



Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies¹

This standard is issued under the fixed designation D 149; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers procedures for the determination of dielectric strength of solid insulating materials at commercial power frequencies, under specified conditions.^{2,3}

1.2 Unless otherwise specified, the tests shall be made at 60 Hz. However, this test method may be used at any frequency from 25 to 800 Hz. At frequencies above 800 Hz, dielectric heating may be a problem.

1.3 This test method is intended to be used in conjunction with any ASTM standard or other document that refers to this test method. References to this document should specify the particular options to be used (see 5.5).

1.4 It may be used at various temperatures, and in any suitable gaseous or liquid surrounding medium.

1.5 This test method is not intended for measuring the dielectric strength of materials that are fluid under the conditions of test.

1.6 This test method is not intended for use in determining intrinsic dielectric strength, direct-voltage dielectric strength, or thermal failure under electrical stress (see Test Method D 3151).

1.7 This test method is most commonly used to determine the dielectric breakdown voltage through the thickness of a test specimen (puncture). It may also be used to determine dielectric breakdown voltage along the interface between a solid specimen and a gaseous or liquid surrounding medium (flash-

over). With the addition of instructions modifying Section 12, this test method may be used for proof testing.

1.8 This test method is similar to IEC Publication 243-1. All procedures in this method are included in IEC 243-1. Differences between this method and IEC 243-1 are largely editorial.

1.9 *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 hazard statements are given in Section 7. Also see 6.4.1.

2. Referenced Documents

2.1 ASTM Standards:⁴

D 374 Test Methods for Thickness of Solid Electrical Insulation

D 618 Practice for Conditioning Plastics for Testing

D 877 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes

D 1711 Terminology Relating to Electrical Insulation

D 2413 Practice for Preparation of Insulating Paper and Board Impregnated with a Liquid Dielectric

D 3151 Test Method for Thermal Failure of Solid Electrical Insulating Materials Under Electric Stress

D 3487 Specification for Mineral Insulating Oil Used in Electrical Apparatus

D 5423 Specification for Forced-Convection Laboratory Ovens for Electrical Insulation

2.2 IEC Standard:

Pub. 243-1 Methods of Test for Electrical Strength of Solid Insulating Materials—Part 1: Tests at Power Frequencies⁵

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

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² Bartnikas, R., Chapter 3, "High Voltage Measurements," *Electrical Properties of Solid Insulating Materials, Measurement Techniques*, Vol. IIB, *Engineering Dielectrics*, R. Bartnikas, Editor, ASTM STP 926, ASTM, Philadelphia, 1987.

³ Nelson, J. K., Chapter 5, "Dielectric Breakdown of Solids," *Electrical Properties of Solid Insulating Materials: Molecular Structure and Electrical Behavior*, Vol. IIA, *Engineering Dielectrics*, R. Bartnikas and R. M. Eichorn, Editors, ASTM STP 783, ASTM, Philadelphia, 1983.

⁴ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

⁵ Available from the International Electrotechnical Commission, Geneva, Switzerland.

2.3 ANSI Standard:

C68.1 Techniques for Dielectric Tests, IEEE Standard No. 4⁶

3. Terminology

3.1 Definitions:

3.1.1 *dielectric breakdown voltage (electric breakdown voltage)*, *n*—the potential difference at which dielectric failure occurs under prescribed conditions in an electrical insulating material located between two electrodes. (See also Appendix X1.)

3.1.1.1 *Discussion*—The term *dielectric breakdown voltage* is sometimes shortened to “breakdown voltage.”

3.1.2 *dielectric failure (under test)*, *n*—an event that is evidenced by an increase in conductance in the dielectric under test limiting the electric field that can be sustained.

3.1.3 *dielectric strength*, *n*—the voltage gradient at which dielectric failure of the insulating material occurs under specific conditions of test.

3.1.4 *electric strength*, *n*—see dielectric strength.

3.1.4.1 *Discussion*—Internationally, “electric strength” is used almost universally.

3.1.5 *flashover*, *n*—a disruptive electrical discharge at the surface of electrical insulation or in the surrounding medium, which may or may not cause permanent damage to the insulation.

3.1.6 For definitions of other terms relating to solid insulating materials, refer to Terminology D 1711.

4. Summary of Test Method

4.1 Alternating voltage at a commercial power frequency (60 Hz, unless otherwise specified) is applied to a test specimen. The voltage is increased from zero or from a level well below the breakdown voltage, in one of three prescribed methods of voltage application, until dielectric failure of the test specimen occurs.

4.2 Most commonly, the test voltage is applied using simple test electrodes on opposite faces of specimens. The specimens may be molded or cast, or cut from flat sheet or plate. Other electrode and specimen configurations may be used to accommodate the geometry of the sample material, or to simulate a specific application for which the material is being evaluated.

5. Significance and Use

5.1 The dielectric strength of an electrical insulating material is a property of interest for any application where an electrical field will be present. In many cases the dielectric strength of a material will be the determining factor in the design of the apparatus in which it is to be used.

5.2 Tests made as specified herein may be used to provide part of the information needed for determining suitability of a material for a given application; and also, for detecting changes or deviations from normal characteristics resulting from processing variables, aging conditions, or other manufacturing or

environmental situations. This test method is useful for process control, acceptance or research testing.

5.3 Results obtained by this test method can seldom be used directly to determine the dielectric behavior of a material in an actual application. In most cases it is necessary that these results be evaluated by comparison with results obtained from other functional tests or from tests on other materials, or both, in order to estimate their significance for a particular material.

5.4 Three methods for voltage application are specified in Section 12: Method A, Short-Time Test; Method B, Step-by-Step Test; and Method C, Slow Rate-of-Rise Test. Method A is the most commonly-used test for quality-control tests. However, the longer-time tests, Methods B and C, which usually will give lower test results, may give more meaningful results when different materials are being compared with each other. If a test set with motor-driven voltage control is available, the slow rate-of-rise test is simpler and preferable to the step-by-step test. The results obtained from Methods B and C are comparable to each other.

5.5 Documents specifying the use of this test method shall also specify:

5.5.1 Method of voltage application,

5.5.2 Voltage rate-of-rise, if slow rate-of-rise method is specified,

5.5.3 Specimen selection, preparation, and conditioning,

5.5.4 Surrounding medium and temperature during test,

5.5.5 Electrodes,

5.5.6 Wherever possible, the failure criterion of the current-sensing element, and

5.5.7 Any desired deviations from the recommended procedures as given.

5.6 If any of the requirements listed in 5.5 are missing from the specifying document, then the recommendations for the several variables shall be followed.

5.7 Unless the items listed in 5.5 are specified, tests made with such inadequate reference to this test method are not in conformance with this test method. If the items listed in 5.5 are not closely controlled during the test, the precisions stated in 15.2 and 15.3 may not be realized.

5.8 Variations in the failure criteria (current setting and response time) of the current sensing element significantly affect the test results.

