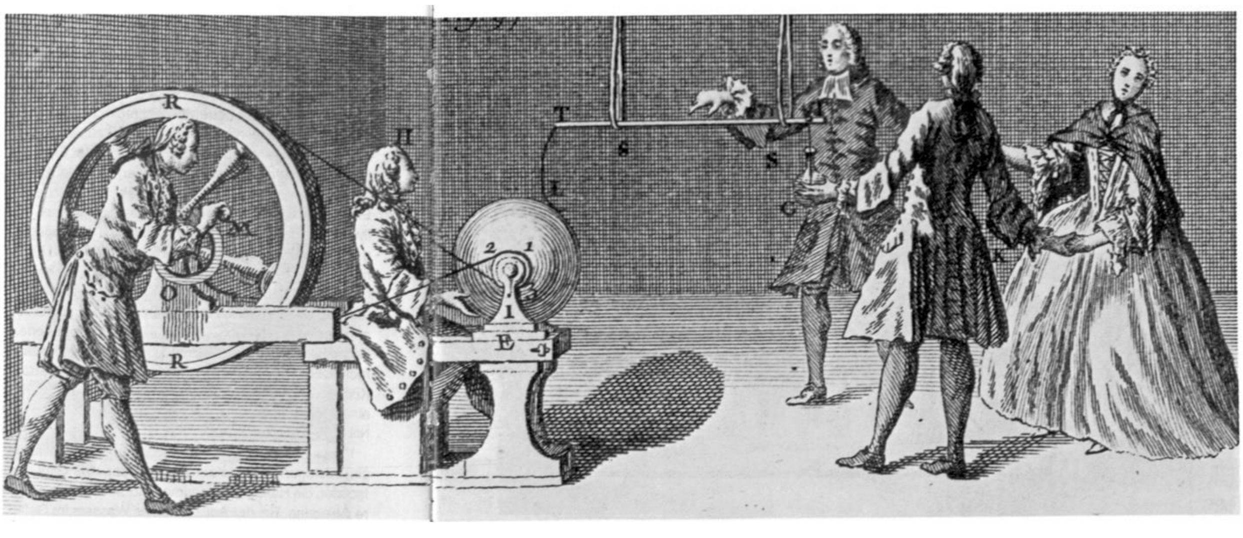
Picture III: Guericke's electrifying set-up (right), Guericke with sulphur sphere (left), of [1], p. 166

Picture IV: Portrait of Otto von Guericke as Mayor of Magdeburg

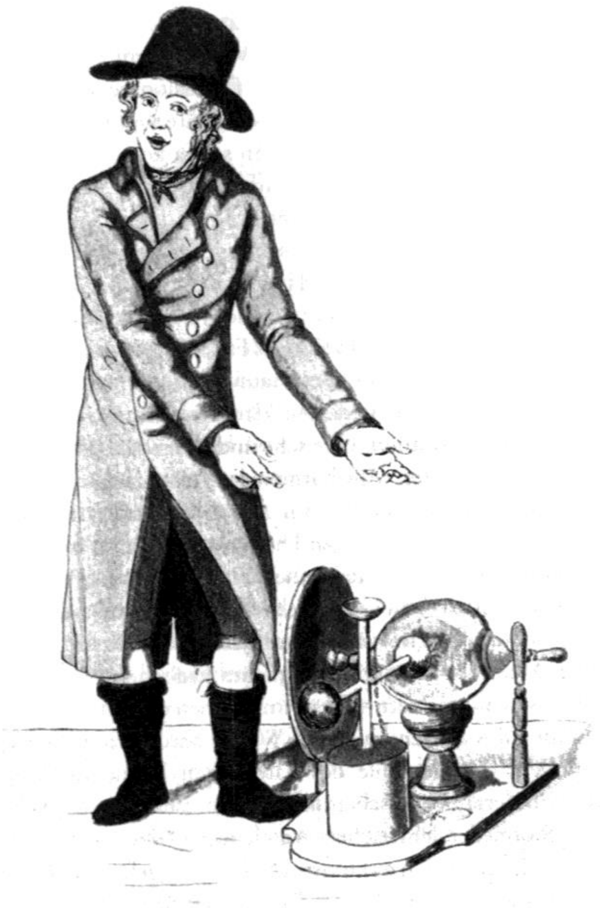
Picture V: Reconstruction of Guericke's set-up with the sulphur sphere (University of Oldenburg)



