

Methods for

Measurements in electrostatics

Part 2. Test methods

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Committees responsible for this British Standard

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- British Rubber Manufacturers' Association
- ERA Technology Ltd.
- Electrical and Electronic Insulation Association (BEAMA Ltd.)
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- Federation of Resin Formulators and Applicators (FeKFA)
- Federation of the Electronics Industry
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Foreword

This Part of BS 7506 was prepared by Technical Committee PRI/25.

BS 7506 Methods for measurement in electrostatics comprises two Parts:

Part 1: *Guide to basic electrostatics*

Part 2: *Test methods*

The test methods described are those considered most appropriate for electrostatic measurements. Several methods described in this Part are simplified versions of existing British Standards, since for the purposes of electrostatics the range of values of significance may be restricted. The methods described give adequate accuracy and precision in these ranges. In many cases more precise or accurate procedures are available, and for these more specialized standards should be consulted. Part 1 of this standard provides information and guidance on methods for making reliable measurements.

Annex A describes procedures for calibration of the instruments used in the test methods specified. Although calibration is not always deemed to be necessarily prescribed, it is considered advisable to provide guidance.

Annex B provides useful references for additional information.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

1 Scope

This Part of BS 7506 comprises standard methods of measurement, providing reliable means of determining the values of those properties of materials relevant to electrostatic phenomena. The range of values of a property which is significant to electrostatic effects is limited, and it is only useful to measure such a property within this range (for example resistance values between $10^6 \Omega$ and $10^{10} \Omega$). For this reason, simpler procedures are acceptable, and fewer problems of interpretation arise. For precise measurements of properties outside these ranges reference should be made to more specialized standard methods and to relevant scientific literature.

2 Informative references

This Part of BS 7506 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 Measurement of electric field

3.1 Principle

3.1.1 General

Electric fields are measured from the charge induced on a conducting surface. Fieldmeters (used for measuring the field) are of two main types: induction probe and field mill instruments.

3.1.2 Induction probe instruments

Induction probe instruments are simple and of relatively low cost. They consist, as shown in figure 1, of a sensing surface with a defined capacitance to earth connected to a very high input impedance amplifier. The signal V (volts) observed at the preamplifier input when a sensing surface of effective area A (m^2) with an input capacitance C (F), is exposed to an electric field E ($\text{V}\cdot\text{m}^{-1}$) is given by:

$$V = \epsilon_0 EA/C$$

where ϵ_0 is the electric constant ($8.85 \times 10^{-12} \text{ F}\cdot\text{m}^{-1}$).

The effective sensing area will depend on the screening arrangements, and should be calibrated in situ. Zero drift can arise from variation of the bias currents and offset voltages at the preamplifier input. Induction probe instruments have a finite input time constant arising from the input capacitance and inevitable input leakage resistance. Consequently, induction probe instruments are used for relatively short term measurements (tens of seconds) and require to be adjusted to zero reading in a zero electric field environment.

