AN INTRODUCTION TO THE TRIBOELECTRIC SERIES

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ABSTRACT—Conservators use materials in their treatments, storage and mounting selected for their archival and long-term stability, their compatible reaction to environment, and tradition. Over time, the selections of preferred materials have become well established, encompassing both natural and synthetic materials, woven and non-woven alike. The phrase 'like with like' is often used when materials are selected. These long-held philosophies perhaps need to be reexamined. How materials behave with one another is related to many things, among them topographic friction, cohesion, and the effects of static charge. Each of these factors additionally influences how materials interact with one another. Could the material selected to be in contact with the artifact also aid in the preservation of an artifact or its support? It turns out that there is a surface phenomenon of electron exchange that occurs when two materials are in contact with one another and this can aid the cohesion of materials to one another. This phenomenon can lead to either positive or negative results. The degree of electron sharing from one material to another is related to their relative placement on what is called the triboelectric series. Some combinations of materials have improved holding powers versus others.

1. INTRODUCTION

Static charge has long been identified as an issue in conservation, especially for fragile and friable materials (Margariti and Loukopoulou 2016). Addressing this concern is usually part of the protocol for framed pastels, charcoals, and friable silks. However, there has been little detailed research into its full role in the field (Commoner 1998). A 'charge' to some degree is present with all materials in contact. What conservators in all specialties and museum professionals need to learn is how to use this to one's advantage or how to lower its risks. This means reconsidering of the use of traditional or new materials when selecting for varied tasks, display, or storage.

2. STATIC CHARGE

Static charge occurs when materials are in contact and then separated without any apparent rubbing, or when materials are rubbed together. More static is created with rubbing than with simple contact and separation (Blythe 1974; Sello and Stevens 1984). When materials are in contact, electrical charges develop - which is usually something a conservator seeks to avoid when working with collections. Electrical charges occur when bonds between electrons, which are established when materials come into contact, are then broken upon separation (Carleton 1962) [1].

All bodies are composed of both positive and negative charges equally (Sello and Stevens 1984). The basis of electrostatic charging is a surface phenomenon where the disruption of the condition of equilibrium is seen in the neutral atom (Commoner 1998). Electrons have a negative charge. When energy is applied to a material system, such as by friction or pressure, a small number of electrons can jump from one material to the other. The material whose atoms gain electrons will become negatively charged with static electricity, while the material that loses electrons will become positively charged. When two materials are in contact, a flow of electrons moves from one to the other, whether it is the same material or between two different types (fig. 1).

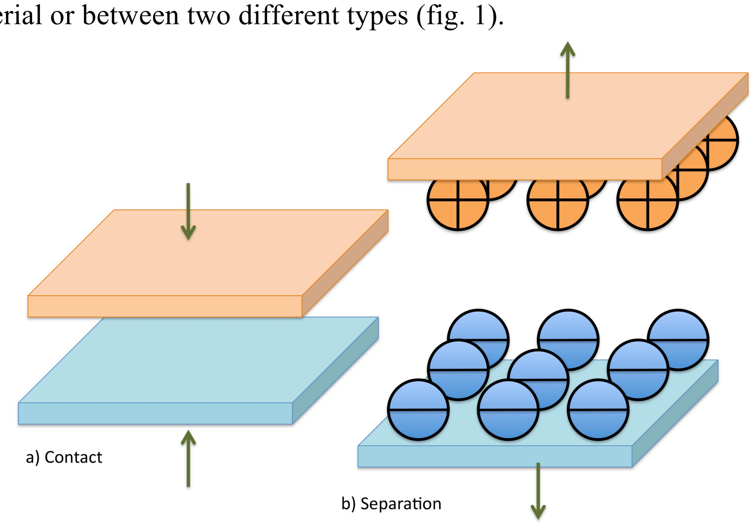

Fig. 1: Schematic of electron exchange when two different materials are in contact and are then separated. The extent of this exchange is based on the materials' placement on the Triboelectric series (table 1).