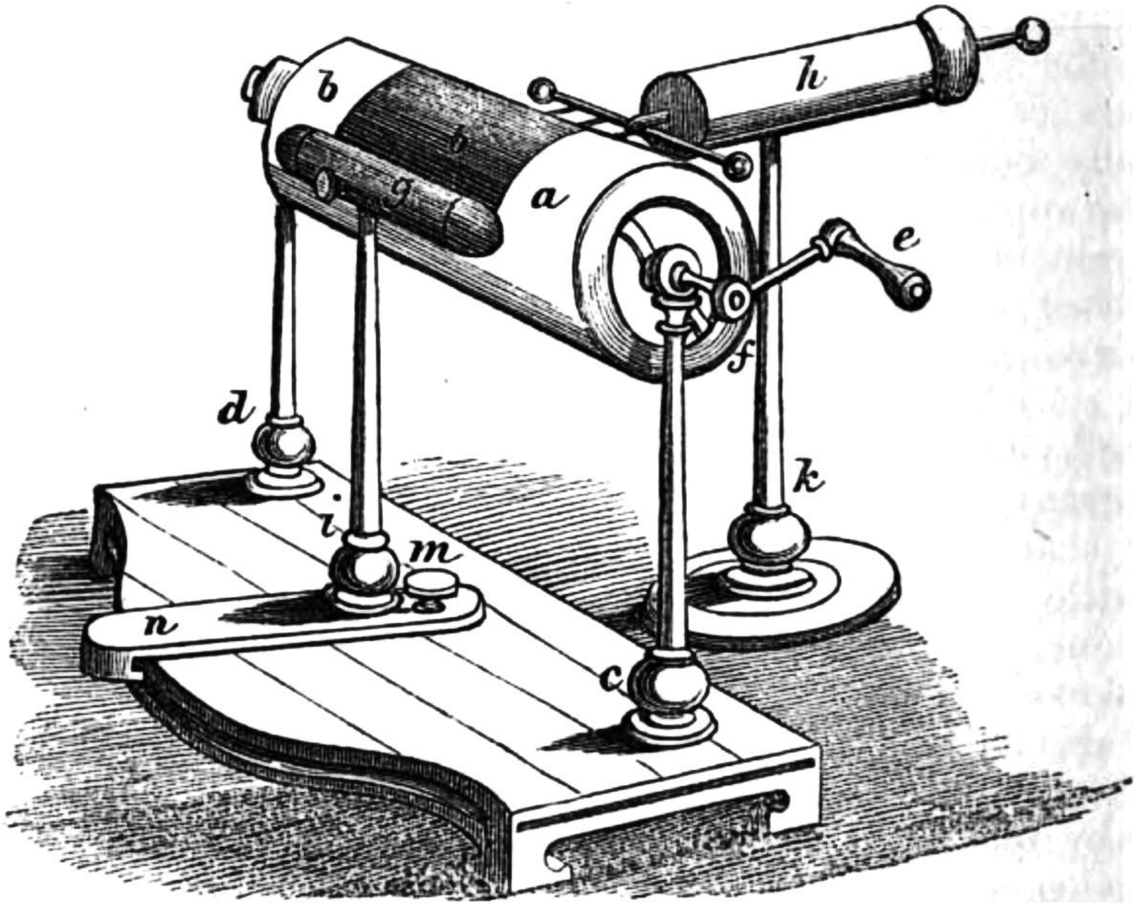
Picture VI: Electrifying machine working with friction – glass sphere rubbed by hand