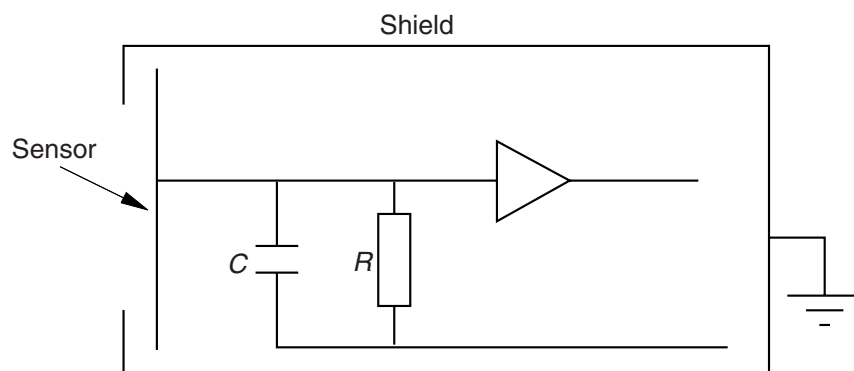


Figure 1. Induction probe fieldmeter

3.1.3 Field mill instruments

Field mill fieldmeters overcome the limitations of induction probes by using a rotating chopper, which is normally earthed, to modulate the coupling of the electric field to the sensing surface. The general arrangement is shown in figure 2. So long as the timescale of modulation is suitably shorter than the product of the input capacitance, C , and the effective input resistance to earth, R , then an alternating signal is generated which is independent of the rate of chopping and the value of the input resistor. The response then depends only on the area of the sensing surface A and the value of the input capacitance C . The change of charge induced on the sensing surface is given by dQ :

$$dQ = A \epsilon_0 dE$$

The peak-to-peak signal V (volts) generated will be:

$$V = dQ/C$$

For a depth of modulation, f , of the observed electric field by the rotation of the chopper:

$$dE = fE$$

and

$$V = \epsilon_0 f E A / C$$

Phase sensitive detection of the observed alternating signal after amplification generates an output signal whose strength and polarity relate proportionally and directly to the observed electric field.

