3. INSTRUMENTS AND MEASUREMENTS

3.3 ASSESSMENT OF MATERIALS

3.3.1 INTRODUCTION

Problems and opportunities for constructive use of static electricity relate directly to the characteristics of the materials involved. The 'suitability' of materials relates to the requirements of the 'end use'. No one single method of measurement of one single characteristic will assess the suitability for all applications. It is always important to start by an appreciation of end use requirements and then to see which established method of measurement, if any, will provide an appropriate assessment. The following list illustrates some general areas where the characteristics of materials need to be assessed in relation to electrostatic applications and problems.

a) body voltage walking on flooring (risk of shock)
b) body voltage getting out of a car (risks of shock and possible fuel vapour ignition)
c) body voltage by rubbing clothing and materials (shocks when changing hospital bedding, risks of ignition for workers in flammable atmospheres, risks in manufacture and assembly of microelectronic devices)
d) cling of lingerie (comfort, personal image)
e) paper and sheet handling (mechanical handling problems)
f) electrostatic clamping
g) attraction of atmospheric dust and debris (contamination in specialist applications and affecting cosmetic appearance and print quality)
h) collection of dust in an electrostatic precipitator
i) electrostatic paint spraying
j) electrophotography
k) risks of ignition from charged bodies (people and at least partially conducting objects - e.g FIBCs)
l) risks of ignition from charged materials (webs, outer clothing, powders, liquids)
m) risks of damage to sensitive devices (semiconductors, explosives) by proximity to charged surfaces
n) shielding against nearby electrostatic discharges (microelectronic damage and system operation)

In the above list:

- Examples a), b) and c), and to an extent k) and m), require easy removal of charge to earth from a relatively conducting body.
- Examples d), e), g), h), i), k), l) and m) require easy/quick movement of charge over materials themselves. A route for charge movement away to earth is also needed.
- Examples k), l) and to an extent b) and c) require information on the ability to support electrostatic discharges that allow extraction of incendive quantities of energy from charged surfaces
- Example n) is on it's own.

Care needs to be exercised in considering the parameters that are appropriate to measure. For instance, electrostatic charge will arise on the outer surface of garment worn by a person when the clothing rubs against another surface. If the charge separated at the garment surface cannot move easily over the surface and away to earth then it will tend to create a high local surface potential relative to the body inside. However, the local voltage relative to the body will depend both on the quantity of charge separated and the effective capacitance experienced by the surface charge to the body inside. If the body is insulated from earth, by footwear or floor covering, then the charge separated at the clothing surfaces will capacitively couple to the body inside and raise the potential of the whole body relative to earth. This applies whether the charge remains where it arises or moves out over the garment surface. An electrostatic discharge from the relatively conducing structure of an unearthed human body is, in general, much more likely to cause an ignition or damage a microelectronic device than a discharge from a charged garment surface. However, the risk may be radically increased if the garment fabric includes threads of high conductivity (e.g. metal). This is because such threads may allow an electrostatic discharge to access charge rapidly from a large area of garment surface. It can thus be appreciated that where a person cannot reliably be linked to earth (e.g. a fire-fighter/rescuer/worker in a flammable atmosphere) then the concerns are both how much charge separated on the particular clothing material in practical operations and also the conductivity of the fastest routes for charge movement.

Local high potentials on the garment surfaces relative to the person's body are less likely to be relevant. Dissipation of charge over the garment itself is not so important – but the presence of high conductivity threads in the fabric will be.

In the microelectronics industry there should be less concern about the total charge separated at rubbing actions because good care should already have been taken to ensure good earth bonding of people's bodies by footwear and flooring - and/or the use of wrist straps). The retention of charge on garment surfaces is thus primarily of interest in relation to the surface voltages created.

If charge is separated on the undergarments worn with cleanroom garments then risks could arise if electric fields and transients created at discharges can cvouple through the outer garment. This is a question of shielding. Shielding is also, of course, relevant to the protection of sensitive microelectronic devices and assemblies during transit through uncontrolled electrostatic environments.

