Methods of test for

Determination of permittivity and dissipation factor of electrical insulating material in sheet or tubular form

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Committees responsible for this British Standard

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British Plastics Federation
British Rubber Manufacturers' Association Ltd.
EEA (Association of Electronics, Telecommunications and Business Equipment Industries)
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Contents

Foreword

This British Standard was prepared under the direction of the Plastics and Rubber Standards Policy Committee.

Useful background information may be obtained from IEC 250 and from BS 2067 both of which cover a wider frequency range than this standard.

The resonance substitution methods described in BS 2067 have become obsolescent owing to the non-availability of suitable commercial equipment. The methods in this standard will, in due course, supersede those in BS 2067, except for materials of very low dielectric loss or for measurements at high frequencies.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 12, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

The methods described may be used for sheet materials in the thickness range 0.3 mm to 5.0 mm. The air substitution method is suitable for sheet materials of thickness 1.0 mm to 5.0 mm.

The two immersion methods are capable of better precision for sheet materials of thickness 0.3 mm to 1.0 mm and have the advantage that accurate knowledge of the specimen thickness is not required.

One of the immersion methods is suitable for measurements on tubular specimens but individually constructed electrodes may be needed for specific sizes of tube.

1 Scope

This British Standard describes three methods for the measurement of permittivity and of dissipation factor of electrical insulating materials in the form of sheets or rigid circular tubes at frequencies between 50 Hz and 1 MHz, under normal ambient temperatures and conditions. The methods described are applicable to sheet materials in the thickness range 0.3 mm to 5.0 mm and for tubes at least 75 mm long.

The methods are:

— an air substitution method, commonly called the "Lynch" method (method A)

— a two fluid immersion method (method B)

— a single fluid immersion method (method C).

Methods A and B are suitable for materials of permittivity up to 10.0. For materials of dissipation factor below 250×10^{-6} the precision achieved by these methods may not be acceptable.

Method A requires accurate knowledge of the specimen thickness and should be used in all cases when this information is available. If the thickness is not accurately known, methods B or C may be used subject to the limitation that method C is suitable for materials for which a liquid matching its permittivity to within 0.1 is available. Method C is suitable for measurement of polyolefin sheets whose permittivity sufficiently closely matches that of silicone oil of kinematic viscosity of 1 cSt to 2 cSt[1)].

Methods B and C are not suitable for materials with an open cell structure.

Method B is suitable for measurements on straight cylindrical tubes of circular cross section.

2 References

2.1 Normative references

This British Standard incorporates, by reference, provisions from specific editions of other publications. These normative references are cited at the appropriate points in the text and the publications are listed on the inside back cover. Subsequent amendments to, or revisions of, any of these publications apply to this standard only when incorporated in it by updating or revision.

2.2 Informative references

This British Standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Definitions

For the purposes of this standard the definitions given in BS 4727-1:Group 10:1991 apply.

4 General

In the methods described, the electrode assembly is an integral part of the specimen holder into which the specimen and appropriate insulating fluid(s) are introduced, the capacitance and dissipation factor of the assembly being measured.

Such systems introduce smaller errors in measurement than intimately applied electrodes, and facilitate the provision of guard electrodes which eliminate electric field distortions and stray capacitances.

Suitable electrode systems for each of the methods are described in **8.2**, **9.2** and **10.2**. Suitable measuring instruments are described in clause **7**.

5 Test conditions

Unless otherwise specified in the materials specification, specimens shall be conditioned for (20 ± 4) h under the following conditions:

— temperature (23 ± 2) °C;

— relative humidity (50 ± 5) % r.h.

Unless otherwise specified in the materials specification, measurements shall be carried out under the same conditions.

The specimen, electrode system and immersion fluid(s) and their environment shall be in thermal equilibrium when the measurement is made, the temperature difference being less than 1 °C.

[1)] 1 cSt = $1 \times 10^{-6} m^2 s^{-1}$

NOTE The permittivity and dissipation factor of a dielectric may change considerably with frequency, temperature and relative humidity. Accordingly the measured values should only be taken to indicate the dielectric properties of the specimen under conditions similar to those used for the test.

6 Number and handling of specimens

In all three methods the test shall be carried out on three specimens unless otherwise specified. Each specimen comprises one test piece for methods A and B, and two test pieces for method C. At all times the specimens shall be handled with stainless steel flat-faced forceps to minimize the likelihood of damage or contamination, taking particular care not to compress or distort flexible or soft materials.

7 Measuring instruments

An instrument of adequate sensitivity[2)] shall provide a minimum detectable change in capacitance of 0.3 fF (i.e. 0.3×10^{-15} F) and a minimum detectable change in dissipation factor of 0.00001 (i.e. 10×10^{-6}).

NOTE 1 A variety of modes of output is offered by commercial measuring equipment. Some of the more sophisticated offer a variety of outputs from the same instrument thus enabling the user to select the appropriate output. This standard assumes that the output is in the form of capacitance (*C*, in pF) and dissipation factor (*D*). See Annex A for conversion of other forms of output to this format.

NOTE 2 The electrode systems described in methods A and B are of three terminal "guarded" design. This practically eliminates the influence of stray electric fields at the electrode edges and removes the need for "edge capacitance" corrections. In method C there is a close match in permittivity between the material and the immersion fluid and thus there is little change in edge capacitance when the specimen is inserted or removed.

NOTE 3 Care should be taken to ensure that all measurement leads are screened and kept as short as possible, consistent with the manufacturers' instructions.

Some types of instrument require a "short" and "open" circuit calibration. The "short circuit" should be established between the electrodes of the electrode system i.e. in the position which the specimen would occupy. Care should be taken to ensure that the short circuit used is of low resistance and inductance and that it does not damage the surfaces of the electrode. It is essential also to ensure the micrometer zero is not altered. A smooth metal disc, the diameter of which, is approximately 75 % that of the guarded electrode and 1 mm to 3 mm thick is suitable for use as a short circuit.

