

ESD ADV11.2-1995

ESD Association Advisory

ESD ADV11.2-1995

*For the Protection of
Electrostatic Discharge
Susceptible Items –*

*Triboelectric Charge
Accumulation Testing*

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ESD Association Advisory
for protection of
electrostatic discharge susceptible items -
Triboelectric Charge Accumulation Testing

Approved September 10, 1995
ESD Association



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Published by:

Electrostatic Discharge Association
7902 Turin Road, Suite 4, Rome, NY 13440

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Printed in the United States of America

ISBN: 1-878303-63-5

(This foreword is not a part of ESD Association ADV11.2)

Foreword

Understanding and measuring triboelectric charging of two materials is a difficult and elusive task. Committees in several standards organizations have struggled for years to develop a test method that will accurately predict triboelectric charging properties. To date, no test method has yielded repeatable results in multi-lab testing.

In an effort to communicate triboelectric theory, testing methodology and the utility of the testing, this Advisory provides a summary of tribocharging theory, test methods, and sample data from the test methods. The inclusion and study of test data are an important part of understanding the performance limits of the test methods presented.

The data and test methods in this Advisory are not intended to be used or regarded as a standard. The intent is to provide practical guidance to the user about the tribocharging and tribocharge testing.

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ADV 11.2 TRIBOELECTRIC CHARGE ACCUMULATION TESTING

1. Scope and Purpose

1.1 Scope

The current level of knowledge and test repeatability does not warrant a full test standard at this time. While the tests in the Appendices of this Advisory represent the best information and methods currently available, these methods should be used for GUIDANCE and not as a specification or a standard.

1.2 Purpose

The purpose of this advisory is to provide guidance in understanding the triboelectric phenomenon, and to relate current information and experience regarding tribocharge testing as used in static control for electronics.

2. Background

Most people are familiar with the effects of triboelectric charging. When a synthetic garment is dried in a clothes dryer, the garment will cling to other garments. If you scuff your shoes across an ordinary carpet and then touch a person or a metal door knob a brief electric spark and shock are produced. With a plastic hair comb charged by combing hair, it is possible to move small objects without physical contact. These common events are caused by static electricity that has accumulated on an object.

Electric fields, arcs, and polarization, that are associated with tribocharging can be damaging to modern electronic circuits. Therefore materials that come into intimate contact with, or close proximity to, electronics need to be relatively low charging. Toward that end, many different kinds of tests have been devised to evaluate materials for packaging, handling, and storage.

These test methods have been designed to predict which materials will charge to what level and polarity when contacted with a given material. Unfortunately, these test methods yield results that indicate gross levels of charge and polarity and become unrepeatable when used to give more exact values in real world situations.

Poor reproducibility in testing and a lack of correlation of test results with actual situations is likely due to the complex nature of tribocharging. At this time, the best method for determining the usefulness of a material is to perform an application specific tribocharging test with the actual product and materials that will be used and in the environment that the use will occur. Repetitive testing is necessary since material properties change from lot to lot.

The term 'tribocharging' has become somewhat generic and is taken to mean both charge accumulation by rubbing and charging by contact and separation. While rubbing may increase the overall charge that is accumulated, a net charge on the materials is detectable only after separation. The distinction is made here to avoid later confusion.

3. Observed Effects

Common experience and theory tell us when two materials are contacted and then separated, one material will be charged positively and the other negatively. The amount of charge depends on the materials, amount of rubbing or contact, pressure, environmental conditions and many other variables.

The Triboelectric Series is a loose and variable ranking of materials that has been assembled based on the observed polarities of the materials after rubbing. See Table 1.¹ Materials are arranged from positive to negative. A material higher on the list will generally charge positively when separated from a material lower on the list. Materials closer together in the series, can switch polarity. The amounts of charge accumulated by any two materials is variable. This series has little use in practical material evaluation or selection applications.

Insulative materials retain the charge accumulated during rubbing or contact and separation in the area where the charging occurred because there is no electrical path (high surface or volume resistance) to redistribute the charges. Conductive materials allow accumulated charge to be redistributed. When a conductive material is grounded, the accumulated charge will dissipate at a rate governed by the material's surface or volume resistance, and resistance to ground. See Figure 1.