The retention of charge on materials is a major feature of interest in many situations – for example, the cling of lingerie and in paper handling. This is also of importance to many useful applications of static electricity and to many of the risks and problems that static electricity can cause (as noted above). Two features of importance are:

a) the surface potentials that may arise
b) the time that significant surface potentials are present.

The quantity of electrostatic charge transferred to materials by rubbing and sliding type actions is limited by the character of the materials involved and by the intensity of the mechanical operation. What is then important in practice is the maximum surface potential that will arise for the maximum likely quantity of charge. This potential will be limited if the timescale for dissipation of charge is short compared to the time at which the rubbing surfaces separate. It will also be limited if the separated charge experiences a high capacitance that suppresses the surface potential. Either or both aspects may be used to assess whether risks and problems are associated with retained static charge with particular materials [1,2].

In relation to many practical applications it is important that this timescale is adequately long. In the case of electrostatic precipitation and paint spraying the time for which charge is retained needs to be adequately long – for example, to avoid material falling off prematurely.

The following sections describe approaches for the assessment of materials in terms of charge decay (3.3.2), of capacitance loading (3.3.3), of chargeability (3.3.4), of body voltage during practical activities (3.3.5), of leakage resistance(3.3.6) and of shielding (3.3.7).

3.3.2 CHARGE DECAY

The retention of charge on materials themselves and the problems and risks this presents is assessed by measuring the 'self-dissipation' charge decay capability. This is a question of the time it takes for surface voltages to fall away. Resistivity measurement does not provide this information for materials themselves. This is because resistivity measurement shows the fastest route for charge migration available at the surface of a material, not the slowest. Thus for example with cleanroom and personal protective garment type fabrics that include surface conductive threads it is the resistivity of the threads that is measured, not the charge retaining capability of the fabric between the threads. Studies on a variety of materials have shown no direct relation between charge decay time and resistivity [5].

The most appropriate approach for self-dissipation measurement is simply to separate charge on the surface of the material to be tested by rubbing the surface (triboelectric charging) and observing, without contact, the time it takes for this charge to migrate away. This is the way charge arises in practice and therefore remains the ultimate point of reference to which any other methods must relate.

Tribocharging has been used in a number of studies [1,2,4,5]. Such measurements are not simple to implement and have not yet been packaged into an instrument suitable for easy industrial use. The approach is only really suitable for sheet and layer type materials.

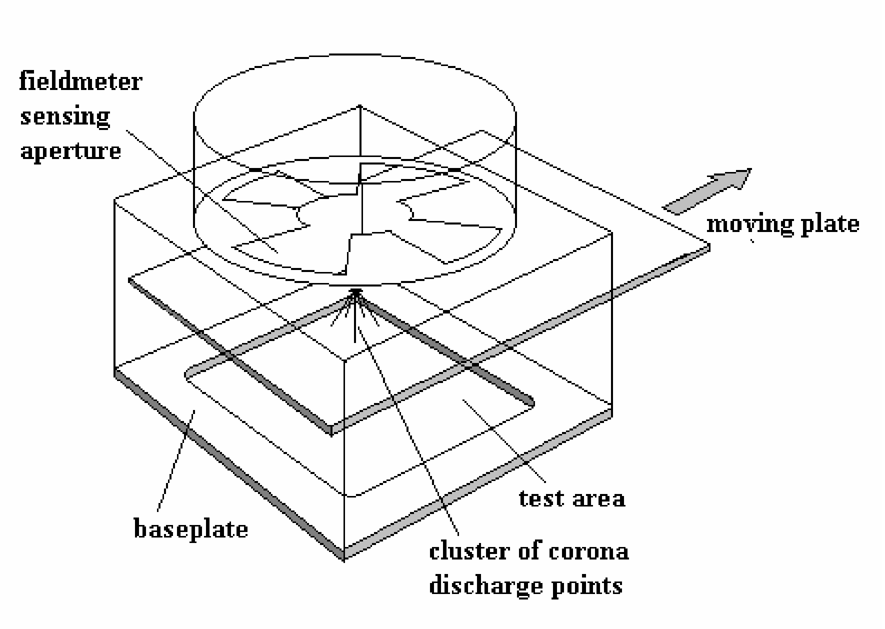
A simple and easy to use approach for charge decay measurement is to use a high voltage corona discharge to deposit a small patch of charge on the material to be tested, move the corona charging electrodes quickly out of the way and use a fast response 'field mill' electrostatic fieldmeter to measure how quickly the deposited charge migrates away by the decrease in the surface voltage. This arrangement has been described in a number of papers [1,2,3,5,6] and is included in a British Standard [7] and an international standard [8]. The corona charge decay approach method avoids problems inherent is other methods of charge decay measurement, such as Federal Test Standard 101C [9,10]. It has been shown in a number of studies that there is reasonable match between charge decay measurements with corona charging and measurements with tribocharging [1,2,11].

