8 Static Electricity

8.1 INTRODUCTION

The term *static electricity* implies electricity not in motion or electricity that is stationary; in other words, electrons that normally constitute the flow of electricity are in a state of balance appearing static or stationary. In a broad sense, static electricity may represent a battery or a cell, where a potential difference exists across the two terminals. No current can flow until a closed circuit is established between the two, and a fully charged capacitor may be viewed as having static electricity across its plates. However, the aspect of static electricity that this chapter will focus on is the effect of stationary electrical charges produced as the result of contact between two dissimilar materials. Static electricity has been recognized since the mid-1600s. Scientists such as William Gilbert, Robert Boyle, and Otto Von Guericke experimented with static electricity by rubbing together certain materials that had a propensity toward generating electrical charges. Subsequently, large electrostatic generators were built using this principle. Some of the machines were capable of generating electrostatic potentials exceeding 100 kV.

Static electricity is a daily experience. In some instances, the effects are barely noticed, such as when static electricity causes laundry to stick together as it comes out of the dryer. Sometimes static electricity can produce a mild tingling effect. Yet, other static discharges can produce painful sensations of shock accompanied by visible arcs and crackling sounds. Static electricity can be lethal in places such as refineries and grain elevators, where a spark due to static discharge can ignite grain dust or gas vapors and cause an explosion. An understanding of how static electricity develops and how it can be mitigated is essential to preventing problems due to this phenomenon. This chapter discusses static electricity and its importance in the field of electrical power quality.

8.2 TRIBOELECTRICITY

Triboelectricity represents a measure of the tendency for a material to produce static potential buildup. Figure 8.1 contains the triboelectric series for some common materials. The farther apart two materials are in this series, the greater the tendency to generate static voltages when they come into contact with each other. Cotton, due to its ability to absorb moisture, is used as the reference or neutral material. Other materials such as paper and wood are also found at the neutral portion of the triboelectric series. Substances such as nylon, glass, and air are tribo-positive and materials such as polyurethane and Teflon are tribo-negative in the series. Triboelectric substances are able to part with their charges easily. Substances that come into contact with materials positioned away from the neutral part of the series capture electrical charges more readily.

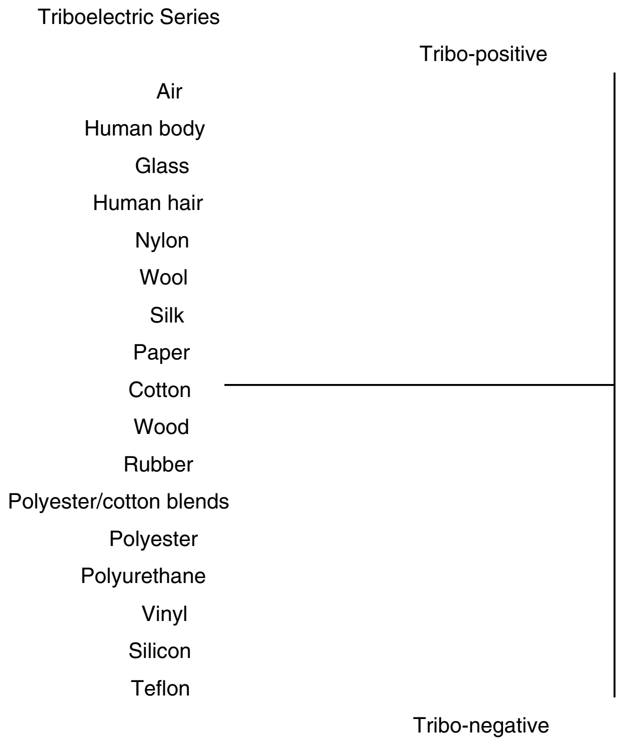

FIGURE 8.1 Triboelectric series of materials. Cotton is used as the neutral or reference material. Tribo-negative materials contain free negative charges, and tribo-positive materials contain free positive charges. These charges are easily transferred to other materials that they might contact.