3. TRIBOELECTRIC SERIES

Materials that can gain or lose electrons are called triboelectric materials. The order of propensity to gain or lose electrons is called the triboelectric series (Sello and Stevens 1984). The series is based on the conductivity of the individual material. The level of charge is linked to a material's placement in this series (table 1). It is the distance of the two materials from one another on the series that increases the charge effect rather than the specific location in the series. Therefore, if two materials in contact are neighbors on the scale, there is less exchange, like cotton and steel. But if they are far apart, no matter where on the scale, exchange occurs. Table 1, compiled from many sources, shows the ranking of commonly used mounting materials and artifacts.

3.1 TYPES OF MATERIALS AND THEIR LOCATION ON THE SERIES

In general, proteins tend to be located at the upper part of the series, where materials prone to losing electrons and becoming positively charged are located with metals in the lower part; lead and aluminum are exceptions to this rule. Synthetics tend to be located at both far ends, and both glass and acrylic are together at the upper end of the series.

When treating military wool uniforms, polyester fibers present are very attracted to the surface of the wool fabric. Is it because of the rough surface of the fabric? Then cotton fibers would do the same. But, no, it is just those pesky polyester fibers (fig. 2). The triboelectric series explains it all: The cohesion between the wool and polyester is very strong due to electron sharing.

Fig. 2: Polyester fibers attached to wool fabric of a military uniform

<u>*A few observations about the location of materials in the series:*</u>

- Cellulosic plant fibers are in the neutral section, located in the middle of the table, along with wool and are very close together in the series.
- When mounting paper items, consider using a synthetic material to strengthen the holding power.
- Proteins, such as animal fibers, are located exclusively in the upper, positive section of the table, perhaps because amino acids tend to donate electrons.
- Synthetics are at opposing ends, with nylon and acrylic at the most positive end and polyester, polyethylene, and silicone at the most negative end.
- The topography of materials matters; the more surface area in contact between materials, the higher chance they will exchange electrons.
- Environmental conditions matter; hydrophilic materials at low relative humidity exchange charge more readily than at high relative humidity, while hydrophobic materials are less likely to exchange a charge [2].
- A material may become soiled while it is positively charged because it attracts negatively charged dirt particles in the air.

4. ADHESIONS

The triboelectric effect is considered to be very similar to the phenomenon of adhesion, in which two materials composed of different molecules tend to stick together on contact as a result of a chemical reaction. Adhesion is very similar to a chemical bond in which adjacent yet dissimilar atoms exchange electrons. When one material is physically moved away from the other, the bonding forces appear to the human eye as 'friction.' One material gains electrons, thereby creating excess electrons, while the other material loses them, thereby creating a deficit of electrons.

Adhesion can be so firm that it can be difficult to remove materials that are adhered to one another (Morton and Hearle 1962). Adhesion can even occur when charged fibers come in contact with uncharged particles.

5. CONCLUSIONS

Many of these observations go counter to our conventional ‘museum thinking.’ Other features of the series relate to the preservation of collections and clearly would benefit from more study and attention [3]. For instance, note that the phenomena involving electron exchange are related to light fastness and the pH of materials (Commoner 1998). Conservators routinely regard static as an unavoidable difficulty. From the above discussion, the exchange of electrons and the buildup of static charge can sometimes be beneficial; friction can be either an asset or a liability, but abrasion is generally undesirable. Perhaps the conservation field needs to reconsider the phrase ‘like with like’ or at least when consideration of material selection with an artifact is determined.

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APPENDIX

Measuring Conductivity

The conductivity or resistivity of a material is listed in Material Safety Data Sheets (MSDS). The unit used is ohms/cm. Below 106 ohms/cm = 1.06 ohms/m, the material will not build up or hold static. Higher than 106 ohms/cm, the material will tend to create more static. Unfortunately, because companies that are required to produce MSDS manufacture synthetic materials, they therefore omit from these sheets any textile materials made of natural fibers. (An ohm unit is the amount of electric resistance in a circuit transmitting a current of ampere when subjected to a potential difference of 1 volt.)