The effective control of surface voltages requires that charge can migrate away in a time somewhat shorter than the time for separation of the tribocharging surfaces. Where manual operations are involved it has been suggested that a decay time (initial peak voltage to 1/e of this) of half a second will be adequate [4]. Recent studies suggest that decay times may need to be appreciably shorter, under ¼ s, to avoid problems [1,2,3]. Even shorter decay times may be needed with high speed mechanical handling operations. Longer decay times may be acceptable in relation to retention of cosmetic appearance against attraction of atmospheric dust.

Decay times need to be measured from the initial peak voltage to some specified fraction of this. It is general experience that such decay times depend little, if at all, upon the quantity of charge transferred to the surface and hence the level of initial peak voltage generated. The fraction chosen for the end point of timing may conveniently be 1/e (37%) and/or 10% of the initial peak voltage. The fraction chosen should be clear in the reporting of results. The advantage of using a 10% figure is that if the form of the decay curve flattens out then by the time this level is reached there is not much charge left. The disadvantage is that this may involve excessively long test times. It is suggested that measurement to both levels should be made whenever practical and also that the form of the decay curve is recorded to be available for any fuller analysis deemed necessary.

A physical arrangement for corona charge decay measurement is shown below. A brief pulse of high voltage corona discharge, from a small cluster of discharge points mounted on a moveable plate, is used to deposit a patch of charge on to the surface to be tested. A 'field mill' electrostatic fieldmeter with a fast response (better than 10ms) is used to measure, without contact, the voltage developed on the surface by this charge and how quickly this voltage falls as the charge migrates away. The plate carrying the corona discharge points is moved quickly away (within 20 ms) immediately after corona charge deposition. A corona charging duration of 20ms is convenient. Fast operation enables good measurements to be made of the initial peak surface voltage and decay times even with quite short decay times –

down to less than 50ms. The zero and operational stability of field mill type fieldmeters means that decay times can be measured with confidence out to a million seconds or more if necessary.



Arrangement for measurement of corona charge decay

In practice materials may be used as supported freely and well awy from any earthed surfaces or, at the other extreme, actually resting against an earthed surface. These two extreme situations may be described as 'open backing' and 'earthed backing'. Charge decay measurements need to be made with both these test conditions in assessing general suitability of materials [7,8]. The longer of the open and earthed decay time values should be used.

It is considered generally most appropriate to make measurements on test areas that are initially charge neutral, or nearly so.

The surface voltage measurement performance of charge decay test instruments is appropriately calibrated in terms of a voltage applied to a conducting plane across the whole test aperture area [6]. Decay time measurement performance is calibrated in relation to the RC time constants of combinations of calibrated resistors and capacitors connected from this test surface to earth [6].