5.9 Appendix X1. contains a more complete discussion of the significance of dielectric strength tests.

6. Apparatus

6.1 *Voltage Source*—Obtain the test voltage from a step-up transformer supplied from a variable sinusoidal low-voltage source. The transformer, its voltage source, and the associated controls shall have the following capabilities:

6.1.1 The ratio of crest to root-mean-square (rms) test voltage shall be equal to $\sqrt{2} \pm 5\%$ (1.34 to 1.48), with the test specimen in the circuit, at all voltages greater than 50 % of the breakdown voltage.

6.1.2 The capacity of the source shall be sufficient to maintain the test voltage until dielectric breakdown occurs. For most materials, using electrodes similar to those shown in Table 1, an output current capacity of 40 mA is usually satisfactory. For more complex electrode structures, or for

⁶ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

TABLE 1 Typical Electrodes for Dielectric Strength Testing of Various Types of Insulating Materials^A

Electrode Type	Description of Electrodes ^{B,C}	Insulating Materials
1	Opposing cylinders 51 mm (2 in.) in diameter, 25 mm (1 in.) thick with edges rounded to 6.4 mm (0.25 in.) radius	flat sheets of paper, films, fabrics, rubber, molded plastics, laminates, boards, glass, mica, and ceramic
2	Opposing cylinders 25 mm (1 in.) in diameter, 25 mm (1 in.) thick with edges rounded to 3.2 mm (0.125 in.) radius	same as for Type 1, particularly for glass, mica, plastic, and ceramic
3	Opposing cylindrical rods 6.4 mm (0.25 in.) in diameter with edges rounded to 0.8 mm (0.0313 in.) radius ^D	same as for Type 1, particularly for varnish, plastic, and other thin film and tapes: where small specimens necessitate the use of smaller electrodes, or where testing of a small area is desired
4	Flat plates 6.4 mm (0.25 in.) wide and 108 mm (4.25 in.) long with edges square and ends rounded to 3.2 mm (0.125 in.) radius	same as for Type 1, particularly for rubber tapes and other narrow widths of thin materials
5	Hemispherical electrodes 12.7 mm (0.5 in.) in diameter ^E	filling and treating compounds, gels and semisolid compounds and greases, embedding, potting, and encapsulating materials
6	Opposing cylinders; the lower one 75 mm (3 in.) in diameter, 15 mm (0.60 in.) thick; the upper one 25 mm (1 in.) in diameter, 25 mm thick; with edges of both rounded to 3 mm (0.12 in.) radius ^F	same as for Types 1 and 2
7	Opposing circular flat plates, 150 mm diameter ^G , 10 mm thick with edges rounded to 3 to 5 mm radius ^H	flat sheet, plate, or board materials, for tests with the voltage gradient parallel to the surface

^A These electrodes are those most commonly specified or referenced in ASTM standards. With the exception of Type 5 electrodes, no attempt has been made to suggest electrode systems for other than flat surface material. Other electrodes may be used as specified in ASTM standards or as agreed upon between seller and purchaser where none of these electrodes in the table is suitable for proper evaluation of the material being tested.

^B Electrodes are normally made from either brass or stainless steel. Reference should be made to the standard governing the material to be tested to determine which, if either, material is preferable.

^C The electrodes surfaces should be polished and free from irregularities resulting from previous testing.

^D Refer to the appropriate standard for the load force applied by the upper electrode assembly. Unless otherwise specified the upper electrodes shall be 50 ± 2 g.

^E Refer to the appropriate standard for the proper gap settings.

^F The Type 6 electrodes are those given in IEC Publication 243-1 for testing of flat sheet materials. They are less critical as to concentricity of the electrodes than are the Types 1 and 2 electrodes.

^G Other diameters may be used, provided that all parts of the test specimen are at least 15 mm inside the edges of the electrodes.

^H The Type 7 electrodes, as described in the table and in Note^G, are those given in IEC Publication 243-1 for making tests parallel to the surface.

testing high-loss materials, higher current capacity may be needed. The power rating for most tests will vary from 0.5 kVA for testing low-capacitance specimens at voltages up to 10 kV, to 5 kVA for voltages up to 100 kV.

6.1.3 The controls on the variable low-voltage source shall be capable of varying the supply voltage and the resultant test voltage smoothly, uniformly, and without overshoots or transients, in accordance with 12.2. Do not allow the peak voltage to exceed 1.48 times the indicated rms test voltage under any circumstance. Motor-driven controls are preferable for making short-time (see 12.2.1) or slow-rate-of-rise (see 12.2.3) tests.

6.1.4 Equip the voltage source with a circuit-breaking device that will operate within three cycles. The device shall disconnect the voltage-source equipment from the power service and protect it from overload as a result of specimen breakdown causing an overload of the testing apparatus. If prolonged current follows breakdown it will result in unnecessary burning of the test specimens, pitting of the electrodes, and contamination of any liquid surrounding medium.

6.1.5 The circuit-breaking device should have an adjustable current-sensing element in the step-up transformer secondary, to allow for adjustment consistent with the specimen characteristics and arranged to sense specimen current. Set the sensing element to respond to a current that is indicative of specimen breakdown as defined in 12.3.

6.1.6 The current setting can have a significant effect on the test results. Make the setting high enough that transients, such as partial discharges, will not trip the breaker but not so high that excessive burning of the specimen, with resultant electrode damage, will occur on breakdown. The optimum current setting is not the same for all specimens and depending upon the intended use of the material and the purpose of the test, it may be desirable to make tests on a given sample at more than

one current setting. The electrode area may have a significant effect upon what the current setting should be.

6.1.7 The specimen current-sensing element may be in the primary of the step-up transformer. Calibrate the current-sensing dial in terms of specimen current.

6.1.8 Exercise care in setting the response of the current control. If the control is set too high, the circuit will not respond when breakdown occurs; if set too low, it may respond to leakage currents, capacitive currents, or partial discharge (corona) currents or, when the sensing element is located in the primary, to the step-up transformer magnetizing current.

6.2 *Voltage Measurement*—A voltmeter must be provided for measuring the rms test voltage. A peak-reading voltmeter may be used, in which case divide the reading by $\sqrt{2}$ to get rms values. The overall error of the voltage-measuring circuit shall not exceed 5 % of the measured value. In addition, the response time of the voltmeter shall be such that its time lag will not be greater than 1 % of full scale at any rate-of-rise used.

6.2.1 Measure the voltage using a voltmeter or potential transformer connected to the specimen electrodes, or to a separate voltmeter winding, on the test transformer, that is unaffected by the step-up transformer loading.

6.2.2 It is desirable for the reading of the maximum applied test voltage to be retained on the voltmeter after breakdown so that the breakdown voltage can be accurately read and recorded.

6.3 *Electrodes*—For a given specimen configuration, the dielectric breakdown voltage may vary considerably, depending upon the geometry and placement of the test electrodes. For this reason it is important that the electrodes to be used be described when specifying this test method, and that they be described in the report.

