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Evaluation Report for the Museum of Science and Industry
**Exhibit: Moving charges: Wimshurst Machine**
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The Museum of Science and Industry (MSI) is currently designing three new permanent exhibits. The most advanced of these is an exhibit hall presently referred to as “Science Storms”. The goal of the exhibit is to introduce basic chemistry and physics concepts in the context of weather phenomena. We were asked to evaluate the visitors’ interaction with and understanding of the historical electrostatic generator known as the “Wimshurst Machine”. MSI currently has a working Wimshurst machine in the Grainger Hall of Basic Science as well as the largest, although no longer functioning, Wimshurst Machine built by James Wimshurst in 1885 on display. Both will be included in the new exhibition hall and paired with the lightning weather phenomenon,.

MSI summarizes the exhibit as follows: Visitors separate charge using historic Wimshurst static electricity machine that produces high voltage current by electrostatic induction. The exhibition development and evaluation staff envisions the potential interactive opportunity as one where the visitor operates a small Wimshurt machine artifact to generate static electricity and a discharge of sparks. The goal of the current evaluation is to answer the following questions:

1. Can people understand how it works, particularly that the machine is separating charges?
2. What contextual information (graphics or text) are most effective in promoting conceptual understanding?

## Scientific Background

*How the Wimshurst Machine works*

Static electricity is the accumulation of unmoving electrical charges. There are two ways of making static electricity: 1) friction, by rubbing two materials; and 2) induction, or creating an electrified state in one body by bringing it close to another electrified body.

The Wimshurst Machine converts mechanical energy into electrostatic energy by separating positive and negative charges across several components of the machine and allowing them to accumulate until a spark is created. The mechanical energy is supplied by a crank which sets two plastic disks rotating in opposite directions via a drive pulley (Figure 1).