3.3.3 CAPACITANCE LOADING

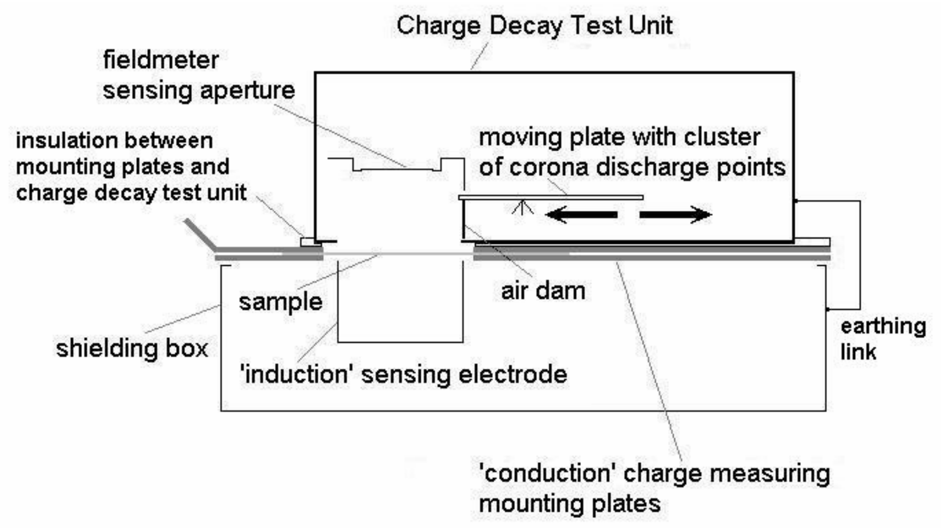
The influence of electrostatic charge on materials to items nearby depends on the level of surface voltage and for how long this is present. The quantity of charge per unit of initial peak surface voltage is effectively a 'capacitance'. If this capacitance is large then only low surface voltages will arise from the quantities of charge likely to arise in practical tribocharging events. Conversely, if the 'capacitance' is low then high voltages will arise. For instance, fabrics that include conductive threads, such as for personal protective clothing and cleanroom garments, show high values of 'capacitance'. Although some such materials show long charge decay times they may present little risk of causing problems [1,2,5]. Thus for many situations it seems that the suitability of materials to avoid problems from retained static charge may be judged by both the charge decay time and by the capacitance exhibited to surface charge.

The 'capacitance' calculated from the quantity of charge required required to create a measured value of surface voltage is not fully valid. The area over which charge is deposited (by tribocharging or by corona) is likely to be much smaller than the area of material of uniform potential for which the voltage measurement instrument was calculated. So the local 'initial peak voltage' will be rather higher than the value interpreted from the fieldmeter measurements. Rather than guess an area for the deposited charge, in order to calculate a real 'capacitance' it is more practical to assess materials in terms of their 'capacitance loading' [1,2]. This is the apparen 'capacitance' as observed for the test material (as $C = Q / V_{pk}$) divided by the apparent 'capacitance' observed for a very thin dielectric layer, such as cling film. It is assumed that there are similar distributions of surface charge for the two materials. This ratio approach takes out concern over differences between instruments and test arrangements.

The charge transferred to a test surface can be measured with the arrangement shown below. The charge is measured as a combination of the conduction and induction signals [1,2]. The conduction charge signal relates to the charge that moves or couples fairly immediately to the sample mounting plates. The induction signal relates to charge held for a time near where it has been deposited and is free to couple up to the inside of the chasrge dcesay test unit and down to the induction electrode. The induction electrode is physically similar to the sensing region of the charge decay test unit so the induction fields from the retained charge is partitioned about equally between the two. The total charge may be expressed as:

$$Q_{tot} = Q_c + f\ Q_I$$

- where the factor f is expected to be about 2.



Arrangement for measuring received charge

With a simple dissipative sample material, such as paper or cling film, it is observed that nearly all the initial observations are associated with 'induction' charge effects and that this decreases as the conduction signal increases. The total corona charge deposited is of course constant, hence the fall of the induction signal, $Q_{i,}$ must match the increase in the conduction signal Q_c. A factor, f, may hence be found that gives a good match between the fall of induction signal to the rise of the conduction signal.

Charge decay and capacitance loading characteristics of materials can vary with the quantity of charge deposited. It is wise to make tests with quantities of charge comparable to those likely to arise in the practical situation or, if this is not known, over a range of quantities of charge. Tribocharging by rubbing may involve quantities of charge in the range 10-50nC so it is appropriate to make measurements down over this range of quantities of charge.