6.3.1 One of the electrodes listed in Table 1 should be specified by the document referring to this test method. If no electrodes have been specified, select an applicable one from Table 1, or use other electrodes mutually acceptable to the parties concerned when the standard electrodes cannot be used due to the nature or configuration of the material being tested. See references in Appendix X2 for examples of some special electrodes. In any event the electrodes must be described in the report.

6.3.2 The electrodes of Types 1 through 4 and Type 6 of Table 1 should be in contact with the test specimen over the entire flat area of the electrodes.

6.3.3 The specimens tested using Type 7 electrodes should be of such size that all portions of the specimen will be within and no less than 15 mm from the edges of the electrodes during test. In most cases, tests using Type 7 electrodes are made with the plane of the electrode surfaces in a vertical position. Tests made with horizontal electrodes should not be directly compared with tests made with vertical electrodes, particularly when the tests are made in a liquid surrounding medium.

6.3.4 Keep the electrode surfaces clean and smooth, and free from projecting irregularities resulting from previous tests. If asperities have developed, they must be removed.

6.3.5 It is important that the original manufacture and subsequent resurfacing of electrodes be done in such a manner that the specified shape and finish of the electrodes and their edges are maintained. The flatness and surface finish of the electrode faces must be such that the faces are in close contact with the test specimen over the entire area of the electrodes. Surface finish is particularly important when testing very thin materials which are subject to physical damage from improperly finished electrodes. When resurfacing, do not change the transition between the electrode face and any specified edge radius.

6.3.6 Whenever the electrodes are dissimilar in size or shape, the one at which the lowest concentration of stress exists, usually the larger in size and with the largest radius, should be at ground potential.

6.3.7 In some special cases liquid metal electrodes, foil electrodes, metal shot, water, or conductive coating electrodes are used. It must be recognized that these may give results differing widely from those obtained with other types of electrodes.

6.3.8 Because of the effect of the electrodes on the test results, it is frequently possible to obtain additional information as to the dielectric properties of a material (or a group of materials) by running tests with more than one type of electrode. This technique is of particular value for research testing.

6.4 *Surrounding Medium*—The document calling for this test method should specify the surrounding medium and the test temperature. Since flashover must be avoided and the effects of partial discharges prior to breakdown minimized, even for short time tests, it is often preferable and sometimes necessary to make the tests in insulating liquid (see 6.4.1). Breakdown values obtained in insulating liquid may not be comparable with those obtained in air. The nature of the insulating liquid and the degree of previous use may influence

the test values. Testing in air may require excessively large specimens or cause heavy surface discharges and burning before breakdown. Some electrode systems for testing in air make use of pressure gaskets around the electrodes to prevent flashover. The material of the gaskets or seals around the electrodes may influence the breakdown values.

6.4.1 When tests are made in insulating oil, an oil bath of adequate size shall be provided. (**Caution**—The use of glass containers is not recommended for tests at voltages above about 10 kV, because the energy released at breakdown may be sufficient to shatter the container. Metal baths must be grounded.)

It is recommended that mineral oil meeting the requirements of Specification D 3487, Type I or II, be used. It should have a dielectric breakdown voltage as determined by Test Method D 877 of at least 26 kV. Other dielectric fluids may be used as surrounding mediums if specified. These include, but are not limited to, silicone fluids and other liquids intended for use in transformers, circuit breakers, capacitors, or cables.

6.4.1.1 The quality of the insulating oil may have an appreciable effect upon the test results. In addition to the dielectric breakdown voltage, mentioned above, particulate contaminants are especially important when very thin specimens (25 μm (1 mil) or less) are being tested. Depending upon the nature of the oil and the properties of the material being tested, other properties, including dissolved gas content, water content, and dissipation factor of the oil may also have an effect upon the results. Frequent replacement of the oil, or the use of filters and other reconditioning equipment may be necessary to minimize the effect of variations of the quality of the oil on the test results.

6.4.1.2 Breakdown values obtained using liquids having different electrical properties may not be comparable. (See X1.4.7.) If tests are to be made at other than room temperature, the bath must be provided with a means for heating or cooling the liquid, and with a means to ensure uniform temperature. Small baths can in some cases be placed in an oven (see 6.4.2) in order to provide temperature control. If forced circulation of the fluid is provided, care must be taken to prevent bubbles from being whipped into the fluid. The temperature shall be maintained within $\pm 5^\circ\text{C}$ of the specified test temperature at the electrodes, unless otherwise specified. In many cases it is specified that specimens to be tested in insulating oil are to be previously impregnated with the oil and not removed from the oil before testing (see Practice D 2413). For such materials, the bath must be of such design that it will not be necessary to expose the specimens to air before testing.

6.4.2 If tests in air are to be made at other than ambient temperature or humidity, an oven or controlled humidity chamber must be provided for the tests. Ovens meeting the requirements of Specification D 5423 and provided with means for introducing the test voltage will be suitable for use when only temperature is to be controlled.

6.4.3 Tests in gasses other than air will generally require the use of chambers that can be evacuated and filled with the test gas, usually under some controlled pressure. The design of such chambers will be determined by the nature of the test program to be undertaken.

6.5 *Test Chamber*—The test chamber or area in which the tests are to be made shall be of sufficient size to hold the test equipment, and shall be provided with interlocks to prevent accidental contact with any electrically energized parts. A number of different physical arrangements of voltage source, measuring equipment, baths or ovens, and electrodes are possible, but it is essential that (1) all gates or doors providing access to spaces in which there are electrically energized parts be interlocked to shut off the voltage source when opened; (2) clearances are sufficiently large that the field in the area of the electrodes and specimen are not distorted and that flashovers and partial discharges (corona) do not occur except between the test electrodes; and (3) insertion and replacement of specimens between tests be as simple and convenient as possible. Visual observation of the electrodes and test specimen during the test is frequently desirable.

7. Hazards

7.1 **Warning**—Lethal voltages may be present during this test. It is essential that the test apparatus, and all associated equipment that may be electrically connected to it, be properly designed and installed for safe operation. Solidly ground all electrically conductive parts that any person might come into contact with during the test. Provide means for use at the completion of any test to ground any parts which: were at high voltage during the test; may have acquired an induced charge during the test; may retain a charge even after disconnection of the voltage source. Thoroughly instruct all operators in the proper way to conduct tests safely. When making high-voltage tests, particularly in compressed gas or in oil, the energy released at breakdown may be sufficient to result in fire, explosion, or rupture of the test chamber. Design test equipment, test chambers, and test specimens so as to minimize the possibility of such occurrences and to eliminate the possibility of personal injury.