3.2 Fieldmeters

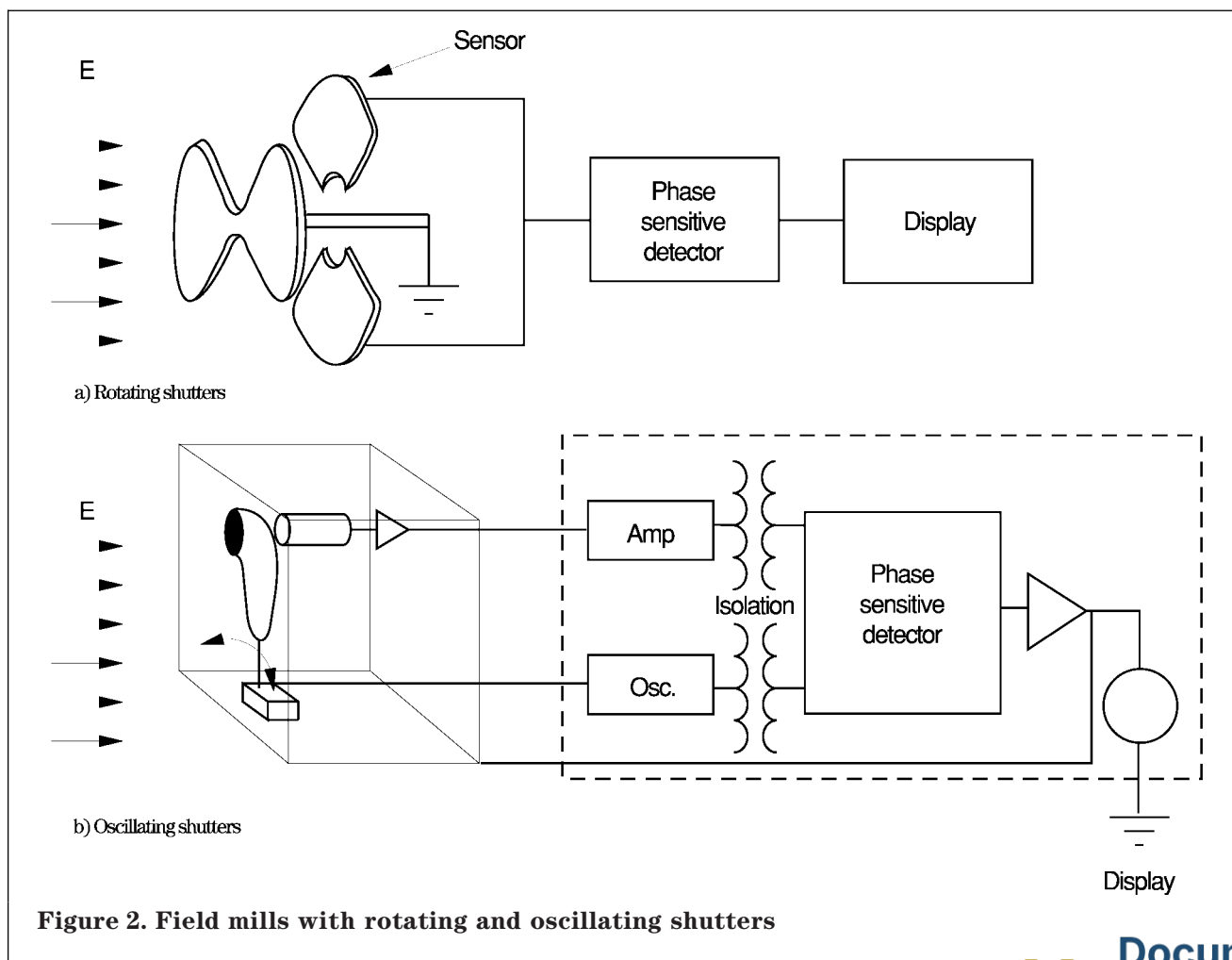
3.2.1 Construction

The case of the fieldmeter shall be of a conductive or static dissipative material.

No insulating materials shall be visible on or near the sensing aperture.

NOTE. Insulating materials acquire and retain static charge which will affect the readings and the zero setting. This is particularly important for high sensitivity instruments and for instruments used near air ionizer units.

The sensing aperture of the fieldmeter shall be defined within a flat conducting region of the case, mounted flush with a surrounding surface for application measurements and for calibration. Readings shall relate to the electric field at this aperture.



Fieldmeter instruments shall include provision for external adjustment of the zero reading when observing a zero electric field environment. This shall be the only adjustment of basic instrument operation directly accessible by the user.

3.2.2 Reference potential

An earth bonding point shall be provided and be clearly identified. The fieldmeter shall be bonded to a defined reference potential, usually earth potential, before and during use.

3.2.3 Susceptibility to interference

Operation shall not be adversely affected by exposure to high value or fast changing electric fields; for example from nearby spark discharges.

3.2.4 Sensitivity

Fieldmeter instruments are categorized in terms of sensitivity and accuracy.

High sensitivity fieldmeters are able to measure and display values of electric field of $100 \text{ V}\cdot\text{m}^{-1}$ with the zero stable within $50 \text{ V}\cdot\text{m}^{-1}$ over at least 1000 s. A reading of $100 \text{ V}\cdot\text{m}^{-1}$ shall be at least 10 % of an analogue scale reading or at least the second decimal digit of a digital display.

For accurate measurements with field mill instruments the time constant of the input resistance and capacitance shall be at least five times the half cycle time of the minimum chopping frequency of the instrument. Also, the time constants of any high pass noise reduction filtering in signal amplification shall be four to five times the half cycle time multiplied by the number of such filtering stages. To avoid interaction with alternating mains supply signals the chopping frequency shall be at least three times the frequency of the supply.

3.2.5 Display

The instrument display, and any signal output, shall give a linear response to electric field, symmetrical with polarity and with no hysteresis. For high accuracy instruments these properties of the instrument shall be within $\pm 1\%$ of full scale reading of the operating range and for lower accuracy instruments within $\pm 5\%$. The output time constant at the display shall be less than 1 s.

NOTE. This is particularly important for handheld instruments used to search for sources of static charge. The display shows electric field values with polarity. Scale readings are to be given in $\text{V}\cdot\text{m}^{-1}$ or $\text{kV}\cdot\text{m}^{-1}$ as appropriate.

In battery powered instruments warning shall be given when the battery voltage is at a level at which readings may become unreliable.

3.3 Procedure

If using an induction probe fieldmeter, switch on in a region free of electric fields.

Before starting measurements check and record the zero reading and stability. Check the zero with the fieldmeter looking into a clean metal chamber in which the nearest surfaces are at least 50 mm away from the sensing apertures, avoiding the influence of contact potential and contamination effects. Make readings relative to the instrument zero.

