KEITHLEY

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Model 2501 and Model 2503
Product Notes
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STATIC CHARGE MEASUREMENTS USING KEITHLEY EQUIPMENT

INTRODUCTION

Electrostatic charge is a deficiency or excess of electrons on an ungrounded surface. Charges are readily acquired on poor conductors of electricity (such as plastics, synthetic fibers, fabrics, paper, and hydrocarbon solids and liquids) during handling and industrial processing of these materials due to friction with themselves, other materials, or machine parts. The effect of static potentials is depicted in Figure A. Once acquired, the charges are not easily dissipated because of the low conductivity of the material.

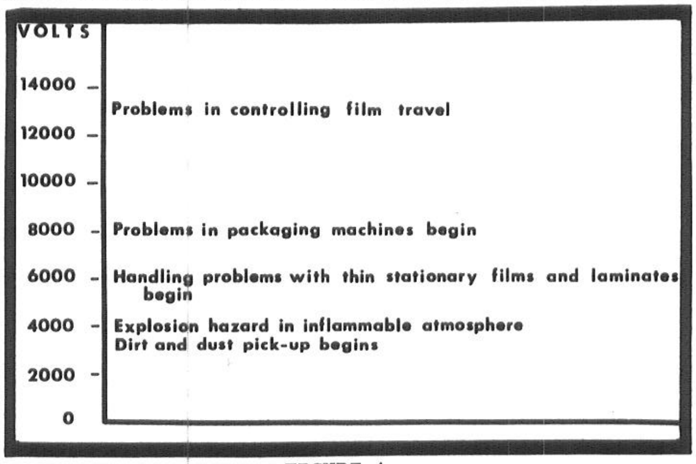

FIGURE A
EFFECT OF STATIC POTENTIALS

The annoyances and hazards of such static charges have long been familiar to the plastics, paper, printing, and textile industries, and to those working with explosives, inflammable liquids, or working in explosive dust or vapor atmospheres. Electrostatic forces cause the attraction of dust and dirt, and cause self-attraction of the charged material, which makes it difficult to operate fabric looms, stack plastic bags, handle webs of plastic or paper, and many others. The consequences of electrostatic spark discharges range from the annoyance of personal shocks to an explosion in a factory, arsenal, grain elevator, or gasoline tanker.

The Keithley Static Charge measuring systems consist of the Static Detector Model 2501 or 2503, which is held near the surface to be measured, an inter-connecting low noise cable for the Model 2501, and a Keithley Electrometer, used as a high impedance voltmeter, which is calibrated to read the surface potential near the Detector. The Model 2501 measures static volts to 30KV and the Model 2503 measures static volts to 15KV. Static voltages up to one megavolt can possibly be measured with the Model 2501 and appropriate Electrometer, provided the system is recalibrated. That is, the Detector Head must be far enough away from the charged surface to avoid corona discharge to the Head and input cable length should be shortened.

GENERATION OF ELECTROSTATICS

It is necessary to study quantitatively the location and intensity of accumulated charges. The Keithley Model 2501 or 2503 Static Detectors (described in Figures B and C) and an appropriate Keithley Electrometer are reliable, self-contained measuring systems designed for measuring electrostatic charges on webs of plastic, laminates, paper, or any relatively flat surface where static charges are distributed.

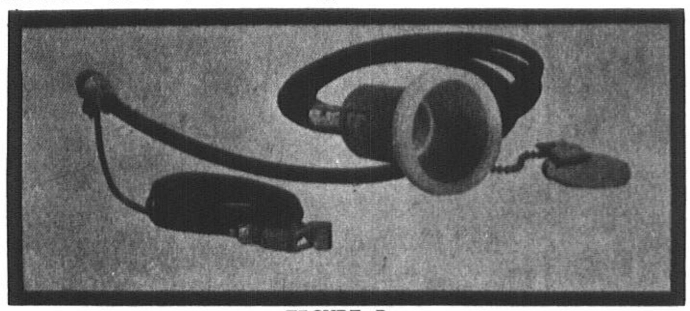

FIGURE B
MODEL 2501 STATIC DETECTOR HEAD is 3" in diameter and comes with a 10 foot cable. It gives a voltage division ratio of 10,000:1 ±10% when held 3/8" away from a charged plane at least 3" in diameter.

