

NFPA®

77

Recommended Practice
on Static Electricity

2024



NFPA[®] 77

Recommended Practice on Static Electricity

2024 Edition



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NFPA® 77

Recommended Practice on

Static Electricity

2024 Edition

This edition of NFPA 77, *Recommended Practice on Static Electricity*, was prepared by the Technical Committee on Static Electricity. It was issued by the Standards Council on April 23, 2023, with an effective date of May 13, 2023, and supersedes all previous editions.

This edition of NFPA 77 was approved as an American National Standard on May 13, 2023.

Origin and Development of NFPA 77

An NFPA project addressing static electricity was initiated in 1936, and a progress report was presented to NFPA in 1937. A tentative edition of NFPA 77 was adopted in 1941. This tentative edition was further revised and officially adopted by the NFPA in 1946. Revisions were adopted in 1950, 1961, 1966, 1972, 1977, 1982, 1988, and 1993.

The 2000 edition of NFPA 77 presented a totally revised overview of the subject of static electricity and its hazards, including the level of understanding of static electricity at that time and considerable new information explaining the fundamental aspects of the phenomenon and recommendations for evaluating and controlling potential hazards. Also included were sections addressing specific hazards of flammable gases and vapors and combustible dusts, sections on specific industrial processes and operations, a database of relevant properties of numerous commercially significant materials, a glossary of terms, and diagrams showing acceptable methods of bonding and grounding.

The 2007 edition of NFPA 77 included the following changes:

- (1) Recommendations for the self-checking bonding clamps and bond wires that continuously monitor the resistance to ground and verify that resistance is maintained within acceptable levels
- (2) Cautionary statements regarding the use of appropriate instruments based on the electrical classification of the area in which the instruments will be used
- (3) Cautionary statements regarding the use of high-voltage static neutralizers in electrically classified areas and the use of such static neutralizers as inductive neutralizers when de-energized or at failure

The 2014 edition of NFPA 77 included the following changes:

- (1) Reorganization into a more logical arrangement, with some large chapters divided into several small chapters that focus on a single topic
- (2) Revision to Chapter 5 for clarity on the mechanisms of static electric charging and discharging
- (3) Addition of information to Chapter 9 on the hazards of switch loading
- (4) Rewriting of recommendations for filling storage tanks
- (5) Rewriting of recommendations for flexible intermediate bulk containers
- (6) Rewriting of recommendations for web processes

The 2019 edition included the following changes:

- (1) Changes to the definitions for *combustible dust* and *grounding* to reflect the use of the terms specific to NFPA 77
- (2) Changes to the characterization of low, medium, and high resistivity powders in Chapter 15 to reflect generally accepted international standards

The 2024 edition includes the following changes:

- (1) Revisions to the entire recommended practice for readability and consistency, and the addition of clarifications for users not familiar with static electric control

- (2) Addition of US units throughout the document and revision of Greek symbol nomenclature
- (3) Correlation of the definitions for the terms *grounded (grounding)* and *grounding electrode connector* with NFPA 70, *National Electrical Code*, and addition of a definition for the term *verified ground point*
- (4) Addition of liquid classes definitions from NFPA 30, *Flammable and Combustible Liquids Code*, and clarification of the ignitable liquid nomenclature to correlate with NFPA 30
- (5) Revisions to Chapter 7, including the following:
 - (a) Reorganizing the chapter such that the static electric control practices are placed in the order of how they are approached in industry
 - (b) Establishing the difference between a grounding conductor, a bonding conductor, and an active bond monitoring system
 - (c) Providing guidance on resistance measurements for bonding connections and total resistance to ground
 - (d) Recommending separate ground systems for electrostatic systems and not connecting electrostatic grounds to either electrical grounds or lightning protection systems
- (6) Addition of a recommendation that combustible liquids (Class II or Class III liquids, as designated by NFPA 30) heated at or above their flashpoints be handled as flammable liquids (Class I liquids, as designated by NFPA 30)
- (7) Revision of the streaming current axis in Figure 10.7.1(a) to correlate with new data
- (8) Provision of a reference to data on safe fill rates for tanks and containers
- (9) Description of electrostatic ignition risks when handling nonconductive vessels with ignitable and nonignitable liquids
- (10) Reorganization of Chapters 13 and 14 into a single chapter because Chapter 14 was viewed as a continuation of recommendations for process vessels
- (11) Provision of references on powder charge relaxation time measurements
- (12) Clarification as to why bonding a hose helix wire might not be sufficient on its own to provide static electricity protection (i.e., the primary purpose of the helix wire is to provide structural strength) and recommended use of conductive or static-dissipative hoses instead
- (13) Expansion of the description of risks from introducing solids into vessels
- (14) Elaboration on the risks of inducing electrostatic charges at intermediate bulk containers (IBCs) with fully open tops
- (15) Addition of a new section on flexible IBCs (FIBCs) without bottom spouts and large filter bags
- (16) Significant expansion of Chapter 17 on web and sheet processes that includes new sections on identifying static charging sources, static control best practices, and maintaining static control
- (17) Extensive revision of Annex G that includes new figures showing state-of-the-art bonding and grounding systems

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Static Electricity

2024 Edition

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

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Information on referenced and extracted publications can be found in Chapter 2 and Annex I.

Chapter 1 Administration

1.1 Scope.

1.1.1 This recommended practice applies to the identification, assessment, and control of static electricity for purposes of preventing fires and explosions.

1.1.2* This recommended practice does not apply directly to shock hazards from static electricity. However, application of the principles set forth in this recommended practice can reduce such shock hazards to personnel.

1.1.3 Reserved.

1.1.4* This recommended practice does not apply to lightning.

1.1.5* This recommended practice does not apply to stray electrical currents or to induced currents from radio frequency (RF) energy.

1.1.6* This recommended practice does not apply to fueling of motor vehicles, marine craft, or aircraft.