When using an induction probe instrument make measurements within a shorter time relative to the input decay time constant and without re-zeroing.

Ensure that surfaces around the sensing region are clean.

NOTE 1. This is particularly important with high sensitivity instruments and in work involving insulating particles. Insulating particles readily become charged and any such particles deposited in or around the sensing region will offset the instrument zero. Air purging helps prevent particle deposition.

Check the zero reading at appropriate intervals (see item b) and record its value.

NOTE 2. On first use of a particular fieldmeter it is important for the user to carry out the following checks.

- a) Bond the instrument to earth.
- b) Switch the instrument on in a region free of static charges and electric fields and check the stability of the zero reading over times comparable to the times needed for the measurements.
- c) Switch the instrument on in a field-free region and move it to observe a constant high value of electric field, for example a steady voltage on a metal plate at a stable distance. Observe the rate of change of reading and estimate the input decay time constant. After a time return it to a field-free region and check if the zero reading has changed.

3.4 Expression of results

The results of electric field measurements are the values of electric field observed at particular times in $\text{V}\cdot\text{m}^{-1}$.

3.5 Test report

The report shall include at least the following information:

- a) the number and date of this standard;
- b) date and time of measurements;
- c) location, arrangement and time when measurements made;
- d) ambient temperature and relative humidity in measurement region;
- e) identification of instrumentation used and date of most recent calibration.

4 Measurement of potential

4.1 Principle

The potential of a conducting object may be measured by direct connection to an electrostatic voltmeter or voltmeter with a suitably high input impedance.

The potential of a charged surface, insulating or conducting, may be measured by the electric field which it creates at a nearby fieldmeter held at a fixed potential, usually earth.

A more accurate measure is obtained if the potential of the fieldmeter is adjusted to give zero field at the fieldmeter, the potential of the meter then being equal to that of the surface or location in the volume, described usually as the 'voltage follower configuration'.

The potential of a localized region in a volume can be measured using a fieldmeter in either a simple or a voltage follower configuration as above.

4.2 Fieldmeters and voltmeters

4.2.1 Simple configuration fieldmeter

The potential of a surface is calculated from the electric field at a nearby electrostatic fieldmeter at earth or a defined potential.

Induction or field mill fieldmeter instruments shall be as described in 3.2.

The electric field between the body and the fieldmeter is usually non-uniform and the surface voltage is not a simple product of the electric field E ($\text{V}\cdot\text{m}^{-1}$) and the separation distance d (m). A geometric factor f may need to be used; for plane surfaces which have a radial extent less than five times the separation gap the correction factor will be affected by the size and form of the surface on which the potential is measured.

NOTE. In these circumstances the factor f may be determined by calibration (see annex A) or computer modelling of the particular geometric arrangement. The potential is given by:

$$V = Efd$$

For accurate measurements it is necessary that the fieldmeter is well separated from the object to minimize added capacitance but near enough to avoid the influence of charges and potentials on other nearby objects and surfaces. Instruments used solely for measurement of potential are used at fixed distances from the objects to be measured and are calibrated directly in units of potential.

NOTE. The simple fieldmeter can also be used in a region of space charge for measurement of local space potential.

4.2.2 Fieldmeter used as voltmeter

When using a fieldmeter the potential of a conducting body is measured by connection to an electrode mounted in a fixed geometrical relationship to the fieldmeter, the whole being shielded from the surrounding environment. The assembly is calibrated to indicate the potential of the connected body.

The input capacitance of the electrode and connecting leads shall be small in comparison with the self-capacitance of the object under test.

4.2.3 Fieldmeter connected in voltage follower configuration

a) Surface potential

The potential of an insulating or conducting surface is measured using a fieldmeter close to the surface and adjusting the potential of the fieldmeter so that the indicated field is brought to zero, usually achieved dynamically with a feedback circuit. The applied potential is then equal to the potential of the surface to be measured.

