

***Institute of Environmental Sciences and
Technology***

IENT-RP-CC052

Contamination Control Division
Recommended Practice 052

**Understanding, Identifying,
and Controlling Electrostatic
Charge in Cleanrooms and
Other Controlled
Environments**



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First printing, August 2021

ISBN: 978-1-937280-46-8

ISBN: 978-1-937280-45-1

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Understanding, Identifying, and Controlling Electrostatic Charge in Cleanrooms and Other Controlled Environments

IEST-RP-CC052.1

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1 SCOPE AND LIMITATIONS

1.1 Scope

This Recommended Practice (RP) provides a basis for understanding how electrostatic charge occurs. This RP discusses problems caused by electrostatic charge in cleanrooms, as related to particle management, physical damage from discharge and process interruptions from transient electromagnetic interference (EMI). This RP also provides suggestions for identifying and resolving such risks by means such as dissipation of charge from conductors and process-essential insulators that have an opportunity to interact with ESD sensitive (ESDS) items. Such conductors include personnel, conductive components in production equipment and associated fixtures.

This RP discusses sources of electrostatic charge generation in cleanrooms and other controlled environments and how the environment, products and equipment will be affected when such charges are uncontrolled. Methods for monitoring the risk of electrostatic charge issues, minimizing generation, and selection of equipment for the remediation of charges will also be discussed.

The user is referred to step by step procedures for measurement of electrostatic issues in standards and recommended practice documents by the ESD Association. This RP provides supplemental information which is required to understand and execute the prescribed measurements.

1.2 Limitations

This RP excludes specific evaluation and qualification related to the protection of ordnance, flammable materials, and explosives. This RP does not prescribe design or control limits; quality acceptance standards; process issues; or health, safety, and environmental issues and practices outside of contamination control issues. Users should establish their own quality standards.

Whereas there is a summary of tests of electrostatic control parameters shown in Appendix B, the main emphasis of this document remains on understanding how to deal with static charge rather than quantifying the appliances of charge mitigation.

This RP does not purport to address safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use of this RP.

2 REFERENCES

The cited editions of the following documents are incorporated into this Recommended Practice to the extent specified herein. Users are encouraged to investigate the possibility of applying the most recent editions of the references.

2.1 Reference Documents

ANSI/ESD S1.1-2013: ESD Association Standard for the Protection of Electrostatic Discharge Susceptible Items – Wrist Straps.

ANSI/ESD STM2.1-2018: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Garments – Resistive Characterization.

ANSI/ESD STM3.1-2015: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Ionization.

ANSI/ESD SP3.3-2016: ESD Association Standard Practice for the Protection of Electrostatic Discharge Susceptible Items – Periodic Verification of Air Ionizers.

ANSI/ESD STM4.1-2017: ESD Association Standard for the Protection of Electrostatic Discharge Susceptible Items – Worksurfaces – Resistance Measurements.

ANSI/ESD STM4.2-2012: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items - ESD Protective Worksurfaces - Charge Dissipation Characteristics.

ANSI/ESDA/JEDEC JS-001: ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing – Human Body Model (HBM) – Component Level.

ANSI/ESDA/JEDEC JS-001-2017: ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing – Human Body Model (HBM) – Device Level.

ANSI/ESD S8.1-2017: ESD Association Standard for the Protection of Electrostatic Discharge Susceptible Items – Symbols – ESD Awareness.

ANSI/ESD STM9.1-2014: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Footwear – Resistive Characterization.

ANSI/ESD SP9.2-2019: ESD Association Standard Practice for the protection of Electrostatic Discharge Susceptible Items - Footwear - Foot Grounders Resistive Characterization (not to include static control shoes).

ANSI/ESD SP10.1-2016: ESD Association Standard Practice for the Protection of Electrostatic Discharge Susceptible Items – Automated Handling Equipment (AHE).

ESD ADV11.2-1995: ESD Association Advisory for the Protection of Electrostatic Discharge Susceptible Items - Triboelectric Charge Accumulation Testing.

ANSI/ESD STM11.11-2015: ESD Association Standard for Protection of Electrostatic Discharge Susceptible Items – Surface Resistance Measurement of Static Dissipative Planar Materials.

ANSI/ESD STM11.12-2015: ESD Association Standard Test Method for Protection of Electrostatic Discharge Susceptible Items – Volume Resistance Measurement of Static Dissipative Planar Materials.