How are static charges generated? In Figure 8.2, one tribo-negative material (A) and one tribo-positive material (B) come into contact with each other. Figure 8.2A shows the two materials prior to contact and Figure 8.2B illustrates the condition just after contact. During contact, electrons from the negative materials are quickly transferred to the positive material. Some of the electrons neutralize the free positive charges in B; the rest of the electrons remain free and produce a net negative charge. The faster the contact and separation between the substances, the greater the amount of charges trapped on material B. The net charge is a measure of the static electricity. This charge remains on surface B until being discharged to another surface or neutralized.

This is the same phenomenon that takes place when a person walks across the carpet at home and then touches a water faucet or other grounded device in the house. Walking across the carpet allows charges to be picked up from the carpet material, which are stored on the body of the person. When a grounded object such as a faucet is touched, the charge contained on the body is discharged to the ground. At low levels, the discharge produces a tingling sensation. At high charge concentrations, an arc may be produced along with a sharp sensation of pain.

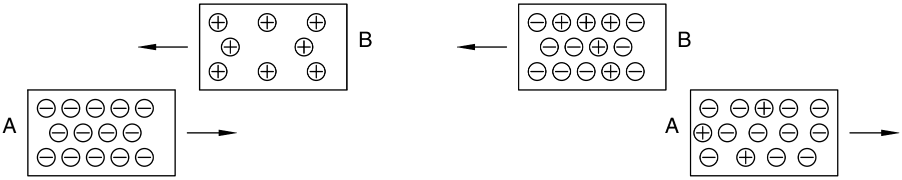

FIGURE 8.2 Mechanism of charge transfer between two materials due to contact and separation.

How many of us can relate to the experience of getting out of a car and receiving an electrical shock when touching the metal body of the car? Walking through a grocery store and experiencing an electrical shock when touching the refrigerated food case is another example of static buildup and discharge. These examples have two things in common: relative motion and contact between two substances that are insulators. A car moving through air, especially if the air is dry and of low humidity, collects electrical charges on its body. When contact is made with the car, electrical charges tend to equalize between the body of the car and the person touching the car. This exchange of charges gives a sensation of electrical shock. The synthetic flooring material used in stores is highly tribo-negative. On a dry day, just walking across the floor can cause accumulation of a charge on a person. When any grounded object is touched, the collected charges are discharged to the object. In these examples, moisture plays an important role in determining the level of electrostatic charges that accumulate on an object or a person. Static discharges are rarely a problem on rainy days due to considerable charge bleeding off that occurs when the air is full of moisture. The moisture may also be present on a person's hands, clothing, and shoes. Also, the body of a car that is damp does not generate large amounts of static electricity. Even though small levels of electrostatic voltages may still be produced on wet days, the levels are not sufficient to cause an appreciable charge buildup and discharge.

8.3 STATIC VOLTAGE BUILDUP CRITERIA

Table 8.1 shows the voltage levels that can build up on a surface due to static electricity. The threshold of perception of static discharge for average humans is between 2000 and 5000 V. A static voltage buildup of 15,000 V or higher is usually required to cause a noisy discharge with accompanying arc. From the table, it can be readily observed that such voltage levels are easily generated during the course of our everyday chores. The type of footwear worn by an individual has an effect on static voltage accumulations. Shoes with leather soles have high enough conductivity to minimize static voltage buildup on the person wearing them. Composite soles and crepe soles have higher resistance, which permits large static buildups. The walking style of a person also affects static discharge. Fast-paced walking on a carpeted floor or synthetic surface tends to produce higher static voltages than slower paced walking, as the electrical charges that are transferred do not have sufficient time to recombine with the opposite-polarity charges present in the material

TABLE 8.1
Static Voltages Generated During Common Day-to-Day Activities

Action	Static Voltage (V)
Person walking across carpet wearing sneakers (50% RH[a])	5000
Plastic comb after combing hair for 5 sec	2000
100% acrylic shirt fresh out of the dryer	20,000
Common grocery store plastic bag (65˚F, 50% RH)	300
Car body after driving 10 miles at 60 mph on a dry day (60°F, 55% RH)	4000
Person pushing grocery cart around a store for 5 min (45°F, 40% RH)	10,000

[a] RH = relative humidity.

