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Standard Test Methods for Thermoplastic Insulations and Jackets for Wire and Cable[1]

This standard is issued under the fixed designation D 2633; 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.

1. Scope

1.1 These test methods cover procedures for the testing of thermoplastic insulations and jackets used on insulated wire and cable. To determine the test to be made on the particular insulation or jacket compound, reference should be made to the product specification for that type. These test methods do not apply to the class of products known as flexible cords. The electrical tests on insulation and water-absorption tests do not apply to the class of products having a separator between the conductor and the insulation.

1.2 These test methods pertain to insulation or jacket material for electrical wires and cables. In many instances the insulation or jacket cannot be tested unless it has been formed around a conductor or cable. Therefore, tests are done on insulated or jacketed wire or cable in these test methods solely to determine the relevant property of the insulation or jacket and not to test the conductor or completed cable.

1.3 The values stated in inch-pound units are the standard, except in cases where SI units are more appropriate. The values in parentheses are for information only.

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.* For specific hazards see Sections 4 and 63.

1.5 The procedures appear in the following sections:

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Cold Bend Test	75 to 77
Dielectric Strength Retention Test	45 to 51
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2. Referenced Documents

2.1 *ASTM Standards:*

D 149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies[2]

D 150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials[2]

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 471 Test Method for Rubber Property-Effect of Liquids[3]

D 573 Test Method for Rubber-Deterioration in an Air Oven[3]

D 638 Test Method for Tensile Properties of Plastics[4]

D 1248 Specification for Polyethylene Plastics Molding and Extrusion Materials[4]

D 2132 Test Method for Dust-and-Fog Tracking and Erosion Resistance of Electrical Insulating Materials[2]

D 3755 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Under Direct-Voltage Stress[5]

D 5025 Specification for a Laboratory Burner Used for Small-Scale Burning Tests on Plastic Materials[6]

D 5207 Practice for Calibration of 20 and 125 mm Test Flames for Small-Scale Burning Tests on Plastic Materials[6]

D 5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation[5]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[7]

2.2 *Federal Standard:*

[1] These methods are under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and are the direct responsibility of Subcommittee D09.18 on Solid Insulations, Non-Metallic Shieldings, and Coverings for Electrical and Telecommunications Wires and Cables.

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[2] *Annual Book of ASTM Standards*, Vol 10.01.
[3] *Annual Book of ASTM Standards*, Vol 09.01.
[4] *Annual Book of ASTM Standards*, Vol 08.01.
[5] *Annual Book of ASTM Standards*, Vol 10.02.
[6] *Annual Book of ASTM Standards*, Vol 08.03.
[7] *Annual Book of ASTM Standards*, Vol 14.02.

Federal Specification for Tape; Paper, Gummed (Kraft) (PPP-T-45D)[8]

2.3 *ICEA Standard:*

T-24-380 Guide for Partial-Discharge Procedure[9]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *aging (act of), n*—exposure of material to air or oil at a temperature and a time as specified in the relevant material specification for that material.

3.2 *Symbols:Symbol:*

3.2.1 kcmil = thousands of circular mils.

4. Hazards

4.1 *Mercury*:

4.1.1 **Caution:** Mercury metal vapor poisoning has long been recognized as a hazard. When using equipment containing or requiring the use of mercury, take all precautions and care to avoid the escape of mercury vapor or the spillage of mercury. Maximum limits for mercury concentrations in industrial atmospheres are set by governmental agencies. These limits are usually based upon recommendations made by the American Conference of Governmental Industrial Hygienists.[10] It is possible for the concentration of mercury vapors accompanying spills from broken thermometers, barometers, and other instruments using mercury to exceed these limits. Mercury, being a heavy liquid with high surface tension, readily disperses into small droplets after spills, lodging in cracks and crevices. Resultant increased surface area of the mercury due to this dispersion promotes higher mercury concentrations in the surrounding air. Mercury vapor concentrations are readily measured using commercially available instrumentation. To monitor environmental hazards it is advisable to make periodic checks for mercury content at locations where mercury is exposed to the atmosphere. Use a spill kit for clean-up whenever spillage occurs. After spills and clean-up, make thorough checks for mercury vapor concentrations in the atmosphere.

4.2 *High Voltage*:

4.2.1 **Caution**: Lethal voltages are a potential hazard during the performance of this test. It is essential that the test apparatus, and all associated equipment electrically connected to it, be properly designed and installed for safe operation. Solidly ground all electrically conductive parts which it is possible for a person to contact 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 or have the potential for acquiring an induced charge during the test or retaining a charge even after disconnection of the voltage source. Thoroughly instruct all operators as to the correct procedures for performing tests safely. When making high voltage tests, particularly in compressed gas or in oil, it is possible for the energy released at breakdown to 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. If the potential for fire exists, have fire suppression equipment available. See 20.1, 27.1, 33.1, 42.1, 48.1, 55.1, 65.1, 69.1, and 79.1.

PHYSICAL TESTS OF INSULATIONS AND JACKETS

5. Scope

5.1 Physical tests include determination of the following properties of insulations and jackets:

5.1.1 Thickness,

5.1.2 Tensile strength,

5.1.3 Ultimate elongation,

5.1.4 Accelerated aging,

5.1.5 Effects of oil immersion,

5.1.6 Accelerated water absorption,

5.1.7 Flame test evaluation,

5.1.8 Heat shock,

5.1.9 Heat distortion, and

5.1.10 Cold bend.

6. Significance and Use

6.1 Physical tests, properly interpreted, provide information with regard to the physical properties of the insulation or jacket. The physical test values give an approximation of how the insulation will physically perform in its service life. Physical tests may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

7. Sampling

7.1 *Number of Samples*—Unless otherwise required by the detailed product specification, sample the wire and cable to do the physical tests other than the tests for insulation and jacket thickness, as follows:

7.1.1 *For sizes of less than 250 kcmil (127 mm^2)*—Select one sample for each quantity ordered between 2000 ft (600 m) and 50 000 ft (15 200 m) of wire or cable. Select one additional sample for each additional 50 000 ft thereafter. Do not select a sample from lots of less than 2000 ft.

7.1.2 *For sizes of 250 kcmil (127 mm^2) and over*—Select one sample for each quantity ordered between 1000 ft (300 m) and 25 000 ft (7600 m) of wire or cable. Select one additional sample for each additional 25 000 ft thereafter. Do not select a sample from lots of less than 1000 ft.

7.2 *Size of Samples*—Choose samples at least 6 ft (2 m) in length when the wire size is less than 250 kcmil (127 mm^2). Select a sample at least 3 ft (1 m) in length when the wire size is 250 kcmil or larger.

8. Test Specimens

8.1 *Number of Specimens*—From each of the samples selected in accordance with Section 7, prepare test specimens as follows:

Test	Number of Test Specimens

[8] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

[9] Available from Insulated Cable Eng. Assoc. Inc., P.O. Box 440, South Yarmouth, MA 02664.

[10] The American Conference of Governmental Industrial Hygienists is located at Bldg. D-7, 6500 Glenway Ave., Cincinnati, OH 45211.

For determination of original tensile strength and ultimate elongation	3
For aging test	3
For oil immersion	3

When only one or two samples are selected, test all three specimens of each sample, and report the average result of each. Otherwise, test one specimen of each three and hold the other two specimens in reserve.

8.2 *Size of Specimens*—When testing wire smaller than 6 AWG (13.3 mm^2) which has an insulation thickness less 0.095 in. (2.41 mm), test the entire specimen cut from the section of the insulation. When testing wire of 6 AWG and larger, or wire smaller than 6 AWG having an insulation thickness greater than 0.095 in., cut specimens approximately square in section, with a cross section not greater than 0.025 in.^{2} (1.6 mm^2) from the insulation. In extreme cases, it may be necessary to use a segmented or sector-shaped specimen. Make the test specimens approximately 6 in. (150 mm) long. Take the jacket compound test specimens from the complete wire assembly. Cut the specimens parallel to the axis of the wire. Cut a test specimen (either a segment or sector) with a suitable sharp instrument. Alternatively, use a die to prepare a shaped specimen with a cross-sectional area not greater than 0.025 in.^{2}.