ANSI/ESD STM11.13-2018: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Two-Point Resistance Measurement.

ANSI/ESD STM12.1-2019: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items - Seating - Resistance Measurement.

ANSI/ESD S13.1-2019: Provides electrical soldering/desoldering hand tool test methods for measuring current leakage, tip to ground reference point resistance, and tip voltage.

ANSI/ESD STM15.1-2019: Methods for the Resistance Testing of Gloves and Finger Cots.

ANSI/ESD S20.20-2014: ESD Association Standard for the Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

ESD ADV53.1-1995: ESD Association Advisory for Protection of Electrostatic Discharge Susceptible Items - ESD Protective Workstations.

ANSI/ESD STM97.1-2015: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Footwear/Flooring System – Resistance Measurement in Combination with a Person.

ANSI/ESD STM97.2-2016: ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items – Footwear/Flooring System – Voltage Measurement in Combination with a Person.

ANSI/ESD S541-2019: ESD Association Standard for the Protection of Electrostatic Discharge Susceptible Items.

ESD TR53-01-18: ESD Association Technical Report for the Protection of Electrostatic Discharge Susceptible Items – Compliance Verification of ESD Protective Equipment and Materials.

ESD TR55.0-01-04: ESD Association Technical Report - Electrostatic Guidelines and Considerations for Cleanrooms and Clean Manufacturing.

SEMI E78-0912: Electrostatic Compatibility – Guide to Assess and Control Electrostatic Discharge (ESD) and Electrostatic Attraction (ESA) for Equipment.

IEST RP CC022.2 (2004): *Recommended Practices: Electrostatic Charge in Cleanrooms and other Controlled Environments*. Schaumburg, IL: Institute of Environmental Sciences and Technology.

ISO 14644-1 Cleanrooms and Associated Controlled Environments - Part 1: Classification of Air Cleanliness by Particle Concentration.

IEST RP CC012: *Considerations in Cleanroom Design*. Schaumburg, IL: Institute of Environmental Sciences and Technology.

IEST NANO-RP200: Planning of Nanoscale Science and Technology Facilities: Guidelines for Design, Construction, and Start-up. Schaumburg, IL: Institute of Environmental Sciences and Technology.

(Ref: NASA-STD 8739.6 with the title IMPLEMENTATION REQUIREMENTS FOR NASA WORKMANSHIP STANDARDS.)

2.2 Sources and Addresses

ASTM

American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959, USA
Phone: 610-832-9585
Fax: 610-832-9555
www.astm.org

EOS/ESD

EOS/ESD Association, Inc.
7900 Turin Road, Building 3
Rome, NY 13440-2069, USA
Phone: 315.339.6937
www.esda.org

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1827 Walden Office Square, Suite 400
Schaumburg, IL 60173-4277, USA
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Fax: 847-981-4130
www.ient.org

ISO (National Standards)

International Organization for Standardization
In the USA, ISO 14644 documents available from:
IENT
1827 Walden Office Square, Suite 400
Schaumburg, IL 60173, USA
Telephone: 847-981-0100
Fax: 847-981-4130
www.ient.org

All other ISO Standards

International Organization for Standardization
ISO Central Secretariat
1, ch. de la Voie-Creuse
Case postale 56
CH-1221 Geneva 20 Switzerland
Telephone: 41 22 749 01 11
Fax: 41 22 733 34 30
www.iso.org

SEMI

Semiconductor Equipment and Materials International
673 South Milpitas Blvd.
Milpitas, CA 95035, USA
www.semi.org

3 TERMS, DEFINITIONS, ABBREVIATIONS, AND UNITS OF MEASURE

3.1 Terms

bandwidth

A measure of the response speed of an electrical circuit or the frequency content of an electrical waveform (Hz or cycles/sec).

body contact point (BCP)

An appliance to connect an operator in a cleanroom garment to ground.

charge conservation

A principle of physics that states that the net charge of an isolated system cannot be changed.

cleaning

For this document, any physical process used to remove contamination including wiping, rubbing, rinsing, or polishing.