7.2 **Warning**—Ozone is a physiologically hazardous gas at elevated concentrations. The exposure limits are set by governmental agencies and are usually based upon recommendations made by the American Conference of Governmental Industrial Hygienists.⁷ Ozone is likely to be present whenever voltages exist which are sufficient to cause partial, or complete, discharges in air or other atmospheres that contain oxygen. Ozone has a distinctive odor which is initially discernible at low concentrations but sustained inhalation of ozone can cause temporary loss of sensitivity to the scent of ozone. Because of this it is important to measure the concentration of ozone in the atmosphere, using commercially available monitoring devices, whenever the odor of ozone is persistently present or when ozone generating conditions continue. Use appropriate means, such as exhaust vents, to reduce ozone concentrations to acceptable levels in working areas.

8. Sampling

8.1 The detailed sampling procedure for the material being tested should be defined in the specification for that material.

8.2 Sampling procedures for quality control purposes should provide for gathering of sufficient samples to estimate both the average quality and the variability of the lot being examined; and for proper protection of the samples from the time they are taken until the preparation of the test specimens in the laboratory or other test area is begun.

8.3 For the purposes of most tests it is desirable to take samples from areas that are not immediately adjacent to obvious defects or discontinuities in the material. The outer few layers of roll material, the top sheets of a package of sheets, or material immediately next to an edge of a sheet or roll should be avoided, unless the presence or proximity of defects or discontinuities is of interest in the investigation of the material.

8.4 The sample should be large enough to permit making as many individual tests as may be required for the particular material (see 12.4).

9. Test Specimens

9.1 *Preparation and Handling:*

9.1.1 Prepare specimens from samples collected in accordance with Section 8.

9.1.2 When flat-faced electrodes are to be used, the surfaces of the specimens which will be in contact with the electrodes shall be smooth parallel planes, insofar as possible without actual surface machining.

9.1.3 The specimens shall be of sufficient size to prevent flashover under the conditions of test. For thin materials it may be convenient to use specimens large enough to permit making more than one test on a single piece.

9.1.4 For thicker materials (usually more than 2 mm thick) the breakdown strength may be high enough that flashover or intense surface partial discharges (corona) may occur prior to breakdown. Techniques that may be used to prevent flashover, or to reduce partial discharge (corona) include:

9.1.4.1 Immerse the specimen in insulating oil during the test. See X1.4.7 for the surrounding medium factors influencing breakdown. This may be necessary for specimens that have not been dried and impregnated with oil, as well as for those which have been prepared in accordance with Practice D 2413, for example. (See 6.4.)

9.1.4.2 Machine a recess or drill a flat-bottom hole in one or both surfaces of the specimen to reduce the test thickness. If dissimilar electrodes are used (such as Type 6 of Table 1) and only one surface is to be machined, the larger of the two electrodes should be in contact with the machined surface. Care must be taken in machining specimens not to contaminate or mechanically damage them.

9.1.4.3 Apply seals or shrouds around the electrodes, in contact with the specimen to reduce the tendency to flashover.

9.1.5 Materials that are not in flat sheet form shall be tested using specimens (and electrodes) appropriate to the material and the geometry of the sample. It is essential that for these materials both the specimen and the electrodes be defined in the specification for the material.

9.1.6 Whatever the form of the material, if tests of other than surface-to-surface puncture strength are to be made, define the specimens and the electrodes in the specification for the material.

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

9.2 In nearly all cases the actual thickness of the test specimen is important. Unless otherwise specified, measure the thickness after the test in the immediate vicinity of the area of breakdown. Measurements shall be made at room temperature ($25 \pm 5^\circ\text{C}$), using the appropriate procedure of Test Methods D 374.

10. Calibration

10.1 In making calibration measurements, take care that the values of voltage at the electrodes can be determined within the accuracy given in 6.2, with the test specimens in the circuit.

10.2 Use an independently calibrated voltmeter attached to the output of the test voltage source to verify the accuracy of the measuring device. Electrostatic voltmeters, voltage dividers, or potential transformers having comparable accuracy may be used for calibration measurement.

10.3 At voltages above about 12 kV rms (16.9 kV peak) a sphere gap may be used to calibrate the readings of the voltage-measuring device. Follow procedures as specified in ANSI C68.1 in such calibration.

11. Conditioning

11.1 The dielectric strength of most solid insulating materials is influenced by temperature and moisture content. Materials so affected should be brought to equilibrium with an atmosphere of controlled temperature and relative humidity before testing. For such materials, the conditioning should be included in the standard referencing this test method.

11.2 Unless otherwise specified, follow the procedures in Practice D 618.

11.3 For many materials the moisture content has more effect on dielectric strength than does temperature. Conditioning times for these materials should be sufficiently long to permit the specimens to reach moisture equilibrium as well as temperature equilibrium.

11.4 If the conditioning atmosphere is such that condensation occurs on the surface of the specimens, it may be desirable to wipe the surfaces of the specimens immediately before testing. This will usually reduce the probability of surface flashover.

12. Procedure

12.1 (**Caution**—see Section 7 before commencement of any test.)

12.2 Methods of Voltage Application:

12.2.1 *Method A, Short-Time Test*—Apply voltage uniformly to the test electrodes from zero at one of the rates shown in Fig. 1 until breakdown occurs. Use the short-time test unless otherwise specified.

12.2.1.1 When establishing a rate initially in order for it to be included in a new specification, select a rate that, for a given set of specimens, will give an average time to breakdown of between 10 and 20 s. It may be necessary to run one or two preliminary tests in order to determine the most suitable rate-of-rise. For many materials a rate of 500 V/s is used.

12.2.1.2 If the document referencing this test method specified a rate-of-rise, it shall be used consistently in spite of

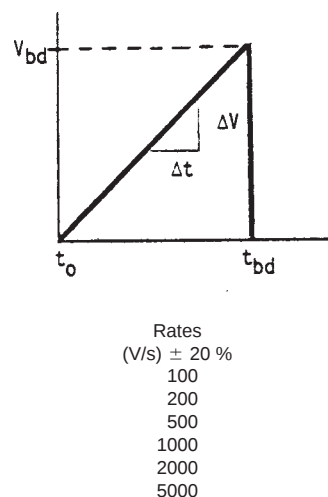


FIG. 1 Voltage Profile of the Short-Time Test

occasional average time to breakdown falling outside the range of 10 to 20 s. In this case, the times to failures shall be made a part of the report.

12.2.1.3 In running a series of tests comparing different material, the same rate-of-rise shall be used with preference given to a rate that allows the average time to be between 10 and 20 s. If the time to breakdown cannot be adhered to, the time shall be made a part of the report.

12.2.2 *Method B, Step-by-Step Test*—Apply voltage to the test electrodes at the preferred starting voltage and in steps and duration as shown in Fig. 2 until breakdown occurs.

