



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 D149; 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~~ is suitable for use at any frequency from 25 to 800 Hz. At frequencies above 800 Hz, dielectric heating ~~may be~~ is a potential 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 need to~~ specify the particular options to be used (see 5.5).

1.4 It ~~may be used~~ is suitable for use 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 D3151).

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 is also be used~~ is also suitable for use to determine dielectric breakdown voltage along the interface between a solid specimen and a gaseous or liquid surrounding medium (flashover). With the addition of instructions modifying Section 12; ~~this test method may be used for proof testing~~, this test method is also suitable for use 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

D374 Test Methods for Thickness of Solid Electrical Insulation

D618 Practice for Conditioning Plastics for Testing

D877 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes

D1711 Terminology Relating to Electrical Insulation

D2413 Practice for Preparation of Insulating Paper and Board Impregnated with a Liquid Dielectric

D3151 Test Method for Thermal Failure of Solid Electrical Insulating Materials Under Electric Stress

D3487 Specification for Mineral Insulating Oil Used in Electrical Apparatus

D5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

2.2 IEC Standard:

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; 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.

*A Summary of Changes section appears at the end of this standard.

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⁴ Available from the International Electrotechnical Commission, Geneva, Switzerland.

⁵ Available from International Electrotechnical Commission (IEC), 3 rue de Varembeé, Case postale 131, CH-1211, Geneva 20, Switzerland, <http://www.iec.ch>.

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 D1711.

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 options for the specimens may be that they be molded or cast, or cut from flat sheet or plate. Other electrode and specimen configurations may be used are also suitable for use 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 are suitable for use 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 will potentially 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, it is possible that the precisions stated in 15.2 and 15.3 ~~may not be realized.~~ will not be obtained.

⁶ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

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 testing high-loss materials, it is possible that higher current capacity may will 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~~ 6.1.5 It is important for the circuit-breaking device should to 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 is likely to 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 is often desirable to make tests on a given sample at more than one current setting. The electrode area may is likely to have a significant effect upon what the current setting should be choice of current setting.

~~6.1.7~~ 6.1.7 It is possible that the specimen current-sensing element may will be in the primary of the step-up transformer. Calibrate the current-sensing dial in terms of specimen current.

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. It is acceptable to use 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 It is acceptable to use 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.

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 be possible that it will 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~~ If 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, it is possible that the dielectric breakdown voltage may will 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~~ shall 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~~ shall 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~~ shall 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~~ shall 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, ensure that the one at which the lowest concentration of stress exists, usually the larger in size and with the largest radius, ~~should be~~ is 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 it is possible that these may will 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~~ needs to 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~~ are often not be comparable with those obtained in air. The nature of the insulating liquid and the degree of previous use ~~may influence~~ are factors influencing the test values. ~~Testing~~ In some cases, testing in air may will 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~~ has the potential to influence the breakdown values.

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

It is recommended that mineral oil meeting the requirements of Specification D3487, Type I or II, be used. It ~~should~~ shall have a dielectric breakdown voltage as determined by Test Method D877 of at least 26 kV. Other dielectric fluids ~~may be used~~ are suitable for use 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~~ has the potential to 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

potential to affect the results. Frequent replacement of the oil, or the use of filters and other reconditioning equipment ~~may be necessary~~ is important 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~~ often not 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 D2413). 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 D5423 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**—It is possible that lethal voltages ~~may~~ will 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 fall into any of the following cases: (a) were at high voltage during the test; ~~may~~ (b) have acquired the potential to acquire an induced charge during the test; ~~may~~ or (c) have the potential to 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, it is possible that the energy released at breakdown ~~may~~ will 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. 49-09

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~~ needs to be defined in the specification for that material.

8.2 Sampling procedures for quality control purposes ~~should~~ shall 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~~ Avoid 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, roll, unless the presence or proximity of defects or discontinuities is of interest in the investigation of the material.

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

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

⁷ Available from American Conference of Governmental Industrial Hygienists, Inc. (ACGIH), 1330 Kemper Meadow Dr., Cincinnati, OH 45240, <http://www.acgih.org>.