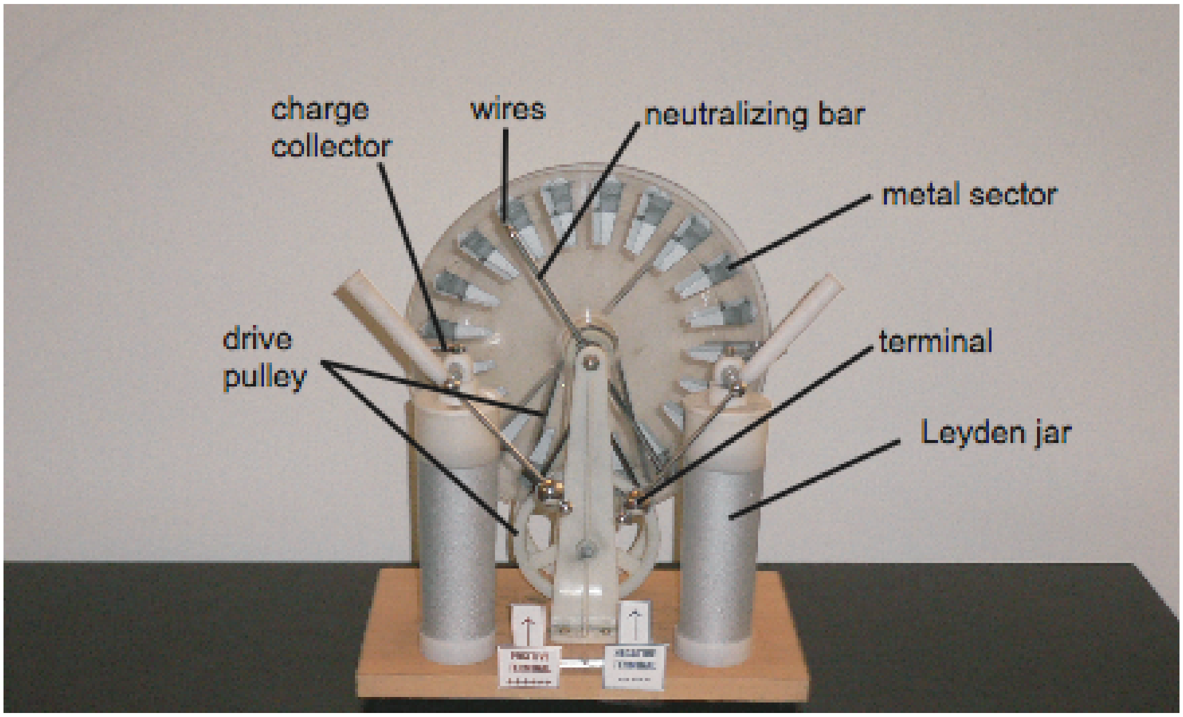


Figure 1. Wimshurst machine.

Metal sectors on the disks pass by neutralizing rods with wires that are in contact with the disk. The wires serve to electrify the metal sectors by separating the charges between the disks. The neutralizing rods are aligned about perpendicular to one another such that the metal sectors on each disk come in contact with the wires at different spaces within the machine. Because the disks are rotating in opposite directions, the metal sectors on each disk will change polarity as they pass by the wires on the neutralizing rods. The space around the disks is effectively divided into quarters by the neutralizing bars. In the top and bottom spaces between the neutralizing bars, one disk carries positive charge and the other disk carries negative charge. In one of the lateral spaces between the neutralizing bars, both disks carry a negative charge; in the other lateral space, both carry positive charge. The best graphic we found describing the separation of charges around the two disks was at the following website: http://physicscourses.okstate.edu/ackerson/museum/WhimshurstMachine.htm.

The negative and positive charges in the lateral spaces attract the opposite charges at the charge collectors. Thus the charge collectors are electrified through induction. The metal balls, or terminals, at the opposite ends of the charge collectors build up in the opposing charge that is not attracted to the disk. Leyden jars, or empty plastic containers covered with a metal coating act as capacitors, providing energy storage (Ford, 2002). The charge that builds up across the terminals can be of extremely high voltage. The current itself is relative small and discontinuous.

### *How lightning is created*

Lightning is the result of the accumulation of separated charges between clouds and the ground. There are several theories regarding how charges are separated in the clouds, including those involving induction, ion capture, and convection (MacGorman and Rust, 1998; Rakov and Uman, 2003). There is growing consensus that the ice-graupel mechanism is the dominant cloud electrification mechanism, at least in cumulonimbus clouds (Rakov and Uman, 2003), and this is the one we used in our proto-labels. Under this model, the electification of clouds occurs with the separation of charges via friction as ice and precipitation (graupel) particles collide with one another. Separation of charges is due to gravity (negative charges sink over positive charges).

There are also a number of types of lightning, both cloud flashes and ground flashes (MacGorman and Rust, 1998). We chose to describe one of the most common ground flashes. The negative charges at the base of the cloud attract positive charges in the ground below. After sufficient accumulation of charges, a negatively charged leader propagates downward and is followed by an upward return stroke. The net effect is to lower negative charge from the cloud to the ground (MacGorman and Rust, 1998). The speed of the leader can be extremely fast (on the order of 200,000 mph); the return stroke can be several orders of magnitude faster.

## **Evaluation process**

Our evaluation process consisted of interviews where we asked groups of visitors a series of questions and recorded their answers ourselves. Interviews were conducted on Tuesday afternoons in the rotunda on the main floor at MSI. MSI had recently opened their Christmas trees exhibit which consists of Christmas trees decorated by different Chicago cultural groups. Most of these trees were set up in the rotunda and we were able to solicit visitors passing though the exhibit. One person demonstrated the machine and spoke with the visitors while the other took notes (Figure 2). All groups were asked the same questions. The interviews were conducted in two steps. First, the Wimshurst machine was demonstrated for visitors and then asked a few questions regarding their experience and understanding without any supplementary information provided for them. The only labeling provided was a tag that identified one terminal as positive and one terminal as negative (Figure 3a). Following this, labels were produced and the same visitors were asked to read as much or as little of the information as they chose (Figure 3b). This activity was followed by another series of questions.