The "open" circuit is established by disconnection of the electrodes at the end of the cables furthest from the capacitance meter, i.e. so that allowance is again made for the effect of the measuring leads. Reference should be made to the manufacturer's instructions to discover whether it is necessary to link the outer connections of the coaxial cables during this calibration and whether the error introduced by omission of the electrode system is small and may be ignored.

Accordingly it is to be preferred if a three terminal measuring instrument, with for example "high", "low" and "guard" connections can be used.

NOTE 4 Many commercial instruments are now based on measurement of current, voltage and phase angle. These instruments are commonly of four (or five) terminal design. Reference should be made to the manufacturer's instructions before connecting a three terminal electrode system to such an instrument, since the preferred mode of connection may differ between instruments.

8 Method A: Air substitution technique

8.1 Principle

The test piece is inserted into a guarded electrode system in which the electrode separation is variable. Small air gaps are left between the sample and electrodes to ensure that the test piece is not mechanically stressed. The capacitance and dissipation factor of the assembly are measured.

The test piece is removed and the electrode separation adjusted so that the capacitance is restored to its original value. The electrode movement and the new value of dissipation factor are measured.

The permittivity and dissipation factor of the test material are calculated, as shown in **8.5.2**, from the test piece thickness, the change in electrode spacing and the change in observed values of dissipation factor.

8.2 Electrode system

The electrode system shall be of rigid mechanical design and of sufficient thermal capacity that rapid changes in ambient temperature do not significantly affect its dimensions. It shall comprise three parallel concentric electrodes, one of which is a guard. The electrode surfaces shall be flat and shall remain substantially parallel at all times.

Figure 1 illustrates a possible construction and means of connection to a three terminal measuring instrument.

NOTE 1 For connection to four or more terminal instruments, reference should be made to the manufacturer's instructions.

The system comprises a circular measuring electrode surrounded by a concentric coplanar guard electrode, and a movable electrode whose separation from the measuring electrode is controlled by a micrometer head. Rotation of the drive mechanism should not be transmitted to the electrode.

NOTE 2 A more precise means of determining the changes in electrode spacing, e.g. a displacement transducer, which will not disturb the electric field between the electrodes may be introduced.

8.3 Test pieces

The test piece shall be flat and uniform in thickness and shall extend beyond the unguarded electrode by at least 5 mm.

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2) For information on the availability of suitable instruments and electrode systems write to Customer Services Information, Services Group, BSI, Linford Wood, Milton Keynes MK14 6LE.

Where possible, test pieces shall be used as prepared by the manufacturer. For the electrode system shown the test piece shall be either:

a) a flat circular sheet (61 ± 1) mm in diameter; or

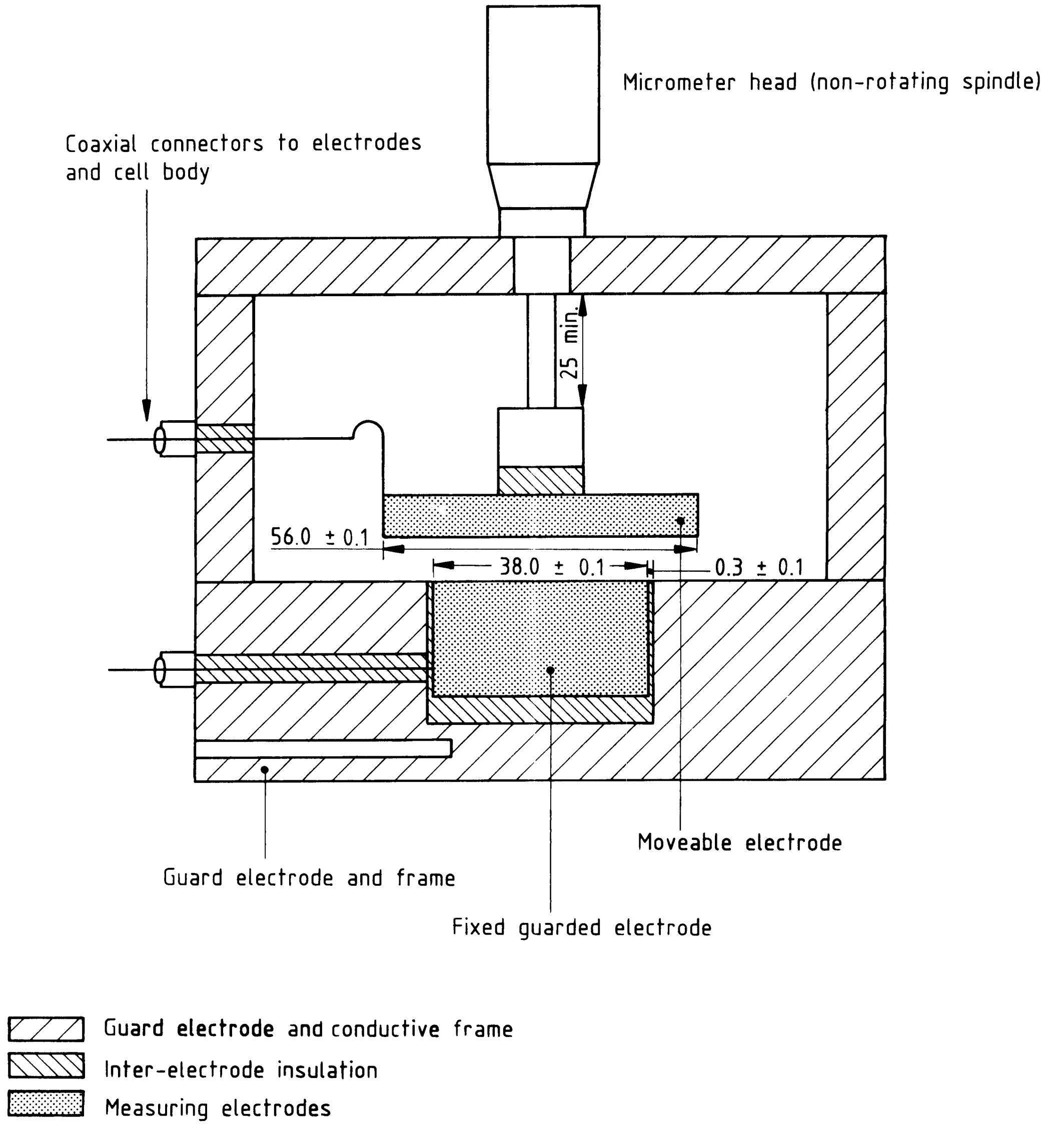
b) a flat rectangular sheet (61 ± 1) mm by (100 ± 1) mm.