8.3 *Preparation of Specimens*—Prepare specimens having smooth uncut surfaces. Remove irregularities and corrugations by buffing, planing, or skiving so that the test specimen is smooth and uniform in thickness. Remove reinforcing cords or wires carefully. Do not heat, immerse in water, or subject specimens to any mechanical or chemical treatment not specifically prescribed in these test methods. Additional treatments must be agreed upon by the producer and the purchaser.

8.4 Insulation removal is often facilitated by stretching the conductor to the breaking point in a tensile-strength machine, or by cutting the insulation through to the conductor, longitudinally, and carefully removing it. Usually, in the case of insulated tinned conductor, a complete test specimen can be obtained, free from surface incisions and imperfections, by use of mercury. The mercury is introduced at one end of the specimen between the insulation and the tinned surface of the conductor. The specimen is inclined on a support. Introduce the mercury at the top. Amalgamation of the mercury and tin causes the insulation to separate. Amalgamation is aided by immersing and rubbing the tinned wire on the exposed end of the conductor in the mercury. **Caution:** See 4.1.

9. Measurement of Thickness of Specimens

9.1 Make thickness measurements of the insulation with any type of micrometer reading to 0.001 in. (0.025 mm) and suitable for measurements of this characteristic. See Method A or B of Test Methods D 374. The average thickness of the insulation is calculated as one half the difference between the mean of the maximum and minimum diameters over the insulation at one point and the average diameter of the conductor measured at the same point. The minimum thickness of the insulation is calculated as the difference between a measurement made over the conductor plus the thinnest insulation wall, and the diameter of the conductor. (Make the first measurement after slicing off the thicker side of the insulation.) When the wire or cable has a jacket, remove the jacket and determine its minimum and maximum thickness by micrometer measurement. Take the average of these determinations as the average thickness of the jacket.

9.2 If the procedures given in 9.1 cannot be followed conveniently, an optical micrometer may be used.

9.3 *Number of Thickness Measurements*—When the lot of wire to be inspected consists of two or fewer coils or reels, make at least one determination of the thickness on each coil or reel. When the lot is greater than two coils or reels and fewer than 20 coils or reels, make at least one determination of the thickness on each of two coils or reels selected at random. For lots greater than 20 coils or reels, randomly select a minimum of 10 % of the coils or reels. Make at least one determination of thickness on each coil or reel selected.

10. Physical Test Procedures

10.1 Determine the physical properties in accordance with Test Method D 638, except as specified in 10.2, 10.3, and 10.4.

10.2 Test the specimens at a temperature of 68 to 82°F (20 to 28°C).

10.3 Mark specimens for all physical tests with gage marks 1 in. (25 mm) apart. Place a specimen in the jaws of the testing machine. The maximum distance between the jaws is 2 in. (50 mm).

10.4 Test insulation or jacketing at a jaw separation speed as specified in Specification D 1248 or other applicable product specification.

11. Calculation of Area of Specimens

11.1 Calculate the area of a test specimen as follows:

11.1.1 When the total cross section of the insulation is used, calculate the area as the difference between the area of the circle whose diameter is the average outside diameter of the insulation and the area of the conductor. Calculate the area of a stranded conductor from its maximum diameter.

11.1.2 Where the specimen is a slice cut from the insulation by a knife held tangent to the wire, and the resulting cross-section of that slice is not a segment of a circle, calculate the area from a direct measurement of the volume or from the specific gravity and the weight of a known length of the specimen having a uniform cross section.

11.1.3 When a portion of a sector of a circle is taken from a large conductor, calculate the area as the thickness times the width. (This applies either to a die cut specimen or one from which all corrugations have been removed.)

11.1.4 Determine the dimensions of specimens to be aged before the aging cycle is begun.

12. Aging Test

12.1 Age specimens in accordance with Test Method D 573, except as specified in 12.2, 12.3, and 12.4.

12.2 Use an oven that meets the requirements given in Specification D 5423 for Type II ovens.

12.3 The product specification defines the test period and temperature of heat aging.

12.4 Test the tensile strength and ultimate elongation of the specimens between 16 and 96 h after completion of heat aging. Use the procedure described in Section 11. Perform physical tests on both aged and unaged specimens at the same time.

13. Oil Immersion Test

13.1 *Oil Immersion Test for Poly(Vinyl Chloride) Insulation and Jacket*—Immerse the following test specimens in ASTM Oil No. 2, IRM902, or equivalent, described in Table 1 of Test Method D 471, at 158 ± 1.8°F (70 ± 1°C) for 4 h.

13.1.1 When using insulated conductors in sizes smaller than 6 AWG (13.3 mm^2), do not immerse the ends of the specimens.

13.1.2 Buffed die-cut specimens of the insulation in sizes 6 AWG (13.3 mm^2) and larger.

13.1.3 Buffed die-cut specimens of the jacket.

13.2 After a 4 h exposure period to ASTM Oil No. 2, IRM902, or its equivalent, remove the specimens from the oil. Blot specimens to remove excess oil, and condition at room temperature for a period of 16 to 96 h. Determine the tensile strength and elongation at the same time that the original properties are determined.

13.3 *Calculations for Tensile Strength and Measurement of Elongation*—Base the calculations for tensile strength on the cross-sectional area of the specimen obtained before immersion in the oil. Base the calculation for ultimate elongation on the original distance between the gage marks applied to the specimen before immersion in the oil.

14. Retests

14.1 Any specimens that fail to conform to the values specified for any test, either before or after aging, are required to have two additional specimens retested from the same sample. Failure of the retests indicates nonconformity of the sample to the requirement specified.

15. Report

15.1 Report the following information:

15.1.1 Identification of the wire or cable sampled and tested by manufacturer, lot number if applicable, gage, sheath type, reel number, length, etc.,

15.1.2 Identification of the material sampled and tested by how it was used (insulation, jacket, etc.) and by type (for example, polyethylene as specified in Specification D 1248),

15.1.3 Date of testing,

15.1.4 Name and location of testing laboratory and the person responsible for the testing,

15.1.5 Remarks indicating the method or procedure used and the deviation, if any, from the standard procedure,

15.1.6 Indication of the variance in test measurements such as high, low, standard deviation, etc., and

15.1.7 Minimum, maximum, and average values as applicable and any other information that is appropriate to the test being performed.

15.2 The test results shall be reported as calculated or observed values rounded to the nearest unit in the last right hand place of figures used in the wire or cable specification to express the limiting value. (See the rounding method of Practice E 29.)

16. Precision and Bias

16.1 These test methods have been in use for many years. No statement of precision has been made, and no activity is planned to develop such a statement.

16.2 A statement of bias is not possible due to a lack of a standard reference material.

ELECTRICAL TESTS OF INSULATION

17. Significance and Use

17.1 Electrical tests, properly interpreted, provide information with regard to the electrical properties of the insulation. The electrical test values give an indication as to how the insulation will perform under conditions similar to those observed in the tests. Electrical tests may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

18. Types of Voltage Tests

18.1 Perform voltage withstand tests using either alternating or direct current, or both, applied in accordance with Test Methods D 149 and D 3755, and as specified in the following sections. Perform the partial discharge, ac voltage, insulation resistance, and dc voltage tests on entire lengths of completed cable.

19. Order of Testing

19.1 Perform the partial discharge, ac voltage, insulation resistance, and dc voltage tests in that order when any of these tests are required. The sequence of other testing is not specified.