1.1.7* This recommended practice does not apply to clean-rooms.

1.1.8 This recommended practice does not apply to control of static electricity and its hazards as they might affect electronic components or circuits, which have their own requirements.

1.2 Purpose. The purpose of this recommended practice is to assist the user in controlling the hazards associated with the generation, accumulation, and discharge of static electricity by providing the following:

- (1) Basic understanding of the nature of static electricity
- (2) Guidelines for identifying and assessing the hazards of static electricity
- (3) Techniques for controlling the hazards of static electricity
- (4) Guidelines for controlling static electricity in selected industrial applications

1.3 Application. (Reserved)

1.4 Equivalency. Nothing in this recommended practice is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this recommended practice.

1.4.1 Technical documentation should be submitted to the authority having jurisdiction to demonstrate equivalency.

1.4.2 The system, method, or device should be approved for the intended purpose by the authority having jurisdiction.

1.5 Symbols, Units, and Formulas. The units of measure and symbols used in this recommended practice are as described in Chapter 4.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this recommended practice and should be considered part of the recommendations of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 30, *Flammable and Combustible Liquids Code*, 2024 edition.

NFPA 33, *Standard for Spray Application Using Flammable or Combustible Materials*, 2021 edition.

NFPA 69, *Standard on Explosion Prevention Systems*, 2019 edition.

NFPA 70®, *National Electrical Code®*, 2023 edition.

NFPA 495, *Explosive Materials Code*, 2023 edition.

NFPA 498, *Standard for Safe Havens and Interchange Lots for Vehicles Transporting Explosives*, 2023 edition.

NFPA 652, *Standard on the Fundamentals of Combustible Dust*, 2019 edition.

NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, 2020 edition.

NFPA 1124, *Code for the Manufacture, Transportation, and Storage of Fireworks and Pyrotechnic Articles*, 2022 edition.

NFPA 1125, *Code for the Manufacture of Model Rocket and High-Power Rocket Motors*, 2022 edition.

2.3 Other Publications.

2.3.1 AIChE Publications. American Institute of Chemical Engineers, 120 Wall Street, Floor 23, New York, NY 10005-4020.

Britton, L. G., “Using material data in static hazard assessment,” *Process Safety Progress*, April 1992, pp. 56–70.

Britton, L. G. and H. L. Walmsley, “Static electricity: New guidance for storage tank loading rates,” *Process Safety Progress*, September 2012, pp. 219–229.

Britton, L. G. and H. L. Walmsley, “Static hazards of container filling,” *Process Safety Progress*, December 2021, pp. 195–214.

2.3.2 API Publications. American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001-5571.

API RP 2003, *Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents*, 2015, reaffirmed 2020.

2.3.3 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM D257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*, 2014, reapproved 2021e1.

ASTM E502, *Standard Test Method for Selection and Use of ASTM Standards for the Determination of Flash Point of Chemicals by Closed Cup Methods*, 2021.

ASTM F150, *Standard Test Method for Electrical Resistance of Conductive and Static Dissipative Resilient Flooring*, 2006, reapproved 2018.

2.3.4 BSI Publications. BSI Group, 12950 Worldgate Drive, Suite 800, Herndon, VA 20170.

BS PD CLC/TR 60079-32-1, *Explosive atmospheres — Part 32-1: Electrostatic hazards, guidance*, 2018.

2.3.5 Elsevier Publications. Elsevier, Radarweg 29, 1043 NX Amsterdam, Netherlands.

Britton, L. G. and J. A. Smith, “Static Hazards of the VAST,” *Journal of Loss Prevention in the Process Industries*, March 2012, pp. 309–328.

Perrin, L., et al., “Dust and electrostatic hazards, could we improve our standards?” *Journal of Loss Prevention in the Process Industries*, May 2007, pp. 207–217.

Walmsley, H. L., “Avoidance of Electrostatic Hazards in the Petroleum Industry,” *Journal of Electrostatics*, 1992.

2.3.6 IEC Publications. International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland.

IEC/TS 60079-32-1, *Explosive atmospheres — Part 32-1: Electrostatic hazards, guidance*, 2013.

IEC 60079-32-2, *Explosive atmospheres — Part 32-2: Electrostatic hazards — Tests*, 2015.

IEC 61340-4-4, *Electrostatics — Part 4-4: Standard test methods for specific applications — Electrostatic classification of flexible intermediate bulk containers (FIBC)*, 2018.

ISO/IEC 80079-20-2, *Explosive atmospheres — Part 20-2: Material characteristics — Combustible dusts test methods*, 2016.

2.3.7 IEEE Publications. IEEE, 3 Park Avenue, 17th Floor, New York, NY 10016-5997.

Robinson, K. S., “Static Control for Roll-to-Roll Manufacturing,” *IEEE Transactions on Industry Applications*, October 2022, pp. 1–12.

2.3.8 IME Publications. Institute of Makers of Explosives, 1212 New York Avenue, NW, Suite 650, Washington, DC 20005.

IME Safety Library Publication No. 3, *Suggested Code of Regulations for the Manufacture, Transportation, Storage, Sale, Possession, and Use of Explosive Materials*, 2021.

IME Safety Library Publication No. 17, *Safety in the Transportation, Storage, Handling, and Use of Commercial Explosive Materials*, 2021.

2.3.9 ISO Publications. International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandinnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

ISO 8031, *Rubber and plastics hoses and hose assemblies — Determination of electrical resistance and conductivity*, 2020.

2.3.10 JIS Publications. Japan Industrial Standards, 1-3-1 Kasumigaseki, Chiyoda-ku, Tokyo 100-8901, Japan.

JIS B 9915, *Measuring Methods for Dust Resistivity (with Parallel Electrodes)*, 1989.

2.3.11 UN Publications. United Nations Publications Customer Service, P.O. Box 960, Herndon, VA 20172.

ADR 2021, *Agreement Concerning the International Carriage of Dangerous Goods by Road*, 2021.