TABLE 8.2
Electrostatic Susceptibility of Common Semiconductor Devices

Device Type	Susceptibility (V)
MOS/FET	100–200
J-FET	140–10,000
CMOS	250–2000
Schottky diodes, TTL	300–2500
Bipolar transistors	380–7000
ECL	500
SCR	680–1000

they are in contact with. A person's clothing also has an effect. Cotton fabrics do not tend to collect static charges, whereas clothing made of synthetics and polyester allows large static accumulations. A person's skin condition can also influence static discharge. People with drier skin are more prone to large static charge buildup and subsequent discharges that are painful. This is because the surface resistivity of dry skin is considerably higher than for skin that is moist.

To humans, experiencing static discharge may mean nothing more than possible brief discomfort, but its effect on electronic devices can be lethal. Table 8.2 indicates typical susceptibility levels of solid-state devices. Comparing Tables 8.1 and 8.2, it is easy to see how electrostatic voltages are serious concerns in facilities that manufacture or use sensitive electronic devices or circuits. Discharge of electrostatic potential is a quick event, with discharges occurring in a range of between several nanoseconds (10^{-9} sec) and several microseconds (10^{-6} sec). Discharge of static charges over a duration that is too short, causes thermal heating of semiconductors at levels that could cause failures. The reaction times of protective devices are slower than the discharge times of static charges; therefore, static charges are not easily discharged or diverted by the use of protective devices such as surge suppressers or zener diodes.

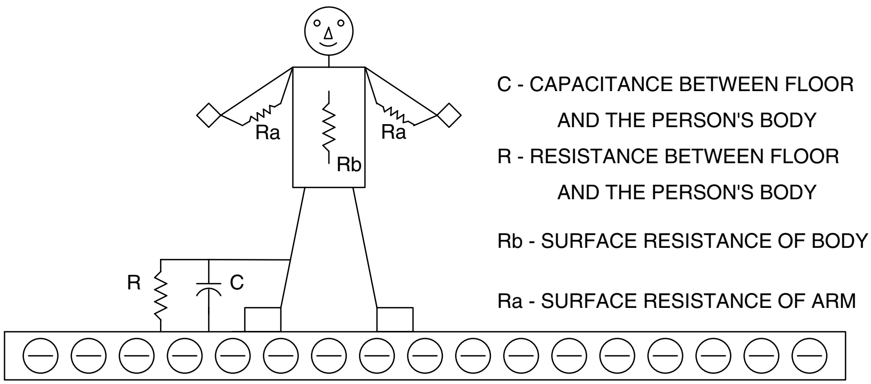

FIGURE 8.3 Static generator model of person walking across a tribo-negative floor.

Static voltages are not discharged by grounding an insulating surface such as a synthetic carpet or a vinyl floor because electric current cannot flow across the surface or through the body of an insulating medium. This is why control of static charge is a careful science that requires planning. Control of static charge after a facility is completely built is often a difficult and expensive process.

8.4 STATIC MODEL

All models constructed for the study of static voltages involve two dissimilar materials with capacitance coupling formed by an intervening dielectric medium. Figure 8.3 shows an example of a static generator model. Here, two electrodes form capacitor *C*, one of which might be the body of a person and the other highly tribo-negative flooring material. The footwear worn by the person is the dielectric medium helping to form a capacitor-resistive network. The body surface resistance of the person is the discharge path for any accumulated potentials. This resistance determines how quickly the charges might be dissipated through air or via contact with a grounded object. In any problems involving suspected static electricity, the three factors of static generator, capacitor network, and discharge path should be included in the model. Once these are determined, a solution to the problem becomes more evident.

