Standard Test Method for D-C Resistance or Conductance of Moderately Conductive Materials[1]

This standard is issued under the fixed designation D 4496; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—The adjunct number was editorially corrected to ADJD4496 in September 1999.

1. Scope

1.1 This test method covers the determination of the measurement of electrical resistance or conductance of materials that are generally categorized as moderately conductive and are neither good electrical insulators nor good conductors.

1.2 This test method applies to all materials that exhibit volume resistivity in the range of 1 to $10^7\Omega$-cm or surface resistivity in the range of 10^3 to $10^7\Omega$ (per square).

1.3 This test method is designed for measurements at standard conditions of 23°C and 50 % relative humidity, but its principles of operation can be applied to specimens measured at lower or higher temperatures and relative humidities.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in 8.3.

2. Referenced Documents

2.1 *ASTM Standards:*

D 257 Test Methods for D-C Resistance or Conductance of Insulating Materials[2]

D 374 Test Methods for Thickness of Solid Electrical Insulation[2]

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[3]

D 991 Test Method for Rubber Property Volume Resistivity of Electrically Conductive and Antistatic Products[4]

D 1711 Terminology Relating to Electrical Insulation[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *moderately conductive*—a solid material having volume resistivity between 1 and $10^7\Omega\cdot$cm.

3.1.2 For definitions of other terms used in this standard, refer to Terminology D 1711.

3.2 *Description of Term Specific to This Standard:*

3.2.1 *steady state*—for the purpose of this test method, steady-state is attained if any rate of change in the observed resistance (or conductance) averages less than 0.25 %/s.

4. Summary of Test Method

4.1 Specimens of material are conditioned in prescribed environments and subjected to direct-voltage stress. Resistance or conductance is measured and used with the dimensional aspects of the specimen to compute a resistivity of the material. The apparatus and techniques used in this test method are in accordance with the general principles set forth in Test Methods D 257.

5. Significance and Use

5.1 This test method is useful for the comparison of materials, as a quality control test, and may be used for specification purposes.

5.2 This test method is useful in the selection and use of materials in wires, cables, bushings, high-voltage rotating machinery, and other electrical apparatus in which shielding or the distribution of voltage stress may be of value.

5.3 Commercially available "moderately conductive" materials frequently are comprised of both conductive and resistive components (that is, cellulose fibers with colloidal carbon black particles attached to portions of the surfaces of those fibers, or discrete conductive particles adhered to the surfaces of electrical insulating polymers). Such commercially available materials are often manufactured in a manner that may result in anisotropy with respect to electrical conduction. Hence, the significance of tests using this test method may depend upon the orientation of the specimen tested to the electric field and

[1] This test method is under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.12 on Electrical Tests.

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[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vol 08.01.

[4] *Annual Book of ASTM Standards*, Vol 09.01.

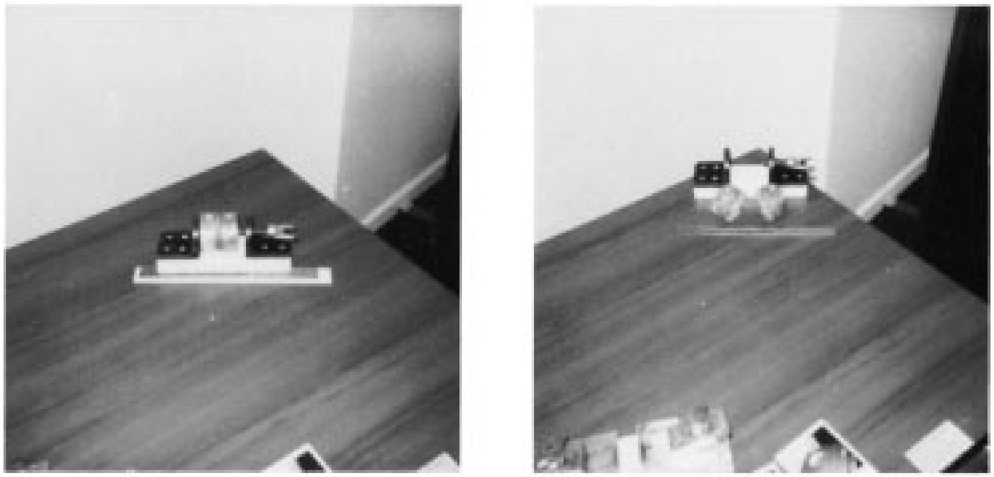


FIG. 1 Cell For Volume Resistivity 1-in.^{2} Electrode (Mercury)

the relationship between this orientation and the orientation of the material in the electrical apparatus which uses these materials.