2.3.12 US Department of Defense Publications. US Department of Defense, 4100 Defense Pentagon, Room 5D636, Washington, DC 20301-4100.

Standard 4145.26M, *DOD Contractor’s Safety Manual for Ammunition and Explosives*, 2008.

Standard 6055.9, *DOD Ammunition and Explosives Safety Standards*, 1999.

2.3.13 US Government Publications. US Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401-0001.

Title 49, Code of Federal Regulations, Parts 100-180, “Hazardous Materials Regulations.”

2.3.14 Other Publications.

Glor, M., *Electrostatic Hazards in Powder Handling*, Research Studies Press, Ltd., Letchworth, Hertfordshire, England, 1988.

International Safety Guide for Oil Tankers and Terminals (ISGOTT), Witherby and Co., Ltd., London, 6th edition, 2020.

Merriam-Webster’s Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2020.

Pratt, T. H., *Electrostatic Ignitions of Fires and Explosions*, Burgoyne, Inc., Marietta, GA, 1997.

Robinson, K. "Assess Static Risks Using Electric Fields," PFFC Online, www.pffc-online.com/static-beat/15664-assess-static-risks-using-electric-fields, May 2019 (accessed April 2022).

2.4 References for Extracts in Recommendations Sections.

NFPA 30, *Flammable and Combustible Liquids Code*, 2024 edition.

NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, 2018 edition.

NFPA 70®, *National Electrical Code*®, 2023 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter apply to the terms used in this recommended practice. Where terms are not defined in this chapter or within another chapter, they should be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, is the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

3.2.3* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.4 Recommended Practice. An NFPA standard similar in content and structure to a code or standard but that contains only nonmandatory provisions using the word "should" to indicate recommendations in the body of the text.

3.2.5 Should. Indicates a recommendation or that which is advised but not required.

3.3* General Definitions.

3.3.1 Antistatic. Capable of dissipating a static electric charge at an acceptable rate for the intended purpose.

3.3.1.1* Antistatic Additive. An additive used to increase the surface or volume conductivity of a liquid or solid material.

3.3.2* Bonding. For the purpose of controlling static electric hazards, the process of connecting two or more conductive objects together by means of a conductor so that they are at the same electrical potential, but not necessarily at the same potential as the earth.

3.3.3 Breakdown Strength. The minimum electric field, measured in volts per meter, necessary to cause a spark through a material that is held between electrodes that produce a uniform electric field under specified test conditions.

3.3.4 Breakdown Voltage. The minimum voltage, necessary to cause a spark through a material under a given set of conditions.

3.3.5* Capacitance. The amount of charge, measured in coulombs per volt or in farads, that must be stored on a specified body or material to raise the potential difference by 1 volt.

3.3.6 Charge. A collection or imbalance of electrons or of positive or negative ions that can accumulate on both conductors and insulators and that has both magnitude and polarity. Movement of charge constitutes an electric current. Excess or deficiency of electrons is expressed in coulombs. An electron carries a charge of -1.6×10^{-19} coulomb.

3.3.6.1 Charge Decay Time. The time for static electric charge to be reduced to a specified percentage of the charge's original magnitude.

3.3.6.2 Charge Density. The charge per unit area on a surface or the charge per unit volume in space. Surface charge density is measured in coulombs per square meter. Volume charge density, also called *space charge density* or *space charge*, is measured in coulombs per cubic meter.

3.3.6.3 Charge Relaxation. The process by which separated charges recombine or by which excess charge is lost from a system.

3.3.7 Charging.

3.3.7.1 Induction Charging. The act of charging an object by bringing it near another charged object, then touching the first object to ground; also known as *induction*. Charge polarization is induced on a grounded object in the vicinity of a charged surface due to the electric field existing between the object and the surface. If the ground connection is removed from the object during this period, the induced charge remains on the object. Induction charging occurs where a person walks from a conductive floor covering onto an insulating floor in the presence of an electric field.

3.3.7.2* Triboelectric Charging. Static electric charging that results from contact or friction between two dissimilar materials; also known as frictional charging and contact-separation charging.

3.3.8 Combustible. Capable of undergoing combustion.

3.3.9 Combustible Dust. For the purposes of this recommended practice, a combustible particulate solid that presents a fire or deflagration hazard when suspended in air or other oxidizing medium over a range of concentrations, regardless of particle size or shape.

3.3.10 Combustion. A chemical process of oxidation that occurs at a rate fast enough to produce heat and usually light in the form of either a glow or a flame.

3.3.11 Conductive. Possessing the ability to allow the flow of an electric charge; typically, liquids possessing a conductivity greater than 10^4 picosiemens per meter (pS/m) or solids having a resistivity less than 10^5 ohm-meters (Ω -m).

3.3.12* Conductivity (σ). The reciprocal of resistivity, that is, $1/\text{resistivity}$. An intrinsic property of a solid or liquid that governs the way electrical charges move across its surface or through its bulk.

3.3.13 Conductor. A material or object that allows an electric charge to flow easily through it.

3.3.14 Current (I). A measure of the rate of transport of electric charge past a specified point or across a specified surface. The symbol *I* is generally used for constant currents, and the symbol *i* is used for time-variable currents. The unit of current is the ampere; 1 ampere equals 1 coulomb/sec (6.24×10^{18} electrons/sec).

3.3.14.1 Charging Current (I_c). The rate of flow of charge into a given system per unit of time, expressed in amperes.

3.3.14.2 Streaming Current (I_s). The current produced by the flow of a charged liquid or solid.

N 3.3.15 Deflagration. Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium. [68, 2018]

3.3.16* Dielectric Constant. The ratio of the permittivity of a material to the permittivity of a vacuum that indicates a material's ability, relative to a vacuum, to store electrical energy or charge, where the material is placed in an electric field.