Voltage follower probes can be used to measure the potential of any charged surface, solid or liquid. The main advantages are the low added capacitance, the lack of influence of separation distance and the good accuracy of measurement. The main disadvantage is the risk of damage by electrical discharges if voltage changes occur faster than the ability to follow the voltage.

Measurements using a voltage follower probe only require the probe to be sufficiently close to the surface for the response to relate only to the local voltage of the surface and to be unaffected by charges on any other nearby surfaces.

b) Space potential

When an earthed fieldmeter is introduced into a potential distribution it will perturb the distribution and create an electric field at the sensing aperture linearly related to the potential which existed at the fieldmeter location before the fieldmeter was introduced. The degree of perturbation depends on the diameter of the fieldmeter sensing head. The relation between the local space potential V and the observed electric field E ($\text{V}\cdot\text{m}^{-1}$) and the diameter d (m) of the fieldmeter is given by:

$$E = fV/d$$

where f is a factor near unity.

This relationship can be tested and the factor f checked by applying a voltage to a battery powered fieldmeter to null the reading. The relationship remains true so long as the fieldmeter sensing head is reasonably far away (several diameters) from nearby earthed surfaces and structures and the ambient field in the space is low compared to the field values observed.

When fieldmeters are used as potential probes it is necessary for the electric field at the fieldmeter to be below the level at which corona or water spray discharges can occur.

NOTE. Local electrical discharges can generate local space charge which will affect readings.

4.2.4 *Electrostatic voltmeter*

Electrostatic voltmeters operate by using the electrostatic force between conductors at different potentials to move an indicating pointer. They can be used to measure potential differences between conducting bodies, one of which is at a reference potential, usually earth.

The input capacitance of an electrostatic voltmeter (including the connecting conductors) shall be small compared to the self-capacitance of the object being measured.

4.2.5 *Other high resistance voltmeters*

High input resistance voltmeters are used to measure potentials so long as the product of the input resistance of the meter and the capacitance of the object being measured is long compared to the time needed for measurement. The decay time constant of the system shall be checked and recorded.

4.3 Procedure

4.3.1 *Preparation*

Switch on the measuring instrument and allow it to stabilize. Check the zero of the instrument before making measurements.

4.3.2 *Measurement of potential of conducting surfaces*

Measure the potential of a conducting body by any of the methods listed in 4.2 with the restrictions on position, resistance and capacitance indicated.

4.3.3 *Personnel potential*

Measure the potential acquired by a person walking on flooring, moving on a chair or rubbing against furnishings by one of the following methods.

- a) Measurement of potential by connection to an electrostatic voltmeter or fieldmeter with an auxiliary electrode.

NOTE 1. Care is needed to avoid leakage or induction of charge to the connecting lead.

- b) A person's potential may be measured by holding a battery powered fieldmeter at a known distance from an earthed surface.

NOTE 2. A geometrical factor f is usually needed for interpretation of the reading.

4.3.4 *Space potentials*

Measure the potential of a localized region in a volume using a fieldmeter in either a simple (see 4.2.1) or a voltage follower (see 4.2.3) configuration.

4.4 Expression of results

Record the values of potential obtained from measurements at particular times as V or kV.

4.5 Test report

The report shall include at least the following information:

- a) the number and date of this standard (date and time of measurements);
- b) location, arrangement and conditions when measurements made;
- c) ambient temperature and relative humidity in measurement region;
- d) identification of instrumentation used and date of most recent calibration.

5 Measurement of charge

5.1 General

The net electrostatic charge on an object or on a quantity of liquid or solid material is measured by enclosing it in an isolated, screened conducting chamber known as a Faraday pail. If all the charge introduced into the pail couples to the inside of the pail with no residual coupling to external surroundings then the net quantity of charge introduced appears as induced charge of the same sign and magnitude on the outside of the pail and is available for measurement either directly or as associated potential or current.