Many static problems are encountered with stationary films or laminates. Plastic bags clinging together or repelling each other would fall into this category.

A potential may be induced on the film or laminate for measuring the leakage time by either of two methods.

In the first method, the charge is induced on the film by manual rubbing contact between the stationary film or laminate and a rapidly moving cloth or tissue. This method is difficult to standardize and would also tend to remove surface coatings of anti-static agents. Its main virtues are simplicity and speed.

The second method of producing a static charge on the film or laminate is to bring it near an assembly of needlepoints charged to a high dc potential of from 10 to 50 kilovolts. The potential is set to a known value and the film or laminate becomes charged by the ionized air and by induction. This method is more quantitative than the first but requires the use of specialized equipment.

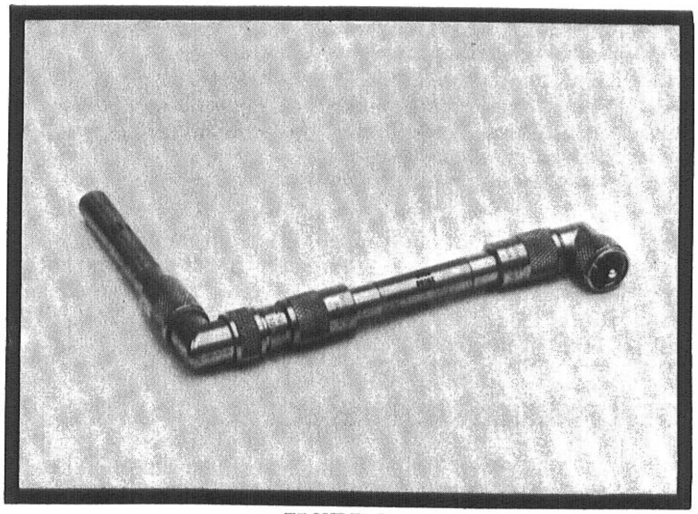

FIGURE C
MODEL 2503 STATIC DETECTOR PROBE
Solid coaxial tube 1/2" in diameter, consisting of a 3 1/2" head, 3 1/2" coupler, 1" adapter, and two 90° angle adapters which may be placed anywhere along the probe. It gives a 10,000:1 ±10% voltage division ratio when held 1/4" away from a charged plane at least 1/2" in diameter.

APPLICATIONS

THE EFFECTS OF STATIC ELECTRICITY

Dust and dirt will be attracted to moving or stationary plastic films or laminates which possess electrostatic charges. Thus anti-static measures must be used until a method is found which will reduce the potential on the film or laminate under the severest of static generating conditions.

Electrostatic charges can cause spark discharges of sufficient energy levels to cause explosions in an inflammable atmosphere. The minimum voltage necessary for ignition may be 200 volts between close needlepoints and 2,500 volts for a discharge between spheres 1/2" apart.

For a given capacity between parallel plates, the energy of the charge is proportional to the square of the voltage. (For example, the electrostatic energy of a plastic film charged to 1,000 volts is about 1,500 ergs or 0.00015 joule; if the potential of the plastic film is raised to 10,000 volts, then the energy rises to 150,000 ergs or 0.015 joule.) If the use of an anti-static measure reduces the voltage on the film or laminate to one-tenth of its former value, then the energy of the spark will be reduced to one-hundredth. If the minimum electrostatic potential in volts required to ignite a particular explosive gas is known. the Keithley Static Charge measuring system may be used to determine whether a dangerous situation exists. Anti-static measures can then be evaluated as previously described.

When the charged film or laminate comes near a charged surface of the same polarity, a repulsive electrostatic force will result. This force could be of sufficient strength to cause the film to fly away from a machine part or to fly away from lower film layers during wind-up. Under such conditions, stacking of bags made from plastic film could become difficult.

Static charges on plastic film will induce charges of opposite polarity on nearby ungrounded (electrically neutral) machine parts. The resultant electrostatic field will set up attractive forces between the film and the machinery. The intensity of the electrostatic field will depend upon the distance separating the machine part from the film and the magnitude of the charges on the plastic film. This field may be strong enough to cause sticking or jamming of the film in a processing machine. Methods of computing these forces will be found in the section entitled "Quantitative Evaluation".

MEASUREMENT TECHNIQUES

The Keithley Static Charge measuring systems are designed to measure the static voltage on flat surfaces for evaluating the reduction of charge buildup.