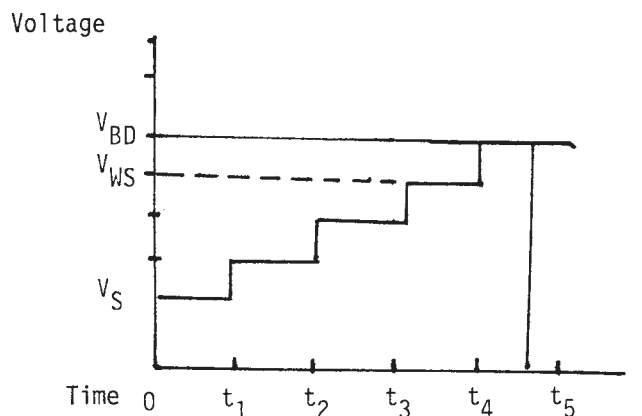
12.2.2.1 From the list in Fig. 2, select the initial voltage, V_s , to be the one closest to 50 % of the experimentally determined or expected breakdown voltage under the short time test.

12.2.2.2 If an initial voltage other than one of the preferred values listed in Fig. 2 is selected, it is recommended that the voltage steps be 10 % of the preferred initial voltage immediately below the selected value.

12.2.2.3 Apply the initial voltage by increasing the voltage from zero as rapidly as can be accomplished without introducing a peak voltage exceeding that permitted in 6.1.3. Similar requirements shall apply to the procedure used to increase the voltage between successive steps. After the initial step, the time required to raise the voltage to the succeeding step shall be counted as part of the time at the succeeding step.

12.2.2.4 If breakdown occurs while the voltage is being increased to the next step, the specimen is described as having sustained a dielectric withstand voltage, V_{ws} , equal to the voltage of the step just ended. If breakdown occurs prior to the end of the holding period at any step, the dielectric withstand voltage, V_{ws} , for the specimen is taken as the voltage at the last completed step. The voltage at breakdown, V_{bd} , is to be used to calculate dielectric breakdown strength. The dielectric withstand strength is to be calculated from the thickness and the dielectric withstand voltage, V_{ws} . (See Fig. 2.)

12.2.2.5 It is desirable that breakdown occur in four to ten steps, but in not less than 120 s. If failure occurs at the third step or less, or in less than 120 s, whichever is greater, on more than one specimen in a group, the tests should be repeated with



Preferred starting voltages, V_s , are 0.25, 0.50, 1, 2, 5, 10, 20, 50, and 100 kV.

Step Voltage	Increment (kV)
when V_s (kV) ^A is	
5 or less	10 % of V_s
over 5 to 10	0.50
over 10 to 25	1
over 25 to 50	2
over 50 to 100	5
over 100	10

^A $V_s = 0.5 (V_{bd})$ for Short-Time Test) unless constraints cannot be met.

Constraints
 $(t_1 - t_0) = (t_2 - t_1) = \dots = (60 \pm 5)s$
 Alternate step times, $(20 \pm 3)s$ and $(300 \pm 10)s$
 $120s \leq t_{bd} \leq 720s$, for 60s steps

FIG. 2 Voltage Profile of Step-by-Step Test

a lower initial voltage. If failure does not occur before the twelfth step or greater than 720 s, increase the initial voltage.

12.2.2.6 Record the initial voltage, the voltage steps, the breakdown voltage, and the length of time that the breakdown voltage was held. If failure occurred while the voltage was being increased to the starting voltage the failure time shall be zero.

12.2.2.7 Other time lengths for the voltage steps may be specified, depending upon the purpose of the test. Commonly used lengths are 20 s and 300 s (5 min). For research purposes, it may be of value to conduct tests using more than one time interval on a given material.

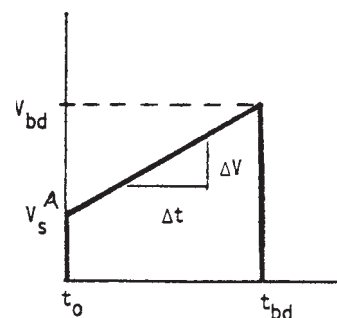
12.2.3 *Method C, Slow Rate-of-Rise Test*—Apply voltage to the test electrodes, from the starting voltage and at the rate shown in Fig. 3 until breakdown occurs.

12.2.3.1 Select the initial voltage from short-time tests made as specified in 12.2.1. The initial voltage shall be reached as specified in 12.2.2.3.

12.2.3.2 Use the rate-of-voltage rise from the initial value specified in the document calling for this test method. Ordinarily the rate is selected to approximate the average rate for a step-by-step test.

12.2.3.3 If more than one specimen of a group of specimens breaks down in less than 120 s, reduce either the initial voltage or the rate-of-rise, or both.

12.2.3.4 If more than one specimen of a group of specimens breaks down at less than 1.5 times the initial voltage, reduce the initial value. If breakdown repeatedly occurs at a value



Rates (V/s) $\pm 20\%$

1
2
5
10
12.5
20
25
50
100

Constraints
 $t_{bd} > 120 s$

$V_{bd} > 1.5 V_s$

FIG. 3 Voltage Profile of Slow Rate-of-Rise Test

greater than 2.5 times the initial value (and at a time of over 120 s), increase the initial voltage.

12.3 *Criteria of Breakdown*—Dielectric failure or dielectric breakdown (as defined in Terminology D 1711) consists of an increase in conductance, limiting the electric field that can be sustained. This phenomenon is most commonly evidenced during the test by an abrupt visible and audible rupture through the thickness of the specimen, resulting in a visible puncture and decomposition of the specimen in the breakdown area. This form of breakdown is generally irreversible. Repeated applications of voltage will sometimes result in failure at lower voltages (sometimes unmeasurably low), usually with additional damage at the breakdown area. Such repeated applications of voltage may be used to give positive evidence of breakdown and to make the breakdown path more visible.

12.3.1 A rapid rise in leakage current may result in tripping of the voltage source without visible decomposition of the specimen. This type of failure, usually associated with slow-rise tests at elevated temperatures, may in some cases be reversible, that is, recovery of the dielectric strength may occur if the specimen is allowed to cool to its original test temperature before reapplying voltage. The voltage source must trip rapidly at relatively low current for this type of failure to occur.

12.3.2 Tripping of the voltage source may occur due to flashover, to partial discharge current, to reactive current in a high capacitance specimen, or to malfunctioning of the breaker. Such interruptions of the test do not constitute breakdown (except for flashover tests) and should not be considered as a satisfactory test.

12.3.3 If the breaker is set for too high a current, or if the breaker malfunctions, excessive burning of the specimen will occur.

12.4 *Number of Tests*—Make five breakdowns unless otherwise specified for the particular material.

13. Calculation

13.1 Calculate for each test the dielectric strength in kV/mm or V/mil at breakdown, and for step-by-step tests, the gradient at the highest voltage step at which breakdown did not occur.