Materials that have a low propensity to tribocharge are said to be antistatic. Antistaticity is not a function of surface resistance. Relatively large, conductive materials may appear to be antistatic because of their ability to redistribute charge and because of their capacitance making the measurable field smaller. Antistatic materials charge less because of lower area of contact, improved charge backflow, same material contact, or reduced frictional heating. A typical example of an antistatic material is the dissipative poly bag. Here, the insulative polyethylene plastic has a surface coating of chemicals (antistat). This mixture transfers to other surfaces so that there is antistat to antistat contact. The moisture layer acts to reduce any charge accumulated by redistributing the charge over the bag's surface, or by backflowing charge from the antistat on one material to the antistat that has transferred to the other material.

Since two materials are required for tribocharging, both materials must be specified when a material's antistaticity is discussed. For example, if a charge value, due to tribocharging, is given for the above noted dissipative poly bag, the material used to tribocharge the bag must also be reported. Materials other than those reported will give different charge values.

Static fields that are present on triboelectrically charged materials may damage electronic circuits. These charged materials may also be the source for electrostatic discharge (ESD). The two most common sources of ESD from triboelectrically charged sources are people (Figure 2) and production machines like conveyors. Proper material selection or grounding techniques can alleviate these problems.

4. Theory of Tribocharging

There are several mechanisms that contribute to the final level of charge accumulated and to charge transfer. Unfortunately, the amount that each mechanism contributes to the phenomenon, as a part of the whole, is not known. There are several theories that fit experimental data, but the experiments are laboratory based and are practical only for demonstration purposes. Information presented here is a summary of the currently prevailing theory and is helpful in understanding testing variation issues. There appear to be four factors that have the greatest theoretical influence on tribocharging: Surface Contact Effects, Material work function, Charge Back Flow, and Gas Breakdown. Current discussion can be found in the *Journal of Applied Physics*, *Physics Review Letters*, *Journal of Electrostatics* or *Science*.

4.1 Surface Contact Effects^{2,3,4}

Surfaces of solid materials contact each other at many small sites instead of the entire area of a material's surface. A material that is optically smooth will have surface features of 10^3 Angstroms. An electron microscope reveals surface variations on the order of 10 to 10^2 Angstroms. See Figure 3. The pressure applied to the materials is translated to these sites, suggesting that extreme pressures and heating are possible on this small scale. Increased pressure will also increase the number of contacting sites, and the force required to separate the material by sliding.

Frictional heating caused by sliding could cause the temporary material fusion and subsequent fracture and scoring of the materials at numerous sites of contact. Increased charge transfer is possible in these areas. Repeated rubbing passes in the same area will remove any extraneous surface contamination and eventually contact the base material. The likelihood of reproducing the same rubbing motion and area on this scale is low. Therefore the amount of charging will be effected by the contact area, pressure, and material surface features. It has been suggested that only free charges are able to be transferred. However, by frictional heating, contact is increased and electron transfer due to increased temperature may occur. In this way, friction of materials contributes to the amount of accumulated charge.

Charge transfer may be less dependent on the material contact area in situations where moisture or other substances reside on the material surfaces.

4.2 The Influence of Material Work Function^{5,6}

Two materials with different work function values can exchange charge simply by touching. This is the most difficult theory to understand. To gain a basic understanding of this charging mechanism, we must discuss the structures of matter.

Matter is comprised of atoms and collections of atoms that form molecules. An atom consists of a cloud of electrons orbiting a center cluster, or nucleus, of other charged particles. See Figure 5. This cloud of electrons can be visioned as an onion, with layers of electrons at different energy states. (distances from the nucleus). The outermost layer of 1 to 8 electrons is the interactive layer for our interest.

A material's work function describes how strong the outermost layer of electrons on the atom are bound to the rest of the atom.

When materials with different work functions come into contact (<4 Angstroms), electrons from the material with the lower work function (binding strength) will move to the material with a higher work function. The material with the higher work function will become negatively charged. See Figure 4.

The charge (electron) transferring process continues until the outermost layer of electrons on both materials is at the same energy level and has the same distribution of charges.

This mechanism of charging is thought to be the greatest single contributor to the overall amount of charge.

Please note that this is a simplified and somewhat incomplete description. Interested readers may wish to consult reference materials.

4.3 Charge Limiters - Charge Backflow^{4,7}

When two materials are separated, some of the charge may flow back to its original material. This occurs since it is unlikely that all of the points of the materials are separated simultaneously. Charge transfer would occur at the points of last contact, causing total charge accumulation to be reduced. Insulators will have greater localized charges on the last contact sites.

4.4 Charge Limiters - Gaseous Breakdown^{8,4}

Charge redistribution after material separation also may occur due to the breakdown of the air separating the two materials.

Microscopic “peaks” in a material's surface act to focus electrical forces. The air, which is acting as a dielectric between the oppositely charged materials, breaks down and charge is transferred (discharged) between the materials.