Figure 2. Thomaie Hilaris interviewing visitors. Photo: M. Hopkins

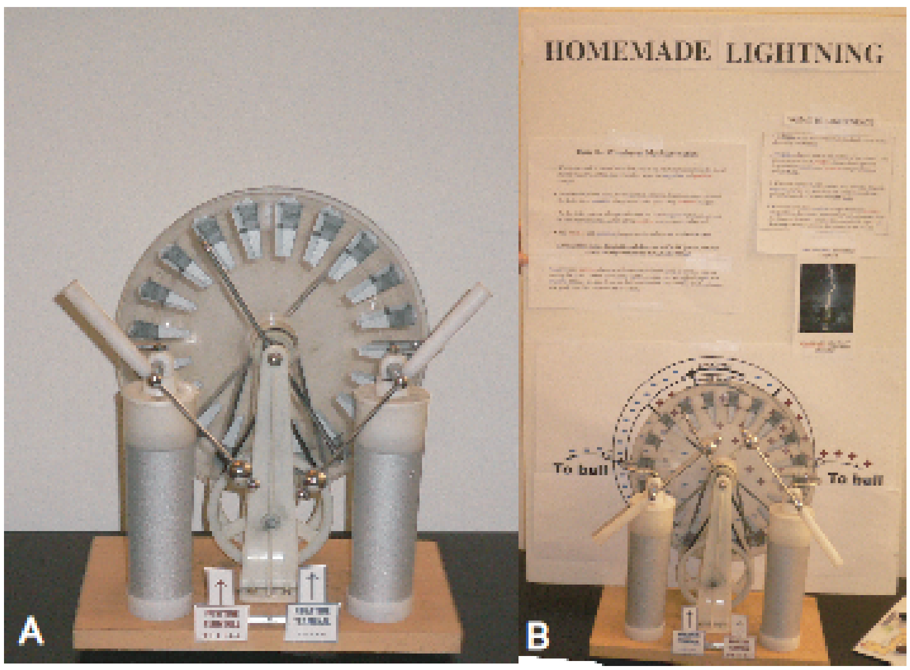


Figure 3. Demonstration without (A) and with (B) labels.

After 5 preliminary interviews, we revised both the labels and the questionnaire. The responses which prompted us to do this included immediate feedback about reducing text and increasing graphic explanation. Our questionnaire changed only in the manner that we were asking the questions in an effort to solicit more specific information about what visitors understood. For example, instead of asking “Is it important to you to know what the machine is used for or is it interesting just for what it does (creating a spark)?”, we asked visitors to rank different topics according to their relative importance or interest to them (see final questionnaire, question 8).

*Questionnaire*

The final questionnaire consisted of the following questions. After the first four questions, visitors were shown the labels.

1. What do you see happening when the crank is turned?
2. How would you explain this exhibit to someone who has not seen it?
3. What parts of the machine are easy to understand?
4. What parts of the machine are difficult to understand?

SHOW LABELS HERE

5. Is it clear that there is a difference between the two balls (terminals)?
6. Is it clear how the positive and negative charges move through the machine?
7. Does the comparison with lightning improve the clarity or interest of the exhibit? How?
8. Rank these in order of most importance or interest to you:
   ________Why the machine was built/what it is used for
   ________How it generates electricity
   ________How it is like lightning

If there was disagreement regarding the last question within groups, each individual was asked to rank the three topics separately.

*Labels*

Labels explaining the Wimshurst machine consisted of a graphic illustrating where charges were being separated along the disks as well as explanatory text (Appendix 1). Labels explaining lightning included a graphic illustrating the separation of charges between the cloud and the ground as well as explanatory text (Appendix 2). The appearance of the Wimshurst machine with and without labels is shown in Figure 3.