conductive straps

Braids or ribbons with very low resistance ($< 1 \Omega$). Used for grounding of tools and equipment

conductors

For the purpose of controlling static charge, materials having a surface resistivity of less than $10^5 \Omega$ / square or a volume resistivity of less than $10^4 \Omega\text{-cm}$

corona discharge

Electrical discharge caused by the ionization of a fluid, typically air, surrounding an electrically charged tip. Spontaneous corona discharges occur in high-voltage systems unless care is taken to limit the electric field strength.

dielectric strength

A measure of the amount of voltage across a sample required to cause an electrical breakdown.

dissimilar materials

For the purpose of this RP, dissimilar materials are those that have a different tendency to gain or lose electrons. Referring to the table in section 6, the farther apart a material is from another, the more dissimilar they are.

dissipative

Short form of Static Dissipative.

drag chains and weighted wires

A form of a dynamic electrical connection of a chair or cart to a grounded floor.

electrometer

An electrical instrument for measuring electric charge or electrical potential difference.

electrostatic discharge control (ESDC)

The limitation or elimination of electrostatic charge transfer.

electrostatic charge control (ESCC)

A system of installations, materials, accessories, and procedures that maintains electrostatic effects below the tolerance limits for a given product or process.

EMI

Electromagnetic interference. Unwanted electromagnetic energy.

environmentally protected area (EPA)

A section of the manufacturing area (cleanroom area) that has environmental controls such as meticulous grounding, use of materials that do not charge easily and may have air ionization.

equipotential bonding

The process of connecting all conductors and static dissipative objects to a single electrical point. This is done instead of grounding when it is impractical or impossible to connect to ground (e.g., the space station).

foot grounder

Any type of strap or shoe cover that contacts the operator electrically and provides a dissipative connection to a grounded floor.

field meter

A handheld device for measuring electrical field without contacting the surface being measured.

floating

Any electrically conducting object that has no electrical path to ground is said to be floating.

ground

The reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the earth.

grounding

The action of connecting an object to ground by using a conductor (most often a wire) from the object to ground or a known grounded object.

high density polyethylene (HDPE)

A thermoplastic polymer made from petroleum

HEPA (high-efficiency particle air) filter

An extended-medium, dry type filter in a rigid frame when tested at rated airflow having a minimum particle collection of 99.97% for 0.3- μm mass median diameter particles of DOP (dioctyl phthalate) when tested in accordance with MIL-STD-282.

insulators

Materials with a surface resistivity of greater than $10^{11} \Omega$, that conduct electricity extremely poorly.

isolator or minienvironment

An environment that provides localized control of airborne contaminants by means of an enclosure designed to isolate product handling areas from personnel and the surrounding room environment

ion

An atom or molecule that has gained or lost electrons to become negatively or positively charged in air and other gases.

ionization

The process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons. The resulting electrically charged atom or molecule is called an ion. This produces ions for the purpose of neutralizing static surface charge.

Marangoni effect (dry)

An extremely clean drying process utilizing surface tension between water and isopropyl alcohol.

macroscopic

For the purpose of this document, particles visible to the naked eye, generally larger than 100 microns.

monolayer

A single molecular layer

nanometer (nm)

One billionth of a meter or 1×10^{-9} meter

Ohm's Law

A law that states that the voltage across an object is directly proportional to the current flowing through the resistance of the object.

PFA

Fluoropolymers have a variety of uses. In particular, they are impervious to strong acids and, as such, are used to hold acid, both in storage and in processing.

PTFE

Polytetrafluoroethylene other fluoropolymers used as a coating to protect components from harsh chemicals or for promoting low friction contact.

photolithography

A technique for optically imaging a pattern onto a photo sensitized substrate that results in a permanent image after chemical processing.

photomicrograph

A photographic image of a microscopic item or feature, sufficiently enlarged to be viewed with the naked eye, often produced using a scanning electron microscope.

resistance

The amount that an object impedes electrical current flow (see Ohm's Law).

resistivity

A measure of the amount that a bulk material limits electrical current flow. Resistance of an object of a given resistivity depends also upon details of the size and shape of object.