20. Hazards

20.1 These tests involve the use of high voltages. See 4.2.

21. Sampling, Test Specimens, and Test Units

21.1 The specimen is defined in each test method.

AC AND DC VOLTAGE WITHSTAND TESTS

22. Significance and Use

22.1 Voltage withstand tests are useful as an indication that the cable can electrically withstand the intended rated voltage with adequate margin. These tests are normally performed in the factory and are used for product acceptance to specification requirements.

23. Apparatus

23.1 *AC Apparatus*—For ac tests, use a voltage source and a means of measuring the voltage that is in conformance with the voltage source and voltage measurement sections of the apparatus section of Test Method D 149. Use a power supply having a frequency of 49 to 61 Hz.

23.2 *DC Apparatus*—For dc tests, use any source of dc, but if using rectified alternating current, limit the dc ripple to 4 %. Measure the voltage with an electrostatic voltmeter or, in the case of the rectifying equipment, with suitable low-voltage indicators, provided the latter are so connected that their indications are independent of the test load. See Test Method D 3755.

23.3 *Grounded Water Tank*—For tests requiring immersion in water, a metal water tank connected to ground or a tank of other material containing a grounded metal plate or bar is required.

24. Sampling, Test Specimens, and Test Units

24.1 The specimen consists of entire lengths of completed cable.

25. Rate of Voltage Application

25.1 Increase the applied voltage (from zero unless otherwise specified), at a uniform rate, from the initial value to the specified full test voltage within 60 s.

26. Application of Voltage to Cable

26.1 *Cables Without Metallic Sheath, Metallic Shield, or Metallic Armor*:

26.1.1 When single-conductor cables of this type are twisted together into an assembly of two or more conductors without an overall jacket or covering, apply the specified voltage between each conductor and the water. Test such assemblies after immersion for at least 1 h and while still immersed.

26.1.2 Test all other single and multiple conductor cables of this type, after immersion in water for at least 6 h and while still immersed.

26.1.3 Test each conductor against all other conductors connected to the grounded water tank.

26.2 *Cables with Metallic Sheath, Metallic Shield, or Metallic Armor*:

26.2.1 Test all cables of this type with the metallic sheaths, shields, or armors grounded, without immersion in water, at the specified test voltage. For cables having a metallic sheath, shield, or armor over the individual conductor(s), apply the specified test voltage between the conductor and ground. For multiple-conductor cables with nonshielded individual conductors having a metallic sheath, shield, or armor over the cable assembly, apply the specified test voltage between each conductor and all other conductors and ground.

27. Procedure

27.1 **Caution—**These tests involve the use of high voltages. See 4.2.

27.2 Where the insulation on a single-conductor cable or on individual conductors of a multiple-conductor cable is covered with a thermoplastic jacket, either integral or separate from the insulation, or where the insulation is increased for mechanical reasons, determine the test voltage by the size of the conductor and the rated voltage of the cable and not by the apparent thickness of the insulation.

27.3 *AC Tests*:

27.3.1 Test each insulated conductor for 5 min at the ac withstand voltage given in the applicable product specification. This test may be omitted for non-shielded conductors rated up to 5000 V, if the dc withstand voltage test described in 27.4 is to be performed.

27.3.2 Do not apply a starting ac voltage (initial voltage) greater than the rated ac voltage of the cable under test.

27.4 *DC Tests*:

27.4.1 Do not apply a starting dc voltage greater than 3.0 times the rated ac voltage of the cable. The test voltage may be of either polarity.

27.4.2 Upon completion of the insulation resistance test, test each insulated conductor rated for service at 5001 V and above for 15 min at the dc withstand voltage given in the applicable product specification.

27.4.3 For cables rated up to 5000 V, upon completion of the insulation resistance test, test each insulated conductor without shielding over the insulation for 5 min at the dc withstand voltage given in the applicable product specification, unless the ac withstand voltage test described in 27.3 was performed.

28. Report

28.1 Report the following information:

28.1.1 Manufacturer's name,

28.1.2 Manufacturer's lot number, if applicable,

28.1.3 Description of the cable construction,

28.1.4 Voltage and time of application,

28.1.5 Whether or not the cable was immersed in water, and

28.1.6 Whether or not the cable withstood the required voltage for the specified time.

29. Precision and Bias

29.1 No statement is made about either the precision or bias of this test since the result merely states whether there is conformance to the criteria for success specified in the procedure.

INSULATION RESISTANCE TESTS ON COMPLETED CABLE

30. Significance and Use

30.1 The insulation resistance of a cable is primarily a measurement of the volume resistance of the insulating material, although surface resistance across the ends can be significant for short specimens or when atmospheric humidity is high. It is usually desirable for a cable to have a high value of insulation resistance. This test is used for product acceptance to specification requirements, but can also be useful for quality control purposes in indicating consistency of manufacture. See Test Methods D 257 for a more complete discussion of the significance of insulation resistance tests.

31. Apparatus

31.1 *Megohm Bridge*—Use a megohm bridge capable of supplying a constant dc potential from 100 to 500 V. See Test Methods D 257.

32. Sampling, Test Specimens, and Test Units

32.1 The specimen consists of entire lengths of completed cable.

33. Procedure

33.1 **Caution—**This test involves the use of high voltages. See 4.2.

33.2 Unless otherwise specified in the product specification:

33.2.1 Perform this test only after performing the completed cable ac voltage tests as specified in 27.3.

33.2.2 Perform this test only before performing the completed cable dc voltage tests as specified in 27.4.

33.2.3 Perform this test in accordance with Test Methods D 257, and as follows:

33.2.3.1 Where the voltage tests are made on wire and cable immersed in water, measure the insulation resistance while the cable is still immersed.

33.3 *Testing*:

33.3.1 For single conductor cables test between the conductor and its metallic sheath or between the conductor and surrounding water.

33.3.2 *Multiple-Conductor Cables*:

33.3.2.1 For cables with unshielded conductors, test between each conductor and all other conductors, and between each conductor and the overall sheath or surrounding water.

33.3.2.2 For cables having shielded conductors, test between each conductor and its shield.

33.3.3 Connect the conductor of the specimen under test to the negative terminal of the test equipment, and take readings after an electrification of 1 min. On short sections of wire or cable, use a guard circuit to prevent end leakage. Maintain the temperature of the water between 50° and 85°F (10° and 30°C).

33.3.4 When the length of cable under test differs from 1000 ft (305 m), correct the measured value of insulation resistance to MΩ-1000 ft by multiplying by the ratio $L/1000$ (or $L/305$) where L is the length in feet (or metres).

34. Calculation

34.1 Calculate the minimum insulation resistance in MΩ-1000 ft (305 m) at a temperature of 60°F (15.6°C) for each coil, reel, or length of wire or cable as follows:

$$R = K \log_{10} (D/d) \quad (1)$$

where:
R = minimum insulation resistance, MΩ-1000 ft (305 m),
K = constant for the grade of insulation, (see 34.1.1),
D = diameter over the insulation, and
d = diameter under the insulation.

34.1.1 Obtain the constant K, for the type of insulation in the cable under test, by reference to the product specification.

34.1.2 Where a nonconducting separator is applied between the conductor and the insulation, or where an insulated conductor is covered with a nonmetallic jacket, the insulation resistance shall be at least 60 % of that required for the primary insulation based on the thickness of that insulation.

34.2 The insulation resistance of wires and cables varies widely with temperature. If the temperature at the time measurement was made differs from 60°F (15.6°C), adjust the resistance to that at 60°F by multiplying the measured value by the proper correction factor from Table 1. Use the coefficient furnished by the manufacturer for the particular insulation and temperature or determine it in accordance with Section 35.