## Results

*Demographics*

We interviewed a total of 26 groups made up of a total of 77 individuals. Groups consisted mostly of families (at least one adult and one child) and occasionally by younger or older couples. We interviewed one school group of 6 middle-school-age boys with a chaperone. Of these groups, three visitors identified themselves as scientists, specifically two electrical engineers and one atmospheric scientist. Gender distribution was about equal: 40 males and 37 females. Age distribution was heaviest among children under 20 years old. The 30-50 year old range was the least well represented (Figure 4).

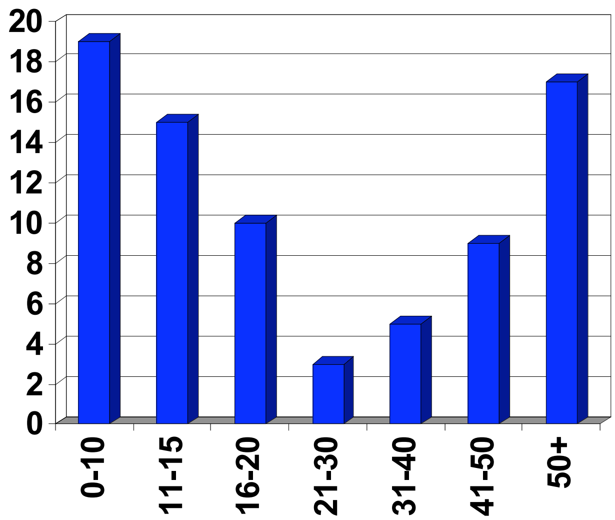


Figure 4. Age distribution among groups interviewed.

*Questions*

Results to all questions are described below. Numbers in parentheses refer to the number of groups in which at least one person provided such an answer.

*Question 1: What do you see happening when the crank is turned?*

Most groups used the words "electricity" (13) or "spark" (11) to answer this question. Some groups specified "static electricity" (04). Several children described the phenomenon as "lightning" (05). Answers that were mentioned once included "optical effect", "cracking", and "fire". One group described the phenomenon as "positive and negative attracting".

*Question 2: How would you explain this exhibit to someone who has not seen it?*

Most groups mentioned that the disks were turning (18). A subset of these groups mentioned that the crank was turning the disks (09) and a subset noticed that the disks were turning in different directions (04). A small number of groups mentioned that there was a build-up of electric charge (04) and a couple of these explained further that when the charge built up enough, the spark jumped across the terminals (02). A few groups noted that the faster the crank was turned, the faster the machine sparked (04). A few groups used the words “magnetic field” (03) or “friction” (04) to describe the machine. About half a dozen groups said that they did not know how to describe the exhibit (05).

*Question 3: What parts of the machine are easy to understand?*

The most common response to this question was the rotating disks (10). A smaller number of groups said that the activity of a person turning the crank or disks was easy to understand (06) and one group mentioned specifically that it was mechanical (01). A similar number of groups said that the terminals were easy to understand (05). A similar number of groups noted that it was easy to understand that the machine was creating electricity (05). Other parts of the machine that were mentioned only once included the “metals parts”, “gears”, “rods”, “labels”. One group decided that the parts were moving too fast to see.

*Question 4: What parts of the machine are difficult to understand?*

The most common answer to this question was the Leyden jars (15), perhaps because they are so prominent but also because the coating makes them look like they have something in them. A few groups asked specifically if there was liquid in them. Other parts that visitors found perplexing included the charge collectors (03) and the metal sectors on the disks (03). The labels and the terminals were each mentioned once. A third of the groups noted that it was difficult to understand how the electricity is created by the machine or how the electricity is transferred to the terminals (08). One group asked why the spark was jumping across the terminals. One group was confused by the noise that machine was making. One group said that nothing was hard to understand.