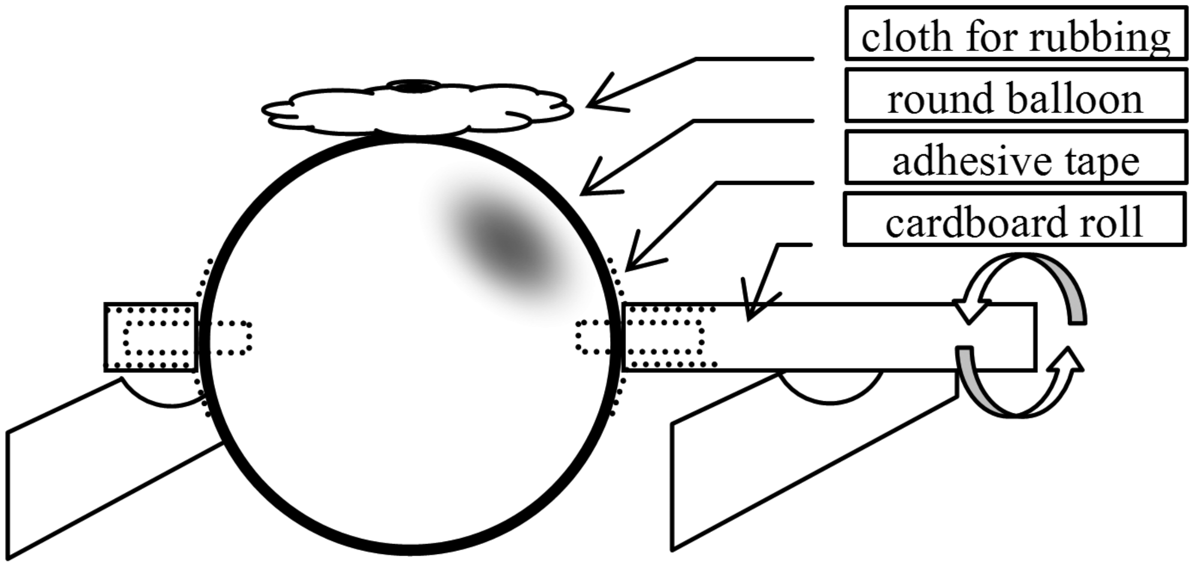
Picture VII: Electrifying machine working with friction – glass sphere turned on a silk cushion



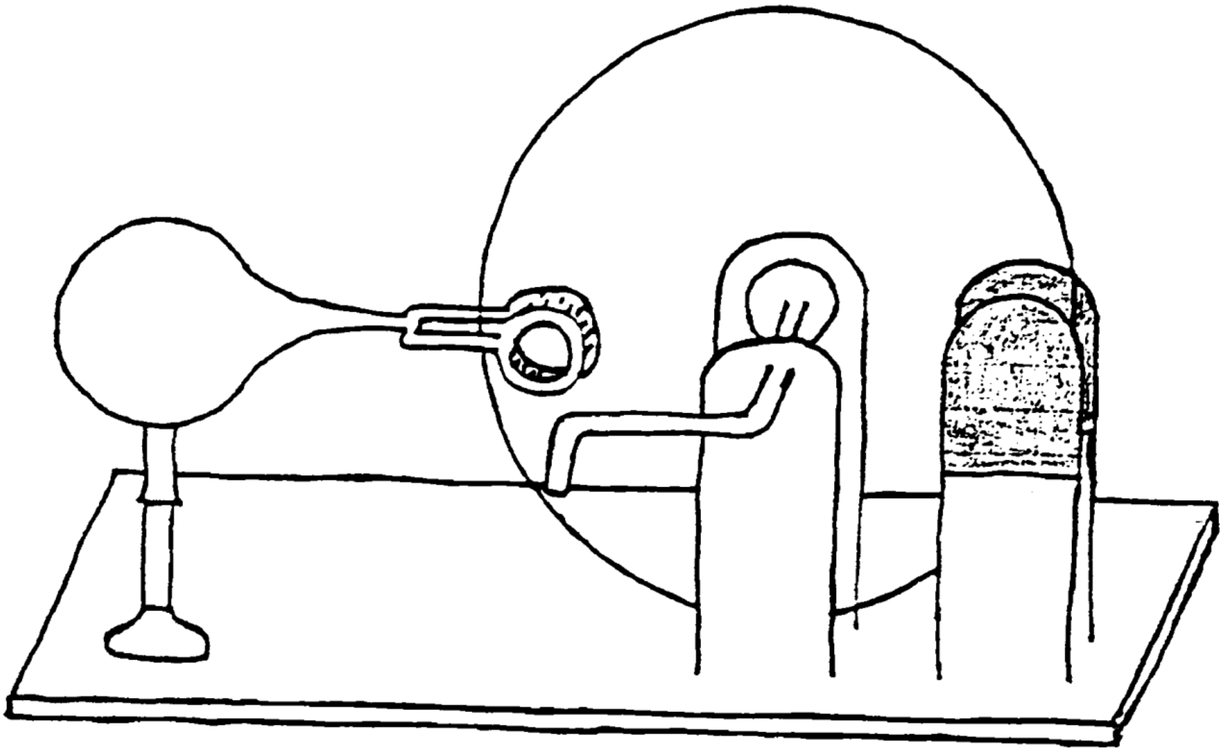
Picture VIII: Electrifying machine working with friction – glass cylinder with fixed woollen or silk cloth