8.5 STATIC CONTROL

In facilities that handle or manufacture sensitive electronic devices, static control is a primary concern. The two important aspects of static control are control of static on personnel and control of static in the facility. Both these issues are part of a composite static control strategy. Static control in personnel starts with attention to the clothing and shoes worn by people working in the environment. Use of cotton clothing is essential, as cotton is neutral in the triboelectric series. Leather-soled shoes are preferred to shoes with composite or crepe soles. Shoe straps made of semiconductive material can be wrapped around a person's ankles and attached to the heels of his shoes so that any charge collecting on the body or clothing of the individual is promptly discharged. Charge accumulation is kept to a minimum in much the same way as a capacitor shunted by a resistor would have smaller charge buildup across its electrodes. Straps worn around the wrist are attached to a ground electrode by means of a suitable ground resistor, which plays an important role in the effectiveness of wrist straps. The resistor helps prevent the buildup of static voltages on the person and limits the rate of discharge of static voltage that does build up to a safe level. Typically, ground resistors in the range of 1 to 2 MΩ are used for the purpose. Too high of a grounding resistance would allow static potential to build up to levels that might be hazardous to sensitive devices being handled. Too low of a resistance could result in a high rate of discharge of static potential, which can cause damage to equipment containing sensitive devices.

Antistatic mats are provided for the operators of sensitive equipment to stand on. Antistatic mats are made of semiconductive material, such as carborized rubber, which provides surface-to-ground resistances ranging between 10^4 and 10^6 Ω. The mats are equipped with pigtail connections for attachment to a ground electrode. When the operator stands on the mat, the semiconductive material discharges any static potential present on the person to a safe level in a methodical manner so as to prevent damage to equipment or electrical shock to the person being discharged. As long as the operator is standing on the mat, static voltages are kept to low levels that will have no deleterious effect on sensitive equipment the person might contact. Figure 8.4 contains a typical representation of an operator in a static discharge environment operating a sensitive electrical machine. As mentioned earlier, the clothing and shoes worn by the person are also part of the overall static control plan and ought to be treated as equally important.

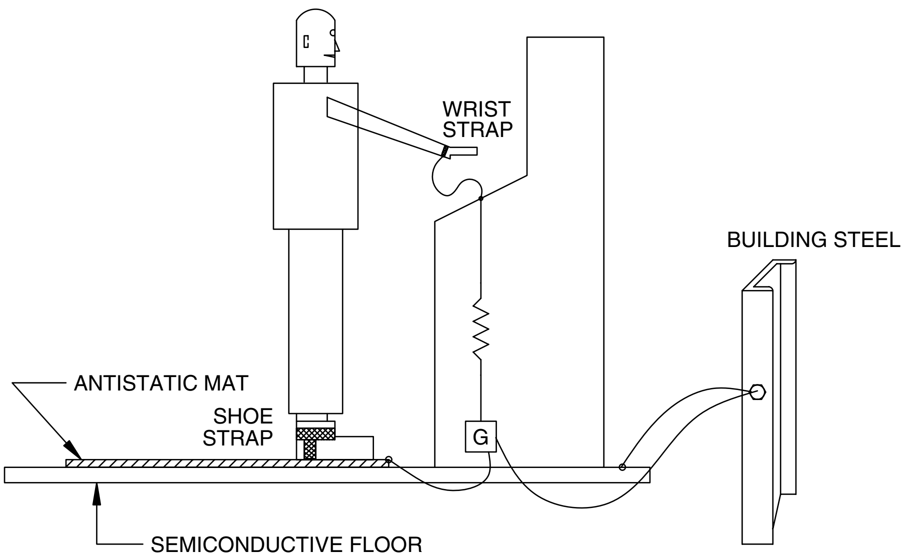

FIGURE 8.4 Static-protective workstation setup showing the use of a wrist strap, a shoe strap, and an antistatic floor mat.