3.3.17* Dielectric Strength. The maximum electrical potential gradient (electric field) that a material can withstand without electric breakdown, usually specified in volts per millimeter of thickness; also known as *electric strength* or *breakdown strength*.

3.3.18 Discharge.

3.3.18.1* Brush Discharge. A higher energy form of corona discharge characterized by low-frequency bursts or by streamers, which can form between charged nonconductive surfaces and grounded conductors.

3.3.18.2* Bulking Brush Discharge. A partial surface discharge over the top of solid piles that is created during bulking of powder in containers and that appears as a luminous, branched channel flashing radially from the wall toward the center of the pile.

3.3.18.3* Corona Discharge. A low energy electrical discharge that results from a localized electrical breakdown of gases near sharp conductive edges, needle points, and wires.

3.3.18.4* Propagating Brush Discharge. An energetic discharge caused by electrical breakdown across a dielectric layer having equal and opposite charges on the opposite sides of the layer.

3.3.19* Dissipative. A material or a construction that will reduce static charge to acceptable levels.

3.3.20* Double Layer. A phenomenon usually associated with a solid-liquid interface where ions of one charge type are fixed to the surface of the solid, and an equal number of mobile ions of opposite charge are distributed through the neighboring region of the liquid.

3.3.21 Electrometer. A device used to measure static electric charge with high-input impedance, typically greater than 10^{13} ohms, which draws negligible current from the measured object.

3.3.22 Flammable Limit.

3.3.22.1 Lower Flammable Limit (LFL). The lowest molar (or volume) concentration of a combustible substance in an oxidizing medium that will propagate a flame.

3.3.22.2 Upper Flammable Limit (UFL). The highest molar (or volume) concentration of a combustible substance in an oxidizing medium that will propagate a flame.

Δ 3.3.23 Grounded (Grounding). Connected (connecting) to ground or to a conductive body that extends the ground connection. [70, 2023]

N 3.3.24 Grounding Electrode Conductor. A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system. [70, 2023]

3.3.25 Ignitable Mixture. A gas-air, vapor-air, mist-air, or dust-air mixture, or combinations of such mixtures, that can be ignited by a sufficiently strong source of energy, such as a static electric discharge.

3.3.26 Ignition Energy. The energy required to effect ignition of a specified fuel mixture under specified conditions of test.

3.3.26.1 Minimum Ignition Energy (MIE). The energy, usually expressed in millijoules, stored in a capacitor that, upon discharge, is just sufficient to effect ignition of the most ignitable mixture of a given fuel mixture under specified test conditions.

3.3.27 Incendive. Able to cause ignition.

3.3.28 Induction. The process by which charges are moved to new locations on a conductor by the action of an electric field or the movement of a conductor into the influence of an existing electric field.

3.3.29* Induction Bar. A device that produces air ions by means of corona discharge when in close proximity to a charged nonconductive surface.

3.3.30 Inert Gas. For the purpose of controlling static electric hazards, a nonflammable, nonreactive gas that renders the combustible material in a system incapable of supporting combustion.

3.3.31 Ionization. A process by which a neutral atom or molecule loses or gains electrons, thereby acquiring a net charge and becoming an ion.

N 3.3.32 Liquid.

N 3.3.32.1* Combustible Liquid. An ignitable liquid that is classified as a Class II or Class III liquid. [30, 2024]

N 3.3.32.2* Flammable Liquid. An ignitable liquid that is classified as a Class I liquid. [30, 2024]

N 3.3.32.3 Ignitable Liquid. Any liquid or liquid mixture that has a measurable closed-cup flash point. [30, 2024]

N 3.3.32.4 Liquid Class. A uniform system of classifying ignitable liquids. [30, 2024]

N 3.3.32.4.1 Class I Liquid. A liquid with a closed-cup flash point below 37.8°C (100°F).

- N 3.3.32.4.2 Class IA Liquid.** A liquid that has a flash point below 22.8°C (73°F) and a boiling point below 37.8°C (100°F).
- N 3.3.32.4.3 Class IB Liquid.** A liquid that has a flash point below 22.8°C (73°F) and a boiling point at or above 37.8°C (100°F).
- N 3.3.32.4.4 Class IC Liquid.** A liquid that has a flash point at or above 22.8°C (73°F), but below 37.8°C (100°F).
- N 3.3.32.4.5 Class II Liquid.** A liquid with a closed-cup flash point at or above 37.8°C (100°F) but below 60°C (140°F).
- N 3.3.32.4.6 Class III Liquid.** A liquid with a closed-cup flash point at or above 60°C (140°F).
- N 3.3.32.4.7 Class IIIA Liquid.** A liquid that has a flash point at or above 60°C (140°F), but below 93°C (200°F).
- N 3.3.32.4.8 Class IIIB Liquid.** A liquid that has a flash point at or above 93°C (200°F).

3.3.33 Megohmmeter. A meter used to measure high resistance values that typically operates at higher test voltages than standard ohmmeters, usually in the range of 100 volts to 1000 volts.

3.3.34 Minimum Explosible Concentration (MEC). The lowest concentration of a combustible dust in air, expressed in grams per cubic meter, that will propagate a flame.

3.3.35 Nonconductor (Insulator). A material that has the ability to accumulate charge, even when in contact with ground.

3.3.36 Ohms per Square. A unit of surface resistivity determined by use of a square electrode configuration to measure the resistance.

3.3.37 Relaxation Time Constant (τ). The time, in seconds, for charge to decay by Ohm's law to e^{-1} (36.7 percent) of its initial value. For a capacitor, the relaxation time constant is the product of resistance (ohms) and capacitance (farads).

3.3.38 Resistance (R). The opposition that a material offers to the flow of current, expressed in ohms, and which is equal to the voltage (V , in volts) between two points divided by the current (I , amperes) that flows between those points.

3.3.39 Resistivity. The intrinsic property of a homogeneous material that opposes the flow of electric current. A low resistivity (high conductivity) indicates a material that readily allows the movement of electrical charge. The resistivity across the surface of a material will differ from the resistivity through a volume of the same material. Also, the *resistance* of a material depends on its resistivity and its geometry. Resistivity is the reciprocal of conductivity.