'Capacitance loading' measurements are appropriate to make in combination with charge decay measurement. This is true both for corona charging based studies and for triboelectric charging. [1,2,26]. This approach was the basis of the 'New Work Item' that was proposed to the IEC Standards Committee TC101 in November 2002 [25].

With information on the quantities of charge that can arise from various practical activities it will be feasible to select values of ‘capacitance loading’ that will limit surface voltages to levels below those at which risks and problems can be expected.

Recent studies have shown that the surface voltages that may arise when inhabited cleanroom garment are rubbed, depend primarily to the value of the capacitance loading of the garment fabric, rather than the charge decay time [24, 26,27].

3.3.4 COMMENT ON APPROACHES FOR MEASUREMENT OF ‘CHARGE DECAY’

There are several methods for measurement of ‘charge decay’ described in ‘standard’ documentation and in published literature. The methods of measurement are very different and many of the methods do not actually provide the information likely to be expected by uninitiated/unskilled users and are susceptible to the construction of the materials tested. For methods of charge decay measurement to be considered valid and generally applicable they should fulfill the following requirements:

- they should have demonstrated relevance to end user applications
- they should have demonstrated matching to tribocharging characteristics
- results should not be dependent on particular constructions or features of materials
- results should be independent of the operator so long as appropriate test procedures are followed
- there should be no modification of the material by the conduct of the test and this should be tested (this should also apply to tribocharging methods).
- the method should be quick and easy to use and interpret by non-specialist staff
- suitable equipment should be easy to construct or commercially available.
- approaches should also be backed by peer reviewed published papers describing the equipment and giving supporting experimental measurements. These papers should be referenced in any related ‘standard’ document.

The following notes describe and comment on a number of methods of charge decay measurement in use with their strengths and limitations. The term ‘charge decay’ here covers the voltage created by rubbing a material or surface initially at earth potential and the time taken for this voltage to fall away as the charge migrates away. As will be noted, most of the methods do not fulfill the requirements outlined above.

Corona charging (JCI)

The corona charging approach to charge decay measurement described above offers many practical advantages and has been implemented in compact and easy to use commercial instrumentation. It is in use by non-specialist staff with many types of material in a wide variety of industries around the world. It is included in formal standards documents [7,8]. The method can appropriately be used in conjunction with measurement of ‘capacitance loading’ [1,2].

An uncertainty of this approach is that charging is by a high voltage corona discharge rather than be tribocharging – so comparability needs to be demonstrated as does lack of modification of the surface by the action of corona ionisation.

To enable short decay times to be measured, the method is limited to modest size areas of charge and test area. It is applied to test areas that are initially charge neutral, or nearly so.

Studies have been reported that show comparability between corona and tribocharge decay for a variety of materials [1,2,11] and lack of damage by the action of corona ionisation [11]. These factors should continue to be checked as should the apparent independence to the area charged, the area of the sample and the level of the initial peak surface voltage achieved.

FTS 101C Method 4096

Federal Test Standard 101C Method 4046 [9] has been around for many years and has been subject to a number of comments and refinements [12,13]. The basic approach involves mounting a 5” long 3” wide strip of material between supporting clamps in front of a fieldmeter. A voltage of 5000V is applied to the clamps and the build up of fieldmeter signal observed. The clamps are then earthed and the decay of the fieldmeter signal observed and timed. It is noted in the specification that the method should only be used for ‘homogeneous materials’ - but no guidance is given on how to recognise such materials! Comparative tests showed that many practical materials gave much shorter charge decay times by FTS 101C than are observed with corona charge decay measurements [10]. These tests confirmed that comparable results were indeed obtained with truly homogeneous materials. It was concluded that FTS 101C basically responded to the fastest route for charge movement in the layer of material, whereas corona charge decay showed how charge moved on the surface of materials. This equipment is available commercially from ETS.

ITV Denkendorf

ITV Denkendorf developed a tribocharging method (ITV-TEV) in which a nearly vertical strip of material is held between two earthed clamps and rubbed by polythene rollers on either side as these are moved down the strip under tension. The rubbed area is held stably in front of a fieldmeter to observe the initial peak voltage and the rate of charge decay. The principle of the method seems sound but is only applicable to flexible layer materials and to materials with decay times longer than several tenths of a second. With fabrics rather different behaviour is observed in the warp and in the weft directions. The equipment is not now available commercially.