GLOSSARY OF TERMS

Mostly Positive: Materials that tend to give up electrons and are thus positively charged (+); materials that tend to be light sensitive.

Mostly Negative: These materials tend to attract electrons (-); materials that tend to be more acidic.

Relatively Neutral or Not Charged: Neutrally charged materials are very few, and do not tend to give up electrons. Some examples are cotton and steel.

NOTES

[1] An electric current is the movement or exchange of electrons from one material to another. All materials are composed of atoms with a surface phenomenon whereby there are an equal number of positive and negative charges (Sello and Stevens 1984). When energy is applied to materials in contact, such as through friction or pressure, a small number of electrons can jump from one material to the other (fig. 1). Both positive electrons, known as positrons, and negatively charged electrons flow continuously in both directions. The basis of the surface phenomenon of electrostatic charging is that the equilibrium condition of the neutral atom becomes disrupted, allowing electrons to

move more freely (Commoner 1998). The material that gains electrons becomes negatively charged while the material that loses electrons becomes positively charged.

Unlike magnets, which only attract materials that can be magnetized, a much larger range of materials can hold an electrical charge. In addition, a charged body can lose some, if not all, of its charge when touched by a neutrally charged body, while a magnet will not lose any of its efficacy from being touched.

Since ancient times, it has been known that rubbing certain materials such as amber would enable it to lift light objects of certain materials (Feynman 1964), such as bits of papyrus, straw, and dust. In addition, sparks could be created if amber was rubbed long enough. At the time, the attraction was believed to be magnetic. Gilbert's work in year 1600 determined that lodestone was magnetic and that this was distinct from static electricity produced by rubbing amber. Thus, Gilbert coined the word *electricus*, from the Greek word *λεκτρον* for 'amber,' to describe the attraction between small objects that exists after being rubbed. Of course, the story eventually came full circle when later scientists found the link between magnetism and electricity (Feynman 1964).

[2] The presence of moisture in the air limits any charge buildup on a surface. Therefore, the higher the relative humidity of the environment, the less static potential a material will have (Suh et al. 2010). In this way, moisture serves as a ground and reduces the static charge, thereby increasing the conductivity of the material (Commoner 1998). Natural fibers tend to be hydrophilic, or water absorbing, and are more influenced by the environment, where as most synthetics are hydrophobic, or water resistant, and are therefore less influenced by environmental conditions and more readily build up a charge.

[3] Industries of all types are concerned with the build-up of static electricity, such as those that manufacture finely-tuned, sensitive electronics, flammable vapors and dust, and printing materials, to name a few. Hospital operating rooms also work to minimize static electricity.

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Table 1: Material Order of the Triboelectric Series

Charge	***Material***	***Notes***
+ + +	Air	
	Polyurethane foam	
	Hair	
	Nylon, Dry skin	Dry skin has the greatest tendency to give up electrons and becoming highly positive in charge.
	Glass	This is why TV screens collect dust on their surfaces.
	Acrylic, Lucite	This is why these materials are not used to frame pastels.
	Leather	
	Rabbit's fur	Fur is often used to create static electricity.
	Quartz	
	Mica	
	Lead	Surprisingly close to cat fur.
	Cat's fur	
	Silk	
	Aluminum	
	Paper	
	Cotton	Best for non-static clothes
	Wool	
NEUTRAL		
	Steel	Not useful for static electricity
	Wood	Attracts some electrons, but is almost neutral
	Amber	
	Sealing wax	
	Polystyrene	
	Rubber balloon	
	Resins	
	Hard rubber	
	Nickel, Copper	
	Sulfur	
	Brass, Silver	
	Gold, Platinum	
	Acetate, Rayon	
	Synthetic rubber	
	Polyester	
	Styrene and Polystyrene	Why packing peanuts seems to stick to everything.
	Plastic wrap	A.k.a. “Cling” wrap
	Polyethylene	
	Polypropylene	
	Vinyl, PVC	

	Silicon	
	Teflon	Teflon has the greatest tendency of gathering electrons on its surface and becoming highly negative in charge.
	Silicone rubber	
- - -	Ebonite	