3.3.39.1 Surface Resistivity. The electric resistance of the surface of an insulator, in ohms per square, as measured between the opposite sides of a square on the surface, and whose value in ohms is independent of the size of the square or the thickness of the surface film.

3.3.39.2* Volume Resistivity. The intrinsic property of a material that offers resistance to the flow of electric current through the material, expressed in ohm-meters (ohm-m) or ohm-centimeters (ohm-cm).

3.3.40 Semiconductive (Static Dissipative). Liquids that typically possess a conductivity between 10^2 pS/m and 10^4 pS/m or

solids that typically possess a resistivity between 10^5 Ω -m and 10^9 Ω -m.

3.3.41 Spark. A short-duration electric discharge due to a sudden breakdown of air or some other insulating material separating two conductors at different electric potentials, accompanied by a momentary flash of light; also known as *electric spark*, *spark discharge*, and *sparkover*.

3.3.42 Static Electric Discharge. A release of static electricity in the form of a spark, corona discharge, brush discharge, bulk-ing brush discharge, or propagating brush discharge that might be capable of causing ignition of a flammable atmosphere under appropriate circumstances.

3.3.43 Static Electricity. The branch of electrical science dealing with the effects of the accumulation of electric charge.

3.3.44* Surface Streamer. A surface-to-wall discharge observed on charged liquids during tanker filling, appearing as a flash up to 30 cm (11.8 in.) long and accompanied by a crackling sound.

3.3.45* Triboelectric Series. A ranking of materials according to their affinity to accept or donate electrons.

N 3.3.46 Verified Ground Point. A ground rod or ground grid with a resistance of less than 1×10^6 ohms.

Chapter 4 Units and Symbols of Measure

4.1 Units. (Reserved)

4.2 Symbols. The following symbols are used throughout this recommended practice and are defined as follows:

Δ C	= capacitance (farads)
D	= thickness (meters)
d	= diameter [meters (feet)]
E	= electric field strength (volts per meter)
e	= base of Napierian (natural) logarithms = 2.718
ϵ	= electrical permittivity of a material (farads per meter)
ϵ_0	= electrical permittivity of a vacuum (8.845×10^{-12} farads per meter)
ϵ_r	= relative dielectric constant of a material (dimensionless)
F	= volumetric flow [cubic meters per hour (gallons per minute)]
I	= electric current (amperes)
I_s	= streaming current (amperes)
mA	= milliamperes = 1×10^{-3} amperes
σ_L	= liquid conductivity (siemens per meter)
σ_q	= surface charge density (coulombs per square meter)
μ	= ion mobility (square meters per volt-second)
μA	= microamperes = 1×10^{-6} amperes
μm	= micrometers (microns) = 1×10^{-6} meter
Ω	= electric resistance (ohms)
Ω -m	= electrical resistivity (ohm-meters)
Q	= quantity of electrical charge (coulombs)
R	= electrical resistance (ohms)
ρ_q	= surface charge density (coulombs per cubic meter)
ρ_v	= volumetric resistivity (ohm-meters)

(continues)

S	=	electrical conductance (siemens)
t	=	elapsed time (seconds)
τ	=	charge relaxation time constant (seconds)
U	=	web speed (meters per second)
v	=	flow velocity [meters per second (feet per second)]
V	=	electrical potential difference (volts)
W	=	energy or work done (joules)

Chapter 5 Fundamentals of Static Electricity

5.1 General.

5.1.1 The most common experiences of static electricity are the crackling and clinging of fabrics as they are removed from a clothes dryer or the electric shock felt when touching a metal object after walking across a carpeted floor or stepping out of an automobile. Nearly everyone recognizes that these phenomena occur mainly when the atmosphere is very dry, particularly in winter. To most people, static electricity is simply an annoyance. In many industries, particularly those where combustible materials are handled, static electricity can cause fires or explosions.

5.1.2 The word *electricity* is derived from *elektron*, the ancient Greek word for *amber*. The phenomenon of electrification was first noticed when pieces of amber were rubbed briskly. For centuries, the word *electricity* had no meaning other than the ability of some substances to attract or repel lightweight objects after being rubbed with a material such as silk or wool. Stronger electrification accompanied by luminous effects and small sparks was first observed about 300 years ago by Otto von Guericke.

5.1.3 In comparatively recent times, when the properties of flowing (current) electricity were discovered, the term *static* came into use to distinguish a charge that was at rest from one that was in motion. Today the term is used to describe phenomena that originate from an electric charge, regardless of whether the charge is at rest or in motion.

5.1.4 All materials, whether solid or fluid, are composed of various arrangements of atoms. Atoms are composed of positively charged nuclear components, which give them mass, surrounded by negatively charged electrons. Atoms can be considered electrically neutral in their normal state, meaning that there are equal amounts of positive and negative charge. They can become charged where there is an excess or a deficiency of electrons relative to the neutral state. Electrons are mobile and of insignificant mass and are the charge carriers most associated with static electricity.

5.1.5 In materials that are conductors of electricity, such as metals, electrons can move freely. In materials that are insulators, electrons are more tightly bound to the nuclei of the atoms and are not free to move. Examples of materials that often are insulators include glass, rubber, plastics, gases, paper, and petroleum products.

5.1.6 The mobility of electrons in materials known as semiconductors is freer than in insulators but is still less than in conductors. Semiconductive materials are commonly characterized by their high electrical resistance, which can be measured with a megohmmeter.

5.1.7 In otherwise insulating fluids, an electron can separate from one atom and move freely or attach to another atom to

form a negative ion. The atom losing the electron then becomes a positive ion. Ions are charged atoms and molecules.

5.1.8 Unlike charges attract each other, and the attractive force can draw the charges together if the charges are mobile. The energy stored is the result of the work done to separate the charges.