NASA

A tribocharging method for testing layer materials has been developed at NASA by Gompf [4]. This uses a rotating Teflon brush to tribocharged the sample surface that is earthed around its edge. At cessation of charging the sample is quickly dropped in front of a fieldmeter and the initial peak surface voltage is measured and the rate of decay of this voltage. This seems a good, valid and useful approach. Results are reported to correlate well with safety experience at NASA. There also seems reasonable correlation with two other test methods [14]. As implemented the approach has been limited by using an induction probe type fieldmeter, rather than a 'field mill' type fieldmeter, and by the time taken to move the sample at the cessation of rubbing to the position of observation (a few tenths of a second). Use of an induction probe limits the sensitivity for low surface voltages and the length of decay times that can usefully be measured. The method is also, of course, limited to layer type materials that can be presented as cut samples and those not likely to be damaged by the tribocharged rubbing action. This equipment is not available commercially.

A modification has been proposed to the above approach [15] to try to simulate the risk from the charging of an unearthed person’s body while wearing personnel protective clothing. An isolated pick up disc has been mounted as a backing support for the sample with 220pF capacitance to earth. The idea is that the electrostatic energy picked up by this disc will represent the energy available to create risks of ignition. However, if the sample is mounted on an earthy support then the presence of conductive threads in the test fabric could diminish the quantities of charge observed because of shielding effects. It needs to be recognised that risk may also arise if there are local areas of high voltage on garment fabric surfaces relative to the body – although the incendivity of such discharges will be affected by characteristics of the fabric.

BTTG

A tribocharging method for testing materials is used at British Textile Technology Group (BTTG) [16]. A 300mm diameter disc of material is held under radial tension in a circular conducting frame. The material is charged by hand rubbing with chosen materials. The total quantity of charge separated on the surface is measured in a Faraday Pail unit. A fieldmeter then observes how the surface potential of the middle of the disc varies when the mounting frame is earthed.

As with the ITV and NASA approaches this measures the chargeability of the material. Charge decay behaviour needs to be assessed with care because this will comprise components associated with capacitive coupling via any relatively high conductivity components of the fabric as well as possible slow components of the basic material surface. The approach seems fair in terms of charging the material, but charge decay observations will not be the same as those of observations from the spreading of charge from a local area that is charged by rubbing an initially charge neutral material. It is only applicable for layer type materials that can be presented as cut samples and those not likely to be damaged by the tribocharged rubbing action. This equipment is not available commercially.

BTTG has also developed a corona charging method (Shirley Method for Charge Decay Time Measurement on a Full Garment) for testing whole garments. This involves using a corona discharge to charge an area of the garment, while the garment is hung up vertically from insulated supports. The variation of the potential at the charged area is observed from the time the corona charging electrode system is removed. Charge decay behaviour is observed with four test procedures: charging with the garment unearthed and then earthed via the cuff and ankle area and then charged while continuously earthed via the cuff and via the ankle area. This equipment is not available commercially.

STFI

A method for assessing materials has been developed by STFI [17]. This involves observation of the form of components of the signal observed on the far side of a sample in response to a step function potential applied to an electrode on the near side. With careful interpretation these observations seem to relate to the risks of incendive electrostatic discharges from charged surfaces. The method is not, however, very useful for measuring the charge decay capabilities of the layer. The material is 'charged' by induction so a material will only be charged to a low level if the decay time is long. This means that only small surface voltages will be available for decay time measurements. A field mill type fieldmeter is needed, rather than an induction type, to monitor charging and charge decay. If conductive threads are included in the material tested then their influence will depend on the resistive and capacitance coupling to the earthed mounting. This will affect charge decay observations. The response time of observations to the fast rising applied electric field gives indication of the effective conductivity within the material providing shielding performance. It seems very reasonable that this has a relation to the opportunity for drawing incendive electrostatic discharges from the material surface [18,19]. Again, however, observations could be affected by the resistive and capacitance coupling at the earthed mounting of the sample boundary. This equipment is not available commercially.