RF (radio frequency)

Generally, electrical AC signals with a frequency content with components in excess of 10 kHz.

sampling rate

The rate at which a digitizing circuit (such as a digital oscilloscope) samples an electrical waveform (samples/sec).

static dissipative straps

Ribbons or braids used to provide a path to ground for personnel. Resistance is in the range $10^4 - 10^{11} \Omega$.

static dissipative

Materials, generally with an electrical resistivity 10^4 to $10^{11} \Omega\text{-cm}$ that limit current in an electrostatic discharge.

stoichiometric

The ratio of elements or components in a physical reaction.

submicron

The size of an object less generally less than one millionth of a meter or 1×10^{-6} meter

surface resistance

The point-to-point resistance in Ω of an object that only conducts electricity over its surface.

tribo(electric) charging

Electron transfer as a result of two objects coming into contact with one another and then separating.

triboelectric effect

The phenomenon that describes transfer of charge between two objects when they are brought into contact.

triboelectric series

A ranking of the tendency of a material to gain or lose electrons.

topical antistats

Chemical agents that, when applied to surfaces of insulative materials, reduce the ability of those surfaces to accumulate electrostatic charge; usually act by increasing the surface lubricity of the material.

Townsend discharge

Gas ionization process where free electrons are accelerated by an electric field, collide with gas molecules, thereby freeing additional electrons.

ULPA (ultra-low-penetration air) filter

A throwaway, extended-medium dry-type filter in a rigid frame, having a minimum particle-collection efficiency of 99.999% (that is, a maximum particle penetration of 0.0010%) when tested in accordance with methods of IEST-RP-CC007).

3.2 Abbreviations

AC – Alternating current
AHE – Automatic handling equipment
 Al_2O_3 – Aluminum oxide
AMC – Airborne molecular contamination
CBM – Charge board model
CDE – Cabled discharge event
CDM – Charged device model
CPM – Charge plate monitor
DC – Direct current
DSO – Digital sampling oscilloscope
EMI – Electromagnetic interference
ESCC – Electrostatic charge control
ESDC – Electrostatic discharge control
EPA – Environmentally controlled area
ESD – Electrostatic discharge
FDM – Field-induced model
FFDCA – Federal Food, Drug, and Cosmetic Act

HBM – Human body model
HDPE – High-density ethylene
HEPA – High-efficiency particulate air
JIT – Just-in-time
LEL – Lower explosive limit
MM – Machine model
N₂ – Nitrogen molecule
NASA – National Aeronautics and Space Administration
NRC – Nuclear Regulatory Commission
PFA – Perfluoro alkoxy alkane
PPE – Personal protective equipment
PTFE – Polytetrafluoroethylene
RF – Radio frequency
RH – Relative humidity
RPMs – Revolutions per second
RTG – Resistance to ground
TP – Test positions
UEL – Upper explosive limit
ULPA – Ultra-low-penetration air
UV - Ultraviolet

3.3 Units of Measure

3.2.1 Size, length, and mass

cm – centimeter (10^{-2} meters)
in – inches
ft – feet
lb. – pound
m – meters
μm – micrometer (10^{-6} meters)
nm – nanometer (10^{-9} meters)
Kg – Kilogram (10^3 grams)

3.2.2 Time

Hz – Hertz (cycles per second)
GHz – Gigahertz (10^9 cycles per second)
GS/s – Gigasamples per second (10^9 samples per second)
μs – microsecond (10^{-6} seconds)

3.2.3 Energy and pressure

atm – atmospheric pressure
°C – degrees Celsius
keV – kilo-electronvolts (10^3 electronvolts)
kPa – kilopascals (10^3 Pascals)
kW – kilowatts (10^3 watts)
psig- gauge pressure in pounds per square inch

3.2.4 Resistive and capacitive units

Ω – ohms
Ω /sq – ohms per square

$\Omega / \square$ – ohms per square
 ρ – rho, resistivity
 ρ_s – sheet rho
 $m\Omega$ – milliohms (10^{-3} ohms)
 $G\Omega$ – Gigohms (10^9 ohms)
 pF – picoFarads (10^{-12} Farads)
 $K\Omega$ – Kiloohms (10^3 ohms)
 $M\Omega$ – Megohms (10^6 ohms)
 $\Omega\text{-cm}$ – ohm centimeters
 $\Omega\text{-m}$ – ohm meters

3.2.5 Voltage and current units

eV – electron Volts
 kV – Kilovolts (10^3 volts)
 μa – microamps (10^{-6} amperes)
 V – Volts
 v/cm – volts per centimeter
 $v/inch$ – volts per inch

4 BACKGROUND AND PURPOSE

Cleanrooms are designed to minimize the risk and occurrence of contamination, which can adversely affect the quality and performance of products and processes. Unfortunately, some of the procedures that are used to control airborne or surface-borne particle contamination can also create a favorable environment for generation of unacceptably high levels of electrostatic charge. Such charge levels can, in turn, cause particulate contamination as well as process inconsistency, product damage, equipment disruptions, safety issues, and other unwanted or destructive phenomena. The potentially harmful effects of electrostatic fields, charge buildup, and subsequent discharge should be considered as serious risks for cleanroom operation. Some of the possible sources of electrostatic charge generation in cleanrooms and other controlled environments are shown in Table 1. Such sources deserve special attention and control in the operation of these environments.