Typical surfaces of interest are sheets of paper or plastic when being used in processing, packaging or converting equipment. When static electricity problems are suspected, measurements can be made on the plastic webs or substrates as they move through the machinery. The measurements should be made across the entire width of the web or substrate and an average value recorded. Measurements at contact points would be made only to assess the explosion hazard of the electrostatic charges in an inflammable atmosphere.

If the static charge of stacking and wind-up operations of the web or substrate is to be determined, the measurements should be made six inches before the wind-up or stack as well as on the wound-up roll or the stack. The measurements should again be made across the entire width of the web or substrate and an average value recorded. These procedures will provide a picture of the charge intensity before entering the roll or stack and on the roll or stack. Calculating the effect of static charges on the machinery will be discussed later.

After the static problem is defined, the effectiveness of anti-static measures can be evaluated. Static measurements should be made on the most convenient and representative area of the film or sheet in the processing equipment. The measuring system should be placed at the same spot on each test run, so that the factors which affect the formation of static will be kept the same for each test run. Comparison runs with an anti-static measure and the control run should be made on the same day so that temperature and humidity, which affect static so much, will have the same effect on the static buildup on the different film samples. The static charge acquired must be measured immediately after charging in either case to have meaningful results.

Since the maximum acquirable potential of films and laminates and the leakage rate of the charge is dependent on the relative humidity and temperature of the surrounding atmosphere, these measurements should be carried out under controlled humidity and temperature conditions.

It is generally preferable to take readings on the underside of a film or sheet since this side has usually been in more intimate contact with the machine parts. The Static Detector should be kept away from the edge of the film because the electrostatic field intensity will be distorted in this area.

The static charges measured in a machine on moving film will vary slightly in intensity from point to point, and the average or most consistent reading should be used for calculations but both high and low peaks should also be reported.

The electrostatic properties of stationary films or laminates can be assessed and anti-static measures evaluated by making two static measurements. The first measurement serves to determine the maximum potential or voltage that the film or laminate can acquire. The second measurement, made at the same time as the first, determines the rate at which the charge leaks away. The charge leakage may be defined as the time in seconds required for the charge to fall to one-half of its original value. A plastic film or laminate can be considered non-static when the leakage time falls below 1/2 second.

THE ELIMINATION OF STATIC CHARGE

The most commonly used method for removing static on film or laminates is the discharge of the static by a conducting metal connection to ground. For example, grounded tinsel or brushes rubbing the charged surface are commonly used.

Conductive discharge will have limited effectiveness. Only the charges picked up by the metal at the friction points will be removed. Conductive discharge is useful because it prevents any spark discharge which might constitute a safety hazard.

Although air is one of the poorest electrical conductors, its conductivity can be markedly improved by increasing its moisture content. If the air possesses sufficient conductivity, the charges on the film thread or fiber surface will drain away rapidly. Also, when the moisture content of the air is raised, a thin layer of moisture may be deposited on the film thread or fiber surface, making it more conductive. In certain cases, the application of steam has been recommended.

Static neutralizers supply ionized air between the grounded neutralizer and the charged film or laminate. The ionized air particles are drawn out of the air and neutralize all or part of the opposite charges residing on the film. There are three main types of static neutralizers in use: high voltage, induction, and radioactive.

A high voltage neutralizer applies a high voltage to needlepoints placed along the neutralizer bar. These needles do not contact the plastic web. An alternating current of 5,000 to 15,000 volts is supplied to the needles from a conductor in the center of the bar. The other terminal of the transformer supplying the high voltage connects to ground. The electrostatic field surrounding the needlepoints is the force which ionizes the surrounding air.

An induction neutralizer uses grounded wire bristles or tinsel, which do not touch the film surface, and which are fastened along metallic or wooden support bars. The needles of these neutralizers acquire a charge by induction from the electrostatic field between them and the electrostatically charged surface. The electric field surrounding the needlepoints is the force which ionizes the surrounding air. The difference between these neutralizers and high voltage neutralizers is the method of charging the needles. With induction neutralizers, the higher the charge on the surface, the greater will be the ionization of the surrounding air.

A radioactive neutralizer generally uses either radium or polonium for ionizing the air. Here, alpha particles are emitted from the disintegrating nuclei of radium, polonium, or other radioactive isotopes and strike the air particles, ionizing them. The ionizing range of alpha emission in air is limited to an effective distance of about three inches.