5.2 Separation of Charge by Contact of Materials. Separation of charge cannot be prevented absolutely, because the origin of the charge lies at the interface of materials. Where materials are placed in contact, some electrons move from one material to the other until a balance (equilibrium condition) in energy is reached. This charge separation is most noticeable in liquids that are in contact with solid surfaces and in solids that are in contact with other solids. The flow of clean gas over a solid surface produces negligible charging.

5.2.1 The enhanced charging that results from materials being rubbed together (triboelectric charging) is the result of surface electrons being exposed to a broad variety of energies in an adjacent material, so that charge separation is more likely to take place. The breakup of liquids by splashing and misting results in a similar charge separation. It is necessary to transfer only about one electron for each 500,000 atoms to produce a condition that can lead to a static electric discharge. Surface contaminants at very low concentrations can play a significant role in charge separation at the interface of materials. [See Figure 5.2.1(a) and Figure 5.2.1(b).]

5.2.2 Charge can also be injected into a stream of nonconductive fluid by submerging within the stream a pointed electrode on which a high voltage has been impressed.

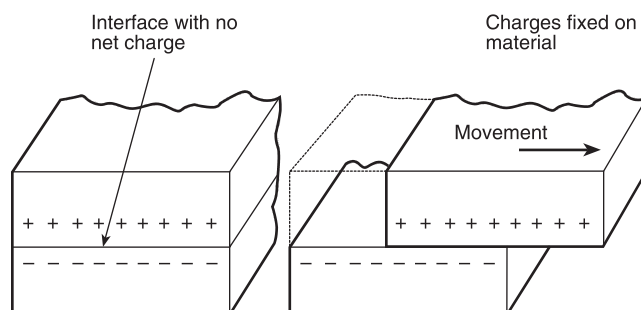


FIGURE 5.2.1(a) Typical Charge Generation by Relative Movement of Insulating Materials. (Source: H. L. Walmsley, "Avoidance of Electrostatic Hazards in the Petroleum Industry," p. 19.)

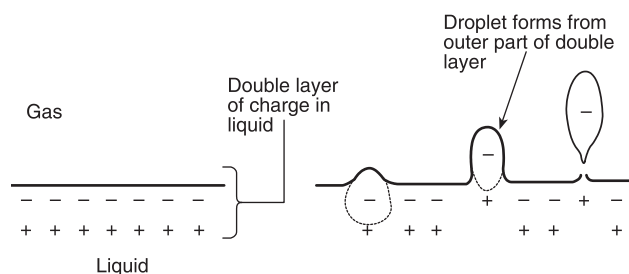


FIGURE 5.2.1(b) Typical Charge Generation by Atomization. (Source: H. L. Walmsley, "Avoidance of Electrostatic Hazards in the Petroleum Industry," p. 19.)

▲ 5.3 Charging by Induction.

5.3.1 Theory of Induction Charging. Conductive materials can become charged when brought near a highly charged surface. Assume a charged insulator, as shown in Figure 5.3.1(a). An ungrounded conductor is brought close to the charged insulator, as shown in Figure 5.3.1(b). Electrons in the conductor are either drawn toward or forced away from the region of closest approach to the charged insulator's surface, depending on the nature of the charge on that surface. If the ungrounded conductor is then touched to ground or to a third object, electrons can flow to or from ground or the object, changing the net charge on the conductor. This is shown in Figure 5.3.1(c). If, as shown in Figure 5.3.1(d), contact is then broken and the conductor and charged surface are separated, the charge on the now isolated conductor remains the same as when contact is broken. The net charge that was transferred during contact is called *induced charge*.

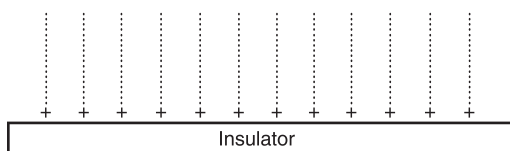


FIGURE 5.3.1(a) Charged Insulator with Field Lines Shown. (Source: T. H. Pratt, *Electrostatic Ignitions of Fires and Explosions*, p. 29.)

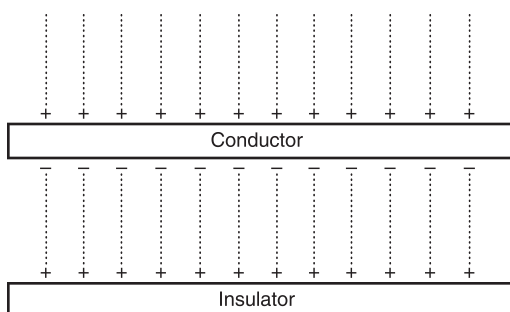


FIGURE 5.3.1(b) Charge Redistribution on a Conductor as It Nears a Charged Surface Charge remains on conductor as conductor is removed from contact with insulator. (Source: T. H. Pratt, *Electrostatic Ignitions of Fires and Explosions*, p. 29.)

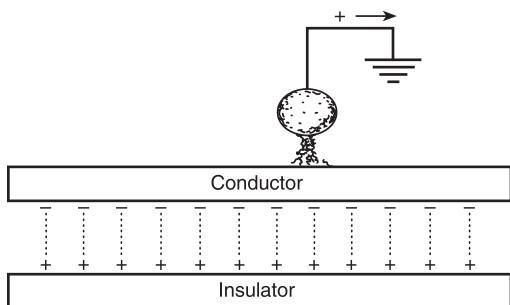


FIGURE 5.3.1(c) Net Charge Transfer to or from Conductor as a Result of Contact or Discharge. (Source: T. H. Pratt, *Electrostatic Ignitions of Fires and Explosions*, p. 29.)

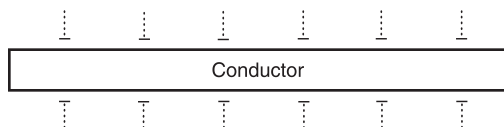


FIGURE 5.3.1(d) Isolated Conductor Carrying a Charge (After Being Separated from Insulator).