6. Apparatus

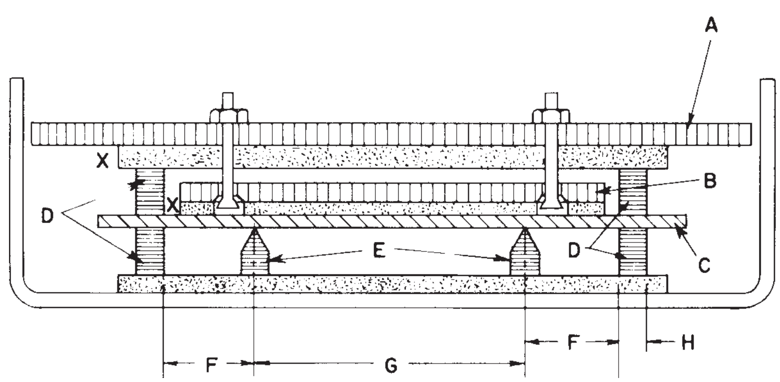
6.1 The apparatus shall conform to the general requirements set forth in Test Methods D 257.

6.2 *Voltage Device*—Capable of limiting the magnitude of the direct voltage applied to the specimen. (See Appendix X1 for discussion of voltage stress and specimen heating.)

6.3 *Test cells*, that have been found to be satisfactory are depicted in Fig. 1, Fig. 2, and Fig. 3.[5]

NOTE 1—Conductive paint may provide suitable electrodes on specimens of certain materials and testing such specimens may not require test cell assemblies as shown in Fig. 1, Fig. 2, and Fig. 3[5] (see Annex A1 for additional information).

[5] Drawings suitable for construction of test cells are available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Request adjunct No. ADJD4496.



A—Mass for applying contact force between current electrodes and the specimen (300 N/m times the specimen width in metres) (Note 1).
B—Mass for applying contact force between potential electrodes and the specimen (60 N/m times specimen width in metres) (Note 2).
C—The specimen.
D—Current electrodes.
E—Potential electrodes.
F—Distance between the current and potential electrodes (20 mm minimum).
G—Distance between potential electrodes depends on specimen size.
H—Width of current electrode, 5 to 8 mm (0.2 to 0.3 in.).
X—Electrical insulating material (10 Ω·cm minimum resistivity).
Note 1—For a specimen 150 mm (6 in.) wide, mass is approximately 4.5 kg (10 lb).
Note 2—For a specimen 150 mm (6 in.) wide, mass is approximately 0.9 kg (2 lb).
Note 3—Fig. 2 is taken from Test Method D 991.

The electrode assembly (Fig. 2) shall consist of a rigid base made from an electrical insulating material having a resistivity greater than 10 ohm-cm (for example, hard rubber, polyethylene, polystyrene, etc.) to which a pair of potential electrodes are fastened in such a manner that the four electrodes are parallel and their top surfaces are in the same horizontal plane. Another pair of current electrodes identical with the first pair shall be fastened to a second piece of insulating material so that they can be superimposed on the specimen directly above the first pair. The current electrodes shall have a length at least 10 mm (0.4 in.) greater than the specimen width, a width between 5 and 8 mm (0.2 and 0.3 in.), and a height uniform with 0.05 mm (0.002 in.) between 10 and 15 mm (0.4 and 0.6 in.). The potential electrodes shall have a length and height equal to the current electrodes, and shall be tapered to an edge having a radius of 0.5 mm (0.02 in.) maximum at the top surface. The distance between the potential electrodes shall be not less than 10 mm (0.4 in.) nor more than 66 mm (2.6 in.) and shall be known within + 2 %. The current electrodes shall be equidistant outside the potential electrodes by at least 20 mm (0.8 in.). The electrodes shall be made from a corrosion-resistant metal such as brass, nickel, stainless steel, etc. Insulation resistance between electrodes shall be greater than 1 TΩ.

FIG. 2 Electrode Assembly

FIG. 3 CELL For Surface Resistance Assembly Photo

7. Specimen Preparation and Selection

7.1 Take specimens from a sample of material that has been obtained in a random manner. Take care to protect the sample and the specimens from any contamination which will affect the results of the resistance or conductance tests. Such contamination can include salts or moisture from human hands, elevated temperatures, extremes of high or low humidity, chemical vapors, etc.