The basic requirement for an anti-static agent is that it should prevent the accumulation of static charges and leak them away rapidly when present. Many anti-static agents are selected primarily to leak static charges from the film surface. They are effective because they increase the electrical conductivity of the film surface, either by increasing the concentration of water on the surface through hygroscopic addition, or by splitting into ions.

Other anti-static agents rely on lubricating effects in order to prevent the generation of the charges through friction. Many agents possess both conductive and lubricating qualities. It is generally believed that agents which have lubricating qualities or conductive and lubricating qualities are the most useful on moving plastics.

In order to be commercially useful an anti-static should:

1. Be unaffected by normal handling.
2. Not affect the physical properties of the film or laminate adversely.
3. Be relatively permanent.
4. Be low in cost, safe to handle and if the application warrants, approved by the Food and Drug Administration.

Numerous chemicals have been proposed as anti-static agents for plastic films or laminates, but most belong to one or the other of the following four classes:

1. Nitrogen compounds, such as long-chain amines, amides, and quaternary bases.
2. Sulphonic acids and sulphonates, such as sodium alkyl benzene sulphonate.
3. Polyglycols and their derivatives, including polyglycol esters of fatty acids and polyglycol aryl or alkyl ethers.
4. Polyhydric alcohols and their derivatives, as, for example, sorbitol laurate.

OPERATION SUMMARY

Connect the Model 2501 or 2503 Detector to the Keithley Electrometer, and connect a ground wire from the Electrometer case to a good external ground point (see Figure D). Turn the Electrometer to the proper sensitivity.

MODEL 2501 OPERATION

With the slide all the way into the Detector Head, press the INPUT SHORT button and set the Electrometer zero. Release the INPUT SHORT button.

Position the Detector Head 3/8 inch from the surface being measured, pull the slide out, and read the potential of the surface being measured.

An alternative method is to withdraw the slide immediately after zeroing, and then move the Detector Head into position while maintaining the 3/8 inch distance.

Reliable results are obtained if the reading is made within about fifteen seconds after removing the slide and if the meter is not driven off scale while moving the cup into position. The exposed target electrode in the Detector Head must not be touched.

MODEL 2503 OPERATION

Set the Electrometer zero by engaging the Electrometer zero check switch.

Disengage the Electrometer zero check switch, position the Detector Probe 1/4 inch from the surface being measured, and read the static potential.

The Detector-to-charged surface spacing must be maintained accurately to within ±1/32 inch, or errors in voltage measurements can readily occur.

In computing charge and charge density, further inaccuracies enter because the area of charged surface affecting the target of the Detector is not sharply defined.

Further, voltage of the charged surface after the Detector has been removed depends upon many capacitances which cannot be readily evaluated. So, here again, the actual value cannot be known to the accustomed accuracy for physical measurements.

The Keithley Static Detectors are carefully designed so that the Detector target can be completely enclosed and brought to ground potential during zeroing. When that is done, the complete change from zero to the unknown potential is applied across capacitance C_1, as described in Figure D. When the Electrometer is zeroed without the Model 2501 slide in place, the measurement will be the potential difference between the desired unknown surface and some unknown arbitrary potential affecting the Detector target when the Electrometer was being zeroed.

Rezero the Electrometer when changing ranges and between readings. And remember to observe correct Detector-to-charged surface distances. Also, the Keithley Electrometer must be used on the VOLTS position.

QUANTITATIVE EVALUATIONS

The Keithley measuring system measures the voltage of the surface to which it is exposed. It measures voltage instead of coulombs, coulombs per cm^2, or electrons per cm^2 because it is possible to build a voltmeter with the special features needed for the task, while direct measurements of charge and/or charge density are much more cumbersome. In measuring and in evaluating the data obtained with the Keithley system it is necessary to keep in mind the concept that voltage is measured directly and charge and charge density are derived by computation.