35. Determining Temperature Coefficients for Insulation Resistance

35.1 Select three specimens, preferably of 14 AWG (2.08 mm^2) solid wire with a 0.045-in. (1.14-mm) wall of insulation, as representative of the insulation under consideration. Use sufficient length to yield insulation resistance values under 25 000 MΩ at the lowest water bath temperature.

TABLE 1 Temperature Correction Factors for Insulation Resistance at 60°F

Temperature		Coefficient for 1°F									
°F	°C	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12
50	10.0	0.75	0.68	0.62	0.56	0.51	0.46	0.42	0.38	0.35	0.32
51	10.6	0.77	0.70	0.65	0.59	0.54	0.50	0.46	0.42	0.39	0.36
52	11.1	0.79	0.73	0.68	0.63	0.58	0.54	0.50	0.47	0.43	0.40
53	11.7	0.82	0.76	0.71	0.67	0.62	0.58	0.55	0.51	0.48	0.45
54	12.2	0.84	0.79	0.75	0.70	0.67	0.63	0.60	0.56	0.54	0.51
55	12.8	0.87	0.82	0.78	0.75	0.71	0.68	0.65	0.62	0.60	0.57
56	13.3	0.89	0.86	0.82	0.76	0.76	0.74	0.71	0.69	0.66	0.64
57	13.6	0.92	0.89	0.87	0.84	0.82	0.80	0.78	0.76	0.73	0.71
58	14.4	0.94	0.93	0.91	0.90	0.88	0.86	0.85	0.83	0.82	0.80
59	15.0	0.97	0.96	0.96	0.95	0.94	0.93	0.92	0.91	0.90	0.89
60	15.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
61	16.1	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10	1.11	1.12
62	16.7	1.06	1.08	1.10	1.13	1.15	1.17	1.19	1.21	1.24	1.27
63	17.2	1.09	1.13	1.16	1.19	1.23	1.26	1.30	1.34	1.38	1.42
64	17.8	1.13	1.17	1.22	1.26	1.31	1.36	1.41	1.47	1.53	1.58
65	18.3	1.16	1.22	1.28	1.34	1.40	1.47	1.54	1.62	1.70	1.78
66	18.9	1.20	1.27	1.35	1.42	1.50	1.59	1.69	1.78	1.88	1.98
67	19.4	1.23	1.32	1.41	1.51	1.62	1.72	1.84	1.96	2.09	2.21
68	20.0	1.27	1.37	1.48	1.60	1.72	1.86	1.99	2.15	2.31	2.48
69	20.6	1.31	1.43	1.55	1.69	1.84	2.00	2.18	2.36	2.57	2.77
70	21.1	1.35	1.48	1.63	1.79	1.97	2.17	2.38	2.60	2.85	3.10
71	21.7	1.39	1.54	1.72	1.90	2.11	2.34	2.59	2.87	3.17	3.48
72	22.2	1.43	1.60	1.80	2.02	2.26	2.53	2.82	3.15	3.52	3.90
73	22.8	1.47	1.67	1.89	2.14	2.42	2.72	3.08	3.46	3.90	4.37
74	23.3	1.52	1.74	1.98	2.27	2.58	2.94	3.35	3.81	4.31	4.88
75	23.9	1.56	1.80	2.08	2.40	2.76	3.18	3.65	4.19	4.78	5.47
76	24.4	1.61	1.87	2.19	2.54	2.96	3.43	3.98	4.61	5.30	6.12
77	25.0	1.66	1.95	2.30	2.70	3.17	3.70	4.34	5.08	5.88	6.85
78	25.6	1.71	2.02	2.41	2.86	3.39	4.00	4.78	5.59	6.51	7.68
79	26.1	1.76	2.11	2.53	3.03	3.62	4.33	5.16	6.14	7.27	8.59
80	26.7	1.81	2.19	2.66	3.21	3.87	4.67	5.61	6.72	8.07	9.65
81	27.2	1.87	2.28	2.80	3.40	4.15	5.04	6.12	7.43	8.98	10.8
82	27.8	1.92	2.37	2.94	3.60	4.43	5.45	6.69	8.18	9.92	12.1
83	28.3	1.98	2.47	3.08	3.82	4.73	5.89	7.28	9.00	11.0	13.6
84	28.9	2.04	2.57	3.23	4.05	5.04	6.35	7.92	9.90	12.2	15.2
85	29.4	2.10	2.67	3.40	4.30	5.42	6.84	8.67	10.8	13.5	17.0

35.2 Immerse the three specimens in a water bath equipped with heating, cooling, and circulating facilities, with the ends of the specimens extended 2 ft (0.6 m) above the surface of the water and properly prepared for minimum leakage. Leave the specimens in the water at room temperature for 16 h before adjusting the bath temperature to 10°C, or transfer the samples to a 10°C test temperature bath.

35.3 Measure the resistance of the conductor at suitable intervals of time until it remains unchanged for at least 5 min. The insulation will then be at the temperature of the bath as read on the bath thermometer. Take insulation resistance readings in accordance with Sections 33 and 34.

35.4 Expose the three specimens to successive water-bath temperatures of 10, 16, 22, 28, and 35°C, returning to 28, 22, 16, and 10°C. Take insulation resistance readings at each temperature after equilibrium is established. Average all the readings taken at each temperature.

35.5 Using semi-log paper (log R versus T), plot the average readings obtained in 35.4.

35.6 *Calculations*:

35.6.1 Using the semi-log plot from 35.5, determine the insulation resistance at 60°F (15.6°C) and at 61°F (16.1°C). Obtain the 1°F coefficient per degree by dividing the insulation resistance at 60°F by the insulation resistance at 61°F.

35.6.2 If a more precise value is desired for the 1°F coefficient per degree, subject the numerical values used in 35.5 to regression analysis in order to determine the parameters of the best fitting curve. The slope parameter is related to the 1°F coefficient per degree.

36. Report

36.1 Report the following information:

36.1.1 Manufacturer's name,

36.1.2 Manufacturer's lot number, if applicable,

36.1.3 Description of the cable construction,

36.1.4 Specimen length,

36.1.5 Whether or not a guard circuit was used,

36.1.6 Whether or not the cable was immersed in water,

36.1.7 Test temperature (air or water as applicable),

36.1.8 Measured value for insulation resistance,

36.1.9 Computed value for insulation resistance, and

36.1.10 1°F coefficient, if used.

37. Precision and Bias

37.1 This test method has been in use for many years, but no statement of precision has been made and no activity is planned to develop such a statement.

37.2 A statement of bias is not possible since the test result is determined solely by this test method.

PARTIAL-DISCHARGE EXTINCTION LEVEL TEST

38. Scope

38.1 This test applies to the detection and measurement of partial discharges occurring in the following types of electric cables:

38.1.1 Single-conductor shielded cables and assemblies thereof, and

38.1.2 Multiple-conductor cables with individually shielded conductors.

39. Significance and Use

39.1 Measurement of the partial-discharge extinction voltage provides useful information regarding the possibility of discharges at a cable's operating voltage. This measurement may contribute to a knowledge of the expected life of the cable since the presence of partial-discharges frequently results in significant reductions in life. Some materials are more susceptible to such discharge damage than others. The partial-discharge extinction level is useful for quality control purposes, and this test is also used for product acceptance to specification requirements.

40. Apparatus

40.1 See ICEA T-24-380 for a description of the required apparatus.

41. Sampling, Test Specimens, and Test Units

41.1 The specimen consists of entire lengths of completed cable.

42. Procedure

42.1 **Caution—**This test involves the use of high voltages. See 4.2.

42.2 Prior to the ac voltage test, perform the partial-discharge test in accordance with ICEA T-24-380 except as modified in the following sections.