The amount of the charge redistribution is influenced by different concentrations of different gases, at different gas pressures, combined with the intermediate charge densities of the materials and the distance of separation of the material “peaks”. There is correlation to a Paschen curve where for a gas, the breakdown voltage between two parallel plates is a function of pressure and distance.

4.5 Summary of Tribocharging Theory

A review of the current theory suggests that we understand enough about tribocharging to allow us to discuss it in the abstract.

Unfortunately, the interaction of numerous variables in this highly complex process prevents us from predicting precise values.

Instead, the collection of values for surface features, frictional heating, work function, and backflowing charge may eventually produce a range of possibilities for charge level and polarity for two tribocharging materials.

Finally, it has been postulated that the variable nature of tribocharging may be a feature of the phenomenon, and that this variability may be yielding clues to the phenomenon, not just making testing difficult⁶.

5. Considerations for Tribocharge Measurement

The best evaluation for a material's useability in a low tribocharging (antistatic) application is an application specific test. The goal in this type of testing is to use the material under test in the place and manner that it would be used in actual practice.

As an illustration, let's assume an antistatic plastic bag is to be tested for use as a package for an electronic circuit card. An application test might be to take the bag into the manufacturing area where it would be used. Charge measurement equipment would be set up and the card tested to determine what normal charge levels are. The card would be placed in the bag and sent through the production process. Charge on the card and bag would then be measured and compared to the level of charge known to be acceptable for that card.

Since this kind of evaluation is usually impractical, tests that replicate the actual use environment are suggested.

5.1 Guidelines to Consider when Developing a Test

- *No one test, currently available, can predict general tribocharging properties for a specific material. The amount of charge a material accumulates is dependent upon the second charging material and all of the variables listed below. In many cases, test data does not relate to actual use situations.*
- Mirror the test method to the intended material usage as much as possible. Relative comparisons of the material's performance that are not based on practical charging situations are likely to yield data dependent upon the test method instead of data dependent upon the materials.
- Design the test to give a comparison value between materials that are "known acceptable", a "known unacceptable", and the unknown material.
- Repeatability is an inherent difficulty with tribocharging tests. Make the movements or rubbing as simple and consistent as possible. Use automation if possible.
- Treat each testing group as independent of other testing groups. Because of the variable nature of material surface conditions,

results from a group tested one month ago should not, in general, be compared with results from a group tested today.

- Compare the average value and distributions of many repeated tests for a given material sample. Because of the inherent variability in tribocharging measurements, one data point may be at an extreme charge level for the material.
- Control as many variables as possible. Please see the list below.

5.2 *Variables that Effect Triboelectric Charging Testing.*

Environmental

Relative Humidity
Temperature
Time of pretest conditioning

Mechanical

Area of contact
Duration of contact
Re-abrasion of same area
Pressure of contact
Speed of separation
Speed of rubbing motion

Electrical

Extraneous electrical fields
Charge neutralization (ionization)
Charge (or Field) measurement equipment

Materials

Geometry
Surface features (roughness)
Conductivity
Surface contamination
Variance between points on same specimens
Work function (Especially non-specific values for plastics)

Miscellaneous

Interpretation of data

6. Appendices - Test Methods for Evaluating Triboelectric Charging

The test methods in these appendices are presented as guidelines that have proven helpful with evaluating the comparative performance of materials. These tests are not capable of defining the true triboelectric nature of materials. However, the tests have been able to discriminate between pairs of materials that tribocharge to high levels and those that charge to a lesser degree. The test data has not, in general, been repeatable from lab to lab. The test methods should be used as a guide and the material user should specify the acceptability of the results for a specific application. The user should remain aware that values obtained in testing do not necessarily provide an indication of performance in actual use situations.

Comparison Tests:

APPENDIX A - MAGAZINES	(LABORATORY)
APPENDIX B - INCLINED PLANE METHOD- LARGE CYLINDERS	(LABORATORY)
APPENDIX C - INCLINED PLANE METHOD- SMALL CYLINDERS	(LABORATORY)
APPENDIX D - CHARGING DUE TO TRANSPORT OR HANDLING IN PACKAGING MATERIALS. (LABORATORY)	
APPENDIX E - HAND HELD CHARGING TEST	(FIELD)
APPENDIX F - CARD PULL TEST	(FIELD)
APPENDIX G - ROLLING FRICTION TESTER	(LABORATORY)
APPENDIX H - ADHESIVE TAPE PULL TEST	(LABORATORY)

Table 1 - Triboelectric Series

This Series is a variable and loose ranking of polarity that has little value for testing or predicting material characteristics.