The charge introduced does not need to be conducted to the inside walls and the method is equally effective for insulating materials and for conductors.

5.2 Conditioning

NOTE. Although the measurement of quantity of charge is not affected by the environmental conditions, the electrical characteristics of materials can vary with temperature and the absorption of moisture.

For reference purposes measurements shall be made at two levels of humidity. Unless otherwise specified these conditions shall be $(23 \pm 2)^\circ\text{C}$, $(50 \pm 5)\%$ r.h. and $(23 \pm 2)^\circ\text{C}$, $(15 \pm 2)\%$ r.h. Materials shall be conditioned for 16 h to 24 h before measurements are taken.

For measurements in industrial situations the ambient temperature and relative humidity shall be recorded.

5.3 Apparatus

NOTE. The apparatus used comprises a Faraday pail into which the charge is transferred, the magnitude of the charge being measured by an ancillary procedure.

The Faraday pail consists of a conducting enclosure (usually in the shape of a simple open topped circular cylinder) mounted within a conducting earthed shield on high quality insulation.

The basic form of a Faraday pail system for measurement of charge is shown in figure 3. For accurate measurements the following dimensional requirements shall be fulfilled.

- a) For less than 1 % leakage of the total flux from charged objects in a Faraday pail, the pail shall have a depth to diameter ratio greater than 1.4.
- b) For less than 5 % leakage the depth to diameter ratio shall be greater than 0.8.

c) The charged objects introduced shall occupy not more than the lower 30 % of the Faraday pail.

d) To avoid interference from external charges the aperture in the shield shall be no larger than 1 pail entrance diameter spaced at least this distance above the pail entrance aperture.

The insulation mounting the pail, and the connections and cabling to any external charge measurement circuits shall be designed and constructed to avoid charge leakage and trapped charge effects. The performance of insulation is dependent on its mechanical rigidity, leakage resistance, piezo-electric characteristics and tendency to moisture absorption.

NOTE. To minimize problems with contact potentials in high sensitivity instruments it is recommended that all surfaces (including the earthing contact) are gold plated.

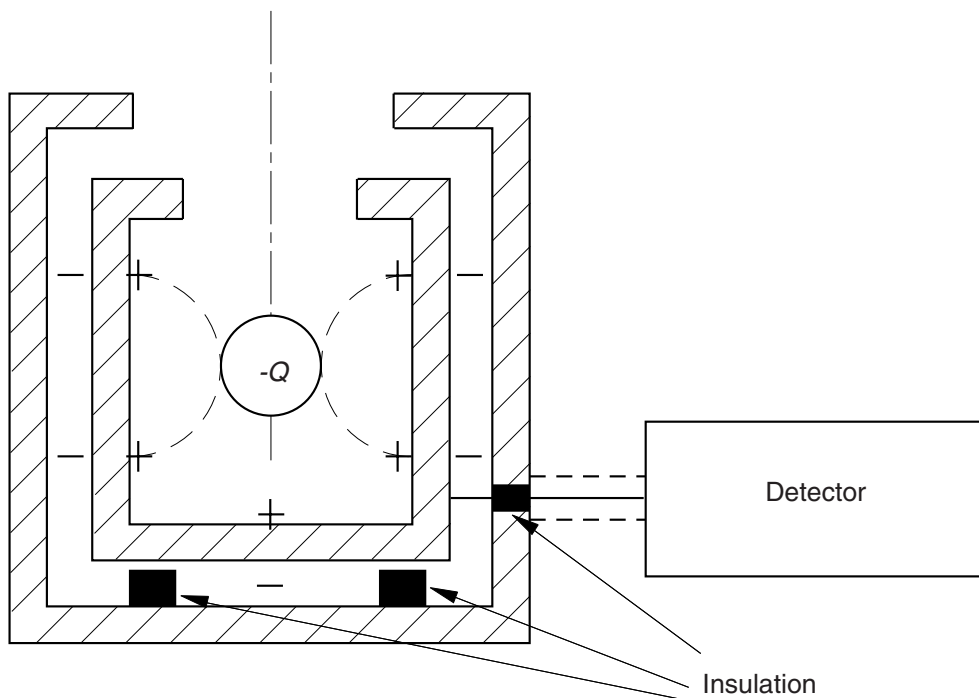


Figure 3. The Faraday pail

5.4 Measurement of charge on Faraday pail

Charge shall be measured using one of three methods.