42.3 Apply an ac test voltage between the conductor and the metallic component of the insulation shield. Increase the applied voltage sufficiently to indicate detector response to partial-discharge, but do not exceed the ac test voltage given in the applicable product specification. Then lower the voltage at a rate not greater than 2000 V/s to determine the partial-discharge extinction level (see 42.4).

42.4 The partial-discharge extinction level is that voltage at which the apparent charge transfer falls to 5 pC or less.

42.5 If the existence of discharges is not evident after the voltage has been raised to a value 20 % above the specified minimum extinction value, the cable shall be considered to have met the requirements for this test.

42.6 Do not maintain the applied voltage for more than 3 min during any single test.

43. Report

43.1 Report the following information:

43.1.1 Manufacturer's name,

43.1.2 Manufacturer's lot number, if applicable,

43.1.3 Description of the cable construction,

43.1.4 Partial-discharge extinction voltage,

43.1.5 Whether or not discharges are evident at a voltage which is 20 % higher than the specified minimum extinction value, and

43.1.6 Method of end preparation.

44. Precision and Bias

44.1 This test method has been in use for many years, but no statement of precision has been made and no activity is planned to develop such a statement.

44.2 A statement of bias is not possible since the test result is determined solely by this test method.

DIELECTRIC STRENGTH RETENTION TEST OF POLY(VINYL CHLORIDE) INSULATIONS

45. Significance and Use

45.1 Measurement of the dielectric strength retention of poly(vinyl chloride) insulations is a way of determining the suitability of the insulation to perform in wet environments by observing the effect of water absorption on the dielectric strength of the insulation.

46. Apparatus

46.1 See 23.1.

47. Sampling, Test Specimens, and Test Units

47.1 Select twenty specimens, preferably of AWG 14 (2.08 mm^2), solid or stranded, with a 0.045 in. (1.14 mm) wall of insulation, each at least 5 ft (1.5 m) long and, cut from a reel or coil chosen at random. When this test is specified, specimens of this length shall be available for test for an inspection lot of cable, regardless of the conductor size of the lot.

48. Procedure

48.1 **Caution**—This test involves the use of high voltages. See 4.2.

48.2 *Immersion of Specimens*:

48.2.1 Immerse ten identified specimens in tap water for 14 days. Maintain the temperature of the water at 50 ± 1°C, 75 ± 1°C, or 90 ± 1°C as specified in the applicable insulation specification.

48.2.2 At the end of 14 days, remove the ten identified specimens from the tap water. Immediately immerse all 20 specimens for 1 h in tap water stabilized at 20 to 30°C. Immerse at least 3 ft (0.9 m) of each specimen, except for the ends.

48.3 *After Immersion of Specimens*:

48.3.1 When the 20 specimens have been immersed in accordance with 48.2.2, apply an ac test voltage between the conductor and surrounding water, starting at zero and increasing at the rate of 500 V/s until breakdown occurs.

49. Calculation

49.1 Calculate the dielectric strength retention as follows:

$$\text{Dielectric strength retention, \%} = (B/A) \times 100 \qquad (2)$$

where:

B = average breakdown voltage of the ten specimens immersed for 14 days at the specified temperature, and

A = average breakdown voltage of the ten specimens not immersed for 14 days at the specified temperature.

50. Report

50.1 Report the following information:

50.1.1 Manufacturer's name,

50.1.2 Manufacturer's lot number, if applicable,

50.1.3 Conductor size,

50.1.4 Conductor stranding,

50.1.5 Average breakdown voltage of specimens not immersed,

50.1.6 Average breakdown voltage of specimens immersed, and

50.1.7 Percent dielectric strength retention.

51. Precision and Bias

51.1 This test method has been in use for many years, but no statement of precision has been made and no activity is planned to develop such a statement.

51.2 A statement of bias is not possible since the test result is determined solely by this test method.

ACCELERATED WATER ABSORPTION TEST

52. Significance and Use

52.1 Water absorption tests, properly interpreted, provide information about the water absorption properties of the insulation. They may indicate the surface condition of the insulation. The water absorption values may indicate how the insulation will perform in a wet environment. Water absorption tests may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

52.2 The gravimetric method may give inaccurate results in tests of compounds containing volatile components. Some of these may evolve during drying.

Electrical Method

53. Apparatus

53.1 *Water Tank*—An electrically isolated water tank of sufficient length to contain a 10 ft length of cable. The tank contains a heater of sufficient capacity to maintain the specified water temperature. The tank has a tightly fitting cover placed directly above the water surface, with suitable water-tight bushings for the ends of the specimen.

53.2 *Capacitance Bridge*—See Test Methods D 150 for apparatus for measuring capacitance.

54. Test Specimen

54.1 Dry a 15-ft (4.6-m) test specimen of the insulated wire for 24 h in air at 70°C. Cool in air to approximately 50°C before immersion in water.

55. Procedure

55.1 **Caution**—This test involves the use of high voltages. See 4.2.

55.2 *Immersion of Specimen*—Immerse the middle 10 ft (3.05 m) of the test specimen in tap water for 14 days. Keep 2.5 ft (0.76 m) of each end above water as leakage insulation. Maintain the water temperature at 50 ± 1°C, 75 ± 1°C, or 90 ± 1°C as specified in the applicable insulation specification. Keep the water level constant.

55.3 *Capacitance Measurements at 60 Hz*—Using the apparatus as described in Test Methods D 150, determine the capacitance of the insulation at an average stress of 80 V/mil (3.2 kV/mm) at a frequency of approximately 60 Hz after 1, 7, and 14 days' immersion. Express the increase in capacitance from 1 to 14 days and from 7 to 14 days as a percentage of the 1 and 7-day values, respectively.

56. Report

56.1 Report the following information:

56.1.1 Manufacturer's name,

56.1.2 Manufacturer's lot number, if applicable,

56.1.3 The temperature of the water,

56.1.4 The size of the conductor,

56.1.5 The type and thickness of the insulation,

56.1.6 The capacitance values after 1, 7, and 14 days,

56.1.7 The increase in capacitance from 1 to 14 days as a percentage of the 1-day value, and

56.1.8 The increase in capacitance from 7 to 14 days as a percentage of the 7-day value.

57. Precision and Bias

57.1 This test method has been in use for many years. No statement of precision has been made, and no activity is planned to develop such a statement.

57.2 A statement of bias is not possible due to a lack of a standard reference material.

Gravimetric Method

58. Test Specimen

58.1 Use an 11-in. (280-mm) test specimen of the insulated conductor, with all coverings removed, for the test, unless the test specimen weighs more than 100 g. For heavier specimens, cut a 4 in. (100 mm) long segment of suitable width from the insulation. Buff to remove all corrugations.

59. Procedure

59.1 *Preparation of Specimen*—Clean the surface of the test specimen by scrubbing with a lintless cloth moistened with water. Dry the specimen for 48 h in a vacuum of 5 mm of mercury or less over calcium chloride at 70 ± 2°C. Cool in a dessicator to room temperature. Weigh the specimen to the nearest 1 mg. Designate this weight as *A*. Calculate the area of the insulation on the 10-in. length of wire or the area of the 4-in. segment of the insulation in square inches (square centimetres) and designate this value as *S*. Bend the insulated wire in the shape of *U* around the mandrel not less than three times the diameter of the specimen. Insert the ends in tight-fitting holes in the cover of the immersion vessel so that 10 in. of the specimen is immersed when the vessel is completely filled with water and the cover applied. The composition of the immersion vessel is stainless steel, or vitreous-enameled steel.