Table 1. Typical sources of electrostatic charge in controlled environments.

Object or Process	Material or Activity
Work surfaces	Waxed, painted, or varnished Some plastics
Floors	Sealed concrete Waxed, 100% vinyl tile or sheeting
Clothing	Synthetic, natural or blended fibers, or both
Footwear	Footwear made from insulative materials
Chairs and Furniture	Plastics, such as vinyl or vinyl-covered Fiberglass
Packaging and handling materials	Plastic bags, wraps, and envelopes Bubble pack, foam Plastic trays, plastic tote boxes, vials, and parts bins Adhesive tapes (sealing, masking, etc.)
Assembly, cleaning, test, and repair areas	Spray cleaners Plastic solder extractors Soldering irons with ungrounded tips Brushes (synthetic bristles)

Assembly, cleaning, test, and repair areas (cont.)	Cleaning or drying by fluid or evaporation Temperature chambers Cryogenic sprays Heat guns and blowers Electrostatic copiers
--	--

Contamination control factors that can generate electrostatic charge include:

- Filtered, constant airflow to maintain a specified level of air cleanliness to protect products and processes from particles.
- Humidity that often must be controlled to low levels.
- Processing equipment, fixtures, handling tools, and storage containers constructed of high-density plastics or fluorinated hydrocarbon polymers to resist chemical interaction.
- Equipment robotics, product transfer carts, and personnel wearing cleanroom garments moving in or through the cleanroom.
- The actions involved (processing and handling) in producing products and cleaning the cleanroom.

Voltage levels in controlled environments can grow to surprising levels, as shown in Figure 1.

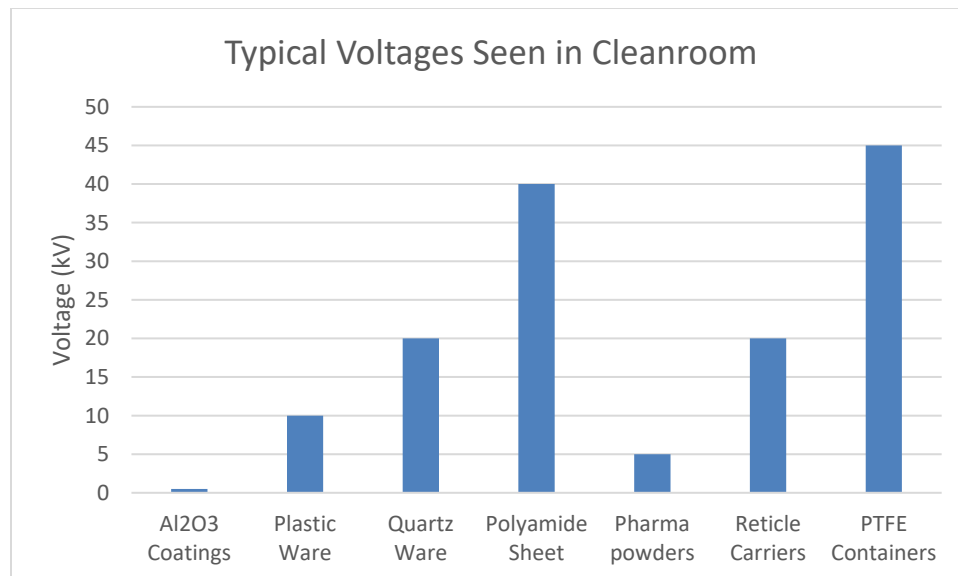


Figure 1. Typical voltage levels on objects in a cleanroom.