The thickness shall be between 1.0 mm and 5.0 mm.

The thickness at any point shall not vary by more than 1 % from the mean value.

NOTE If possible the specimen should be of the same thickness prepared by the same process as the electrical insulating material under test. If it is necessary to reduce its thickness care should be taken to ensure that its surfaces are not contaminated during the process.

The maximum tolerance deviation from a straight edge placed along a diameter or diagonal shall be less than 10 % of the thickness. If the test piece is warped, reject it at this stage and prepare another.



Dimensions in millimetres

Figure 1 — Example of electrode system for method A

8.4 Procedure

8.4.1 *Determination of test piece thickness*

Determine the test piece thickness with a micrometer conforming to BS 870:1950. Measure four values of thickness at points equally spaced around the periphery of the test piece, and a fifth value centrally. Calculate the arithmetic mean thickness of each test piece as t.

NOTE Whilst absolute accuracy in measurement of thickness of the test piece is not important, and the thickness and micrometer movement may be measured in arbitrary units, it is essential that all discrepancies of scale between the micrometer used for thickness measurement and that of the electrode system are minimized.
Any such discrepancy will lead to erroneous results, the fractional error in result being generally greater than that in thickness measurement or electrode movement by a ratio dependent on the permittivity of the specimen.
If the errors in t, ε and tan δ, expressed as fractions of values of t, ε and tan δ are represented by Δt, $\Delta\varepsilon$ and $\Delta(\tan\delta)$ then;

$$\Delta\varepsilon = (1 - \varepsilon)\Delta t \qquad (1)$$

$$\Delta\tan\delta = \varepsilon\Delta t \qquad (2)$$

where

t is specimen thickness;

ε is permittivity;

tan δ is the dissipation factor.

8.4.2 *Measurement of capacitance and dissipation factor*

Insert the test piece between the electrodes and decrease the electrode gap until the upper electrode just fails to touch the test piece.

NOTE Turn the micrometer screw until the upper electrode just touches the test piece, then turn the micrometer screw in the reverse direction until no resistance is felt, i.e. some lateral movement of the sample is possible.

Measure the capacitance and dissipation factor. Record the value of the dissipation factor as D_1, and the electrode spacing as m_1.

Remove the test piece and decrease the electrode gap until the capacitance is returned to the original value. Record the new value of the dissipation factor as D_2 and the electrode spacing as m_2.

Repeat this procedure for a further two test pieces. Calculate the values of permittivity and dissipation factor for each set of measurements as shown in **8.5.2**.

Record the frequency, temperature and relative humidity at which measurements are made.

Calculate the means of these values as the permittivity and dissipation factor of the test material.

8.5 Symbols and calculations

8.5.1 *Symbols*

Symbol	Definition	Unit
D_1	Dissipation factor of electrode assembly with test piece present	
D_2	Dissipation factor of electrode assembly without test piece	
ΔD	$(D_1 - D_2)$	
m_1	Micrometer reading with test piece present	mm
m_2	Micrometer reading without test piece	mm
Δm	difference in micrometer readings $(m_1 - m_2)$	mm
t	specimen thickness	mm
tan δ	dissipation factor of material	
ε_r	relative permittivity of material	

8.5.2 *Calculation of permittivity and dissipation factor*

8.5.2.1 *Permittivity*

Calculate the permittivity (ε_r) from:

$$\varepsilon_r \quad \frac{t}{t - \Delta m} \qquad (3)$$

8.5.2.2 *Dissipation factor*

Calculate the dissipation factor of the material (tan δ) from[3]:

$$\tan\delta \quad \Delta D\left[\frac{2}{t - \Delta m}\right] \qquad (4)$$

8.6 Expression of results

The result shall be the mean of the determinations on individual test pieces. Record also the individual values.

[3] IEC 250 gives:
$\tan\delta = D_1 + M\varepsilon_r\Delta D$

where

$M = (\frac{m_2}{t} - 1)$, which is equivalent to the formula given but less convenient to use.

9 Method B: Two fluid immersion technique

9.1 Principle

As with method A the electrode spacing is only slightly greater than the test piece thickness. Although, in principle, either or both of the fluids used in this method may be liquids or gases, this standard permits only the use of a gas (usually air) as the first fluid, and a liquid as the second fluid.

The test piece is inserted into a guarded electrode system, the electrode spacing adjusted, the test piece removed, and the capacitance and dissipation factor measured. The test piece is replaced and the capacitance and dissipation factor of the electrode system are remeasured. After removal of the test piece the space between the electrodes is filled with the immersion liquid and the capacitance and dissipation factor measured. The test piece is inserted and the capacitance and dissipation factor remeasured. The permittivity and dissipation factor of the test material are calculated as shown in **9.5.2**.