59.2 *Immersion of Specimen*—Immerse the test specimen in freshly boiled distilled water at a temperature of 70 ± 1°C or 82 ± 1°C, as specified in the applicable insulation specification. Continue the immersion for a period of 168 h. Maintain the level of the water flush with the undersurface of the cover during the immersion period. Completely submerge the segment-shaped specimen. After submersion for 168 h, cool the water to room temperature. Then remove the specimen and shake off the adhering water. Blot the specimen lightly with a lintless cloth and within 3 min weigh to the nearest 1 mg, and designate this as weight *B*. Dry the specimen for 48 h in a vacuum of 5 mm of mercury or less over calcium chloride at 70 ± 2°C. Cool in a dessicator to room temperature. Weigh the specimen to the nearest 1 mg and designate this as *C*.

60. Calculation

60.1 Calculate all results in terms of milligrams per square inch (or square centimetre) of surface as follows:

$$\text{Water absorption (if } C \text{ is less than } A) = (B - C)/S \quad (3)$$

$$\text{Water absorption (if } C \text{ is greater than } A) = (B - A)/S \quad (4)$$

$$\text{Water−soluble matter (if } C \text{ is less than } A = (A - C)/S \quad (5)$$

where:

A = weight of the specimen, mg, before submersion,
B = weight of the specimen, mg, after submersion,
C = constant weight of the specimen, mg, after drying in vacuum, and
S = total area, in.^{2}(or cm^2), of the segment of insulated wire used.

61. Report

61.1 Report the following information:

61.1.1 Manufacturer's name,

61.1.2 Manufacturer's lot number, if applicable,

61.1.3 Description of the specimen,

61.1.4 The total area of the specimen,

61.1.5 The weight of the specimen in mg, before submersion,

61.1.6 The weight of the specimen in mg, after submersion,

61.1.7 The constant weight of the specimen, and

61.1.8 The water absorption in mg per in.^{2} of specimen surface area.

62. Precision and Bias

62.1 This test method has been in use for many years. No statement of precision has been made, and no activity is planned to develop such a statement.

62.2 A statement of bias is not possible since the test result is determined solely by this test method.

63. Vertical Flame Test

63.1 *Scope*:

63.1.1 This flame test is applicable to wire sizes less than 0.25 in. (6.4 mm) in outside diameter. Tests on larger wires are less reproducible.

63.1.2 *This standard should be used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions and should not be used to describe or appraise the fire-hazard or fire-risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire-hazard assessment or a fire-risk assessment which take into account all of the factors which are pertinent to an assessment of the fire hazard or fire risk of a particular end use.*

63.2 *Significance*:

63.2.1 The vertical flame test may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

63.3 *Apparatus*:

63.3.1 Construct the test chamber of sheet metal, 12 in. (300 mm) in width, 14 in. (350 mm) in depth, 24 in. (600 mm) in height, and open at the top. Construct the test chamber with a closable front door, hinged or sliding, with a glass window for observing the flame application, which provides a draft restricted, four-sided enclosure when the door is closed. Make three circular draft holes located in a row, parallel to the lower edge of each of the two side panels. Make these draft holes approximately 1 in. (25 mm) above the bottom surface of the chamber and 1.13 in. (29 mm) in diameter. Construct draft holes free of obstructions to air flow.

63.3.2 *Means for Holding Test Specimen Taut* in a vertical position. Provide the test chamber with screws or tension clamps for securing the specimen at the upper and lower ends, approximately centered in the chamber. Use a compact lower clamp designed to afford minimal interference with flaming or dripping particles flowing or falling downward along the vertical wire during the flame test. The lower clamp must not prevent downward flowing or dropping material from direct contact with the cotton layer at the bottom of the chamber.

63.3.3 On a 20° angle block mount a burner meeting the requirements of Specification D 5025 and having the flame calibrated in accordance with Practice D 5207.

63.3.4 *Steel Angle (Jig)*, adjustable, attached to the bottom of the chamber to ensure the correct location of the burner with relation to the test specimen.

63.3.5 Use a supply of 99.97 % methane at a pressure of 4 to 6 in. of water (1 to 1.5 kPa).

63.3.6 *Timing Device*, calibrated in seconds.

63.3.7 *Flame Indicators*, which consist of strips of gummed kraft paper 0.005 in. (0.127 mm) in nominal thickness and 0.5 in. (12.7 mm) in width. The paper used for the indicators is that known to the trade as 60-lb stock, and is material substantially the same as that described in Federal Specification PPP-T-45D.

63.3.8 *Surgical Grade Cotton*, dry.

63.4 *Procedure*:

63.4.1 Make the test in a room generally free from drafts of air, although a ventilated hood may be used if air currents do not affect the test flame. Clamp the test specimen of wire, approximately 22 in. (560 mm) in length, perpendicular and taut. Apply a paper indicator to the specimen so that the lower edge is 10 in. (254 mm) above the point at which the extended axis of the burner stem, with the burner properly spaced, intersects the specimen surface. Wrap the indicator once around the specimen, with the gummed side toward the conductor and the ends pasted evenly together and projecting 0.75 in. (19 mm) from the wire on the opposite side of the specimen to which the test flame is to be applied. Moisten the gummed surface of the paper tab only to the extent that will permit proper adhesion. A layer of cotton is positioned at the lower end of the wire specimen, approximately centered on the axis of the specimen, with the upper surface of the layer no more than 9.5 in. (241 mm) below the point of impingement of the test flame. Make the area of the cotton large enough to encompass any dripping particles, but not so large that the cotton obstructs free air-flow through the chamber draft holes. Place the burner, with only the pilot lighted, in front of the specimen so that the vertical plane through the stem of the burner includes the axis of the wire. Rest the angle block against the jig, which is adjusted so that there is a distance of 1.75 to 1.88 in. (44 to 48 mm) along the axis of the burner stem, between the tip of the stem and the surface of the test specimen. Adjust the tip of the inner cone of the flame so it is between 0.25 and 0.375 in. (6.4 and 9.5 mm) back from the surface of the test specimen. Open the valve supplying the gas to the burner proper thereby applying the flame to the specimen. Hold this valve open for 15 s, and then close it for 15 s. Repeat this process four times. By definition the wire conveys flame if more than 25 % of the extended portion of the flame indicator is burned after the five applications of the flame or if any particles or drops that fall from the specimen at any time during the test or within 30 s after the final application of the gas flame ignite the cotton.

63.5 *Report*:

63.5.1 Report the following information:

63.5.1.1 Manufacturer's name,

63.5.1.2 Manufacturer's lot number, if applicable,

63.5.1.3 Description of specimen,

63.5.1.4 Number of applications of flame if failure occurs before five applications,

63.5.1.5 Percent of flame indicator burned, and

63.5.1.6 If the cotton did or did not ignite.

63.6 *Precision and Bias*:

63.6.1 This test method has been in use for many years, but no statement of precision has been made, and no activity is planned to develop such a statement.

63.6.2 A statement of bias is not possible due to a lack of a standard reference material.

SURFACE RESISTIVITY TEST

64. Significance and Use

64.1 Surface resistivity tests, properly interpreted, provide information about insulation performance in situations similar to those described in the tests. These tests may be used to provide data for research and development, design engineering, quality control, and acceptance or rejection under specifications.

65. Procedure

65.1 **Caution—**These tests involve high voltages. See 4.2.

65.2 This test is intended to be applied to single-conductor nonshielded power cable rated 2001 to 5000 V phase to phase. Subject polyethylene insulation, polyethylene jacket, and poly-(vinyl chloride) jacket to the following test:

65.3 Immerse a specimen of cable of suitable length, except for the ends, in water at room temperature for 48 h. After conditioning, remove the specimen from the water. Wipe off the excess surface moisture with blotting paper and condition the specimen at room temperature for 10 min. Wind two 1-in. (25-mm) wide foil electrodes around the cable surface with 6-in. (152-mm) spacing between the foil strips. Apply a 250 to 500-V dc potential between the two electrodes. Measure the resistance by a suitable instrument in accordance with Test Methods D 257. Calculate the surface resistivity as follows:

$$P = 0.524\ RD \tag{6}$$

where:

P = surface resistivity,
R = surface resistance, MΩ/6-in. (152-mm) spacing, and
D = cable diameter, in. (or mm).