Methods that might typically be employed to eliminate or reduce such voltages in other production facilities or labs may not be suitable for application in cleanrooms:

- Use of electrostatic grounding straps may be difficult or impractical due to workstations and processing equipment being operated by multiple personnel in the course of the workday.
- Many static-dissipative materials used in benches and work surface mats may not be allowed in cleanrooms due to particle generation and retention, incompatible contamination and by-products, or outgassing properties of the polymers.
- While most high technology manufacturing employs air ionization, certain types of ionization are not appropriate in cleanrooms due to particle generation or airflow disruption that would contaminate the airflow and pose a risk to product and process cleanliness levels.

This RP addresses these issues and other factors, focusing on the challenges for minimizing the generation of electrostatic charge and controlling the effects specific to cleanroom operations. Recommended methods and materials for minimizing the generation of electrostatic charge will be discussed. When such methods or materials are not compatible with the process or environment (e.g., acid containers), alternative methods for controlling or dissipating electrostatic charge will be required.

Many valuable methods and instruments for identifying and quantifying electrostatic charge and dissipation have been developed. This RP will cite these as appropriate and will discuss certain limitations when applied to cleanroom application. Other challenges specific to cleanrooms require unique approaches to testing that will not compromise the cleanliness level of the cleanroom when implemented.

A comprehensive program to avoid the negative effects of electrostatic charge begins with a thorough audit of the cleanroom that identifies probable sources. This RP includes detailed sections to aid the user in understanding electrical phenomenon and the sources that can cause uncontrolled electrostatic charge in the cleanroom environment. A thorough reading and understanding of this RP will assist the user in performing a comprehensive audit and finding solutions. Audits performed on a routine basis will help maintain control and identify previously unidentified issues.

Development of an effective electrostatic charge control system for the cleanroom includes both Electrostatic Charge Control (ESCC) and Electrostatic Discharge Control (ESDC) measures that should be taken to minimize electrostatic contamination or damage. This RP discusses elements of such a program in section 8.

5 UNDERSTANDING ELECTRICAL PHENOMENON: ELECTROSTATIC FIELDS, CHARGE, CURRENT FLOW, AND RESISTANCE

Electrostatic charge is a type of contamination that can be difficult to understand since it is invisible to the human eye, unlike conventional contamination, which can be seen or imaged optically. The risks caused by static electricity are varied and often produce unexpected negative results.

A very small imbalance between the negative and positive charge in an object will cause significant effects. Since matter is made up of positively and negatively charged particles (electrons and protons), most things in everyday life exhibit a perfect or very nearly perfect balance of charges.

To illustrate the point, a 1-Kg block of iron contains 2.82×10^{26} electrons. If the mass is divided into two 500-g blocks and separated a distance of 30 cm, with 0.0001% more electrons in one block than the other, the electrostatic force between the two would be nearly 2×10^{10} tons. Without the balance of electrons and protons, the charges within the mass would repel itself and violently blow apart. Even a small charge imbalance can be significant in cleanroom operations.

5.1 Action at a Distance

A charge on one object can exert a force on another charged object in the environment (Figure 2). The force is attractive if the two objects have opposite charges and repulsive if they have the same charge. The closer the two charged objects are moved together, the greater is the force, attractive or repulsive, between them.

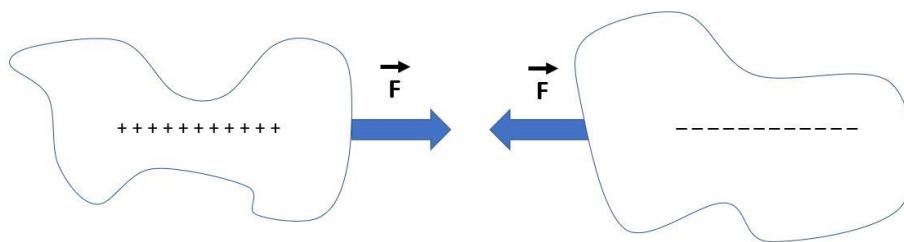


Figure 2. Electrostatic attraction.

If one of the objects is neutral and its negative charge is mobile, the object can be polarized (charge separation in the object) (Figure 3). In this case, there will be an attractive force exerted on the charged object.