13.2 Calculate the average dielectric strength and the standard deviation, or other measure of variability.

14. Report

14.1 Report the following information:

14.1.1 Identification of the test sample.

14.1.2 *For Each Specimen:*

14.1.2.1 Measured thickness,

14.1.2.2 Maximum voltage withstood (for step-by-step tests),

14.1.2.3 Dielectric breakdown voltage,

14.1.2.4 Dielectric strength (for step-by-step tests),

14.1.2.5 Dielectric breakdown strength, and

15. Precision and Bias

15.1 The results of an interlaboratory study with four laboratories and eight materials are summarized in Table 2. This study made use of one electrode system and one test medium.⁸

15.2 *Single-Operator Precision*—Depending upon the variability of the material being tested, the specimen thickness, method of voltage application, and the extent to which transient voltage surges are controlled or suppressed, the coefficient of variation (standard deviation divided by the mean) may vary from a low 1 % to as high as 20 % or more. When making duplicate tests on five specimens from the same sample, the coefficient of variation usually is less than 9 %.

15.3 *Multilaboratory Precision*—The precision of tests made in different laboratories (or of tests made using different equipment in the same laboratory) is variable. Using identical

TABLE 2 Dielectric Strength^A Data Summary From Four Laboratories

Material	Thickness (in. nom.)	Dielectric Strength (V/mil)			Standard Deviation	Coefficient of Variation (%)
		mean	max	min		
Polyethylene	0.001	4606	5330	4100	332	7.2
Terephthalate	0.01	1558	1888	1169	196	12.6
Polyethylene Terephthalate	0.003	3276	3769	2167	333	10.2
Fluorinated Ethylene Propylene	0.005	2530	3040	2140	231	9.1
Fluorinated Ethylene Propylene	0.025	956	1071	783	89	9.3
PETP fiber reinforced epoxy resin	0.060	583	643	494	46	7.9
PETP fiber reinforced epoxy resin	0.065	567	635	489	43	7.6
Epoxy-Glass Laminate	0.044	861	948	729	48	<u>5.6</u>
Crosslinked Polyethylene					Average	8.7

^A Tests performed with specimens in oil using Type 2 electrodes (see Table 1).

14.1.2.6 Location of failure (center of electrode, edge, or outside).

14.1.3 *For Each Sample:*

14.1.3.1 Average dielectric withstand strength for step-by-step test specimens only,

14.1.3.2 Average dielectric breakdown strength,

14.1.3.3 Indication of variability, preferably the standard deviation and coefficient of variation,

14.1.3.4 Description of test specimens,

14.1.3.5 Conditioning and specimen preparation,

14.1.3.6 Ambient atmosphere temperature and relative humidity,

14.1.3.7 Surrounding medium,

14.1.3.8 Test temperature,

14.1.3.9 Description of electrodes,

14.1.3.10 Method of voltage application,

14.1.3.11 If specified, the failure criterion of the current-sensing element, and

14.1.3.12 Date of test.

types of equipment and controlling specimen preparation, electrodes and testing procedures closely, the single-operator precision is approachable. When making a direct comparison of results from two or more laboratories, evaluate the precision between the laboratories.

15.4 If the material under test, the specimen thickness, the electrode configuration, or the surrounding medium differs from those listed in Table 1, or if the failure criterion of the current-sensing element of the test equipment is not closely controlled, the precisions cited in 15.2 and 15.3 may not be realized. Standards which refer to this method should determine for the material with which that standard is concerned the applicability of this precision statement to that particular material. Refer to 5.4-5.8 and 6.1.6.

⁸ The complete report is available from ASTM International. Request RR:D09-1026.

15.5 Use special techniques and equipment for materials having a thickness of 0.001 in. or less. The electrodes must not damage the specimen upon contact. Accurately determine the voltage at breakdown.

15.6 *Bias*—This test method does not determine the intrinsic dielectric strength. The test values are dependent upon specimen geometry, electrodes, and other variable factors, in addition to the properties of the sample, so that it is not possible to make a statement of bias.

16. Keywords

16.1 breakdown; breakdown voltage; calibration; criteria of breakdown; dielectric breakdown voltage; dielectric failure; dielectric strength; electrodes; flashover; power frequency; process-control testing; proof testing; quality-control testing; rapid rise; research testing; sampling; slow rate-of-rise; step-by-step; surrounding medium; voltage withstand

APPENDIXES

(Nonmandatory Information)

X1. SIGNIFICANCE OF THE DIELECTRIC STRENGTH TEST

X1.1 Introduction

X1.1.1 A brief review of three postulated mechanisms of breakdown, namely: (1) the discharge or corona mechanism, (2) the thermal mechanism, and (3) the intrinsic mechanism, as well as a discussion of the principal factors affecting tests on practical dielectrics, are given here to aid in interpreting the data. The breakdown mechanisms usually operate in combination rather than singly. The following discussion applies only to solid and semisolid materials.

X1.2 Postulated Mechanisms of Dielectric Breakdown

X1.2.1 *Breakdown Caused by Electrical Discharges*—In many tests on commercial materials, breakdown is caused by electrical discharges, which produce high local fields. With solid materials the discharges usually occur in the surrounding medium, thus increasing the test area and producing failure at or beyond the electrode edge. Discharges may occur in any internal voids or bubbles that are present or may develop. These may cause local erosion or chemical decomposition. These processes may continue until a complete failure path is formed between the electrodes.

X1.2.2 *Thermal Breakdown*—Cumulative heating develops in local paths within many materials when they are subjected to high electric field intensities, causing dielectric and ionic conduction losses which generate heat more rapidly than can be dissipated. Breakdown may then occur because of thermal instability of the material.

X1.2.3 *Intrinsic Breakdown*—If electric discharges or thermal instability do not cause failure, breakdown will still occur when the field intensity becomes sufficient to accelerate electrons through the material. This critical field intensity is called the intrinsic dielectric strength. It cannot be determined by this test method, although the mechanism itself may be involved.

X1.3 Nature of Electrical Insulating Materials

X1.3.1 Solid commercial electrical insulating materials are generally nonhomogeneous and may contain dielectric defects of various kinds. Dielectric breakdown often occurs in an area of the test specimen other than that where the field intensity is greatest and sometimes in an area remote from the material

directly between the electrodes. Weak spots within the volume under stress sometimes determine the test results.

X1.4 Influence of Test and Specimen Conditions

X1.4.1 *Electrodes*—In general, the breakdown voltage will tend to decrease with increasing electrode area, this area effect being more pronounced with thin test specimens. Test results are also affected by the electrode geometry. Results may be affected also by the material from which the electrodes are constructed, since the thermal and discharge mechanism may be influenced by the thermal conductivity and the work function, respectively, of the electrode material. Generally speaking, the effect of the electrode material is difficult to establish because of the scatter of experimental data.