Picture IX: Simple reconstruction of Guericke's electrifying machine using everyday material

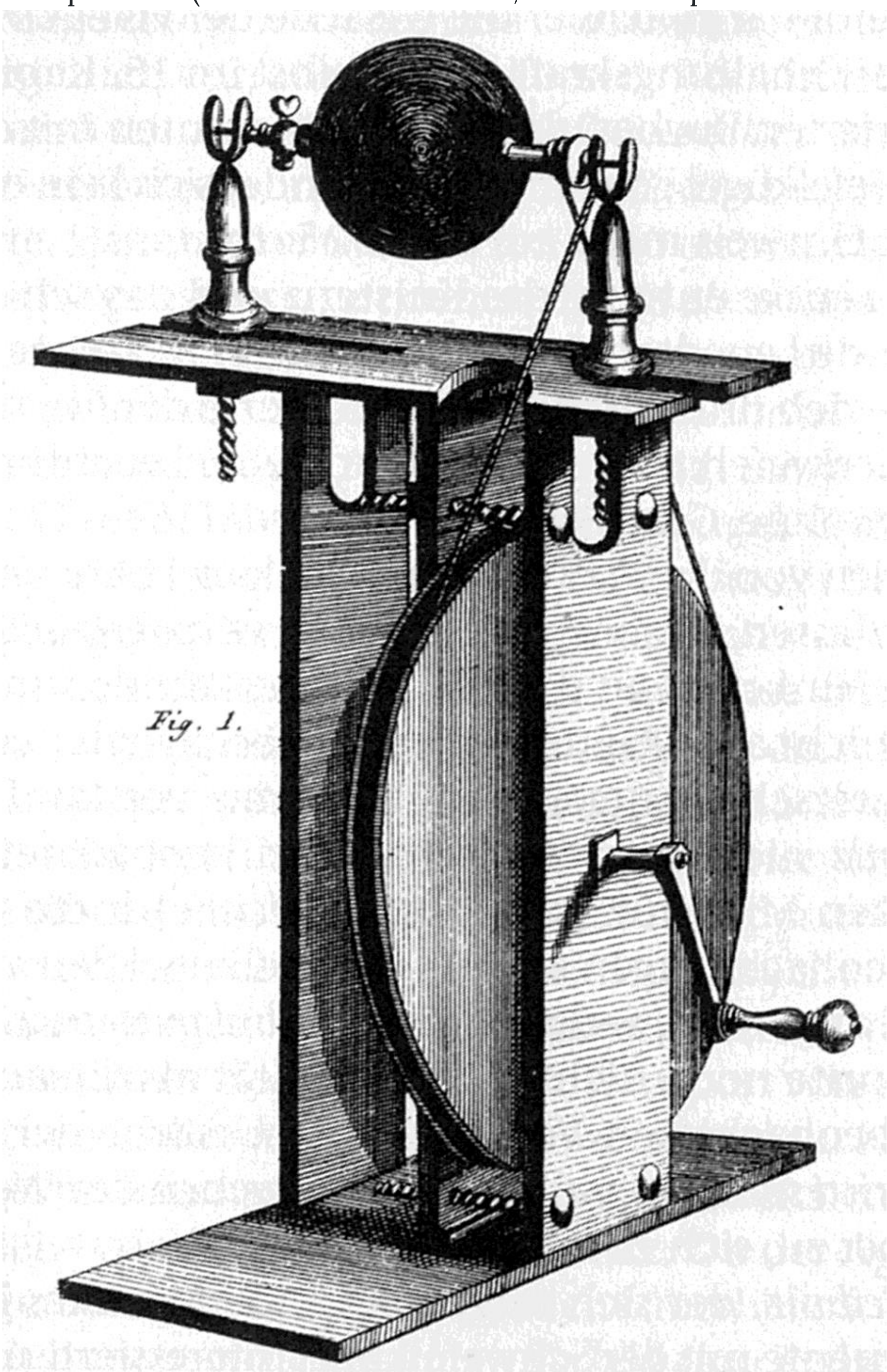


Picture X: Sketch of an electrifying machine consisting of a disc. Left: conductor taking in the charge. Centre: glass disc with handle. Right: two silk cushions between which the disc is rubbing.



Picture XI: Re-enactment of the Magdeburg Hemispheres experiment 1963, [2] pg. 28