Charge plate monitor

Observations are often made using a metal electrode in contact with the test material connected to an electrostatic voltmeter [8,20]. A popular approach is to use a ‘charge plate monitor’. This approach may be useful for assessing how quickly charge may be removed from a conducting item in contact with a material. This is relevant for such situations as a person standing on flooring. It needs to be appreciated that this method does NOT, however, measure the ability of a material to dissipate charge on its own surface. Again, as with FTS 101C etc, the reason is the problem that observations are influenced by linkage to fast routes for charge migration and lack of fair representation of the influence of retained charge. There is also the uncertain influence from the capacitance loading of the contacting electrode. Equipment is available commercially from several sources.

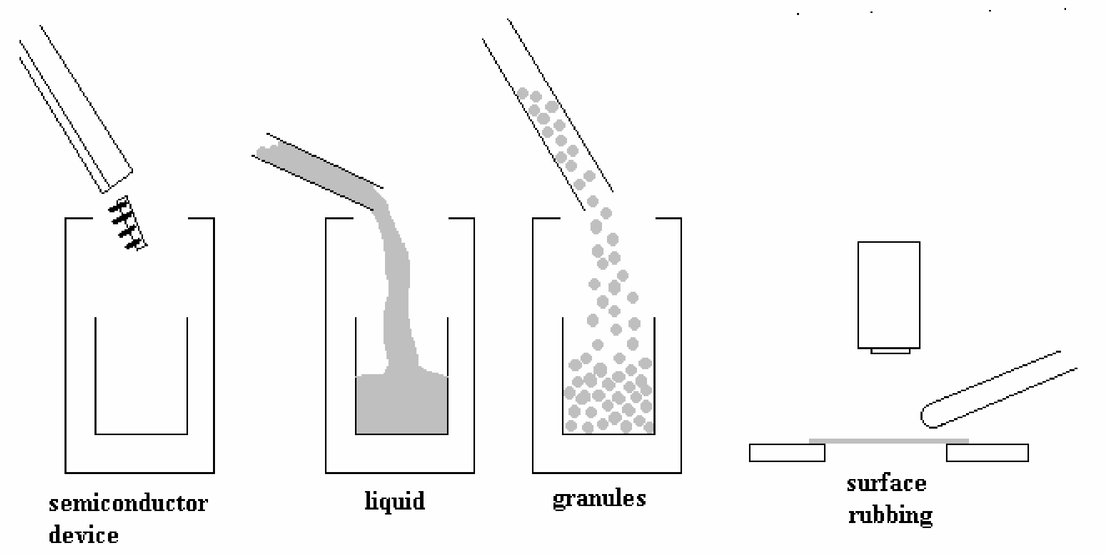
3.3.5 HIGH VALUE RESISTANCE MEASUREMENT

Measurement of high values of resistance, say over 10^{10} ohms, needs to be approached with care [21]. The currents to be measured will be small so care is needed both in the design and construction of measurement circuits and also in the arrangements for measurement. Guard ring techniques need to be used to avoid the chance of leakage affecting readings and electric and magnetic field shielding may be needed. ‘Resistance’ may well be non-linear so values may vary with the voltage applied and with time after application of voltage. The use of high voltages should be avoided as these may lead to surface tracking problems.

Measurement of ‘charge decay’ provides a very easy way to measure very high values of resistance – for example over 10^9 ohms. This may be particularly useful in assessing the leakage resistance of items and connections in practical equipment. A fieldmeter may be used to observe the potential on a relevant metal part and how an applied voltage decays away when the voltage source is removed. With measurement of the capacitance the resistance can be calculated from the RC time constant. For such measurements the set-up needs to be mechanically stable and shielded from the influence of external sources of charge.

3.3.6 CHARGEABILITY

The separation of charge by rubbing is greater with higher speeds and higher pressure of rubbing. It is also affected by the materials involved. Many books on static electricity give a 'triboelectric series' as a list in which the greater separation of materials is supposed to indicate the stronger charging. While the choice of materials may provide some reduction in the maximum charge levels this is not a generally applicable way to control static.