8.6 STATIC CONTROL FLOORS

In static-sensitive areas where no significant level of static voltages may be tolerated, antistatic flooring may be installed. Antistatic flooring is available in two forms: tiles installed on bare concrete surfaces or a coating applied to existing finished floors. Static-control flooring provides surface-to-ground resistances ranging between 10^6 and 10^9 Ω. Semiconductive property enables prompt discharge of static potential accumulated on any person entering the space protected by the floor. Antistatic tiles come in various sizes that can be applied with an adhesive agent to any finished concrete floor surface. Liquid antistatic coatings are applied to clean, finished floor surfaces using any conventional application methods such as rollers or fine brushes. Once cured, such a surface coating provides a semiconductive surface suitable for static prevention. Several precautions are necessary in the installation and care of antistatic floors. Floor mats should be provided at all entrances to the protected area so the amount of debris (dust or dirt) on the floor is kept to a minimum. Floors may be occasionally damp mopped to remove accumulated debris from the floor surface, but floor wax is not to be applied to antistatic floors. Application of floor wax reduces the effectiveness of the flooring in reducing static buildups and in some cases can actually worsen the situation. Grounding the static-control floor is also essential. This is accomplished by using strips of copper in intimate contact with the floor material and bonding the strips to the building ground grid system. Multiple locations of the flooring should be bonded to ground to create an effective antistatic flooring system. Efforts should be made to prohibit abrasive elements such as shoes with hard heels, the wheels of carts, or forklift trucks. Any marking due to such exposure should be promptly removed using wet mops or other suitable cleaners.

8.7 HUMIDITY CONTROL

Humidity is an important factor that helps to minimize static voltage buildups. A 30- to 50-fold reduction of static voltage buildup may be realized by increasing the humidity from 10% to approximately 70 to 80%. A person walking across a carpet and generating 30,000 V at 10% humidity would possibly generate only 600 to 1000 V if the humidity was increased to 80%. The static potential levels might still be high enough to damage sensitive electronic devices, but these are more easily controlled or minimized to below harmless levels. For enclosed spaces containing susceptible devices, humidity enhancement is an effective means of minimizing static voltage accumulations.

8.8 ION COMPENSATION

As noted earlier, static voltages are due to contact between materials that are triboelectric. Such materials have excess charges that are easily imparted to any surface with which they come into contact. If the contact location is well defined, static voltage generation can be minimized by supplying the location with a steady stream of positive and negative ions, which neutralize charges due to triboelectricity. Any

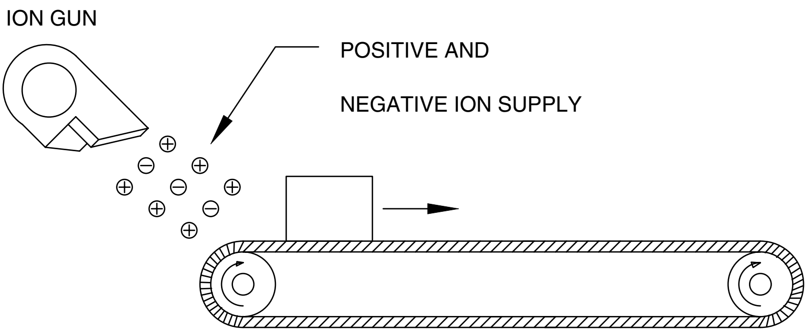

FIGURE 8.5 Use of ion gun to neutralize potential static buildup.

unused ions eventually recombine or discharge to ground. Figure 8.5 illustrates the use of an ion gun in a static control application where friction between a conveyor and the roller generates large static potentials. By providing a steady stream of ions, static potentials can be controlled. Use of an ion gun for static control is suitable only for small spaces. The ions are typically discharged from the gun in the form of a narrow laminar flow with ion concentrations highest at the point of discharge, and the static gun must be pointed directly at the source of the static problem for effective compensation to occur. Away from this targeted location, substantial portions of the positive and negative ions supplied from the gun recombine and are not available for static control. Also, depending upon the application, several ion guns may be necessary to effectively control the static problem.

