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The TriboElectric Effect Series

Dr. William B. Lee, PhD

When two dissimilar materials are rubbed together, electrons are usually transferred from one material to the other. The amount of charge transfer is proportional to the amount of energy that had been used to rub the materials together. This chart shows how much charge is transferred per watt second (joule or "J") of energy for each of several types of insulating materials when rubbed against clean wool. This number is the "Charge Affinity" in units of nC (billionths of a coulomb) per J (joule of energy used to rub the material against wool).

Contrary to what is implied in some triboelectric tables, when insulators are rubbed against a metal (instead of against wool or another insulator), the type of metal does not alter the amount of charge transferred. For example, it makes no difference whether aluminum or brass is rubbed against the given insulator. The amount of charge transferred would be the same. The third column in the table below shows the effect of rubbing metal (copper) against the various insulators. (Rubbing against copper will reduce the total charge transfer, because a conductor will partially "short circuit" the transfer.) This column shows "+N" If the insulator becomes positive when rubbed against copper, "-N" if the material becomes negative. The charge transferred when rubbing against copper is typically 1/3 to 1/10 of what it is when rubbing against wool. The letter "N" ("Normal") indicates a charge transfer in the 1/3 to 1/10 range compared to rubbing against wool. If the charge transferred is less, the letter "W" ("Weak") is shown.

Tests were done by applying a (small) contact pressure to two materials, then sliding them over each other a given distance, and measuring the force applied and the distance, to calculate the rubbing energy. Then the total charge on each was measured using AlphaLab static electricity meters https://www.alphalabinc.com/product-category/static-electricity/

Insulator Name	Charge Affinity nC/J (nano ampsec/wattsec of friction)	(W=weak, N=normal, or consistent with the affinity)	Notes:
Polyurethane foam	+60	+N	All materials are good insulators (>1000 T ohm cm) unless noted.
Sorbothane	+58	-W	Slightly conductiv
Box sealing tape (BOPP)	+55	+W	if sanded down to the BOPP film.
Hair, oily skin	+45	+N	Skin is conductiv metal rubbing.
Solid polyurethane, filled	+40	+N	Slightly conductive. (8 T ohm cm).
Magnesium fluoride (MgF2)	+35	+N	Anti-reflective optical coating.
Nylon, dry skin	+30	+N	Skin is conductiv metal rubbing.
Machine oil	+29	+N	
Nylatron (nylon filled with MoS_2)	+28	+N	
Glass (soda)	+25	+N	Slightly conductive. (Depends on humidity).
Paper (uncoated copy)	+10	-W	Most papers & cardboard hav affinity. Slightly conductive.
Wood (pine)	+7	-W	
GE brand Silicone II (hardens in air)	+6	+N	More positiv chemistry (see below).
Cotton	+5	+N	Slightly conductive. (Depends on humidity).
Nitrile rubber	+3	-W	
Wool	0	-W	