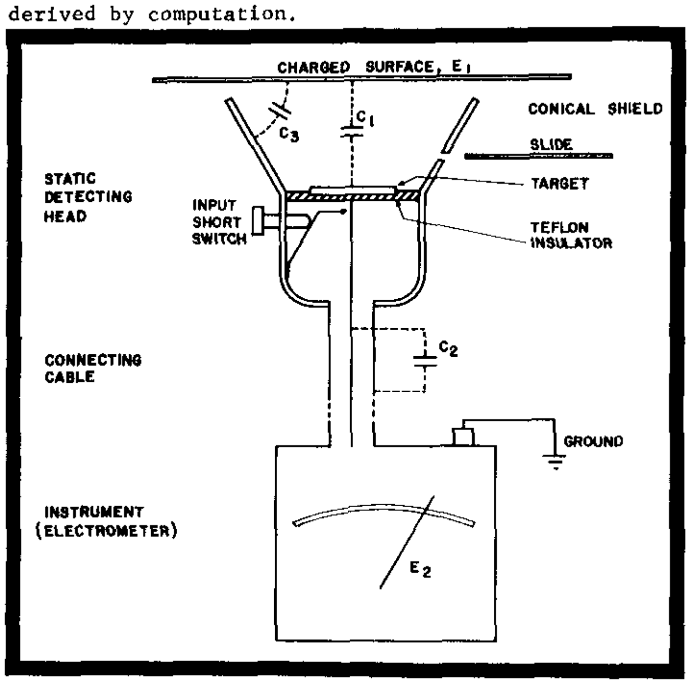

FIGURE D
Schematic Representation of
Keithley Static Detection System with
a Model 2501 Static Detection Head

Figure D shows the Keithley 2501 Detector Head and Electrometer measuring a charged surface, giving the significant electrical parameters. The Static Detector Head consists of a spun aluminum cup, holding a target electrode on a teflon insulator. The Detecting Head also has a Slide, which is at ground potential, as is the Conical Shield. When it is pushed into the Shield, it places the Target in a volume which is free of electrical fields. The input Short switch connects the Target to ground potential, when operated.

C_1 is the capacitance between the charged surface and the Target. C_3 is the capacitance from the charged surface to the Conical Shield and the Target, with the Target connected to the Shield. C_2 is the total capacitance to ground of the Target, the connecting cable Hi conductor, and the input circuit of the Meter. The Meter is an Electrometer Voltmeter which has an input resistance greater than 10^{14} ohms. Its purpose is to measure the voltage of capacitor C_2. There is no significant charging of C_2 by the Electrometer during the time measurements are being made.

Quantitatively:

$C_1E_1=C_2E_2$ where E_1 is the potential across C_1 and E_2 is the potential across C_2. Since charge can be defined as Q=CE, then the charge on C_1 and C_2 is equal. C_2 is principally cable capacitance and is constant since a fixed length of cable is used.

C_1 is determined by the dimensions of the Target, the Conical Shield, and the distance from the charged surface to the Detecting Head and is chosen to give adequate sensitivity and a Head size convenient to use. E_2 is $E_1/10,000$ and C_1 is $C_2/10,000$.

Knowing the voltage of the charged surface, the total charge in the area affecting the target is determined by

$$Q = C_3E_1 \qquad \text{Q coulombs, C farads, E volts} \qquad (1)$$

with the Detector Head 3/8 inch from the charged surface, the area inside the cone, which is the part that affects the target, has a capacitance C_3 of about 2 micro-microfarads to the grounded surfaces. Assume the surface potential E_1 was measured to be 5000 volts. If the charged surface were backed by a ground plane, then the effective value of C_3 and the stored energy would be much greater. Solving (1):

$$Q = 2 \times 10^{-12} \text{ (farad)} \times 5 \times 10^3 \text{ (volts)}$$
$$Q = 10^{-8} \text{ coulombs}$$

The diameter of the surface inside the cone is 3 inches; the area is therefore 7.1 square inches.

With a total charge of 10^{-8} coulombs, the charge density is 1.4×10^{-9} coulombs per square inch.

Charge density as measured by the Model 2501 Detector Head is expressed:

$$\frac{C_3E_1}{\text{AREA}} = 2.8 \text{ X } 10^{-13}\ E_1 \text{ coulombs/in}^2 \qquad (2)$$

The energy expended in moving charge through a potential gradient is expressed:

$W = 1/2\ QE$
W is work in joules (3)
Q is the total charge, in coulombs
E is the potential difference through which the charges are moved

Q is obtained by taking the charge density on a web or sheet of plastic or paper as computed above, then multiplying it by the area that is affected by the processing machine.

