**Designation: D 2477 – ~~96~~02**

# Standard Test Method for
# Dielectric Breakdown Voltage and Dielectric Strength of Insulating Gases at Commercial Power Frequencies[1]

This standard is issued under the fixed designation D 2477; 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 This test method covers the determination of the dielectric breakdown voltage and dielectric strength of insulating gases used in transformers, circuit breakers, cables, and similar apparatus as an insulating medium. The test method is applicable only to gases with boiling points below room temperature at atmospheric pressure.

1.2 This standard may involve hazardous materials, operations, and equipment. *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.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

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[1] This test method is under the jurisdiction of ASTM Committee D~~-~~27 on Electrical Insulating Liquids and Gases and is the direct responsibility of Subcommittee D27.05 on Electrical Test~~s~~.

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D 2864 Terminology Relating to Electrical Insulating Liquids and Gases[2]

2.2 *IEEE Standard:*

No.~~ 4 Measurement of Test~~ 4 Standard Techniques for High Voltage~~ in Dielectric Tests~~ Testing[3]

## 3. Terminology

3.1 *Definitions:~~—S~~* For definitions of terms used in this test method, refer to Terminology~~ D 2864 for definitions.~~ D 2864.

## 4. Significance and Use

4.1 The dielectric breakdown voltage and dielectric strength of an insulating gas in a uniform field depends primarily on the molecular structure of the gas. As different gases are mixed either by plan or by contamination, any change in dielectric breakdown voltage and dielectric strength will depend on both the nature and proportion of the individual gases. This test method uses plane and spherical electrodes which provide a nearly uniform field (see Appendix) in the area of electrical discharge. It is suitable for determining the dielectric breakdown voltage and dielectric strength of different gases and mixtures thereof for research and application evaluations and also as a field test. A more complete discussion of the significance of the dielectric strength test is given in the Appendix.

## 5. Apparatus

5.1 *Electrical Apparatus*:

5.1.1 *Transformer*—The desired test voltage may be most readily obtained by a step-up transformer energized from a variable low-voltage commercial power frequency source. The transformer and controlling element shall be of such size and design that, with the test specimen in the circuit, the crest factor (ratio of maximum to mean effective) of the 60-Hz test voltage does not differ by more than ±5 % from that of a sinusoidal wave over the upper half of the range of test voltage. The crest factor may be checked by means of an oscilloscope, a sphere gap, or a peak-reading voltmeter in conjunction with an rms voltmeter. Where the waveform cannot be determined conveniently, a transformer having a rating of not less than ½ kVA at the usual breakdown voltage shall be used. Transformers of larger kVA capacity may be used, but in no case should the power frequency short circuit current in the specimen circuit be outside the range of 1 to 10 mA/kV of applied voltage. This limitation of current may be accomplished by using a suitable external series resistor or by employing a transformer with sufficient inherent reactance.

5.1.2 *Circuit-Interrupting Equipment*—The test transformer primary circuit shall be protected by an automatic circuit-breaking device capable of opening (as nearly instantaneously as possible) on the current produced by the breakdown of the test specimen; a circuit breaker that opens within 5 cycles may be used if the short-circuit current as described in 5.1.1 does not exceed 200 mA. A prolonged flow of current at the time of breakdown causes contamination of the gases and damage of the electrodes, thereby affecting the subsequent test results, and increasing the electrode and test cell maintenance and time of testing.

5.1.3 *Voltage-Control Equipment*—The rate of voltage rise shall be ½ kV/s ± 20 %. Voltage control may be secured by a motor-driven variable-ratio-autotransformer. Preference is given to equipment having an approximately straight-line voltage-time curve over the desired operating range. Motor drive is preferred to manual drive because of the ease of maintaining a reasonably uniform rate-of-voltage rise with this test method. The rate-of-voltage rise may be calculated from measurements of the time required to raise the voltage between two prescribed values. When motor-driven equipment is used, calibrate the speed control rheostat in terms of rate-of-voltage rise for the test transformer used.