5.3.1.1 The separation of charge on a neutral isolated conductor and its distribution near a charged insulating surface produces electrical stresses near the point of closest approach. Sharp edges on the conductor can yield a localized electrical breakdown of the gas stream, known as *corona*, or an electric spark across the gap. Either of these events can transfer charge between the materials, leaving the isolated conductor charged. Such a transfer occurs, for example, where a person wearing nonconductive shoes receives a static electric shock by contacting the metal frame supporting a highly charged web. As a result, the person acquires a net static electric charge and can receive a second shock after leaving the area by touching a grounded metal object, thereby allowing the acquired charge to flow to earth.

5.3.1.2 Charge can also be imparted to a surface or into the bulk of a material by directing a stream of electrons or ions against the surface or the material. If the surface or material is not conductive or is conductive but isolated from ground, the charge delivered by the bombarding stream remains after the stream stops.

5.3.2 Induction Charging of Personnel.

5.3.2.1 If a person walks about, there is a redistribution of static electric charge on the body as he or she approaches and leaves places where there is charge. Here, the term *person* includes the body, clothing, tools, flashlights, pens, and any other articles carried along, as well as the nature of the electrical connections among them. The total charge on the person does not change as he walks around, unless there is passage of charge from the person to the environment, for example, a charged object, the floor, the air, or anything else in the surroundings that becomes a path for charge redistribution.

5.3.2.2 Induction charging of a person can occur in a variety of ways:

- (1) *The person touches the charged object.* In this case charge flows between the object and the person, and the person's conductivity gives charge the possibility of being distributed farther from the object.
 - (a) If the object is a conductor, charge from its entirety will be reduced by the amount transferred to the person, so that both will end up with the same voltage (potential).
 - (b) If the object is an insulator, local discharge will occur and that charge will be distributed to the person. A moving web would be one case in which the local discharges to the person would add up on the person to produce net charging that is similar to that from a conductor. The person would end up with the average voltage (potential) of the web.
- (2) *An electrical discharge occurs between the person and the charged object.* The result will be very similar to what happens with direct contact, and in fact, a discharge probably will occur as the person approaches and touches the charged

object. The electrical discharge generally occurs from where there is a high concentration of charge — nearby regions on the person or object that are pointed or sharp (e.g., points, corners, or edges). There will be a spark or some form of corona discharge. (See Section 5.5 for descriptions of electrical discharges.)

- (3) *Current is conducted through shoes to the floor.* If there is conduction through the shoes, charge will distribute beyond the person, and an equal amount of charge will be conducted to the person to be drawn closer to the charged object. If the shoes or floor are not good conductors, it will take time for the net charge on the person to grow and be lost as the person walks from the area.
- (4) *The person touches others, structural steel, tool boxes in the area, etc., or provides other paths for charge to redistribute.* Each of these actions gives a larger area for charge redistribution, and when those paths are broken leaves a net charge on the person. If shoes and floor are nonconductive, the charge will remain on the person when he or she leaves the charged object.
- (5) *There is an electrical discharge between the person and something — typically grounded — in the environment.* The discharge can come from the hair, rings, finger nails, conductive clothing, and so forth. In the case of corona, the discharge can be into the air without a nearby grounded surface.

5.3.2.3 The actual redistribution of charge is complex and dynamic, and the net charge on the person changes with time. One must be careful in handling tools and actions performed while working with charged operations in industry. Gravure printing, coating, and finishing with solvent-based materials are particularly hazardous as a result of induction charging. Without good electrostatic charge elimination, pointing a finger at process lines and working with conductive tools can be hazardous. There are numerous opportunities for spark discharges brought on by proximity of workers and charged objects.

5.3.2.4 Pneumatic conveying of bulk solids in nonconductive hoses poses special problems, because charging and discharging along the lines induces complex charges and currents in the work area. The induced charges and currents can be hazardous to workers and electronic equipment.

5.3.2.5 One area often overlooked is the pickup of charge by induction at one workstation, possibly in a nonhazardous area, that is carried to a hazardous location. Appropriate footwear and flooring is advised in the hazardous area.

5.4 Accumulation and Dissipation of Charge.

5.4.1 A static electric charge will accumulate where the rate at which charges separate exceeds the rate at which charges recombine. Work must be done to separate charges, and there is a tendency for the charges to return to a neutral state. The potential difference, that is, the voltage, between any two points is the work per unit charge that would have to be done to move the charges from one point to the other. This work depends on the physical characteristics (that is, shape, size, and nature of materials and location of objects) of the particular system and can be expressed by the following equation:

[5.4.1]

$$C = \frac{Q}{V}$$

where:

C = capacitance (farads)

Q = charge that has been separated (coulombs)

V = potential difference (volts)

5.4.2 Typical examples of accumulation are illustrated in Figure 5.4.2. (See also Table A.3.3.5.)

5.4.3 Separation of electric charge might not in itself be a potential fire or explosion hazard. There must be a discharge or sudden recombination of the separated charges to pose an ignition hazard. One of the best protections from static electric discharge is a conductive or semiconductive path that allows the controlled recombination of the charges.

5.4.4 In static electric phenomena, charge is generally separated by a resistive barrier, such as an air gap or insulation between the conductors, or by the insulating property of the materials being handled or processed. In many applications, particularly those in which the materials being processed are charged insulators (nonconductors), it is not easy to measure the charges or their potential differences.