8.9 STATIC-PREVENTATIVE CASTERS

A problem that has been frequently observed in facilities such as grocery stores is the buildup of static voltage due to the use of metal carts with synthetic casters. Figure 8.6 indicates how static potentials are generated due to relative motion between the cart's wheels and the floor. As the shopper pushes the cart through the store, static voltages are generated at the wheels and transferred to the body of the shopper. Static potentials build to high values in a cumulative manner as the cart is pushed around the store. If the person pushing the cart contacts a grounded object such as the refrigerated food case, sudden discharge of the static potential occurs. Depending on the level of the static voltage, the intensity of the discharge can be high. One means of preventing this phenomenon is the use of antistatic wheels on the carts. These wheels are made of semiconductive materials such as carbon-impregnated rubber or plastics that minimize production of static voltages. Coating the surface of the floor with static-preventive coating is also an option, but due to the degree of traffic involved in applications such as these this is not an effective long-term solution. Incorporating other means of static control, such as the use of antistatic mats at strategic locations of the store, should also be considered. All of these steps should be part of an overall static prevention program for the store.

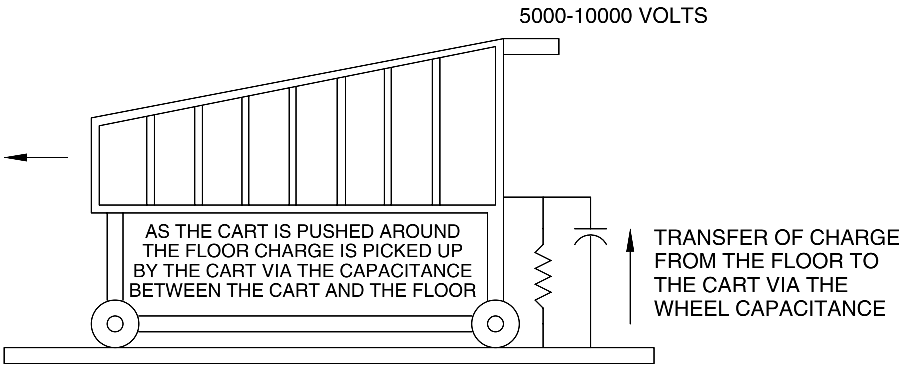

FIGURE 8.6 Generation of static potential due to movement of the cart wheel on the synthetic floor, which supplies the charges caused by triboelectricity.

8.10 STATIC FLOOR REQUIREMENTS

As discussed earlier, many types of facilities require antistatic flooring to prevent buildup of high static potentials. A healthcare facility is one such example of a building that requires antistatic floors, especially in locations where anesthesia is used and in adjoining spaces. The NFPA 99 Standard for Health Care Facilities makes recommendations for static prevention in such applications. These facilities typically require conductive flooring along with a minimum humidity level of 50%. The requirements for healthcare facilities stipulate a maximum resistance of 10^6 Ω for floor resistance measured (Figure 8.7) by using two test electrodes, each weighing 5 lb with a circular contact area 2.5 inches in diameter. The surface is made of aluminum or tinfoil backed by a 0.25-inch-thick layer of rubber. The electrodes are placed 3 ft apart on the floor to be tested. The resistance between the points is measured with an ohm meter, which has an open circuit voltage of 500 VDC and nominal internal impedance of not less than 100,000 Ω. Usually, five or more measurements are made in each room and the values averaged. No individual measurements should be greater than 5 MΩ, the average value should not be less than 25,000 Ω, and no individual measurements should be less than 10,000 Ω. Measurements should also be made between the flooring and the ground grid system of the room, and these values should also be as specified above. Upper limit is not stipulated for resistance measurements made between one electrode and the ground. The lower limit of 25,000 Ω is intended to limit the current that can flow under fault conditions. Such guidelines may also be adopted for facilities that house sensitive electrical or electronic devices. Typically, measurements are made after installation of a new floor. With use, the resistance values typically increase; therefore, periodic tests are necessary to assess the condition of the floor. If high-resistance locations are found, the floor should be cleaned or retreated as needed to ensure that the floor will continue to provide adequate performance.