E is the voltage difference, and can be from zero (assuming that no charge existed on a reel of plastic before it was unwound) to the E_1 read by the Electrometer (assuming that the voltage was measured on the web within a short distance from where it parted from the roll). If E_1 was measured at 30,000 volts, the charge density would be:

$$\text{Charge Density} = 2.8 \text{ X } 10^{-13}\ E_1 \text{ (coulombs/in}^2\text{)}$$
$$= 8.4 \text{ X } 10^{-9} \text{ coulombs/in}^2 \qquad (4)$$

Assume 5000 square inches is the total area of the sheet which is carrying charge through the potential difference. The total charge is:

$$Q = 8.4 \text{ X } 10^{-9} \text{ (coulombs/in}^2\text{)} \times 5000 \text{ (sq. in.)}$$

Inserting these values in (3) gives:

$$W = 6.3 \text{ joules}$$

If this work was accomplished in one-tenth second, 63 watts would be required. This is an appreciable amount of power to be transferred from the mechanical system and put into the electrical system. Such a power level indicates that static electricity generation requires substantial consideration in the design of equipment handling chargeable materials, in the design of static removing equipment, and in the desirability of finding some means to prevent the generation of static electricity in the first place.

When the Head is withdrawn from the charged surface, which is presumed to be an excellent insulator, there is no addition or reduction of charge. But the capacitance of the surface to ground is reduced considerably, depending on how many other conductors at ground potential are in the immediate vicinity unless the charged surface is large enough that the change in capacity is negligible.

From equation (1) $E_1 = \frac{Q}{C_3}$; thus, E_1 increases as C_3 is reduced.

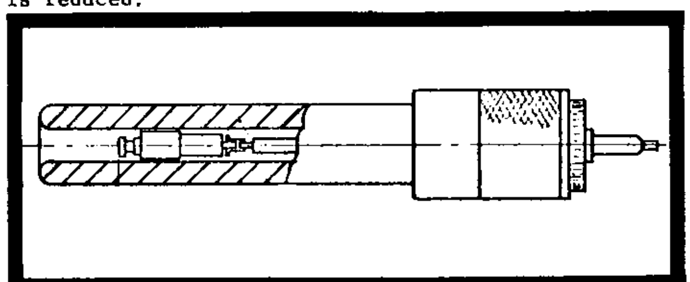

FIGURE E
MODEL 2503 STATIC DETECTOR PROBE TIP
Partial cutaway showing internal construction and probe target area. Drawing does not show the coupler or adapters that make up the probe assembly.

The voltage of a surface which has been measured with the Electrometer, because of the reduction in C_3 as the head is withdrawn, ranges from about twice the reading on the meter down to exactly that read by the meter depending upon the mobility of the charges on the surface and upon the change of capacitance of the surface as it is being measured and as it is being used.

Conducting surfaces attached to a low impedance source of voltage, such as a battery or rectifier power supply, however, gain and lose charge as the external capacitances at their outputs change. Thus, their potentials are not affected by the Detecting Head.

Greater sensitivity can be obtained by increasing C_1 and/or decreasing C_2.

C_1 is determined by the Target area and its spacing from the charged surface. This is determined by the dimensions of the Conical Shield and is difficult to modify without extensive machining. A new Detecting Head could, of course, be fashioned by the user to meet his specific requirements.

C_2 is principally the capacitance of the connecting cable, and will be reduced directly as the length of the cable is reduced. Eliminating the cable altogether produces a substantial increase in sensitivity, but makes the instrument physically awkward to use.

The Model 2503 Static Detector Probe may be evaluated quantitatively as is the Model 2501. Figure E is a cutaway sketch of the Model 2503 showing interior details.

Contact your Keithley Sales Representative for a full description and price of each of the complete line of Keithley Electrometers and both Static Detectors.

If, in addition to static charge measurements you also wish to investigate other material phenomena such as charge dissipation, consider the Keithley Volume and Surface Resistivity system which is comprised of our Model 6105 Resistivity Adapter, Model 610C Electrometer, and Model 240A High Voltage Power Supply. Surface resistivities of up to 10^{18} ohms and volume resistivities of up to 3×10^{19} ohm-cm can be readily measured with this Keithley system which is in accord with the ASTM Standard Method of Test D257-66 for Electrical Resistance of Insulating Materials. For further information see the Keithley Product Notes entitled "Results and Techniques of Volume and Surface Resistivity Measurements Using Keithley Instruments".

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