9.2 Electrode system

9.2.1 *Electrodes for sheet materials*

The electrode system shall be of rigid mechanical design and of sufficient thermal capacity that rapid changes in ambient temperature do not significantly affect its dimensions. It shall comprise three parallel concentric electrodes, one of which is a guard. The electrode surfaces shall be flat and shall remain substantially parallel at all times.

Figure 2 illustrates a possible construction and means of connection to a three terminal measuring instrument.

NOTE For connection to four or more terminal instruments, reference should be made to the manufacturer's instructions.

The system comprises a circular measuring electrode surrounded by a concentric coplanar guard electrode, and a moveable electrode, the separation of which from the measuring electrode is controlled by a micrometer head. The drive mechanism shall be linked with the electrodes so that the electrode does not rotate with the drive mechanism.

Both electrodes are mounted vertically so that air bubbles dragged into the liquid with the specimen may escape.

NOTE 1 The temperature of this cell may be controlled to ± 0.1 °C by a liquid circulation system.

NOTE 2 The electrodes are preferably made from stainless steel. If they are made from brass then all metal parts should be plated with a minimum thickness of 10 µ*m of hard bright gold.*

9.2.2 *Electrodes for tubular materials*

The electrode system shall consist of three coaxial cylindrical electrodes, one guard, one measuring (guarded) electrode and one inner unguarded electrode, fitted with end pieces for locating the test specimen coaxially with the electrodes.

The general layout of electrodes and dimensions suitable for tubes of internal diameter 11 mm to 13 mm and outer diameter 17 mm to 19 mm are illustrated in Figure 3. The electrodes are made from stainless steel, with a stable low-loss material for the insulator.

Electrode dimensions shall be chosen so that there is adequate clearance (about 1 mm) between each side of the specimen and the electrodes; at the same time, the specimen should fill at least 60 % of the inter electrode space.

9.2.3 *Immersion fluids*

Suitable liquids of known permittivity values are listed in Annex B. Liquids which affect the properties of the test material whether by swelling or by any other interaction shall not be used.

NOTE Silicone fluid of viscosity 1 cSt to 2 cSt ($1 \times 10^{-6} m^2 \cdot s^{-1}$ to $2 \times 10^{-6} m^2 \cdot s^{-1}$) is satisfactory for use with many plastic materials, e.g. the polyolefins, PE, PTFE, PET and polycarbonates. Cyclohexane is an acceptable fluid for use with PTFE and many polyesters. Perfluorinated liquids are also excellent as they do not interact with most organic polymers.

The liquid shall not be reused if the value of the dissipation factor of cell in fluid has changed by more than 2 % or 10×10^{-6} whichever is the greater.

9.3 Test pieces

9.3.1 *Sheet materials*

For the electrode system shown the test piece shall be a rectangular sheet (61 ± 1) mm × (100 ± 1) mm. The thickness shall be between 0.3 mm and 1.00 mm.

NOTE The precise specimen thickness is not required, however, it may be measured and used for comparison with that derived from the electrical measurements as a cross-check on the procedure.

Where possible, specimens shall be used as prepared by the manufacturer. However, if it is necessary to reduce their thickness, care shall be taken so that the surfaces are not contaminated during the process.

9.3.2 *Tubular materials*

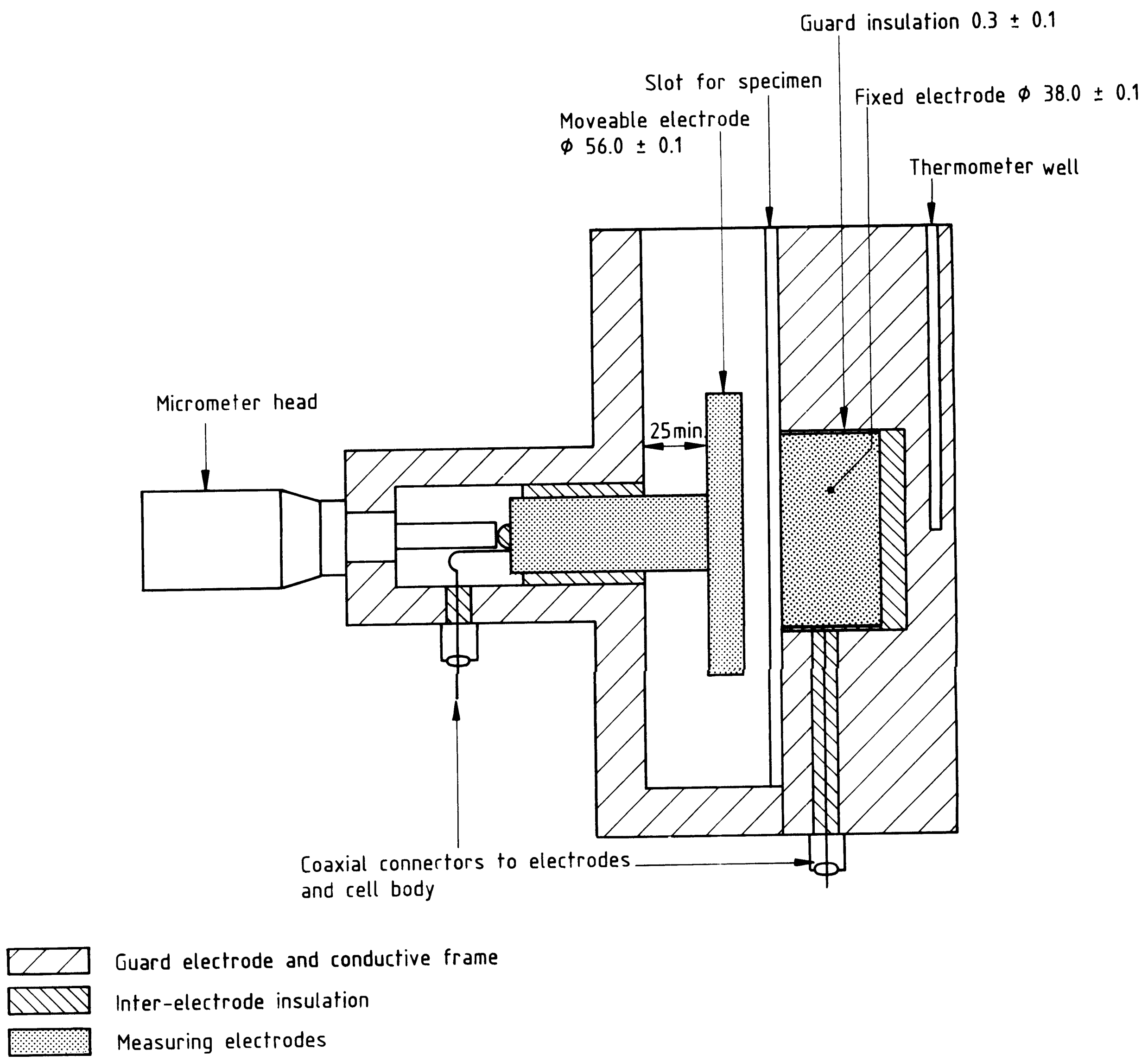
The test piece shall be a straight tube of uniform bore at least 75 mm long. Taking aspect ratio into account the inner and outer diameter are normally defined by the application envisaged for the material and thus there are no recommended or preferred values for these dimensions. Accordingly, the electrode system will need to be designed for the material under test. A clearance of approximately 1 mm is required on the inner and outer diameter to ensure that the test piece is not mechanically stressed.

