How a Wimshurst Machine Works

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The Wimshurst Machine is an electric generator that utilizes electrostatic induction to generate a large potential difference between two capacitors. Before getting into the details of the Wimshurst Machine, let's review some basic electrostatics.

Consider an uncharged conductor that is attached to ground with a wire. If we bring in a positively charged object from infinitely far away and place it near the grounded conductor, electrons from the ground will flow into the conductor, and arrange themselves on the surface of the conductor such that the total electric field inside the conductor is zero. If we were to disconnect the wire that attaches the conductor to ground, the electrons that flowed in from ground are now stuck in the conductor. We can now remove the positively charged object, and our conductor is left with a negative charge.

Note that separating the positively charged object from the negatively charged conductor requires an amount of energy. If our positively charged object is another conductor, we can think of the two conductors as forming a capacitor. From

$$V = \frac{Q}{C} \tag{1}$$

we see that as we decrease the capacitance C while holding the difference in charge Q between the conductors fixed, the potential V between the two conductors must increase. The the dependance of the capacitance on the separation of the two conductors is determined by the geometry of the conductors, and while in general this dependance is not given by a simple expression, the capacitance will drop as the conductors are separated.

If we now look at the energy E_C stored in a capacitor

$$E_C = \int V dQ = \int \frac{Q}{C} dQ = \frac{Q^2}{2C} \tag{2}$$

we see that as we decrease the capacitance, the energy stored in the capacitor will increase. This is the energy we must supply to separate the conductors.

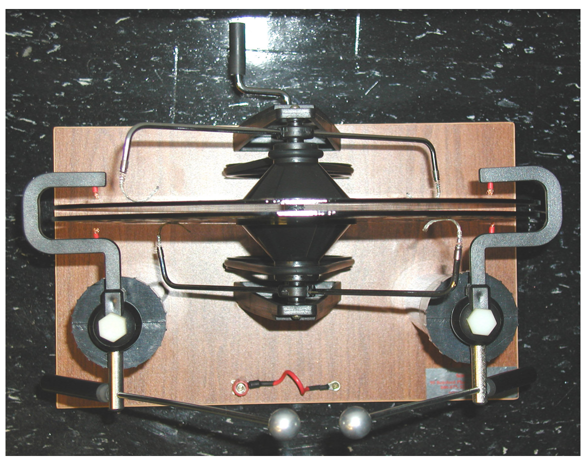
With these ideas in mind, let's now turn to the Wimshurst Machine. An example of a typical Wimshurst Machine is shown in Fig. 1. The Wimshurst Machine has a pair of counter-rotating dielectric disks with a number of conducting patches around the disks. Brushes or sharp Corona wires at opposite ends of the disks connect patches on both disks to two storage capacitors, and a neutralizing bar connects patches at opposite ends of the disks after they pass through the capacitor brushes. The ends of the capacitors that are not connected to the patch brushes are connected to one another, and we can consider them at ground potential. The ungrounded ends of the capacitors form the output of the machine, and are connected to a spark gap that fires when the potential across the gap is sufficient to cause dielectric breakdown of the air[1].

First, let's just consider one disk of the Wimshurst Machine, say, the one closest to us in Fig. 2. In order for the machine to operate, there must be some initial charge. In practice there will always be some charge imbalance. Let's assume the right storage capacitor is positively charged, while the left one is negatively charged. If we rotate the disk counter-clockwise, the patch at A will pick up a positive charge, while the patch at A' will become negatively charged. As we rotate further, the patches will move to B and B' where they are connected to one another through the neutralizing bar. Because of B's proximity to the positive charge from the left capacitor at A, and B''s proximity to negative charge at A', as the patches are rotated further and disconnect from the neutralizing bar, the patch originally at B will be left with a negative charge due to induction, while the patch originally at B' will

[1]The dielectric strength of air is about 3×10^6 V/m, or in other words, each mm corresponds to about 3kV. Sharper electrodes in the spark gap will cause the air to break down at lower voltages, as sharper points produce greater electric fields than smoother ones. Large ball electrodes will allow the Wimshurst Machine to charge up a great deal before the spark gap triggers, while smaller balls will fire earlier given the same separation. The tip of a needle is so sharp that any charge built up will dissipate through Corona discharge rather than an instantaneous spark (this can be seen as a steady dim purple glow near the tip). Corona discharge also produces a significant amount of ozone (triatomic oxygen), which has a distinctive smell.