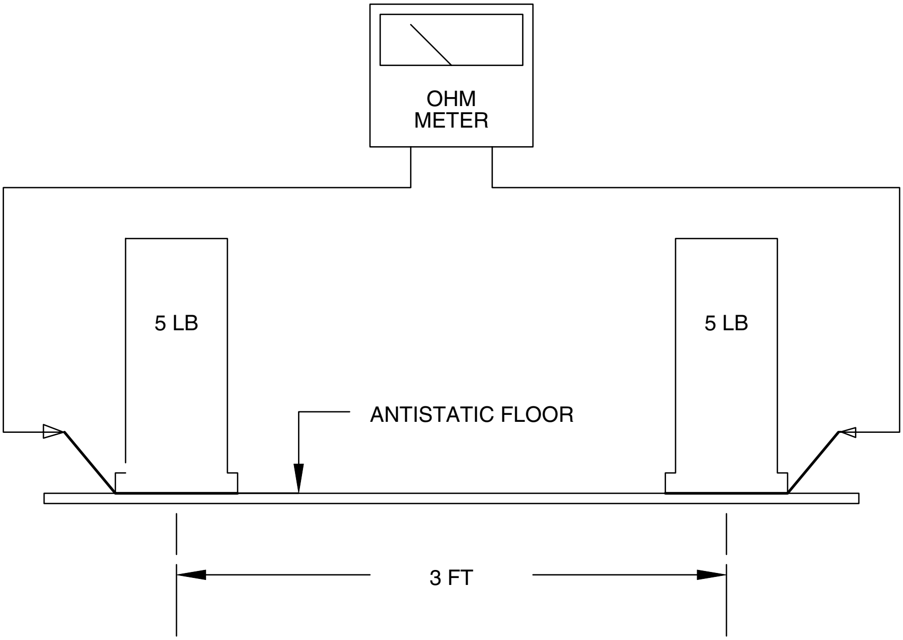

FIGURE 8.7 Measurement of surface resistance using 5-lb electrodes according to the NFPA 99 Standard for Health Care Facilities.

8.11 MEASUREMENT OF STATIC VOLTAGES

Static voltages are measured using an electrostatic meter, a handheld device that utilizes the capacitance in air between a charged surface and the meter membrane. Figure 8.8 shows how a static meter is used to measure static voltages. The meters are battery powered and self-contained; the meter scale is calibrated according to the distance of the meter membrane from the point at which static potentials are to be measured. Static meters are useful for detecting static potentials ranging between 100 and 30,000 V.

8.12 DISCHARGE OF STATIC POTENTIALS

What should be considered a safe static potential level? From Table 8.2, a potential of 100 V may be established as the maximum permissible level for facilities handling or using sensitive devices. A model for safe discharge of static potentials might be developed as follows. A capacitor (C) charged to a voltage of E and discharged through a resistance R will discharge exponentially as determined by the following expression:

$$V = Ee^{-t/RC}$$

where t is the instant in time after closing the switch at which the value of V is required. The voltage across the capacitor decreases exponentially as dictated by the