*Question 5: Is it clear that there is a difference between the two balls?*

*Question 6: Is it clear(er) how the positive and negative charges move through the machine?*

Approximately 80% of groups answered yes to both questions. A subset of these specified that the difference between the two terminals was a difference in charge between them (06). Another subset, however, described the difference between the two terminals as the height of the terminals relative to one another.

*Question 7: Does the comparison with lightning improve the clarity or interest of the exhibit? How?*

Every group but one answered yes to this question. In regards to how, answers that indicated improved clarity were slightly more common than answers that indicated improved interest. Answers regarding the former included "Because they look the same" (05) and "Because it explains lightning" (04). Answers regarding the latter included "Because it's related to the real world" (02), "Because it explains why its on display" (01), and "Because you can control what you want to see" (01). Two groups noted specifically that it the comparison improved interest but not clarity. Two groups said they thought the comparison was good for kids.

*Question 8: Rank these in order of most importance or interest to you. A) Why the machine was built/what it was used for. B) How it generates electricity. C) How it is like lightning.*

Almost everyone ranked (B) as the first or second choice and (C) as their second or third choice (Table 1). (A) was split between first and third choice. There was no information regarding (A) provided in the labels.

Table 1. Tabulated scores for question 8.

| | **A** | **B** | **C** |
|---|---|---|---|
| **1st choice** | 9 | 12 | 4 |
| **2nd choice** | 5 | 10 | 9 |
| **3rd choice** | 11 | 2 | 11 |

**Conclusions and suggestions**

Results of this evaluation have bearing on both questions posed by MSI staff. It is clear to visitors that the machine is generating electricity but not *how*. We suggest that the machine itself requires textual/graphic support. Results also indicate that the mechanical parts of the machine are intuitively clear but the non-moving parts of the machine, namely the Leyden jars and charge collectors, are not.  We recommend that the individual parts and their functions have explanation on or near the machine.

We may have learned more about what the visitors were taking from the labels if we had been more consistent in asking groups why they were answering “yes” or “no” to questions 5 and 6.  (Compare with question 7, where we explicitly asked “how” the comparison to lightning was increasing the clarity or interest of the exhibit).  Nonetheless, while only six groups expanded on their answers to describe the difference between the two terminals as one of positive vs negative charge, they were different groups than the four that had described a build-up of charge in response to question 2.  Therefore, about a quarter of those groups interviewed were able to describe the difference between the balls as one of different charges after reading the labels even though they had not mentioned this when describing the machine earlier in the interview.

Overall, we had a more positive response to graphic explanations over textual ones.  We highly suggest color coding the machine (Figure 5).

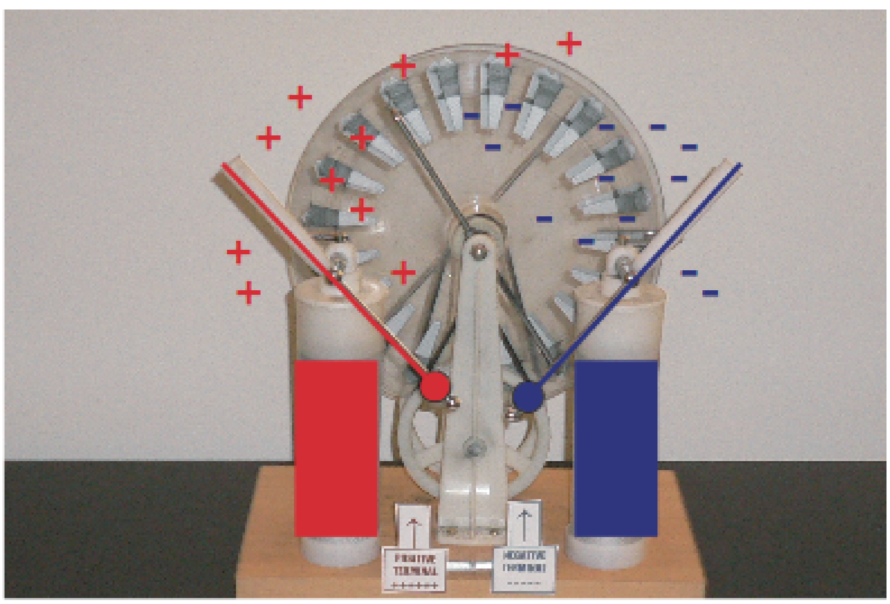

Figure 5.  Suggested color coding on Wimshurst machine.