Polycarbonate	-5	-W	
ABS	-5	-N	
Acrylic (polymethyl methacrylate) and adhesive side of clear carton-sealing and office tape	-10	-N	Several clear tape adhesives have an affinity almost identical to acrylic, even though various compositions are listed.
Epoxy (circuit board)	-32	-N	
Styrene-butadiene rubber (SBR, Buna S)	-35	-N	Sometimes inaccurately called “neoprene” (see below).
Solvent-based spray paints	-38	-N	May vary.
PET (mylar) cloth	-40	-W	
PET (mylar) solid	-40	+W	
EVA rubber for gaskets, filled	-55	-N	Slightly conductive. (10 T ohm cm). Filled rubber will usually conduct.
Gum rubber	-60	-N	Barely conductive. (500 T ohm cm).
Hot melt glue	-62	-N	
Polystyrene	-70	-N	
Polyimide	-70	-N	
Silicones (air harden & thermoset, but *not* GE)	-72	-N	
Vinyl: flexible (clear tubing)	-75	-N	
Carton-sealing tape (BOPP), sanded down	-85	-N	Raw surface is very + (see above), but close to PP when sanded.
Olefins (alkenes): LDPE, HDPE, PP	-90	-N	UHMWPE is below. Against metals, PP is more neg than PE.
Cellulose nitrate	-93	-N	
Office tape backing (vinyl copolymer ?)	-95	-N	
UHMWPE	-95	-N	
Neoprene (polychloroprene, *not* SBR)	-98	-N	Slightly conductive if filled (1.5 T ohm cm).
PVC (rigid vinyl)	-100	-N	
Latex (natural) rubber	-105	-N	
Viton, filled	-117	-N	Slightly conductive. (40 T ohm cm).
Epichlorohydrin rubber, filled	-118	-N	Slightly conductive. (250 G ohm cm).
Santoprene rubber	-120	-N	
Hypalon rubber, filled	-130	-N	Slightly conductive. (30 T ohm cm).
Butyl rubber, filled	-135	-N	Conductive. (900 M ohm cm). Test was done fast.
EDPM rubber, filled	-140	-N	Slightly conductive. (40 T ohm cm).
Teflon	-190	-N	Surface is fluorine atoms– very electronegative.

This table can be used to select materials that will minimize static charging. For example, if uncoated paper (with a positive charge affinity value of +10 nC/J) is squeezed by a pinch roller made of butyl rubber (@-135 nC/J), there will be about 145 nano coulombs of charge transfer per joule of energy (associated with pinch and friction). This is about 20 times more than 7 nC/J, which is the static charge per joule that results from squeezing paper with a roller made of nitrile rubber (@+3 nC/J). In general, materials with an affinity near zero (e.g. cotton, nitrile rubber, polycarbonate, ABS) will not charge much when rubbed against metals or against each other. The table can also be used (with other formulas) to predict the static forces that will arise between surfaces, and to help select materials that will create an intentional charge on a surface.

Symbols in the table— Polyurethane (top) tends to charge positive; teflon (bottom) charges negative. The charge affinity listings show relative charging. Two materials with almost equal charge affinity tend not to charge each other much even if rubbed together. Column 3 shows how each material behaves when rubbed against metal, which is much less predictable and repeatable than insulator-to-insulator rubbing. The charging by metal is strongly dependent on the amount of pressure used, and sometimes will even reverse polarity. At very low pressure (used in this table), it is fairly consistent. A letter "N" (normal) in this column means the charge affinity against metal is roughly consistent with the column 2 value. The letter "W" means weaker than expected (i.e., closer to zero than expected or even reversed.) The "+" or "-" indicates the polarity. In all cases where the polarity in col.3 disagrees with col.2, it is a weak (W) effect.

Limitations of these measurements— Testing was done at low surface-to-surface force (under 1/10 atmosphere) using 1" strips of each of the insulators that are available as smooth solids. (Cotton, for example, could not be made into a solid strip.) The charge affinity ranking of non-smooth solids was interpolated by their effect on smooth solids which had measured affinity values. At this low surface force (typical of industrial conditions), the absolute ranking of charge affinity of various insulating materials was self-consistent. Above about 1 atmosphere, surface distortions caused some rearrangements in the relative ranking, which are not recorded here. Conductor-to-insulator tests were done also, and contrary to prevailing literature, all conductors have about the same charge affinity. However, the metal-insulator charge transfer was strongly dependent on the metal surface texture in a way not seen with insulator-insulator. Metal-insulator transfer was also more pressure-dependent in an unpredictable way, so charge transfer has not been quantified for metal-insulator. The "zero" level in this table is arbitrarily chosen as the average conductor charge affinity. "Very weak conductors", like paper, glass, or some types of carbon-doped rubber, had approximately the same affinity as conductors if rubbing was done very slowly. All tests were done fast enough to avoid this effect. Testing was at approximately 72 F, 35% RH, using an AlphaLab Surface DC Voltmeter Model SVM2 and an Exair 7006 AC ion source to neutralize samples between tests. Applied frictional energy per area was 0.001 J/cm2. Total charge transferred was kept in the linear range, well below spark potential, and was proportional to applied frictional energy per area. All samples needed to be sanded or scraped clean before testing; any thin layer of grease of oil (organic or synthetic) was generally highly positive and would thus distort the values.

