Designation: D 2149 – 97

An American National Standard

# Standard Test Method for Permittivity (Dielectric Constant) And Dissipation Factor Of Solid Dielectrics At Frequencies To 10 MHz And Temperatures To 500°C[1]

This standard is issued under the fixed designation D 2149; 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 relative permittivity (dielectric constant) and dissipation factor of solid dielectrics from 50 Hz to 10 MHz over a range of temperatures from −80 to 500°C.[2,3] Two procedures are included as follows:

1.1.1 *Procedure A*—Using Micrometer Electrode.

1.1.2 *Procedure B*—Using Precision Capacitor.

NOTE 1—In common usage the word "relative" is frequently dropped.

1.2 *This standard does not purport to address 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:*

D 150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials[4]

D 1711 Terminology Relating to Electrical Insulation[4]

E 197 Specification for Enclosures and Servicing Units for Tests Above and Below Room Temperature[5]

## 3. Terminology

3.1 *Definitions:*

3.1.1 Permittivity and dissipation factor are fully defined in Terminology D 1711. Briefly, the permittivity of an insulating material is the ratio of the capacitance between two conductors when embedded in the material to the capacitance between the same configuration of conductors in a vacuum (or air). The dissipation factor is the ratio of the resistive to capacitive currents in the dielectric. The product of the permittivity and dissipation factor is the loss index.

## 4. Significance and Use

4.1 Permittivity and dissipation factor are sensitive to changes in chemical composition, impurities, and homogeneity. Measurement of these properties is, therefore, useful for quality control and for determining the effect of environments such as moisture, heat, or radiation.

## 5. Apparatus

5.1 *Measuring Circuits*—Suitable measuring circuits are described in Test Methods D 150. For measurements from 50 Hz to 100 kHz a substitution method using a low-voltage capacitance bridge is recommended. For measurements at 1 MHz and above, a resonant-circuit susceptance variation method is recommended. The *Q* of the circuit should be at least 200 except for very low loss materials, for which a *Q* of 500 or higher is desirable.

5.2 *Test Enclosure*—Unless testing only at room temperature, it is necessary to adapt a Hartshorn-Ward type specimen holder to a temperature-controlled test enclosure. Where applicable, use the requirements for a grade A enclosure as in Specification E 197. A suggested arrangement is shown in Fig. 1. This arrangement provides terminal connections away from the temperature zone.

5.3 *Specimen Holder*—The suggested arrangement shown in Fig. 1 incorporates the following requirements:

5.3.1 The selection of the metals is of utmost importance. The metal should have good thermal and electrical conductivity and yet be oxidation resistant and have sufficient strength to maintain its mechanical dimensions after repeated heating. AISI Stainless No. 316 fulfills these requirements except for the thermal conductivity. The time required for a specimen to reach equilibrium in a holder made from this material is quite

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

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[2] R. Bartnikas, Chapter 2, "Alternating-Current Loss and Permittivity Measurements," *Engineering Dielectrics, Vol IIB, Electrical Properties of Solid Insulating Materials, Measurement Techniques*, R. Bartnikas, Editor, *ASTM STP 926*, ASTM, Philadelphia, 1987.

[3] R. Bartnikas, Chapter 1, "Dielectric Loss in Solids," *Engineering Dielectrics, Vol IIA, Electrical Properties of Solid Insulating Materials: Molecular Structure and Electrical Behavior*, R. Bartnikas and R. M. Eichorn, Editors, *ASTM STP 783*, ASTM Philadelphia, 1983.

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

[5] Discontinued, see *1980 Annual Book of ASTM Standards*, Part 41.