Picture XII: electrifying machine according to Francis Hauksbee (around 1700) for two persons (one to turn the crank, another to press their hands on the sphere)



Picture XIII: Reenactment of the floating-feather experiment by a member of the Otto-von-Guericke-society.

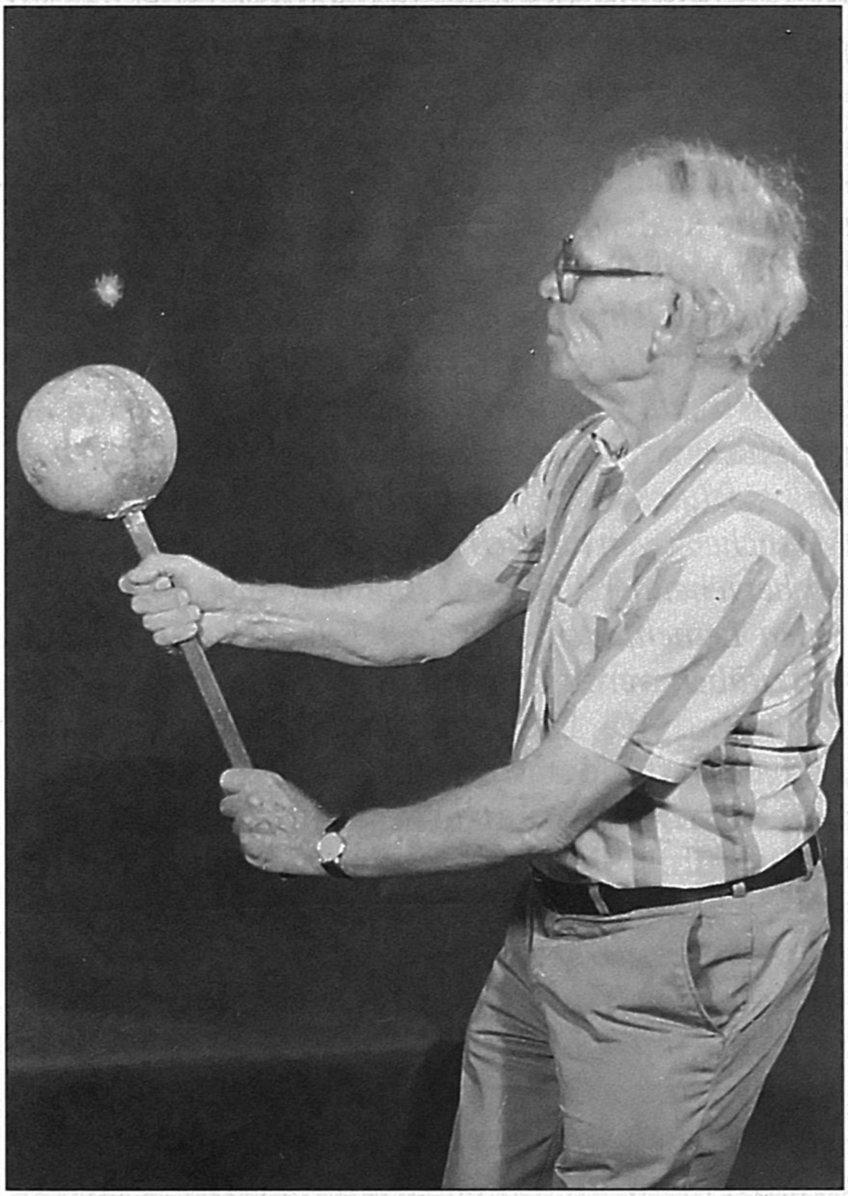


Bild 6
Schwebeversuch mit einer Feder, Dr. *Moewes* bei einem Demonstrationsexperiment [31]