X1.4.2 *Specimen Thickness*—The dielectric strength of solid commercial electrical insulating materials is greatly dependent upon the specimen thickness. Experience has shown that for solid and semi-solid materials, the dielectric strength varies inversely as a fractional power of the specimen thickness, and there is a substantial amount of evidence that for relatively homogeneous solids, the dielectric strength varies approximately as the reciprocal of the square root of the thickness. In the case of solids that can be melted and poured to solidify between fixed electrodes, the effect of electrode separation is less clearly defined. Since the electrode separation can be fixed at will in such cases, it is customary to perform dielectric strength tests on liquids and usually on fusible solids, with electrodes having a standardized fixed spacing. Since the dielectric strength is so dependent upon thickness it is meaningless to report dielectric strength data for a material without stating the thickness of the test specimens used.

X1.4.3 *Temperature*—The temperature of the test specimen and its surrounding medium influence the dielectric strength, although for most materials small variations of ambient temperature may have a negligible effect. In general, the dielectric strength will decrease with increasing temperatures, but the extent to which this is true depends upon the material under test. When it is known that a material will be required to function at other than normal room temperature, it is essential

that the dielectric strength-temperature relationship for the material be determined over the range of expected operating temperatures.

X1.4.4 Time—Test results will be influenced by the rate of voltage application. In general, the breakdown voltage will tend to increase with increasing rate of voltage application. This is to be expected because the thermal breakdown mechanism is time-dependent and the discharge mechanism is usually time-dependent, although in some cases the latter mechanism may cause rapid failure by producing critically high local field intensities.

X1.4.5 Wave Form—In general, the dielectric strength is influenced by the wave form of the applied voltage. Within the limits specified in this method the influence of wave form is not significant.

X1.4.6 Frequency—The dielectric strength is not significantly influenced by frequency variations within the range of commercial power frequencies provided for in this method. However, inferences concerning dielectric strength behavior at other than commercial power frequencies (50 to 60 Hz) must not be made from results obtained by this method.

X1.4.7 Surrounding Medium—Solid insulating materials having a high breakdown voltage are usually tested by immersing the test specimens in a liquid dielectric such as transformer oil, silicone oil, or chlorofluorocarbons, in order to minimize the effects of surface discharges prior to breakdown. It has been shown by S. Whitehead⁹ that in order to avoid discharges in the surrounding medium prior to reaching the breakdown voltage of the solid test specimen, in alternating voltage tests it is necessary that

$$E_m \epsilon'_m \sqrt{D_m^2 + 1} > E_s \epsilon'_s \sqrt{D_s^2 + 1} \quad (X1.1)$$

If the liquid immersion medium is a low loss material, the criterion simplifies to

$$E_m \epsilon'_m > E_s \epsilon'_s \sqrt{D_s^2 + 1} \quad (X1.2)$$

and if the liquid immersion medium is a semiconducting material the criterion becomes

$$E_m \sigma_m > 2\pi f \epsilon_r \epsilon_0 E_s \quad (X1.3)$$

where:

- E = electric strength,
- f = frequency,
- ϵ and ϵ' = permittivity,
- D = dissipation factor, and
- σ = conductivity (S/m).

Subscripts:

- m refers to immersion medium,
- r refers to relative,
- 0 refers to free space,
($\epsilon_0 = 8.854 \times 10^{-12}$ F/m) and
- s refers to solid dielectric.

X1.4.7.1 Whitehead points out that it is therefore desirable to increase E_m and ϵ_m , or σ_m , if surface discharges are to be avoided. Transformer oil is usually specified and its dielectric

properties are usually such that edge breakdown will generally occur if the electric strength, E_s , approaches the value given by:

$$E_s = \left(\frac{4.2}{t_s} + \frac{63}{\epsilon'_s} \right) \text{ kV/mm} \quad (X1.4)$$

In cases of large thickness of specimen and low permittivity of specimen, the term containing t_s becomes relatively insignificant and the product of permittivity and electric strength is approximately a constant.¹⁰ Whitehead also mentions (p. 261) that the use of moist semiconducting oil can affect an appreciable reduction in edge discharges. Unless the breakdown path between the electrodes is solely within the solid, results in one medium cannot be compared with those in a different medium. It should also be noted that if the solid is porous or capable of being permeated by the immersion medium, the breakdown strength of the solid is directly affected by the electrical properties of immersion medium.

X1.4.8 Relative Humidity—The relative humidity influences the dielectric strength to the extent that moisture absorbed by, or on the surface of, the material under test affects the dielectric loss and surface conductivity. Hence, its importance will depend to a large extent upon the nature of the material being tested. However, even materials that absorb little or no moisture may be affected because of greatly increased chemical effects of discharge in the presence of moisture. Except in cases where the effect of exposure on dielectric strength is being investigated, it is customary to control or limit the relative humidity effects by standard conditioning procedures.

X1.5 Evaluation

X1.5.1 A fundamental requirement of the insulation in electrical apparatus is that it withstand the voltage imposed on it in service. Therefore there is a great need for a test to evaluate the performance of particular materials at high voltage stress. The dielectric breakdown voltage test represents a convenient preliminary test to determine whether a material merits further consideration, but it falls short of a complete evaluation in two important respects. First, the condition of a material as installed in apparatus is much different from its condition in this test, particularly with regard to the configuration of the electric field and the area of material exposed to it, corona, mechanical stress, ambient medium, and association with other materials. Second, in service there are deteriorating influences, heat, mechanical stress, corona and its products, contaminants, and so forth, which may reduce the breakdown voltage far below its value as originally installed. Some of these effects can be incorporated in laboratory tests, and a better estimate of the material will result, but the final consideration must always be that of the performance of the material in actual service.

X1.5.2 The dielectric breakdown test may be used as a material inspection or quality control test, as a means of

⁹ Whitehead, S., *Dielectric Breakdown of Solids*, Oxford University Press, 1951.

¹⁰ Starr, R. W., "Dielectric Materials Ionization Study" *Interim Engineering*, Report No. 5, Index No ME-111273. Available from Naval Sea Systems Command Technical Library, Code SEA 09B 312, National Center 3, Washington, DC 20362-5101.

inferring other conditions such as variability, or to indicate deteriorating processes such as thermal aging. In these uses of

the test it is the relative value of the breakdown voltage that is important rather than the absolute value.

X2. STANDARDS REFERRING TO TEST METHOD D 149

X2.1 Introduction

X2.1.1 The listing of documents in this appendix provides reference to a broad range of ASTM standards concerned with determination of dielectric strength at power frequencies or with elements of test equipment or elements of procedural details used to determine this property. While every effort has been made to include as many as possible of the standards referring to Test Method D 149, the list may not be complete, and standards written or revised after publication of this appendix are not included.

X2.1.2 In some standards which specify that the dielectric strength or the breakdown voltage is to be determined in accordance with Test Method D 149, the manner in which the reference is made to this test method is not completely in conformance with the requirements of 5.5. Do not use another document, including those listed in this appendix, as a model for reference to this test method unless there is conformity with 5.5.