5.1.4 *Voltmeter*—Measure the voltage by a method that fulfills the requirements of IEEE Standard No. 4, giving crest and also (if available) rms values, preferably by means of:

5.1.4.1 A voltmeter connected to the secondary of a separate potential transformer, or

5.1.4.2 A voltmeter connected to a well-designed tertiary coil in the test transformer, or

5.1.4.3 A voltmeter connected to the low-voltage side of the test transformer.

5.1.5 *Accuracy*—The combined accuracy of the voltmeter and voltage divider circuit is not to exceed 5 % at the rate of voltage rise specified in 5.1.3.

5.2 *Evacuation and Filling Apparatus*:

5.2.1 *Vacuum Pump*—The vacuum pump shall have sufficient pumping capacity to be able to evacuate the test cell to a pressure below 0.133 kPa (1 torr).

5.2.2 *Vacuum and Pressure Gage*—Either a mercury manometer, or one or more gages, capable of measuring pressures below 0.133 kPa (1 torr) and also near atmospheric pressure. The manometer, or vacuum and pressure gages, shall be calibrated in kPa or millimetres of mercury (torr).

5.2.3 *Connections*—Vacuum-tight tubing and valves shall be used while evacuating and purging the test cell and filling it with the gas sample.

5.3 *Electrodes and Test Cell:*[4]

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[2] *Annual Book of ASTM Standards*, Vol 10.03.

[3] Available from The Institute of Electrical and Electronic Engineers, Inc. (IEEE), 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 0885~~5~~4-1331.

[4] Detailed drawings of this apparatus are available at a nominal cost from ASTM International. Request ADJD2477.

5.3.1 The sphere and plane electrodes shall be mounted vertically as shown in Fig. 1. The sphere shall be a precision steel bearing ball ~~0.75 in. (19.1 mm)~~ 19.1 mm (0.75 in.) in diameter. The plane electrode shall be of brass ~~1.50 in. (38.1 mm)~~ 38.1 mm (1.50 in.) in diameter. The gap setting shall be ~~0.100~~ 2.54 ± ~~0.001 in. (2.54 ±~~ 0.025 mm (0.100 ± 0.001 in.). The tolerance of all dimensions is ±2 %, unless otherwise stated.

5.3.2 The cell shall consist of a borosilicate glass cylinder clamped by flanges to end plates which seal the cell and support the electrodes.[5] The lower plane electrode shall be fixed. The sphere electrode, held in place by a magnet, shall be adjustable by means of a micrometer screw suitably mounted through the top plate. The micrometer screw must be suitable for setting the electrodes to within the specified tolerance. The bottom plate shall have a valved port for evacuation and admission of the sample. If considered more convenient, two ports, one in the top for evacuation and one in the bottom for admission of the sample may be used. The dimensions are shown in Fig. 1.

## 6. Sampling

6.1 Obtain the gas sample from the gas cylinder or gas-filled equipment through a pressure-reducing regulator valve so that the flow into the cell may be controlled. The sample and cell must be at room temperature before the gas is admitted to the cell.

## 7. Preparation of Cell

7.1 Clean the cell except for the electrodes by washing with soap or detergent, then rinse with distilled or demineralized water and oven-dry. Clean the cell whenever necessary to remove detectable decomposition products formed by the breakdown arc, or when testing different gases.

7.2 Clean the electrodes with crocus cloth and naphtha. When the sphere electrode becomes pitted, it may be turned to a new position until it is necessary to replace it.

7.3 Assemble the cell by positioning and tightening the two end flanges and gaskets.

7.4 Turn the micrometer screw until the sphere just touches the plane electrode. The point where contact is made is best checked by a continuity meter connected to the two electrodes.

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[5] Standard laboratory borosilicate glass pipe and connecting flanges may be used.