Explanation of units "nJ/C" used in the table (most readers can ignore this paragraph)— The units shown here are nC (nano coulombs or nano amp sec) of transferred charge per J (joule or watt sec) of friction energy applied between the surfaces. The friction energy was applied by rubbing two surfaces together; however,"adhesion energy" might be substituted for friction energy when using the table. For example, when adhesive tape is removed from a roll, a certain amount of energy per cm2 (of tape removed) must be expended in order to separate the adhesive from the backing material. Although not yet fully verified, newly-dispensed tape becomes charged approximately as is predicted by the table if the adhesion energy is substituted for friction energy. After verifying that charge transferred was approximately proportional to the frictional force (for a given pull length), the contact force was adjusted for each pair so that the friction force was 25 grams on 2.5 cm wide samples. This is 1 millijoule (mJ) per cm2. When a teflon sample (-190 nC/J) was rubbed in this way against nylon (+30 nC/J), the nylon acquired a positive charge and the teflon negative. The amount of transferred charge can be found by first subtracting the two table entries: 30 nC/J – [-190 nC/J] = 220 nC/J. In this case, using 1 mJ (0.001 J) of friction energy per cm2, the charge transferred per cm2 was 220 nC/J x 0.001 J = 0.22 nC.

"Saturation", or maximum charge that can be transferred: Beyond a certain amount of charge transferred, additional friction energy (rubbing) does not produce any additional charging. Apparently, two effects limit the amount of charge per area that can be transferred. If the spark E-field (10 KV/cm) is exceeded, the two surfaces will spark to each other (after being separated from each other by at least about 1 mm), reducing the charge transferred below 10 KV/cm. This maximum charge per area is about Q/A = 1 nC/cm2, from this formula. A second, lower charging limit seems to apply to surfaces with an affinity difference of < (about) 50 nC/J. Two materials that are this close to each other in the triboelectric series never seem to reach a charge difference as high as 2 nC/cm2, no matter how much they are rubbed together. Although not yet fully verified, it is proposed that the maximum Q/A (in nC/cm2) is roughly 0.02 x the difference in affinities (in nJ/C) if the two materials are within 50 nC/J of each other.

Surfaces that cannot reach spark potential obviously cannot spontaneously dump charge into the air. This is therefore a good reason to select contacting materials such that their affinity difference is small.

Inaccurate information about air being "positive", etc.— A triboelectric series table has been circulating on the internet, and it contains various inaccuracies. Though attribution is rarely given, it appears to be mostly from a 1987 book. It lists air as the most positive of all materials, polyurethane as highly negative, and various metals being positive or negative, apparently based on their known chemical electron affinities, rather than on electrostatic experiments. (From actual tests, there is little or no measurable difference in charge affinity between different types of metal, possibly because the fast motion of conduction electrons cancels such differences.) In gaseous form, air is generally unable to impart any charge to or from solids, even at very high pressure or speed. If chilled to a solid or liquid, air is expected to be slightly negative, not positive. There are three cases where air can charge matter (in the absence of external high voltage). 1. If contaminated by dust, high-speed air can charge surfaces, but this charge comes from contact with the dust, not the air. The charge polarity depends on the type of dust. 2. If air is blown across a wet surface, negative ions are formed due to the evaporation of water. In this case, the wet surface charges positive, so the air becomes negative. 3. If air is hot (above about 1000°C), it begins emitting ions (both + and -.) This is thermal in nature, not triboelectric.