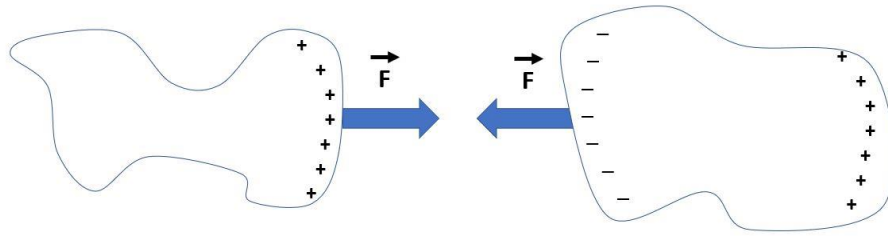


Figure 3. Attraction due to polarization.

5.2 Understanding Conductors, Dissipative Materials and Insulators Description

Solids differ from gases in that the energy levels of the individual gas atoms are corresponding energy bands in a solid. Electrical current flowing through the material is the movement of electrons through the highest (partially) filled energy band, which is called the conduction band. See Figure 4.

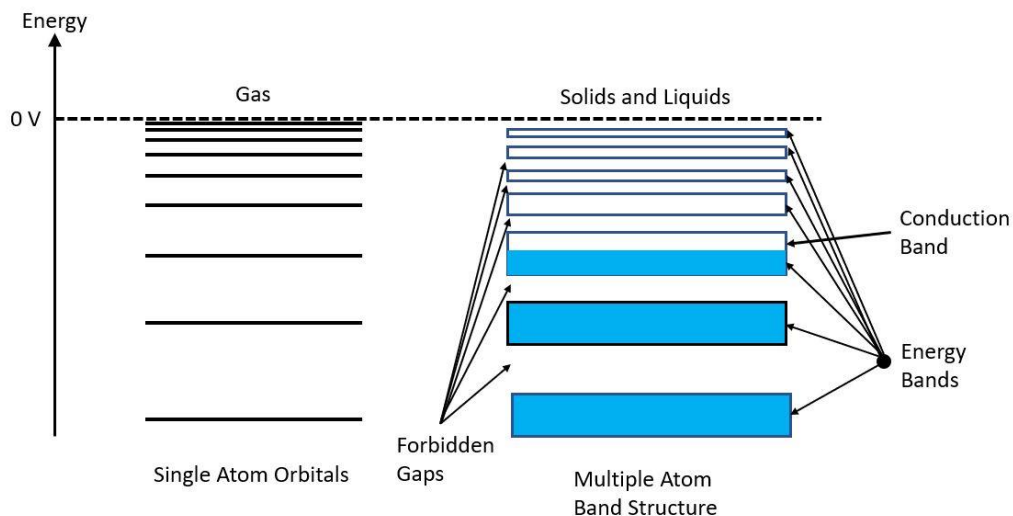


Figure 4. The band structure of solids.

All materials are classified as conductors or non-conductors (insulators) depending on whether they allow conduction of electrical current. When a potential difference is applied across a material, that is not an insulator (see below), electrons move through the solid as an electrical current (Figure 5). Materials that conduct electricity but only poorly are an important class of materials and are referred to as dissipative and are discussed in section 9.

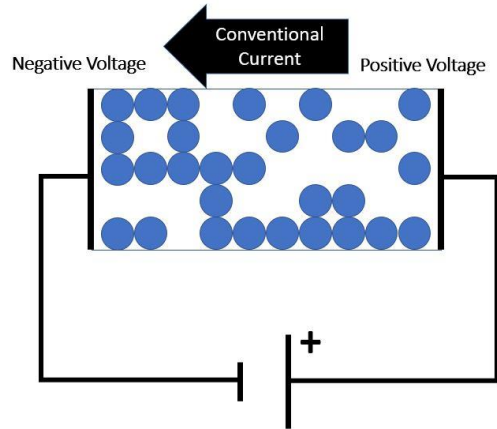


Figure 5. Electron movement conduction.

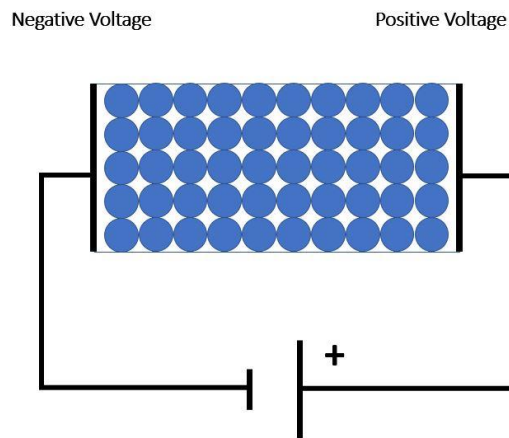


Figure 6. Insulator. The electrons are immobile and no current can flow.