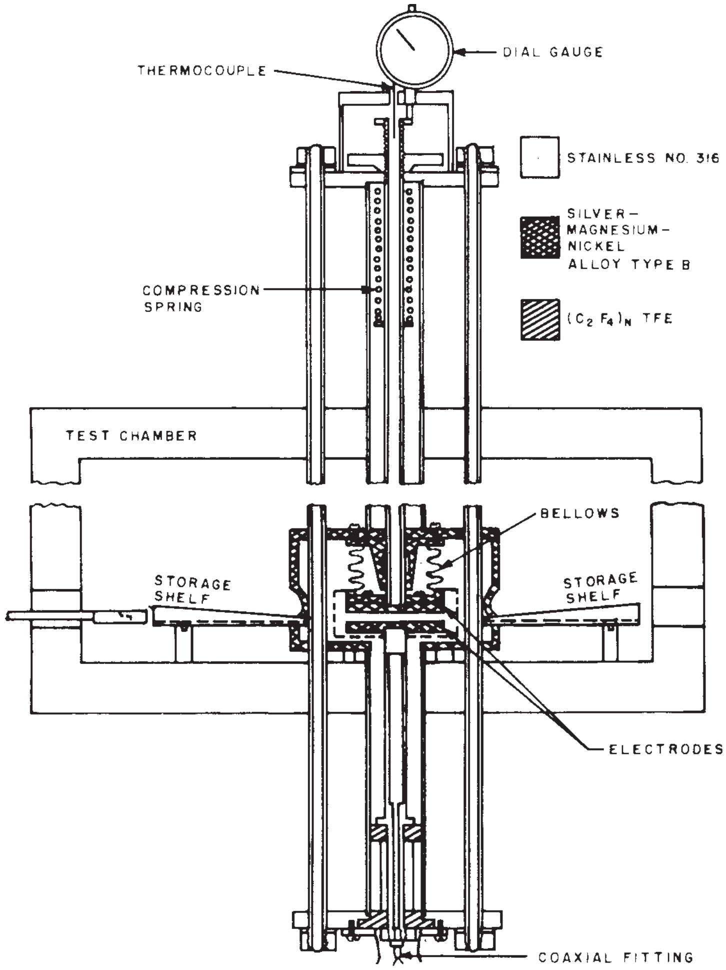


FIG. 1 Suggested Specimen Holder

long. Precious metal alloys such as type B silver-magnesium-nickel have better overall properties but require special heat treating.

5.3.2 The insulators may be aluminum oxide, beryllium oxide, or polytetrafluoroethylene.

5.3.3 Use electrodes 50 mm in diameter and at least 5 mm thick, with sharp corners. Maintain electrode parallellism to within 0.01 mm.

5.3.4 Select a length and cross-section for the lower tube so that the temperature of each insulator does not exceed 100°C when the oven is at 500°C. Select a length and crosssection for the upper tube so that the drive nut can be touched with the operator's fingers (keep the drive nut less than 60°C) when the oven is at 500°C.

5.3.5 Use a micrometer or dial gage with a precision of 0.005 mm to determine electrode separation and to monitor specimen expansion.

## 6. Electrodes

6.1 Prior to measurement, apply conducting film or foil electrodes to both flat surfaces of the specimen. (The specimen thickness should be determined before applying electrodes.) Silver paint, tin or tin-lead foil, or evaporated metal electrodes have ranges of usefulness. Evaporated metal electrodes are the most suitable. When the specimen is porous sprayed-on metal electrodes may be useful. Additional information on the suitability of various electrode systems may be found in Test Methods D 150.

## 7. Sampling

7.1 See ASTM standards for specific materials.

## 8. Test Specimen

8.1 Use a disk test specimen with a diameter of 40.00 ± 0.01 mm and a thickness of 2 to 3 mm. Finish the surfaces to 1.8 µm or better and maintain parallel surfaces to within 0.01 mm. The samples should be free of bubbles and other defects.

## 9. Standard Test Frequencies

9.1 Unless otherwise specified, make measurements at one or more of the following frequencies:

| | |
|---|---|
| 60 Hz | 100 000 Hz |
| 100 Hz | 1 MHz |
| 400 Hz | 10 MHz |
| 1000 Hz | |

Common test frequencies are 60 Hz, 1000 Hz, and 1 MHz.

## 10. Temperature Control

10.1 Take measurements at frequent temperature intervals (not to exceed 20°C), until the required temperature range has been traversed. Reduce the temperature to the lowest required test temperature and leave until equilibrium has been achieved. Determine equilibrium by clamping a specimen between the holder electrodes and balancing or peaking the measuring circuit until no change takes place between balances made 2 min apart. After the required measurements have been made at the lowest test temperature increase the temperature at the rate of 2 ± 0.5°C/min to the next test temperature. Follow this procedure for achieving the test temperature until the required temperature range has been traversed. Take measurements at approximately the same test temperatures as the temperature is increasing and as the temperature is decreasing. Measurements as temperature is being increased and decreased are necessary to guard against possible hysteresis in electrical properties due to such factors as moisture and chemical change.

## 11. Conditioning

11.1 Prior to applying electrodes condition the specimens at 23 ± 1°C and 50 ± 2 % relative humidity for a minimum of 40 h. Carry out room-temperature tests in the Standard Laboratory Atmosphere of 23 ± 1°C and 50 ± 2 % relative humidity.

## 12. Procedure A (Using Micrometer Electrode)

12.1 Refer to Test Methods D 150. Center the specimen between the electrodes and rotate the drive nut until the friction is felt to suddenly decrease. Read this micrometer setting and check it against the setting at which the friction first increases on increasing the electrode spacing. Balance or peak the measuring circuit. Open the electrodes and remove the specimen. Then restore the balance of the measuring apparatus without changing its capacitance setting by reducing the spacing between the electrodes and adjusting the measuring circuit to balance the loss component. Note the new dissipation factor and micrometer setting, etc.

12.2 At each test temperature and each required frequency determine the capacitance and dissipation factor of each specimen.

## 13. Procedure B (Using Precision Capacitor)

13.1 Procedure B can be used when the frequency can be kept constant or when the measuring circuit, as is the case with the bridges, is stable with frequency changes. In this procedure determine the $\Delta C$ at room temperature for each frequency required as in Procedure A. Then center and clamp the specimen between the electrodes and change the temperature to the first temperature, taking measurements at each required frequency to determine the change in capacitance of the specimen.