9.4 Procedure

9.4.1 *Preparation of test cell*

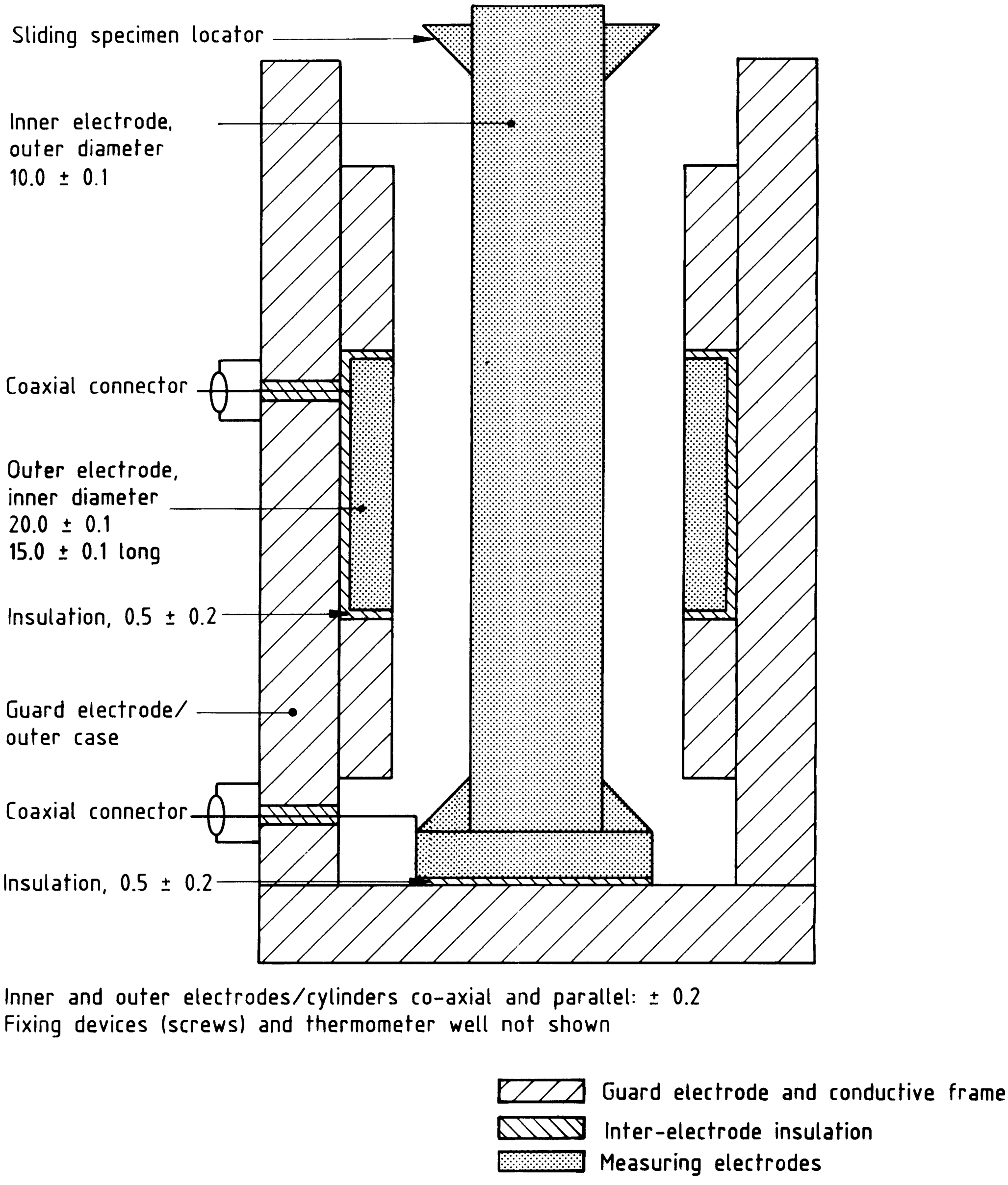
Prepare a cell by rinsing several times with warm de-ionized water and then rinse with acetone. Dry the cell at 50 °C and allow to cool to ambient temperature. After allowing at least 1 h for stabilization the dissipation factor shall be less than 0.00001 (10×10^{-6}).