(a) Front View

(b) Back View



(c) Top View

Figure 1: **Images of a typical Wimshurst Machine. The different colors and shapes of the metal patches on the disks of this particular Wimshurst Machine serve no functional purpose. Note that these are high resolution images, so if you are reading this document in electronic form you may zoom in on the figures for further detail.**

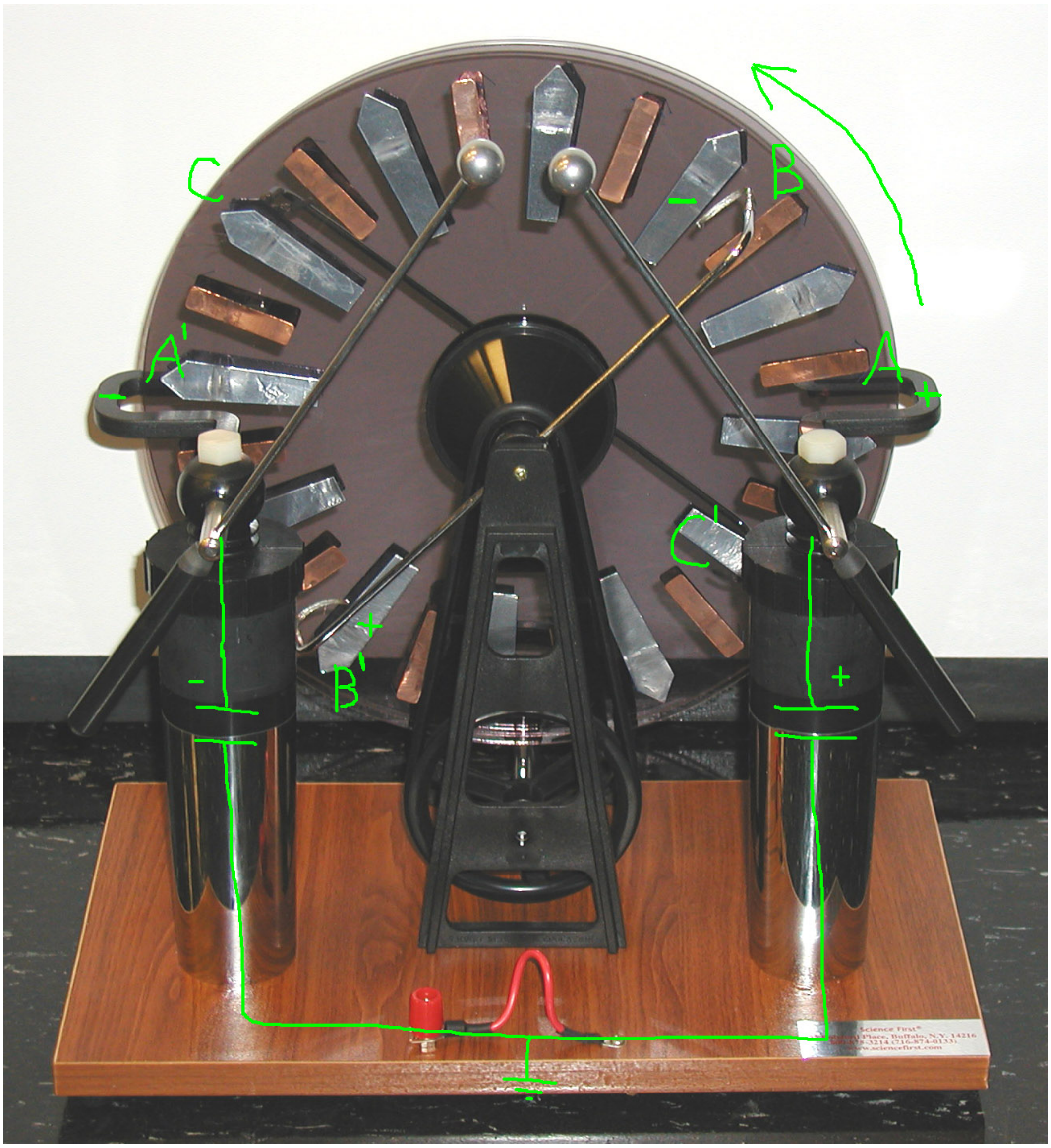


Figure 2: **Movement of charge.**

have a positive charge. The potential difference between these two patches is less than the potential difference between the capacitors, so one disk by itself does nothing more than slowly drain the two capacitors of charge.

When we bring the second disk into the picture, we can think of it as initially undergoing the same sort of process as the first disk described above. If we now look at the patch at position B of the frontmost disk, it not only picks up a negative charge through induction by the proximity to the right capacitor, but it is also influenced by the positive charge on the patch directly behind it on the rear disk (in fact, most of the charge developed through induction is from the influence of patches on the opposite disk). The same thing happens at position B' with the sign of the charges reversed. When we crank further, we separate the patches from the two disks at position B (and B'), and this action is the same as separating the conductors of a capacitor. Thus by cranking the patches apart, we are adding energy to the system, and increasing the potential difference between the patches on the two disks. This potential difference becomes greater than the potential between the two storage capacitors, so by the time the patches reach the capacitor brushes they are able to contribute additional charge to the storage capacitors. When the patches on the front disk reach positions C and C', they contribute to the induction of charge on the patches of the rear disk at these positions, the same way the rear patches contribute to induction to the front disk's patches at B and B'. As the storage capacitors charge up, the charges and voltages developed through induction and separation of patches increases. It is important that the disks be rotated in the correct direction; rotating in the opposite direction will only be effective at neutralizing the storage capacitors.