13.2 Procedure B requires a variable-precision capacitor with a precision of 0.01 pf in parallel with the specimen holder to determine the change in specimen capacitance with temperature and frequency.

## 14. Calculation

14.1 *Procedure A*—Calculate the capacitance, $C_s$, and dissipation factor, $D_s$, of the specimen as follows:

$$C_s = C_o - C_t + C_v \quad (1)$$

$$C_s = \Delta C + C_v \quad (2)$$

$$D_s = C_t/C_s(D_i - D_v) \quad (3)$$

*where*:

$C_o$ = capacitance of the specimen holder with the specimen out,
$C_i$ = capacitance of the electrodes set at the average measured thickness of the specimen (Note 2),
$C_v$ = equivalent geometric vacuum capacitance of the specimen,
$C_t$ = total capacitance at the unknown terminals of the measuring circuit,
$D_i$ = dissipation factor of the measuring circuit as indicated by the measuring circuit when the specimen is between the electrodes, and
$D_o$ = dissipation factor of the measuring circuit as indicated by the measuring circuit when the circuit has been rebalanced with the specimen removed from the electrodes.

NOTE 2—If the secondary electrodes are quite thin and the maximum thickness of the specimen is close to the average thickness, this setting can be considered the same as the micrometer reading when the specimen is clamped between the electrodes.

14.2 *Procedure B*—Calculate the capacitance of the specimen as follows:

$$C_s = \Delta C + C_{RT} - C_T + C_v \quad (4)$$

where:

$C_{RT}$ = capacitance of the precision capacitor at room temperature when the measuring circuit is balanced, and
$C_T$ = capacitance of the precision capacitor at a temperature test point when the measuring circuit is balanced.

14.3 Calculate the dissipation factor as in Procedure A (Eq 3).

## 15. Lead Length Correction

15.1 In both Procedures A and B keep the length of the leads to a minimum between the measuring circuit and the specimen holder. The $\Delta C$ from Procedure *A* will be correct, but the dissipation factors as seen by the measuring instrument and the change from $\Delta C$ as in Procedure B will be in error if the leads are long. The amount of error will depend on the frequency, lead length, and the capacitance of the specimen. To correct for the lead error it is necessary to calibrate the measuring circuit by calibrating the specimen holder at low frequency and using its capacitance ( $C_H$) to calibrate the measuring circuit at higher frequencies. A typical curve is shown in Fig. 2. This type of curve at the measuring frequency can be used to correct for lead errors. The change in capacitance in Procedure B can be directly corrected by the curve $C_m$ versus $C_H$. The dissipation factors from both Procedures A and B can be corrected by the following expression if the dissipation factor of the specimen is less than 0.10:

$$D_s = (C_t/C_s)(D_t - D_o)(C_H/C_m)^2 \quad (5)$$

where:

$C_H$ = capacitance of the specimen holder, and
$C_m$ = capacitance indicated by the measuring circuit.

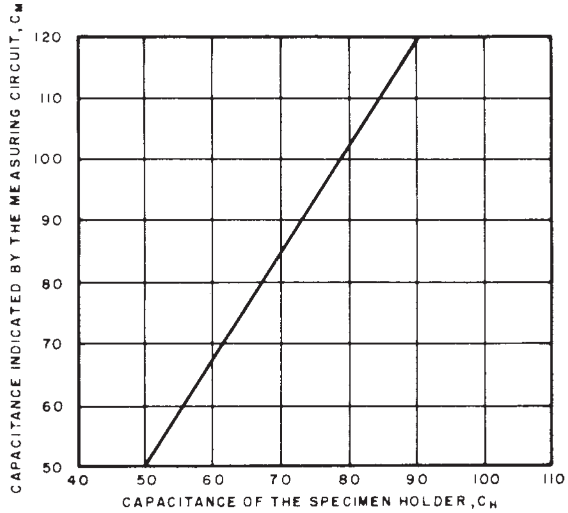


**FIG. 2 Typical Calibration of Measuring Circuit**

If $C_H/C_m$ is not less than 0.99, no correction for lead length is required.

## 16. Report

16.1 Report the following:

16.1.1 Description of the specimen, including name, grade, color, and manufacturer,

16.1.2 Dimensions of test specimen,

16.1.3 Conditioning of test specimen and type of secondary electrodes,

16.1.4 Measuring circuit and procedure,

16.1.5 Test voltage, and

16.1.6 Permittivity and dissipation factor at each temperature and frequency reported.

## 17. Precision and Bias

17.1 *Precision*—The precision of this test method has not been determined.

17.2 *Bias*—The bias of this test method has not been determined.

## 18. Keywords

18.1 dielectric constant; dissipation factor; micrometer electrode; permittivity; precision capacitor; relative permittivity