- a) Measure the charge induced on the outside of the pail with an electrometer amplifier in which the charge sensitivity is defined by a feedback capacitor (C). Ensure that the design and construction of the electrometer circuit and connections from the Faraday pail avoid leakage and microphonic effects and minimize input offset currents and voltages. Determine the zero charge reading by isolating the amplifier input, connecting the pail to earth and then measuring the apparent charge value.
- b) Measure the voltage increase of the pail using a fieldmeter or electrostatic voltmeter with the charge calculated from the change in voltage in relation to the capacitance of the pail system. Ensure that in this mode the capacitance of the pail system is much larger than the capacitance of the charged object to be measured (20 to 100 times) so that the change in pail voltage is small compared to the initial voltage of the object.

NOTE 1. Additional capacitors may be added to adjust sensitivity. C is the value of the total capacitance.

Determine the zero reading using a fieldmeter by connecting the pail to earth.

- c) With continuous charge generation measure the total quantity of charge by integration of the current into the Faraday pail, as indicated by a low resistance meter between the pail and earth.

NOTE 2. Zeroing of current integration measurement requires isolation of the pail from the circuit and checking the zero of the current measurement circuit.

Indicate the quantity of charge transferred to the pail by a direct reading display or calculate it from the measured capacitance and voltage.

5.5 Procedure

5.5.1 Preparation

In preparation for measurement make the following preliminary checks.

- a) Properly bond the operator and all instrumentation to earth.
- b) Remove all materials likely to retain static charge from the vicinity of the area of test. If the operator is wearing garments made of artificial fibre, replace or cover by a suitable static dissipative overgarment.
- c) Check the drift of the displayed reading after zeroing and after introduction of some charge.
- d) Check the absence of influence of the test environment and system, where possible by making measurements with materials or objects expected to give insignificant charge generation (for example a metal object sliding out of an earthed metal tube).

5.5.2 Conduct of tests

Drop samples directly into the pail with no contact to intermediate surfaces. Measure the charge introduced as the difference between the readings before and immediately after introducing the sample.

Allow time to observe both zero drift before introduction of charge and decay of reading after the peak following introduction of charge. Calculate the quantity of charge introduced from the difference between the readings extrapolated to the mid-point time of introduction of the charge.

NOTE. For the transfer of objects into the pail it is important to use the minimum area of contact in the pick up arrangement and avoid any sliding action against insulating surfaces at pick up and release.

Make checks that the method of transfer introduces negligible charge when the charge transfer is expected to be zero. If tests are carried out in a flammable atmosphere then carry out earthing of the pail to remove charge in a safe manner.

Repeat each test measurement five times unless otherwise specified.

Record the temperature and relative humidity of the test environment.

5.6 Expression of results

Charge values are read either directly from a display or calculated from individual parameter measurements using the relationship:

$$Q = CV$$

where:

Q is the charge (coulombs);

C is the capacitance (farads);

V is the voltage (volts).

The capacitance C is either the capacitance of the Faraday pail (including added capacitance) or the feedback capacitor of the electrometer measurement system.

If current to ground is measured then charge is calculated by integrating the current over the duration of the period of measurement.

In studies involving the flow of materials or liquids the mass or volume transferred over the period of measurement shall be measured so that values of charge per unit mass ($C \cdot kg^{-1}$) or per unit volume ($C \cdot m^{-3}$) may be calculated.

Measurements shall be repeated five times so that average values and standard deviations can be calculated and reported unless otherwise specified in product specifications.