When, the conduction band is completely full (Figure 6), no electron flow is possible. Such materials, either elements or molecules, that naturally have a full conduction band are insulators. These materials are inherently non-conductors and not just poor conductors. The periodic table accurately predicts which elements are insulators.

If an insulator becomes charged, that charge is resident on the surface of the material since there are no locations within the lattice for the charges to be held. Such charge is captive on the surface (grounding the material accomplishes nothing) and will require special attention to deal with. See Figures 4 and 6 above.

Insulators and conductors have very different resistivities. Resistivity is a property of matter that characterizes the ability of a type of material to conduct electricity and is typically given the symbol ρ (rho). It is independent of the size and shape of the material under test. Resistivity has units of Siemens/meter or Ω -cm. A conductor has a resistivity of less than $10^4 \Omega$ cm, and insulators have a resistivity of greater than $10^{11} \Omega$ -cm. There is a mid-range of resistivity

$$10^4 \Omega\text{-cm} > \rho > 10^{11} \Omega\text{-cm}.$$

These materials in the midrange are called dissipative materials. See Figure 7.

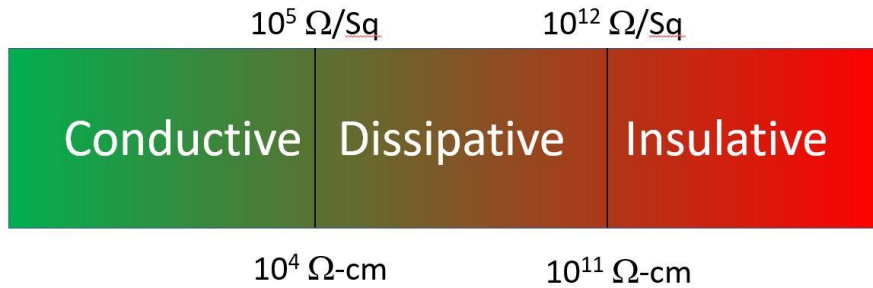


Figure 7. Characterization of the resistance of materials.

Dissipative materials play an important role in a static charge control program. They conduct electricity, therefore dissipating static charge. However, dissipative materials present a large electrical resistance to the discharge, so the current in the discharge is orders of magnitude lower than a discharge through a conductor. Dissipative materials are used for protection against damaging discharge when objects contact the device being manufactured.

Surface resistance, surface resistivity, or surface sheet resistivity are terms used to describe electrical resistance of a material that can only conduct electricity over its surface rather than through the bulk material. Surface resistivity has units of ohms per square (Ω/sq). This parameter is often used loosely and at times, quoting resistance, and surface resistivity in the same context. This often causes confusion. To try to explain proper use of these term, a simple explanation is provided here.

Resistivity is the electrical property of a material describing how the material resists the flow of electric current per unit volume. Expressed as rho (ρ) it is used to calculate the Resistance (R). Resistance, measured in ohms (Ω), is the resistive property that can be calculated for a given object when the dimensions are known. Resistance can also be easily measure with an Ohmmeter. Figure 8 and formula with it illustrate this relationship.

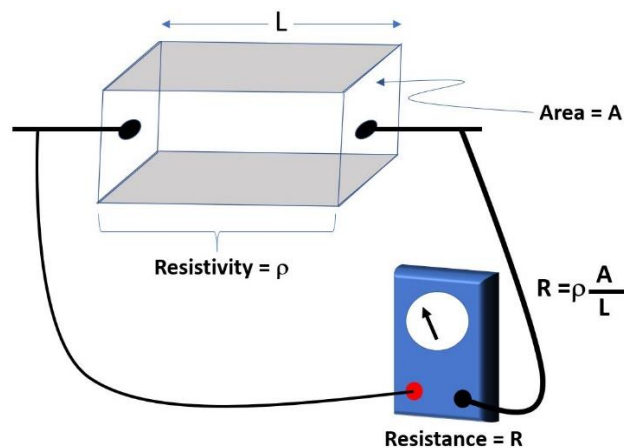


Figure 8. Depiction of resistivity and resistance relationship.

There is a special case where material only has conductivity across its surface as shown in Figure 9.