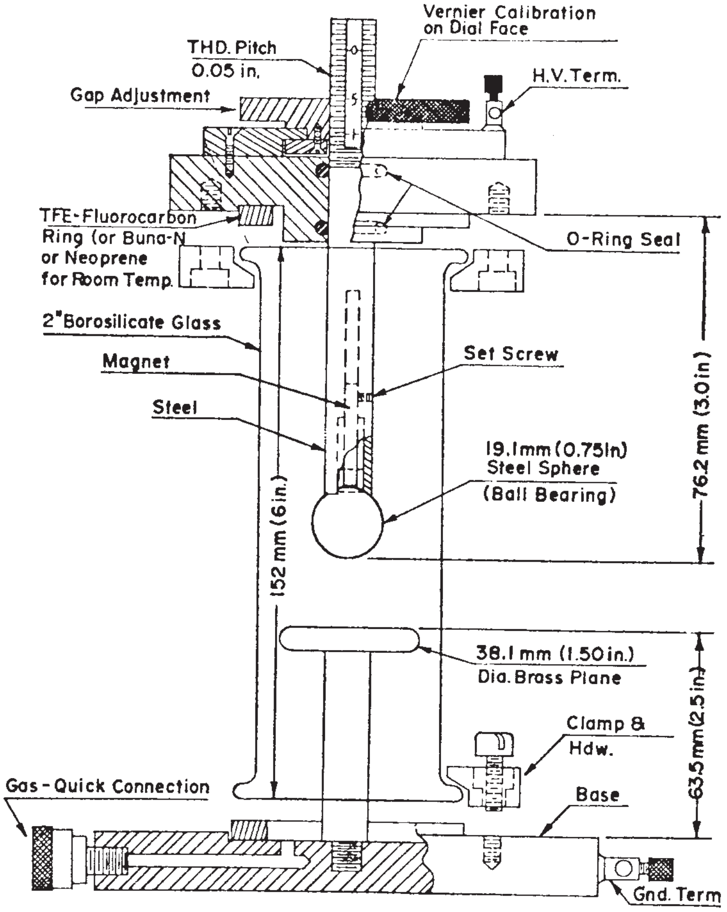

FIG. 1 Test Cell

7.5 Note the reading on the micrometer, add ~~0.100 in. (2.54 mm),~~ 2.54 mm (0.100 in.), and adjust the micrometer to this new setting.

## 8. Test Conditions

8.1 The dielectric breakdown voltage of an insulating gas under ambient conditions varies with temperature and pressure. The standard conditions for the test are 101 kPa (760 torr) and 25°C. If the ambient temperature deviates slightly from 25°C adjust the gas pressure for the test as follows:

~~$P = [(273 + T) \times 760]/298$~~

$$P = [(273 + T) \times 101]/298$$

where:

$P$ = gas pressure~~, t~~ for~~r~~ the test, kPa, and
$T$ = ambient temperature, °C.

8.2 As an alternative to the pressure adjustment in 8.1 the test may be made at ambient temperature and pressure and the dielectric breakdown result multiplied by an approximate factor, $F$, calculated as follows:

~~$F = (273 + T)/0.392\,P$~~

$$F = (273 + T)/2.95\,P$$

where:

$T$ = ambient temperature, °C, and
$P$ = ambient gas pressure, ~~torr.~~ kPa.

8.3 The breakdown voltage of an insulating gas may be affected by irradiation of the gas in the electrode gap. Such irradiation can occur from random sources such as sunlight, artificial lights of various types, and nearby radioactive materials. It is recommended that the test cell be shielded from such sources as much as possible during test runs. See X1.4 and X1.5~~,~~ for further discussion.

## 9. Procedure

9.1 Fill the cell as follows:

9.1.1 Evacuate the cell to a pressure of less than 133 kPa (1 torr).

9.1.2 Fill the cell with the gas to be tested to atmospheric pressure or slightly above.

9.1.3 Again evacuate the cell to a pressure of less than 133 kPa (1 torr).

9.1.4 Fill the cell with the gas to be tested to either the calculated pressure as in 8.1 or to atmospheric pressure and use the factor as calculated in 8.2.

9.2 Apply the voltage by increasing from zero at the rate of approximately ½ kV/s until breakdown occurs as indicated by operation of the circuit-interrupting equipment. Record the breakdown voltage.

9.3 Make five breakdowns on the one filling of the cell.

9.4 To test a second sample, repeat the purging and filling as described in 9.1.1-9.1.4.

## 10. Report

10.1 Report the following information:

10.1.1 Source of gas and its molecular identification,

10.1.2 The five individual breakdown values and their average, all multiplied by the factor, ~~*E*~~*F*, when the procedure in 8.2 is followed,

10.1.3 Ambient temperature and the pressure of the gas when tested, and

10.1.4 Frequency of the voltage source.

## 11. Precision and Bias

11.1 The repeatability to be expected within a laboratory and the agreement that should be obtained between laboratories are tabulated in Table 1 as a guide. The tabulated values are obtained from a cooperative test program involving ten laboratories each testing seven gases in test cells of same design.