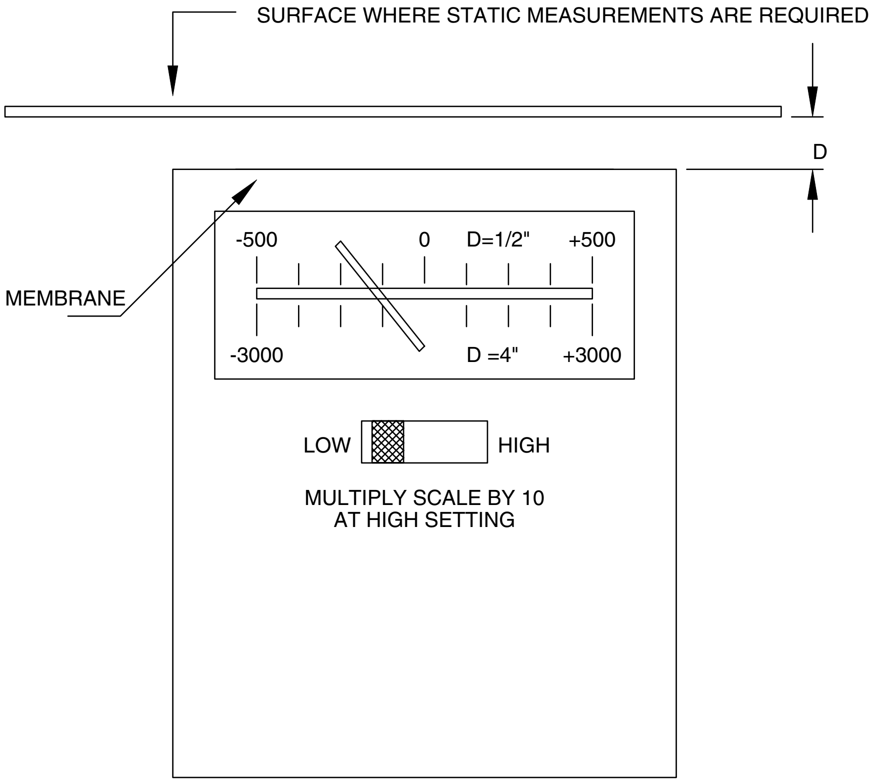

FIGURE 8.8 Static voltmeter. The meter scale is calibrated at .5 and 4 inches away from the test surface.

product of the quantity *RC*, which is known as the time constant of the series resistive/capacitive circuit. The circuit model is shown in Figure 8.9

Example: A triboelectric material with a capacitance of 1 μF is charged to a potential of 20,000 V. What is the value of the resistance required to discharge the material to a safe voltage of 100 V in 1 sec? The expression is given by:

$$100 = 20{,}000e^{-1.0/R(0.000001)}$$

$$1/e^{1{,}000{,}000/R} = 0.005$$

Therefore,

$$e^{1{,}000{,}000/R} = 200$$

$$1{,}000{,}000/R = \ln(200) = 5.298$$

$$R \cong 189\ \kappa\Omega$$

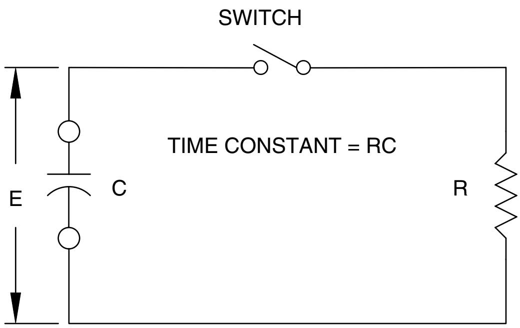

FIGURE 8.9 Capacitance discharge configuration used in static voltage discharge model.

This is the maximum value of resistance to be used to discharge the capacitor to 100 V in 1 sec. In the same example, if the capacitor was initially charged to 30,000 V and using R = 189 kΩ, the time to discharge to 100 volts is 1.078 sec (the reader is encouraged to work this out).

In the design of a static-control system, parameters such as capacitance of the personnel, maximum anticipated potential static buildup, and the time to discharge the personnel to safe levels should be known for the model. This is also true when designing static discharge systems for containers entering static protected environments. Such containers should be discharged to safe levels prior to entering the protected space.

8.13 CONCLUSIONS

Static potentials are troublesome in many ways. While examining many different types of facilities experiencing static phenomena, the author has seen firsthand the damaging effects of such static voltage accumulations. In one case, static voltage problems resulted in disruption of operation of a car dealership by locking up the computers several times a day. A semiconductor manufacturing facility was affected due to static potentials building up to levels exceeding 30,000 V. The voltages built up on personnel walking across the production floor on metal gratings that had been coated with a synthetic coating to prevent corrosion. Grocery stores have been prone to static problems primarily due to the use of carts with wheels made of synthetic materials that are highly nonconductive. A facility that handles hazardous chemicals was shut down by the local jurisdiction because static voltages were creating a variety of problems, including malfunction of material-handling equipment. While the underlying problem was the same in each of these cases, the cures were different. In some instances, the problem was corrected by a single fix and in other cases a combination of fixes was necessary. Static electricity is not easy to identify because even at levels far below the threshold of human perception equipment damage or malfunction can result. This chapter has attempted to provide the basic tools necessary to identify static potentials and solutions for dealing with them.