66. Report

66.1 Report the following information:

66.1.1 Manufacturer's name,

66.1.2 Manufacturer's lot number, if applicable, and

66.1.3 The value of the surface resistivity.

67. Precision and Bias

67.1 This test method has been in use for many years. No statement of precision has been made, and no activity is planned to develop such a statement.

67.2 A statement of bias is not possible since the test result is determined solely by this test method.

U-BEND DISCHARGE TEST

68. Significance and Use

68.1 U-bend discharge tests, properly interpreted, provide information about insulation performance in situations similar to those described in the tests. These tests may be used to provide data for research and development, design engineering, quality control, and acceptance or rejection under specifications.

69. Procedure

69.1 **Caution**—These tests involve high voltages. See 4.2.

69.2 This test is intended to be applied to single-conductor nonshielded power cable rated 2001 to 5000 V phase to phase. Subject polyethylene insulation, polyethylene jacket, and poly-(vinyl chloride) jacket to the following test:

69.3 Bend a specimen of the completed cable in the form of a U, 180° around a mandrel having a diameter specified in Table 2. Mount the specimen with the apex of the U above and in contact with a smooth metal plate. The legs of the U are perpendicular to the plate. Condition the cable in this position a minimum of 30 and a maximum of 45 min. Apply a 60-Hz ac potential between the conductor and the metal plate. Apply the specified voltage potential or use 125 V/mil (4.9 kV/mm) of nominal conductor insulation thickness. Maintain this potential continuously for at least 6 h or until failure occurs. Conduct this test at a temperature between 20 and 30°C (68 and 86°F).

70. Report

70.1 Report the following information:

70.1.1 Manufacturer's name,

70.1.2 Manufacturer's lot number, if applicable, and

70.1.3 Whether the cable withstood the required voltage for the specified time.

71. Precision and Bias

71.1 This test method has been in use for many years. No statement of precision has been made, and no activity is planned to develop such a statement.

TABLE 2 Mandrel Requirements for U-bend Discharge Test

Conductor Size, AWG or kcmil (mm^2)	Diameter of Mandrel as a Multiple of the Outside Diameter of Cable
8 (8.37) to 2 (33.6)	6
1 (42.4) to 3/0 (85.0)	8
4/0 (107) to 500 (253)	10
Over 500 (253)	12

71.2 A statement of bias is not possible since the test result is determined solely by this test method.

THERMAL TESTS

72. Significance and Use

72.1 Thermal tests, properly interpreted, provide information about insulation performance when flexed or subjected to pressure under extremes of temperature. Thermal tests may provide data for research and development, engineering design, quality control, and acceptance or rejection under specifications.

73. Heat Shock Test on Poly(Vinyl Chloride) Insulation and Jacket Compounds

73.1 *Procedure*:

73.1.1 Wind a specimen of the finished wire tightly around a mandrel having a diameter as specified in Table 3 for single-conductor insulated wire. Use a mandrel diameter as specified in Table 4 for jacketed cable. Secure the specimen firmly in place and, while still on the mandrel, place in an oven at 121 ± 1°C for 1 h. Upon removal from the oven, examine the specimen for external or internal cracking. Internal cracking is evidenced by slight depressions in the outer surface.

73.2 *Report*:

73.2.1 Report the following information:

73.2.1.1 Manufacturer's name,

73.2.1.2 Manufacturer's lot number, if applicable,

73.2.1.3 Description of specimen,

73.2.1.4 Mandrel size,

73.2.1.5 Presence or absence of cracks, and

73.2.1.6 Type of cracks (internal or external).

74. Heat Distortion Test

74.1 *Specimen for Poly(Vinyl Chloride) Insulation on Conductors of Sizes AWG 4/0 (107 mm^2) and Smaller*—Measure the diameter of a 1 in. (25.4 mm) length of the insulated conductor with a micrometer caliper that has a flat surface on both the anvil and spindle. Remove the insulation and measure the diameter of the uninsulated conductor. Calculate the original thickness of the insulation, T_1, as follows:

$$T_1 = (D - C)/2 \quad (7)$$

TABLE 3 Mandrel Sizes for Heat Shock Test of Single-Conductor Insulated Wire and Cable

Conductor Size, AWG or kcmil (mm^2)	Number of Adjacent Turns	Mandrel Size, Multiply Outside Diameter of Insulated Wire by
8 (8.37) and under	6	1
6 (13.3) to 2 (33.6)	6	2
1 (42.4)	1	2
0 (53.5) to 4/0 (107)	½ (180° U-bend)	2
250 (127) and larger	½ (180° U-bend)	5
Series lighting cable, sizes 8 (8.37), 6 (13.3), and 4 (21.2)	6	2

TABLE 4 Mandrel Sizes for Heat Shock Test of Jacketed Cable

Outside Diameter of Wire or Cable, in. (mm)	Number of Adjacent Turns	Mandrel Size, Multiply Outside Diameter of Cable by
0 to 0.750 (0 to 19.0) incl	6	3
0.751 to 1.500 (19.1 to 38.0) incl	½ (180° U-bend)	8
1.501 (38.0) and larger	½ (180° U-bend)	12

where:
T_1 = original thickness of the insulation,
D = initial diameter of the insulated conductor, and
C = diameter of the uninsulated conductor.

74.2 *Specimens for Poly(Vinyl Chloride) Insulation on Conductors of Sizes Larger than AWG 4/0 107 mm² and Poly(Vinyl Chloride) and Polyethylene Jackets*—Prepare a smooth sample approximately 8-in. (200-mm) long, trimmed, or buffed to a thickness of 0.05 ± 0.01 in. (1.3 ± 0.25 mm). Use this sample to prepare test specimens 1 in. (25.4 mm) long and 9⁄16 ± 1⁄16 in. (14.3 ± 1.6 mm) wide. Where the diameter of the cable does not permit the preparation of a specimen 9⁄16 in. wide, use a molded sheet of the same compound. Measure the thickness of the specimen, T_1, with a Randall and Stickney, or equivalent gage having a 3⁄8 in. (9.50 mm) foot with no loading other than the 85 g of the gage.

74.3 *Procedure*—Using the specified load indicated in Table 5 place the gage with the specimen beside it in an oven preheated to the specified temperature. Refer to the material specification for the correct temperature. Allow both the gage and the test specimen to remain in the oven for 1 h. After the 1-h conditioning period, place the specimen directly under the foot of the gage. Allow both to remain in the oven under load for 1 h at the specified temperature. After the 1 h test period, read the gage while the specimen is stressed (if necessary, open the door) for:

74.3.1 The value of F for insulated conductors AWG 4/0 (107 mm²) and smaller, and calculate the thickness of the insulation, T_2, as follows:

$$T_2 = (F - C)/2 \quad (8)$$

where:
T_2 = thickness of the insulation after the heat distortion test,
F = final outside diameter as read from the gage, and
C = diameter of the uninsulated conductor.

74.3.2 The value of T_2 for insulated conductors larger than AWG 4/0 (107 mm²) and jackets.

TABLE 5 Gage Loads for Heat Distortion Test

	Load on Gage, g
Poly(vinyl chloride) insulated conductor size, AWG (mm²)	
18 (0.823)	300
16 (1.31)	400
14 (2.08) to 8 (8.37)	500
6 (13.3) to 1 (42.4)	750
1/0 (53.5) to 4/0 (107)	1000
Poly(vinyl chloride) insulated conductors larger than AWG 4/0 (107 mm²) and all poly(vinyl chloride) and polyethylene jackets, buffed samples	2000
Poly(vinyl chloride) insulated series lighting cables, all sizes	1000

74.4 *Calculation*—Calculate the distortion as follows:

$$\text{Distortion, \%} = [(T_1 - T_2)/T_1] \times 100 \quad (9)$$

74.5 *Report*—Report the following information:
74.5.1 Manufacturer's name,
74.5.2 Manufacturer's lot number, if applicable,
74.5.3 Description of specimen,
74.5.4 Load on the gage, and
74.5.5 Percent distortion.