Positive	Human Hands
+	Rabbit fur
	Glass
	Mica
	Human Hair
	Nylon
	Wool
	Fur
	Lead
	Silk
	Aluminum
	Paper
	Cotton
	Steel
	Wood
	Amber
	Sealing wax
	Hard rubber
	Nickel, copper
	Brass, silver
	Gold, platinum
	Sulfur
	Acetate rayon
	Polyester
	Celluloid
	Orlon
	Polyurethane
	Polyethylene
	Polypropylene
	PVC
	KEL F
Negative	Silicon
-	Teflon

Adapted From MIL-HDBK-263

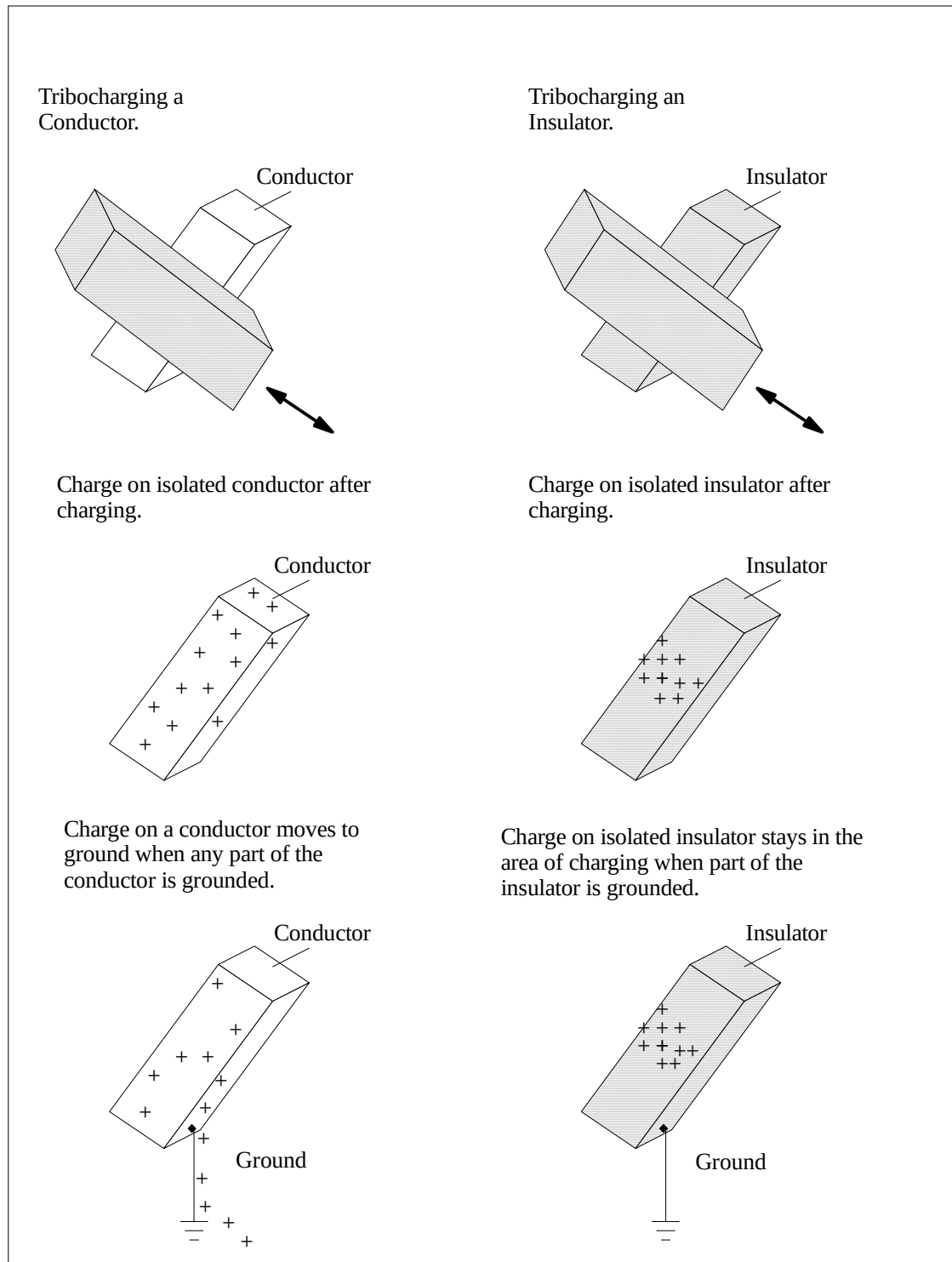


Figure 1 Tribocharging of Insulators and Conductors

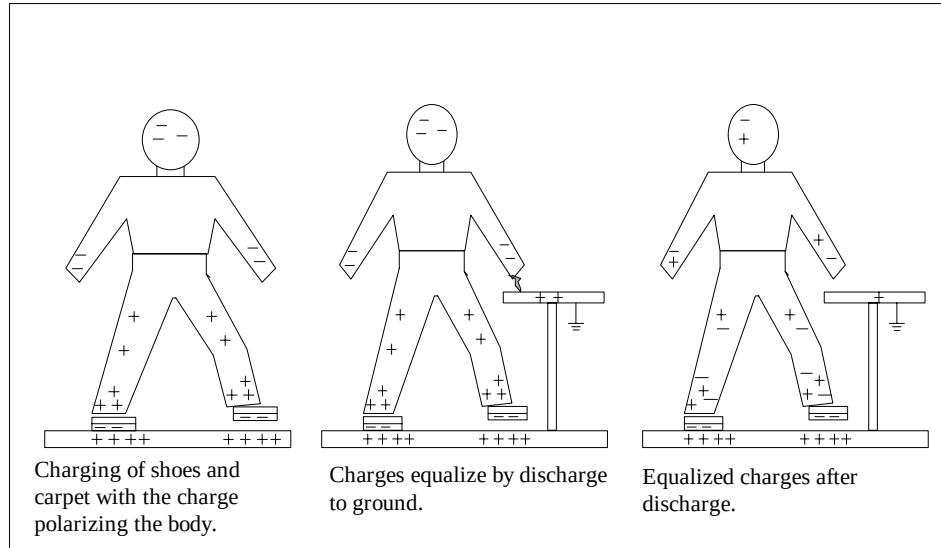


Figure 2 Tribocharging of a person on a carpet

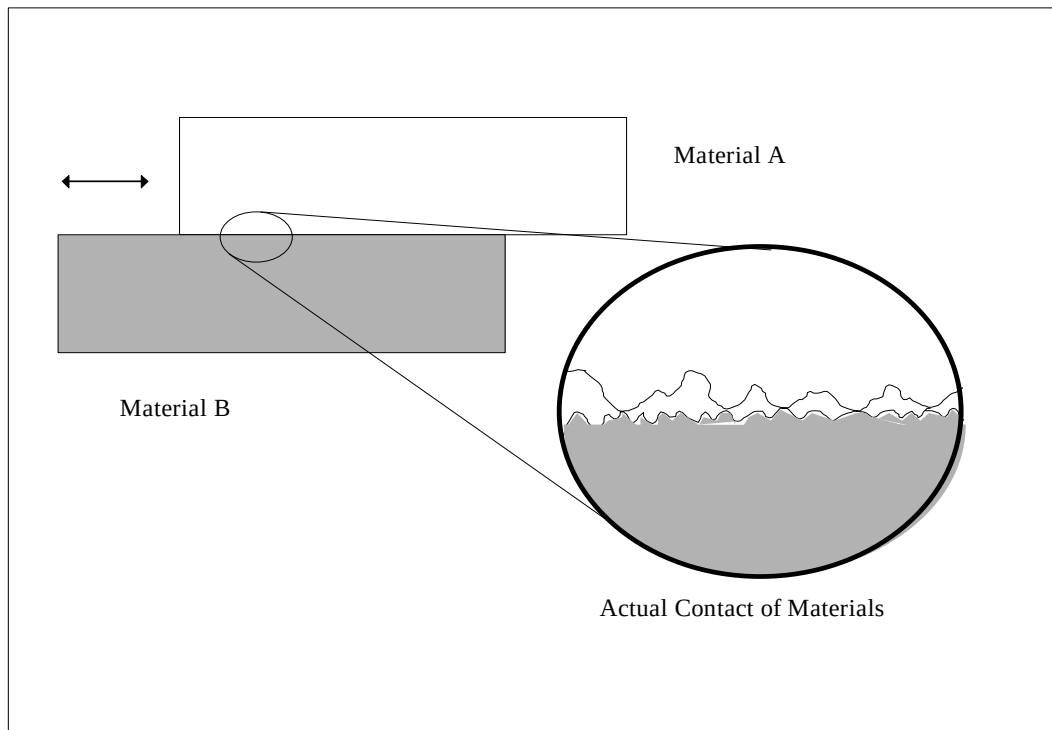


Figure 3 Surface of Tribocharging Materials