Ensure that the electrode assembly materials and test piece are in thermal equilibrium with the environment to within ± 0.1 °C before commencing a test. For sheet specimens adjust the electrode spacing so that the specimen occupies at least 80 % of the gap without actual contact.



Dimensions in millimetres

Figure 2 — Example of electrode system for method B: sheet specimens



Dimensions in millimetres

Figure 3 — Example of electrode system for method B: tubular specimens

9.4.2 ***Measurement of capacitance and dissipation factor***

Connect the leads to the cell and follow the manufacturer's instructions as to the initial bridge calibration. Record the values of capacitance and dissipation factor as C_1 and D_1 with air between the electrodes.

Insert the test piece into the air-filled cell. Record the values of capacitance and dissipation factor as C_2 and D_2. Record the cell temperature to ± 0.1 °C.

Remove the test piece from the cell and fill the cell with the fluid chosen. Measure the capacitance and dissipation factor and record the values as C_3 and D_3.

Insert the test piece into the cell. Measure the capacitance and dissipation factor and record the values as C_4 and D_4. Remove the specimen from the cell immediately after this measurement.

Repeat this procedure for a further two test pieces.

Calculate the values of permittivity and dissipation factor for each set of measurements as shown below.

Calculate the mean values of permittivity and material dissipation factor.

Record the frequency, temperature and relative humidity at which measurements are made.

NOTE For routine measurements, the following sequence may be found more convenient, but in cases of dispute, the sequence of measurements given in the main text shall be used:

Test piece	Fluid	Use reading as
None	Air	$(C_1)_1$ $(C_1)_2$
1	Air	$(C_2)_1$
2	Air	$(C_2)_2$
3	Air	$(C_2)_3$
None	Air	$(C_1)_3$
None	Liquid	$(C_3)_1$ $(C_3)_2$
1	Liquid	$(C_4)_1$
2	Liquid	$(C_4)_2$
3	Liquid	$(C_4)_3$
None	Liquid	$(C_3)_3$

(C_3) 1 implies C_3 for test piece 1.

9.5 Symbols and calculations

9.5.1 *Symbols*

Symbol	Definition	Unit
C_1	Cell capacitance with air alone	pF
C_2	Cell capacitance with specimen in air	pF
C_3	Cell capacitance with fluid alone	pF
C_4	Cell capacitance with specimen in fluid	pF
ΔC_A	Change in capacitance on insertion of specimen in air	$(C_2 - C_1)$ pF
ΔC_F	Change in capacitance on insertion of specimen in fluid	$(C_4 - C_3)$ pF
D_1	Dissipation factor of cell in air	
D_2	Dissipation factor with specimen in air	
ΔD_A	Change in dissipation factor on insertion of specimen in air	$(D_2 - D_1)$
A	Effective electrode area	m^2
ε_0	Electric constant 8.8542	$pF \cdot m^{-1}$

9.5.2 *Calculation of permittivity and dissipation factor*

9.5.2.1 *Permittivity*

Calculate the permittivity (ε_r) from:

$$\varepsilon_r = 1 + \frac{C_4 \Delta C_A (C_3 - C_1)}{C_1 (C_4 \Delta C_A - C_2 \Delta C_F)} \qquad (5)$$

9.5.2.2 *Dissipation factor*

Calculate the dissipation factor ($\tan \delta$) from:

$$\tan \delta = C_s \frac{\Delta D_A}{\Delta C_A}$$

where

$$C_s = \left\{ \frac{C_2 C_4 (C_3 - C_1)}{C_4 \Delta C_A - C_2 \Delta C_F} \right\} \qquad (6)$$

NOTE The calculated specimen thickness (t) is given by:

$$t = \frac{\varepsilon_r \varepsilon_0 A}{C_S} \qquad (7)$$

This may be compared with the measured thickness as an accuracy check.

9.6 Expression of results

The result shall be the mean of the determinations on individual specimens. Record also the individual values.

10 Method C: Single fluid immersion technique[4)]

10.1 Principle

When the permittivity of the test material is approximately known it is possible to use a single fluid immersion method, the fluid having a permittivity approximately equal to that of the test material. Accurate knowledge of the electrode spacing and material thickness is not necessary, but to obtain optimum results the test piece has to nearly fill the space between the electrodes, which are fixed. Details of the measurement procedure are given in **10.4**.

The electrode system is filled with the immersion liquid and the capacitance and dissipation factor measured. The test piece is then inserted and the capacitance and dissipation factor remeasured. The permittivity and dissipation factor of the test material are calculated as shown in **10.5.2**.

The method is capable of high precision, since the result is obtained by a small correction applied to the accurately known permittivity of the immersion liquid.

4) The method is based on ASTM D 1531[1].

10.2 Electrode system

The electrode system is filled with the immersion liquid and the capacitance and dissipation factor measured. The test piece is then inserted and the capacitance and dissipation factor remeasured. The permittivity and dissipation factor of the test material are calculated as shown in **10.5.2**.

The method is capable of high precision, since the result is obtained by a small correction applied to the accurately known permittivity of the immersion liquid.

10.2.1 *Electrodes*

An example of a suitable design of measuring cell is shown in Figure 4. This cell has a two-terminal rectangular design with a central electrode made from gold-plated brass. The electrode faces are flat, parallel and have an area of 5 806 mm[5]. This electrode is supported by five PTFE insulators midway between two gold-plated brass electrodes which form two walls of the cell. The spacing between the electrodes, in the standard design, is (1.52 ± 0.05) mm. Other spacings may be used if test specimens other than 1.27 mm in thickness are to be used.