8. Obstacles to teaching and learning

8.1 The role of scientific instruments

As the instrument is difficult to handle its use has to be practised throughout the experimental phase. Instead of being repelled, light objects often cling to the sulphur sphere (see the comments on the experiments). This should be regarded as a chance to understand that in general, scientific instruments are not machines which produce data, evidence and answers easily at a first attempt. Pupils should understand, that practice and skill has to be developed until experiments with

scientific instruments like the sulphur sphere will be carried out successfully. Repeted attempts are needed in order to dispose of the tacit knowledge necessary to make a light feather levitate in the air above the sulphur sphere. This aspect should be discussed by the pupils with special focus on the role of skill and practice for scientific experimentation.
A discussion of the "WHY?" and "WHAT FOR?" of scientific instruments should be guided by the analysis of Guerickes letter (material I). The students develop their own ideas to these questions, which ususally will be derived from a verificationist perspective: Instruments are made for showning (or "proving") a theory, law etc in a clear-cut manner. This view probably roots in the use of instruments in traditional science courses. There data and evidence are often derived from observations without discussing problems, alternatives, disputable interpretations or general doubts on the construction and handling of an instrument. Before analysing the specific use of an instrument in the research process (inductive, hypthetico-deductive etc.) one basic idea should be clear: Many scientific instruments "transfer nature into the lab in order to tame it subsequently". Nature therefore can be replicated, analysed and studied in a controlled and reliable manner. Nevertheless, there are other ways of producing evidence in science like in astronomy or during field expeditions, where the lab has to be taken into nature to study the phenomena in situ.

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.
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9. Pedagogical skills

The moderation of open-ended activities and discussions possibly provokes feelings of uncertainty among science teachers. Open ended activities generally may best be supported by offering oral or written advice, which pupils can ask for if needed. Open-ended discussions are, in scientific lessons, less common than for instance in social sciences or humanities. The teacher moderates a discussion for example, if he/she collects and structures the ideas, answers and solutions of pupils. A low degree of guidance is recommendable. A graphical representation of the pupils' ideas on the blackboard where central issues are highlighted and clustered may be quite helpful. Only after the graphical representation has been finished, it is judged by the pupils as a whole and thereafter by the teacher. Such methods of moderating open-endedness and student-centeredness shall reduce the role of highly structured teacher-pupil-dialogue, in which pupils quite often try to guess the "right" answer the teacher wants to listen to.

Activities for addressing the nature of science explicitly and reflectively should be instructed according to the method of reflection corner.
Scientific surveys show that knowledge about the nature of science is not simply acquired along the way in otherwise good content-based lessons. This is very unlikely even if the lessons are oriented towards history or philosophy of science. Researchers therefore have recommended to address the nature of science explicitly and reflectivly. Due to this the method of the reflection corner, which is supposed to help the teacher to encourage and moderate the pupils' processes of reflection, has been developed.

10. Research evidence

Students are highly motivated when designing the instruments and are eager to present their upsides and design-principles. Analysing the downsides should be done after discussing general criteria for good scientific instruments, since it provides a structure for discussion and prevents frustration resulting from students' eager, but unguided attempts to disqualify others' instruments designs.

11. Further user professional development

[A] Homepage of the Otto-von-Guericke-Society:
http://www.uni-magdeburg.de/org/ovgg/welcome.html
[1] Guericke, Otto von (1994). The new (so-called) Magdeburg experiments of Otto von Guericke. Dordrecht [u.a.]: Kluwer Acad. Publ.
[2] Monumenta Guerickiana: Magazine of the Otto-von-Guericke-Gesellschaft e.V. / [edited by the President of the Otto-von-Guericke-Society], (26), Issue No. 3, Magdeburg 1996
[3] 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)
[4] I. Bernard Cohen (1951). Guericke and Dufay. Annals of Science, Volume 7, Issue 2, Pages 207 – 209