TABLE X2.1 ASTM Standards Referring to Test Method D 149

ASTM Designation	Volume	Type of Standard	Subject
<i>General Standards not Specific to a Material or Material Class:</i>			
D 1389	10.01	Test Method	Thin Electrical Insulating Materials, Proof Tests
D 1868	10.01	Test Method	Detection and Measurement of Partial Discharge Pulses
D 1999	08.02	Guide	Selection of Specimens and Test Parameters for International Commerce
D 2275	10.01	Test Method	Voltage Endurance with Partial Discharges on the Surface
D 2304	10.01	Test Method	Thermal Endurance, Rigid Insulating Materials
D 3151	10.02	Test Method	Thermal Failure Under Electrical Stress
D 3382	10.02	Test Method	Measurement of Energy and Charge Transfer Due to Partial Discharges
D 3426	10.02	Test Method	Dielectric Strength Using Impulse Waves
D 3755	10.02	Test Method	Dielectric Strength Using Direct Voltage
D 2756	10.02	Test Method	Electrical Breakdown by Treeing
E 1420	12.02	Guide	Specifying Materials for Ionizing Radiation
<i>Fabric, Fiber, Paper, Tape, Film, Flexible Composites, and Coated Fabrics:</i>			
D 69	10.01	Test Method	Friction Tape
D 202	10.01	Test Method	Untreated Insulating Paper
D 295	10.01	Test Method	Varnished Cotton Fabric Tape
D 373	10.01	Specification	Black Bias-Cut Varnished Cloth and Tape
D 619	10.01	Test Method	Vulcanized Fibre
D 902	10.01	Test Method	Resin-Coated Glass Fabrics and Tapes
D 1000	10.01	Test Method	Pressure-Sensitive Tapes
D 1458	10.01	Test Method	Silicone Rubber Coated Glass Fabric and Tape
D 1459	10.01	Specification	Silicone Varnished Glass Cloth and Tape
D 1830	10.01	Test Method	Flexible Materials, Thermal Endurance, Curved Electrode Method
D 2148	10.01	Test Method	Bondable Rubber Tapes
D 2305	10.01	Test Method	Polymeric Films
D 2381	10.01	Test Method	Flexible Composites
D 2413	10.01	Test Method	Impregnated Paper and Board
D 3308	08.03	Specification	PTFE Resin Skived Tape
D 3368	08.03	Specification	FEP Fluorocarbon Resin Sheet and Film
D 3369	08.03	Specification	PTFE Resin Cast Film
D 3664	10.02	Specification	Polyethylene Terephthalate Film
D 4325	10.02	Test Method	Semiconducting and Insulating Rubber Tapes
D 4969	08.03	Specification	PTFE Coated Glass Fabric
D 5214	10.02	Test Method	Polyimide Resin Films
<i>Polymeric Molding and Embedding Compounds:</i>			
D 704	08.01	Specification	Melamine-Formaldehyde Molding Compounds
D 705	08.01	Specification	Urea-Formaldehyde Molding Compounds
D 729	08.01	Specification	Vinylidene Chloride Molding Compounds
D 1430	08.01	Specification	Polychlorofluoroethylene (PCTFE) Plastics
D 1636	08.02	Specification	Allyl Molding Compounds
D 3013	08.02	Specification	Epoxy Molding Compounds
D 3222	08.03	Specification	Poly(Vinylidene Fluoride) Molding, Extrusion, Coating Materials
D 3748	08.03	Practice	High-Density Rigid Cellular Thermoplastics
D 3935	08.03	Specification	Polycarbonate Materials
D 4000	08.03	Classification	System for Specifying Plastics
D 4066	08.03	Specification	Nylon Injection and Extrusion Materials
D 4067	08.03	Specification	Polyphenylene Sulfide Injection and Extrusion Materials
D 4098	08.03	Practice	High-Density Rigid Cellular Thermosets
<i>Mica, Glass, and Porcelain:</i>			
D 116	10.01	Test Method	Vitrified Ceramic Materials
D 352	10.01	Test Method	Pasted Mica
D 748	10.01	Specification	Natural Block Mica
D 1039	10.01	Test Method	Glass-Bonded Mica
D 1677	10.01	Test Method	Untreated Mica Paper
D 2442	15.02	Specification	Alumina Ceramics
<i>Sleeving, Tubes, Sheets, and Rods:</i>			
D 229	10.01	Test Method	Rigid Sheet and Plate Materials
D 348	10.01	Test Method	Laminated Tubes
D 349	10.01	Test Method	Laminated Round Rods
D 350	10.01	Test Method	Flexible Treated Sleeving
D 709	10.01	Specification	Laminated Thermosetting Materials
D 876	10.01	Test Method	Nonrigid Vinyl Chloride Polymer Tubing
D 1675	10.01	Test Method	TFE Fluorocarbon Tubing
D 1710	10.01	Specification	TFE Fluorocarbon Rod
D 2671	10.02	Test Method	Heat-Shrinkable Tubing
D 3293	08.03	Specification	PTFE Molded Sheet
D 3294	08.03	Specification	PTFE Molded Basic Shapes
D 3295	08.03	Specification	PTFE Tubing
D 3296	08.03	Specification	FEP Fluorocarbon Tubing
D 3394	10.02	Specification	Insulating Board (Pressboard)
D 4787	06.01	Practice	Liquid and Sheet Linings

TABLE X2.1 *Continued*

ASTM Designation	Volume	Type of Standard	Subject
D 4923	08.03	Specification	Reinforced Thermosetting Plastic Poles
<i>Varnishes, Coatings, Insulating Fluids and Gasses, and Solvents:</i>			
D 115	10.01	Test Method	Varnishes
D 1932	10.01	Test Method	Thermal Endurance, Flexible Varnishes
D 2477	10.03	Test Method	Insulating Gasses
D 3214	10.02	Test Method	Coating Powders and Their Coatings
D 4733	10.02	Test Method	Solventless Varnishes
<i>Rubber and Rubber Products:</i>			
D 120	10.03	Specification	Rubber Insulating Gloves
D 178	10.03	Specification	Rubber Insulating Matting
D 1048	10.03	Specification	Rubber Insulating Blankets
D 1049	10.03	Specification	Rubber Insulating Covers
D 1050	10.03	Specification	Rubber Insulating Line Hose
D 1051	10.03	Specification	Rubber Insulating Sleeves
<i>Filling Compounds:</i>			
D 176	10.01	Test Method	Solid Filling and Treating Compounds
<i>Adhesives:</i>			
D 1304	15.06	Test Method	Adhesives Relative to Use as Electrical Insulation
<i>Wire and Cable Insulation:</i>			
D 470	10.01	Test Method	Cross-Linked Insulation and Jackets for Wire and Cable
D 1676	10.01	Test Method	Film Insulation on Magnet Wire
D 2307	10.01	Test Method	Film Insulation on Magnetic Wire, Thermal Endurance
D 2633	10.02	Test Method	Thermoplastic Insulation and Jackets for Wire and Cable
D 3032	10.02	Test Method	Hookup Wire Insulation
D 3353	10.02	Test Method	Fibrous Insulation on Magnet Wire

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