The test piece shall occupy at least 80 % of the electrode gap.

The centre electrode may be readily removable for cleaning.

10.2.2 *Immersion fluids*

Suitable liquids of known permittivity value are listed in Annex B. Liquids which affect the properties of the test material, whether by swelling or by any other interaction, shall not be used (see note to **9.2.3**). The liquid shall not be reused if the value of the dissipation factor of cell in fluid has changed by more than 2 % or 10×10^{-6} whichever is the greater.

10.3 Test pieces

For the electrode system shown moulded sheets of the material (1.27 ± 0.12) mm thick shall be prepared and two test-pieces each (100 ± 1) mm × (68 ± 1) mm cut from them. Unless otherwise specified each test measurement shall be made on a specimen consisting of two test pieces.

Measure the thickness of each test-piece to ± 0.025 mm using a micrometer conforming to BS 870:1950. Five values shall be taken along the diagonals of the test piece, one central and one near each end. Calculate the arithmetic mean thickness of each test piece.

10.4 Procedure

10.4.1 *Preparation of test cell*

Rinse a cell with warm de-ionized water before use and then rinse with acetone. Dry the cell at 50 °C for 1 h and allow to cool. Measure and record the capacitance (C_0) and dissipation factor (D_o). The dissipation factor of a clean cell shall be less than 0.00001.

10.4.2 *Capacitance and dissipation factor of cell with liquid*

Fill the cell slowly with clean liquid, directly from the original bottle, until a small quantity overflows.

Connect the cell to the capacitance meter in accordance with the manufacturer's instructions and perform the "closed" and "open" circuit calibrations at the frequency selected for test. Measure and record the capacitance (C_1) and dissipation factor (D_1).

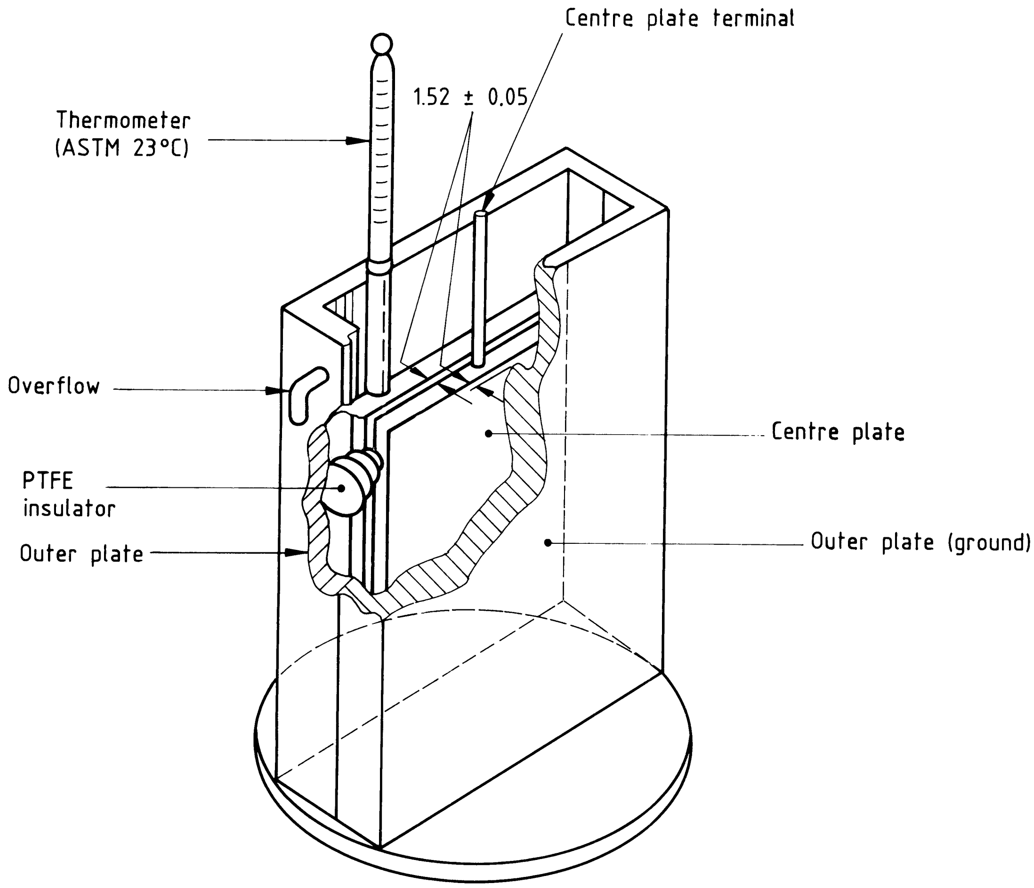
10.4.3 *Capacitance and dissipation factor with test pieces present*

Insert carefully two test pieces between the plates of the test cell. Measure and record the capacitance (C_2) and dissipation factor (D_2).

Remove the test pieces from the cell promptly. Repeat the procedure from **10.4.2** for two further specimens. The liquid in the cell may be reused until the capacitance of the cell has increased to (C_1 ± 0.1) pF or its dissipation factor to (D_1 + 0.00001). If these limits are exceeded, empty, clean and dry the cell (**10.4.1**) and refill with fresh liquid.

Record the frequency, temperature and relative humidity at which measurements are made.

[5] The cell volume is approximately 50 ml.