7.2 Prior to testing, condition all specimens to equilibrium with the standard laboratory atmosphere prescribed in Practice D 618. For many materials the time of conditioning to equilibrium will require only a few hours (that is, less than 24 h). Equilibrium with standard laboratory conditions may be declared attained if two consecutive volume resistance measurements on the same specimen agree within ±1 %. The two consecutive measurements are to be made at intervals separated by at least 4 h.

7.3 Determine the dimensions of the test specimens to within± 2 % on material in equilibrium with the standard laboratory atmosphere. Make all thickness measurements in accordance with Method D of Test Methods D 374 using the appropriate procedure for the material being tested.

7.4 For specimens incorporating conductive paint electrodes see Annex A1.

7.5 For anisotropic materials, label and prepare specimens for testing in each of the principal directions of anisotropy.

NOTE 2—Moderately conductive paper exhibits three axes of anisotropy. The principal axes in paper are machine direction (MD); cross-machine direction (CMD); and thickness direction (TD). Extruded polymeric materials may show anisotropy with the axis of extrusion (direction of flow) compared to the axis of the material at right angles to that direction of flow.

8. Procedure

8.1 Unless otherwise specified, make all measurements using an electrification time of less than 1 min. The electrification time shall be long enough to attain a "steady state" and the magnitude of the voltage shall not be so great as to cause undue heating of the test specimen. See Appendix X1 for discussion of time effects of voltage stress and specimen heating.

8.2 Do not apply to the test specimen a power input exceeding 1 W. For very conductive materials it may be necessary to increase the size of a specimen or to decrease the test voltage by one or more orders of magnitude below 500 V in order to avoid overheating of the specimen.

8.3 Test a minimum of five specimens from each sample in each of the principal directions of anisotropy. Use caution in handling the specimens to avoid contaminating the surfaces.

8.4 Place the specimen in the test cell or attach the leads to the painted-on electrodes. If mercury electrodes are used, take special care in handling the mercury.

8.4.1 **Warning**—Mercury metal-vapor poisoning has long been recognized as a hazard in the industry. The maximum exposure limits are set by the American Conference of Governmental Industrial Hygienists.[6] The concentration of mercury vapor over spills from broken thermometers, barometers, or other instruments using mercury can easily exceed these exposure limits. Mercury, being a liquid and quite heavy, will disintergrate into small droplets and seep into cracks and crevices in the floor. The use of a commercially available emergency spill kit is recommended whenever a spill occurs. The increased area of exposure adds significantly to the mercury vapor concentration in the air. Mercury vapor concentration is easily monitored using commercially available sniffers. Spot checks should be made periodically around operations where mercury is exposed to the atmosphere. Thorough checks should be made after spills.

8.5 Measure the conductance, resistance, or voltagecurrent values, depending upon the type of apparatus shown in Test Methods D 257, that is being used. Record each observed measurement.

8.6 Calculate the resistivity in accordance with Section 9.

9. Calculation

9.1 If the voltmeter-ammeter method of Test Methods D 257 is used in 8.5, calculate the resistance for each specimen using the equation:

$$R = V \div I \tag{1}$$

where:
R = resistance, Ω,
V = applied direct voltage, V, and
I = magnitude of the direct current, A.

9.2 If the direct method of resistance of Test Methods D 257 is used, use the values observed and calculate the resistivity as follows:

9.2.1 Volume Resistivity = ρ_v (in Ω·cm)

$$\rho_v = R_v \frac{A}{t} \tag{2}$$

where:

[6] Available from the American Conference of Governmental Industrial Hygienists, Building No. D-7, 6500 Glenway Ave., Cincinnati, OH 45211.

R_v = volume resistance, Ω,
A = area of the electrodes, cm^2, and
t = distance between the electrodes, cm.

9.2.2 Surface Resistivity in Ω (per square) ρ_s

$$\rho_s = R_s(W/L) \quad (3)$$

where:
R_s = surface resistance, Ω
L = length of the specimen between electrodes, and
W = width of the specimen.

NOTE 3—The ratio (*W/L*) is analogous to the (*P/g*) ratio shown in Test Methods D 257.

NOTE 4—*L* and *W* must be measured in the same units of distance. The unit of surface resistivity is ohms (or megohms). It is common practice to refer to surface resistivity as ohms per square.

10. Report

10.1 The Report shall include:

10.1.1 Complete identification of the material tested.

10.1.2 Average and the standard deviation of the resistivities computed shall be reported as the resistivity of the sample.