75. Cold Bend Tests

75.1 *Poly(Vinyl Chloride) and Polyethylene Insulations*—A sample of insulation is conditioned at a specified temperature for 1 h. Immediately after removal from the cooling chamber, wind the insulated conductor around a mandrel for at least 6 adjacent turns for sizes 3/0 AWG (85.0 mm) or smaller. Sizes larger than 3/0 AWG are immediately bent around a mandrel. The mandrel diameter is specified in Table 6 and Table 7. Bend the insulated conductor at a uniform rate to complete the test in one minute or less. Acceptable insulation must be free of cracking when examined without magnification.

75.2 *Poly(Vinyl Chloride) Jackets*—Condition the finished cable at the specified temperature for 1 h in the cold chamber. Immediately after removing the cable, bend it 180° around a mandrel. The mandrel diameter is specified in Table 8. Acceptable jacket must be free of cracking when examined without magnification.

76. Report

76.1 Report the following information:
76.1.1 Manufacturer's name,
76.1.2 Manufacturer's lot number, if applicable,
76.1.3 Description of specimen,
76.1.4 Diameter of mandrel, and
76.1.5 Presence or absence of cracks.

77. Precision and Bias

77.1 These test methods have been in use for many years. No statement of precision has been made, and no activity is planned to develop such a statement.

TABLE 6 Mandrel Requirements for Poly(Vinyl Chloride) Insulated Conductors

Conductor Size, AWG or kcmil (mm²)	Diameter of Mandrel, in. (mm)	Number of Turns
18 (0.823)	5⁄16 (7.9)	6
16 (1.31)	5⁄16 (7.9)	6
14 (2.08)	½ (12.7)	6
12 (3.31)	9⁄16 (14.3)	6
10 (5.261)	5⁄8 (15.9)	6
8 (8.37)	¾ (19.0)	6
6 (13.3)	1¼ (32.0)	6
4 (21.2)	1⅜ (35.0)	6
2 (33.6)	1 9⁄16 (40.0)	6
1 (43.2)	2 11⁄16 (68.0)	6
1⁄0(53.5)	2⅞ (73.0)	6
2⁄0(67.4)	3 (76.0)	6
3⁄0(85.0)	3¼ (83.0)	6
4⁄0(107)	3½ (89.0)	½ (180° U-bend)
250 (127) to 500 (253)	8 × cable diameter	½ (180° U-bend)
Over 500 (253)	10 × cable diameter	½ (180° U-bend)
Series lighting cable all sizes	5 × cable diameter	½ (180° U-bend)

TABLE 7 Mandrel Requirements for Polyethylene Insulated Conductors

Insulated Conductor Diameter, in. (mm)	Diameter of Mandrel as a Multiple of $D + d^A$
Less than 0.501 (12.7)	3
0.501 to 1.000 (12.7 to 25.4)	5
1.001 to 1.500 (25.5 to 38.1)	7
1.501 to 2.000 (38.2 to 51.0)	9

[A] *D* = diameter of the insulated conductor. *d* = diameter of the bare conductor.

TABLE 8 Mandrel Requirements for Poly(Vinyl Chloride) Jacket

Outside Diameter of Wire or Cable, in. (mm)	Diameter of Mandrel as a Multiple of the Outside Diameter of Cable
0 to 0.800 (20.3)	8
0.801 (20.4) and over	10

77.2 A statement of bias is not possible since the test result is determined solely by this test method.

TRACK RESISTANCE

78. Significance and Use

78.1 Track resistance tests, properly interpreted, provide information about the tracking properties of the insulation in situations similar to those described in the tests. The values obtained in these tests may be used to provide data for research and development, design engineering, quality control, and acceptance or rejection under specifications.

79. Procedure

79.1 **Caution**—This test involves the use of high voltages. See 4.2.

79.2 Determine the track resistance in accordance with Test Method D 2132 using Method A as described in 79.3 or Method B as described in 79.4.

79.3 *Method A:*[11]

79.3.1 Use three test specimens of insulated conductor, each 5.5 in. (140 mm) in length.

79.3.2 Apply seven electrodes to each test specimen, with a 0.75 in. (19 mm) minimum space between each electrode. Each electrode shall consist of at least one turn of a 12 AWG (3.31 mm^2) coated copper wire wrapped tightly around the insulated conductor.

79.3.3 Place three test specimens horizontally in the test chamber at right angles to the axis of the spray and equidistant from the nozzle. Dust the upper half of each specimen. Remove the dust for approximately a 0.03 in. (0.79 mm) width immediately adjacent to both sides of three electrodes that are to be energized.

79.3.4 Ground the end electrodes, each alternate electrode, and the conductor in each test specimen. Apply a 60-Hz potential to the remaining three electrodes of each specimen.

79.3.5 Raise the test potential to 1500 V and adjust the fog deposit to give a current between 4 and 10 mA. Failure occurs when the circuit breaker trips.

79.4 *Method B:*[12]

79.4.1 The test specimen shall be a strip approximately 2.0 in. (50 mm) in length and at least 0.060 in. (1.52 mm) thick, and shall be taken from the outside of the insulation. The conductor shield shall be removed.

79.4.2 Attach an electrode near one end of the specimen and to the surface that was the outside surface of the insulation.

79.4.3 Apply a 60-Hz test potential to the electrode attached to the specimen. Immerse the specimen in a 0.1 % solution of ammonium chloride (NH_4Cl) at the ground potential until the electrode contacts the surface of the solution and then withdraw 1.0 in. (25 mm) of its immersed length. Repeat this procedure four times per minute for a minimum of ten cycles and a maximum of fifty cycles or until failure occurs. A failure occurs when an arc is maintained for two successive cycles between the electrode and solution across 1.0 in. of specimen.

79.4.4 Repeat the test, adjusting the potential, until no failures occur on five consecutive test specimens. This potential is known as the tracking voltage.

80. Report

80.1 Report the following information:

80.1.1 Manufacturer's name,

80.1.2 Manufacturer's lot number, if applicable,

80.1.3 Method used to perform the test,

80.1.4 For Method A, report the hours to failure, and

80.1.5 For Method B, report the tracking voltage.

81. Precision and Bias

81.1 This test method has been in use for many years, but no statement of precision has been made, and no activity is planned to develop such a statement.

81.2 A statement of bias is not possible since the test result is determined solely by this test method.

82. Keywords

82.1 accelerated water absorption; cold bend test; dielectric strength retention; elongation; heat aging; heat distortion; heat shock; insulation resistance; oil immersion; partial discharge extinction level; surface resistivity; tensile strength; thermoplastic insulation; thermoplastic jacket; thickness; track resistance; U-bend discharge; vertical flame test; voltage withstand tests

[11] For further information see Duffy, E. K., Jovanovitch, S., and Marwick, I. J., "Discharge Resistant Characteristics of Polyethylenes of Wire and Cable," *IEEE Transactions on Power Apparatus and Systems*, IEPSA, 1965, Vol 84, Paper 31 TP6, p. 815.

[12] For further information see Wallace, C. F., and Bailey, C. A., "Dip-Track Test," *IEEE Transactions on Electrical Insulation*, IEPSA, December 1967, Vol E1-2, No. 3, Paper 31 TP66-360, p. 137.