Nonetheless, the complexity of charge separation among different parts of the machine and how this “transfers” charges to the balls requires some textual support of the graphics.  For example, note that even the suggested graphic in Figure 5 simplifies the separation of charges by ignoring the separation along the charge collectors and thereby eliminates an attempt to show how induction between the disks and the charge collectors is occurring.  This could be ameliorated by coloring the charge collector accordingly but requires being able to see the machine from the side as they are currently hidden by the Leyden jars from the front.

There was also an overwhelmingly positive response to the comparison with lightning, improving clarity for some and interest for others. Given the suggestion to color code the machine, we also suggest that an explanation for lightning parallel that for the machine (Appendix 2).

Finally, these results indicate that the machine is interesting for its own sake. The phenomenon of lightning appears to be supportive in terms of clarity and interest but visitors are less interested in how the machine is like lightning than in how the machine is generating electricity. We find this result to be surprising because we expected visitors to be more interested in the weather phenomenon. Clearly this could simply be our own misconception. But it also is possible that this result is biased by how the ranking question was posed to visitors. We may have received different responses if we had stated the topic as "How lightning is created" instead of "How [the machine] is like lightning".

The ranking also suggests that the history of the machine is interesting to visitors. This result supports the move to place the large historic Wimshurst machine on the floor, even though it is currently non-functioning. As further anecdotal evidence, we observed visitors taking pictures of each other pretending to turn the crank of the large Wimshurst machine in the Grainger Hall of Basic Science.

**References**

Ford, R.A., 2002, Homemade Lightning: Creative Experiments in Electricity, 3rd edition, McGraw-Hill, 255 p.

MacGorman, D.R., and Rust, W.D., 1998, *The Electrical Nature of Storms*, Oxford University Press, 422 p.

Rakov, V.A., and Uman, M.A., 2003, *Lightning: Physics and Effects*, Cambridge University Press, 687 p.

**Appendix 1. Textual support for Wimshurst Machine.**

# How the Wimshurst Machine works:

- When the crank is turned each disk passes by a bar that electrifies the metal marks (sectors) on the disk by pulling apart the **negative** and **positive** charges.

- Because the plastic disks are rotating in opposite directions, some parts of the disks carry **negative** charges and other parts carry **positive** charges.

- As the disks pass the charge collectors, all of the negative charges are sent to one ball (terminal) and all of the positive charges to the other ball.

- The positive and negative charges on the balls create an **electric field**.

**The machine makes the right conditions for a SPARK just as a storm creates the right conditions for LIGHTNING!**

**Appendix 1.  Textual support for Wimshurst Machine.**

Negative and positive charges will continue to accumulate as long as you are turning the crank.  When the electric field becomes very strongly charged, the negative charges are sent from one ball to the other.  We see this brief exchange as a spark that flies between the two balls.

Appendix 2. Textual and graphic explanation of lightning.

# WHAT IS LIGHTNING?

**NEGATIVELY CHARGED CLOUDS**

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**POSITIVELY CHARGED GROUND**

_ 1. **Colliding** water and ice droplets in clouds create static electricity via **friction**.

2. **Negative** charges sink to the bottom of the clouds. This attracts a build up of **positive** charges in the ground. Together the negative and positive charges create an **electric field.**

3. When the electric field becomes very strongly charged, negative charges are sent from the clouds towards the ground at speeds of around **200,000 mph**!

4. When the speeding negative charges meet the positive charges from the ground, an electrical current passes from the cloud to the earth. As this happens, visible light—or **lightning**—streaks up from the ground to the clouds.