10.1.3 Median (or central value) of the resistivities computed is often of interest and shall be reported.

10.1.4 High and low (or the range of) resistivities.

10.1.5 Average, and the high and low (or the range of) resistivity for each principal direction of anisotropy if anisotropic material is tested.

10.1.6 Listing of any deviations from the prescribed test conditions.

10.1.7 Type of test cell used.

10.1.8 Fact that conductive paint was used, if applicable.

10.1.9 Voltage applied to the test specimen.

10.1.10 Thickness of the specimens tested.

11. Precision and Bias

11.1 Using the test cell shown in Fig. 1 and a voltage stress below 10 direct V/mil (400 kV dc/metre). The results in a single laboratory by three different operators showed agreement within± 3 % of the average value of volume resistivity. The moderately conductive materials tested were carbon-black cellulose papers having volume resistivities 10^3 to 10^5Ω·cm at 23°C and 50 % relative humidity.

11.2 Using the test cell shown in Fig. 2 and a voltage stress of approximately 20 kV (dc)/m, the surface resistivity showed agreement within ±10 % of the average value. The moderately conductive carbon-black cellulose paper ranged from 10^4 to 10^6Ω per square at 23°C and 50 % relative humidity. The surface resistance using silver paint electrodes was not significantly different from the resistance using the test cell of Fig. 2 and strips cut 1-in. wide.

11.3 The bias of this test method has not been determined.

ANNEX

(Mandatory Information)

A1. INFORMATION PERTINENT TO MEASUREMENTS OF SPECIMENS WITH ELECTRODES OF CONDUCTIVE PAINT

INTRODUCTION

It has been found practical to make resistance measurements with conductive paint applied to the surface of a specimen to provide an electrode that has intimate contact with the material.

Not all materials are conducive to the application of conductive inks or paints. Some of these inks, or paints, contain solvents that may be absorbed by the material under test and alter the conductance or resistance of the specimen in an irreversible manner.

The techniques described below are especially convenient for the measurement of surface resistance.

A1.1 Apply conductive paint or ink to the surface of a specimen to provide two electrodes separated by a distance that is known to within ±2 %.

A1.2 Take care to thoroughly agitate or stir the conductive paint or ink each time it is used.

A1.3 Allow the conductive paint or ink to dry thoroughly. The presence of small amounts of solvent can significantly influence the conduction mechanism within a specimen. Do not attempt to make resistance measurements until the paint or ink is completely dry.

A1.4 Make suitable electrical connections to the electrodes produced from the paint or ink.

A1.5 Measure conductance or resistance using the apparatus prescribed in Test Methods D 257.

APPENDIX

(Nonmandatory Information)

X1. DISCUSSION OF FACTORS WHICH ARE KNOWN TO AFFECT THE OBSERVED RESISTANCE (OR CONDUCTANCE) IN MODERATELY CONDUCTIVE MATERIALS

X1.1 Field strength (or voltage stress) at excessive levels can produce electric self heating in the specimen. The heat generated will be proportional to the product of V^2 and I^{-1}. The heat generated can have profound effects upon the observed resistance. Heating may make it impossible to obtain" steady state" conditions, the drift of the meter may never stop. The heat generated could raise the temperature of the specimen and the temperature effect on resistance (conductance) is a well known phenomenon. Additionally, the heat could degrade the polymeric constituents in the material and significantly alter the measurement values.

X1.2 There is a difference of opinion as to the relative importance of volume resistivity and surface resistivity of moderately conductive materials. Many cable engineers put forth the concept that surface resistivity is of primary importance when moderately conductive materials are considered for use as insulation shielding. These same persons admit to the primary importance of volume resistivity when the moderately conductive material is used as "strand shielding".

X1.3 The following factors are known to have an effect upon the resistance of moderately conductive materials:

X1.3.1 Exposure to, or testing in, varying relative humidities,

X1.3.2 Temperature of the specimen at the time of measurement of resistance,

X1.3.3 Voltage stress at time of measurement,

X1.3.4 Flexing of the material and subsequent testing,

X1.3.5 Mechanical stress, compressive or tensile,

X1.3.6 Solvent absorption,

X1.3.7 Abrasion of the surfaces of the materials,

X1.3.8 Burnishing of the surfaces of the material,

X1.3.9 The anisotropy of the specimen,

X1.3.10 Subjecting the material to thermal cycling, and

X1.3.11 Subjecting the material to voltage stresses prior to testing.