Dimension in millimetres

Figure 4 — Example of electrode system for method C

10.5 Symbols and calculations

10.5.1 *Symbols*

Symbol	Definition	Unit
A	Area of centre capacitor plate (one face only)	mm^2
C_o	Cell capacitance in air	pF
C_1	Cell capacitance when filled with liquid	pF
C_2	Cell capacitance with liquid and specimen	pF
ΔC	$(C_2 - C_1)$	pF
D_o	Dissipation factor of cell in air	
D_1	Dissipation factor of cell when filled with liquid	
D_2	Dissipation factor of cell with liquid and test pieces	
t_a	Average separation of capacitor plates	mm
t	Mean of thickness measurements on each test piece	mm
ε_1	Relative permittivity of immersion liquid = $\left(\frac{C_1}{C_o}\right)$	
ε_r	Relative permittivity of specimen	
$\tan \delta$	Dissipation factor of specimen	
ε_o	Electric constant 8.8542	$pF\ m^{-1}$

10.5.2 ***Calculation of permittivity and dissipation factor***

10.5.2.1 *Permittivity*

Calculate the permittivity from the following:

If $|\varepsilon_r - \varepsilon_1| < 0.1$,

$$\varepsilon_r = \varepsilon_1 + \frac{\Delta C}{C_o}\frac{t_a}{t}$$

where

$$t_a = \frac{2\varepsilon_0 A}{C_0} \quad (8)$$

If $|\varepsilon_r - \varepsilon_1| \geq 0.1$

$$\varepsilon_r = \varepsilon_1 + \frac{\Delta C}{(C_o t/t_a) - \Delta C\{1 - (t/t_a)\}/\varepsilon_1} \quad (9)$$

10.5.2.2 *Dissipation factor*

Calculate the dissipation factor from:

$$\tan\delta = \tan\delta_1 + (D_2 - D_1)\frac{t_a}{t} \quad (10)$$

where

$\tan\delta_1$ is the dissipation factor of immersion fluid = $(D_1 - D_o)$.

10.6 Expression of results

The result shall be the mean of the determinations on individual specimens. Record also the individual values.

11 Precision

No precision data is available as yet[6)].

12 Test report

The following information shall be included in the test report:

a) reference to this standard and test method used, i.e. BS 7663:1993, method A, B or C;

b) type or designation of the insulating material and the form in which it was delivered;

c) method of fabrication of material;

d) the specimen thickness and information of the surface treatment (if any) at the contact areas of the electrodes;

e) method and duration of conditioning of the specimens if not as specified;

f) measuring instrument;

g) electrode and specimen dimensions if not as specified;

h) temperature and relative humidity during the test;

i) test voltage;

j) test frequency;

k) relative permittivity ε_r: mean value, individual values;

l) dielectric dissipation factor ($\tan\delta$): mean value, individual values;

m) date of test;

n) any unusual features noticed during the test.

[6)] It is intended that when the standard is reviewed, a precision statement will be included to indicate reproducibility and repeatability of the methods in accordance with BS 5497-1.

Annex A (informative) Modes of representation of capacitance

Some instruments represent a capacitance having finite losses as a parallel combination of conductance and loss-free capacitance, while others use a series combination of resistance and capacitance.

For the purposes of this standard, the parallel representation is used, although theoretically either is a valid approximation. The value of D, the dissipation factor, is the same in both representations, but the values of capacitance differ by an amount dependent on the value of D, and therefore the derived values of permittivity will differ. Thus, a series representing instrument will require conversion of its capacitance value for the purposes of this standard.

Conversion of capacitance is necessary unless: $D_2 \ll 1$. The actual value of D which makes conversion necessary depends upon the accuracy required for the permittivity.

The following relationships are true (see Figure A.1):

Dissipation factor $D = G_p/\omega C_p = \omega C_s R_s$

$C_p = C_s/(1 + D^2)$

$G_p = D^2/(1 + D^2)R_s$

Resistance $R_p = 1/G_p$

$\omega = 2\pi f$

where

f is the frequency (in Hz).

Annex B (informative) Liquids of known permittivity values

Liquids which have been found to be useful are as follows:

Liquids	Permittivity value
silicone (1 cSt to 2 cSt)	
heptane	~ 2.2
perfluorocarbons	
chlorobenzene[a]	5 to 6
1, 2-dichloroethane[a]	9 to 11
ethanol[a]	~ 30
cyclohexane	~ 2.2

[a] The permittivity of these liquids is much more temperature-dependent than that of the other (lower permittivity) liquids.

WARNING. Many of these liquids are toxic and the necessary precautions should be taken.

NOTE For further information see *Tables of dielectric dispersion data for pure liquids* [2].

Symbols

G_p Conductance

C_p Capacitance

a) Parallel representation

Symbols

R_S Resistance

C_S Capacitance

b) Series representation

Figure A.1 — Equivalence of series and parallel representations of a capacitor

List of references (see clause 2)

Normative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 870:1950, *Specification for external micrometers.*

BS 4727, *Glossary of electrotechnical, power, telecommunication, electronics, lighting and colour terms.*

BS 4727-1, *Terms common to power, telecommunications and electronics.*

BS 4727-1:Group 10:1991, *Insulating solids, liquids and gases.*

BS 5497, *Precision of test methods.*

BS 5497-1:1987, *Guide for the determination of repeatability and reproducibility for a standard test method by inter-laboratory tests.*

Informative references

BSI standards publications

BRITISH STANDARDS INSTITUTION, London

BS 2067:1953, *Determination of power-factor and permittivity of insulating materials (IIartshorn and Ward method)*[7].

IEC publications

IEC 250:1969, *Recommended methods for the determination of the permittivity and dielectric dissipation factor of electrical insulating materials at power, audio and radio frequencies including metre wavelengths.*

Other references

[1] ASTM D 1531:1990, *Test method for relative permittivity (dielectric constant and dissipation factor) of polyethylene by liquid displacement procedure.*

[2] National Bureau of Standards. Tables of dielectric disperson data for pure liquids. *In: NBS Circular 589.* Washington. November 1958.

[7] Referred to in the foreword only.

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