Studies of chargeability need to use, or model, practical charging situations. The Faraday Pail is often used for measurements with, for example, semiconductor devices sliding from shipping tubes, fluid flow from a pipe or granules or powders sliding down a chute and dropping directly into a pail. The main points to note are the appropriate design features for the Faraday Pail (see Section 3.2.5), the need to ensure that items or material falls freely and directly into the pail and that the operator and the sliding surface (as far as feasible) are connected to earth. It is usually useful to note the number, mass or volume of material entering the pail for the quantity of charge observed.

Where liquids, granules on powders are charged by flowing or sliding actions, the rate of charge decay may be observed simply by collecting some of the material directly on an earthed surface or in a shallow earthed cup and using an earthed fieldmeter mounted just above to observe the field created by the accumulated charge. The fieldmeter reading will show the strength of the initial charge and how quickly this decays as the charge migrates away.

For people walking on floor coverings the most appropriate measurement parameter is the body voltage. This needs to be measured and recorded using a suitably fast electrostatic voltmeter and recorder a) to show the influence of the frequency of repetitive body movements (e.g. stepping) building up charge, and b) to allow observation of the rate of charge decay as a competing limiting factor when the body action stops. Because body actions, and the associated changes in charge and/or capacitance, can be quite quick the response time of the measuring and recording equipment needs to be better than 1/10 second.

Where measurements are made of chargeability in terms of the surface voltage, or degree of cling, created by rubbing actions it is recommended that the quantity of charge transferred is also measured. Observations from rubbing actions often vary greatly test to test and between different operators. Measurement of the charge transferred provides a way to ‘normalise’ results. If the charge received by the test surface cannot conveniently be measured directly then measurements may equally well be made of the reverse polarity counter charge on the ‘rubber’ using a Faraday Pail (see Section 3.2.5). It is appropriate to use an initially charge neutral rubbing rod or to be sure to measure the change in charge on the rubbing item [1,2].

3.3.7 SHIELDING

Shielding against electric field transients is needed to protect sensitive microelectronic devices and assemblies against electrostatic damage while in electrostatically unprotected areas. Body voltages can rise to around 20kV and spark discharges could arise at any voltage up to this when packages contacted earth. Current risetimes may be down to 1ns, or less. As device sensitivities may be down around 100V or less, it can be appreciated that good shielding performance needs to offer attenuations of at least 200:1 over the frequency range from 10Hz to 1GHz. Methods of performance measurement need to be able to cover this range.

Shielding performance depends upon conductivity within the material. This also has a relevance to the opportunity to draw energetic electrostatic sparks from charged surfaces [17,18]. Studies of shielding performance can hence be expected to have relevance to risks of incendive discharges [19].

From the device protection point of view, the most desirable method to measure shielding performance would be to have a fully isolated discharge source or detector inside the shielded enclosure and the corresponding item outside. This raises many practical difficulties. Probably the nearest approach would be a detector inside the enclosure that modelled the type of device to be protected by the enclosure but included elements that would indicate exposure to electric fields and currents of the level of interest with balanced sensitivity over the frequency range of interest. The nearest approach might be a semiconductor device with a number of breakdown gaps and fusible elements of known failure characteristic. Present methods for assessing shielding performance use application of a unipolar, short risetime electric field pulse with differential oscilloscope observation of signals on the reverse side of the test sample. A 'human body model' type discharge pulse is often used [22,23]. A recent standard has assessed performance in terms of the fractional energy transfer through the sample [23]. A deficiency of present methods is they provide no information on the variation of performance with frequency so no guidance is given on suitability of materials for waveforms other than the test waveform. An approach was developed to provide this information [19,23] but his has not been developed into commercially available equipment.

The approach developed by STFI for assessing materials [17] seems to provide information on the opportunity for occurrence of incendive sparks from charged material surfaces. It may be that measurement of the variation of shielding performance with frequency up to a few MHz will also be able to yield comparable information [19].

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