## 12. Keywords

12.1 breakdown voltage; dielectric strength; gases; insulating gases

**TABLE 1 Precision Data**

| Comparison | 95 % Confidence Limit, [A] kV | Average, [A] kV (approx) |
|---|---|---|
| 1. For any set of five breakdowns made on one filling of the cell: | | |
| (*a*) the standard deviation should be | <1.23 | 0.75 |
| (*b*) the range (highest-lowest) should be | <3.44 | 2.08 |
| 2. For any two sets of five breakdowns made in one laboratory on two separate fillings of the cell, the difference between the average of the first set and the average of the second set should be | <1.56 | 0.64 |
| 3. The difference between the average of five breakdowns made in one laboratory and the average of five breakdowns made in a second laboratory should be: | | |
| (*a*) for different samples of gas | <4.19 | 1.65 |
| (*b*) for the same sample of gas | <3.29 | 1.37 |

[A] Values shown are rms; for crest values, multiply by 1.41.

# APPENDIX

## (Nonmandatory Information)

## X1. SIGNIFICANCE OF THE DIELECTRIC STRENGTH TEST

X1.1 Dielectric breakdown of an insulating gas occurs when the gas is stressed in an electric field that exceeds the dielectric strength of the gas. An electric field can be applied to a gas by means of submerging two metal electrodes of opposite polarity into the gas. As the voltage across the electrodes is raised to a critical value, a spark jumps between the electrodes manifesting a dielectric breakdown of the gas. The dielectric breakdown voltage, however, depends on the electric field produced by the electrodes and the spacing between them. For a given spacing, the highest breakdown voltage can be achieved when the field is uniform between the electrodes, such as that produced by two parallel-plane electrodes of infinite size. The dielectric strength of a gas is then equal to this voltage at a unit spacing and is expressed as kilovolts per centimetre or per inch.

X1.2 Since parallel-plane electrodes of infinite size are impractical, parallel electrodes of finite dimension have been designed with special contours at the electrode edges so that the breakdown spark takes place in the parallel-plane region, although the field outside this region is nonuniform. Rogowski and Rengier [6,7] have utilized exponential and sinusoidal contours, respectively, so that the electric stress is the highest between the planes. However, these electrodes are difficult to manufacture and relatively bulky as compared to the sphere-to-plane electrode configuration used in this test method.

X1.3 Although the field produced by the sphere-plane electrodes is largely nonuniform, yet in the limited region at the minimum spacing, where sparking is observed in the dielectric breakdown tests of insulating gases, the field is practically uniform. The dielectric strength (in terms of average electrical field) of air determined with this test method is 30 kV/cm, which is the same as determined with the parallel-plane electrodes. Consequently, this test method may be used for determining the dielectric strength as well as measuring the dielectric breakdown voltage of insulating gases.

X1.4 The breakdown voltage of insulating gases may be affected by irradiation of the gas in the electrode gap of the test cell. Random irradiation caused by sunlight, some artificial light sources, and nearby radioactive materials, can cause scatter in test results. It is recommended that reasonable care be used in shielding the test cell from such random sources.

X1.5 The committee sponsoring this test method considered modifying the test method to include a specified source of radiation to reduce or eliminate scatter. The aim was to make the irradiation of the gas in the electrode gap constant rather than random. (A 275-W ultraviolet lamp was used as the source in most tests, placed 203 mm (8 in.) from the gap.) Numerous tests in several different laboratories were made to compare the deliberately irradiated cell with the standard test method. An analysis of these test results indicated no definite pattern of improvement. This was particularly true of electro-negative gases such as sulfur hexafluoride. Since there would be no significant change in the precision of the test method, the committee rejected the proposed modification.

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[6] Rogowski, W., “Die Elektrische Feetigkeit am Rande des Platten Kondensators,” *Archiv Elektrotechnik*, Vol XII, 1923, pp. 1–15.

[7] Rogowski, W., and Rengier, H., “Ebene Funkenstrecke mit Richtiger Randansbildung,” *ibid*, Vol XVI, 1926, pp. 73–75.

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