5.4.5 Where recombining of charges occurs through a path that has electrical resistance, the process proceeds at a finite rate, $1/\tau$, and is described by the *charge relaxation time* or *charge*

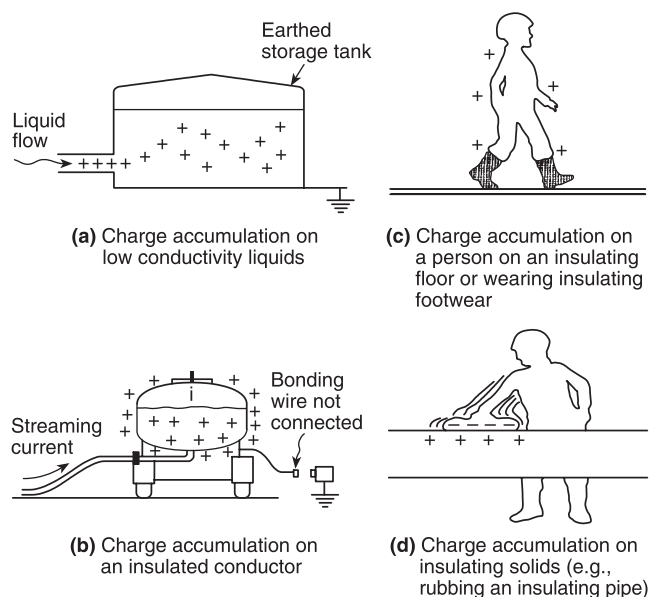


FIGURE 5.4.2 Examples of Charge Accumulation. (Source: H. L. Walmsley, "Avoidance of Electrostatic Hazards in the Petroleum Industry," p. 37.)

decay time, τ . This relaxation process is typically exponential and is expressed by the following equation:

$$Q_t = Q_0 e^{-t/\tau} \quad [5.4.5]$$

where:

Q_t = charge remaining at elapsed time t (coulombs)

Q_0 = charge originally separated (coulombs)

e = base of natural logarithms = 2.718

t = elapsed time (seconds)

τ = charge relaxation time constant (seconds)

5.4.6 The rate of charge recombination depends on the capacitance of the material and its resistance and is expressed as follows:

$$\tau = RC \quad [5.4.6]$$

where:

τ = charge relaxation time constant (seconds)

R = resistance (ohms)

C = capacitance (farads)

5.4.7 For bulk materials, the relaxation time is often expressed in terms of the volume resistivity of the material and its electrical permittivity as follows:

$$\tau = \epsilon_r \epsilon_0 \rho_v \quad [5.4.7]$$

where:

τ = charge relaxation time constant (seconds)

ϵ_r = relative dielectric constant of the material

ϵ_0 = electrical permittivity of a vacuum (8.845×10^{-12} farads per meter)

ρ_v = volumetric resistivity (ohm-meters)

5.4.8 The exponential decay model described in 5.4.5 is helpful in explaining the recombination process but is not necessarily applicable to all situations. In particular, nonexponential decay is observed where the materials supporting the charge are certain low-conductivity liquids or powders composed of combinations of insulating, semiconductive, and conductive materials. The decay in such cases is faster than the exponential model predicts.

5.4.9 Dissipation of static electric charges can be achieved by one or more of the following methods: modifying the volume or surface resistivity of insulating materials with antistatic additives, by grounding isolated conductors, or by ionizing the air near insulating materials or isolated conductors. Air ionization involves introducing mobile electric charges (positive, negative, or both) into the air around the charged objects. The ions are attracted to the charged objects until the charges on the objects are neutralized. The ion current in the air serves as the mechanism that brings the neutralizing charge to the otherwise bound or isolated charge.

5.5 Discharge of Static Electricity and Ignition Mechanisms.

5.5.1 General. As electric charge accumulates through separation, there is an increase in the electrical forces trying to restore a neutral condition by reuniting those charges in the form of a static electric discharge. Many types of discharges can occur and are illustrated broadly in Figure 5.5.1. For a static electric discharge to be a source of ignition, the following four conditions must be met:

- (1) An effective means of separating charge must be present.
- (2) A means of accumulating the separated charges and maintaining a difference of electrical potential must be available.
- (3) A discharge of the static electricity of adequate energy must occur.
- (4) The discharge must occur in an ignitable mixture.

5.5.2 Corona Discharge. As defined in 3.3.18.3, corona discharge is a low energy electrical discharge that results from localized electrical breakdown of gases near sharp conductive edges, needle points, and wires. (See Figure 5.5.2.)

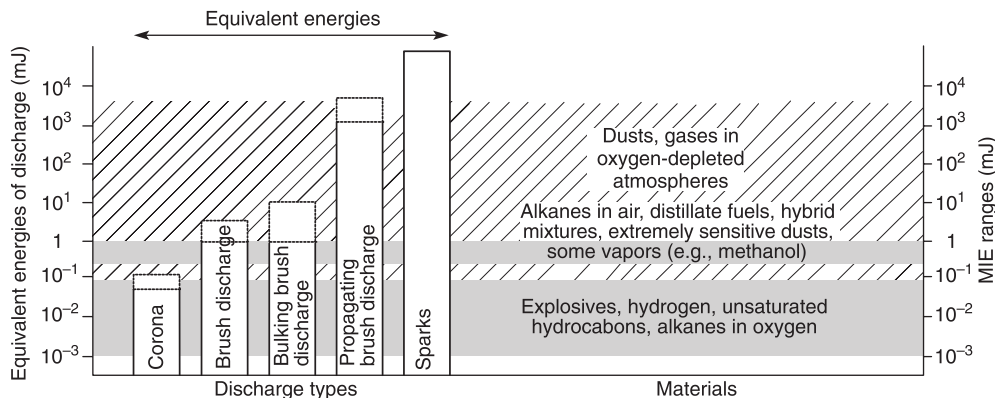


FIGURE 5.5.1 Approximate Energies of Types of Discharges Compared with Minimum Ignition Energies (MIEs) of Typical Combustible Materials. (Adapted from H. L. Walmsley, "Avoidance of Electrostatic Hazards in the Petroleum Industry," p. 26.)

5.5.2.1 In most cases, the energy density of corona discharge is very low. Consequently, the hazard from corona discharge is small. Where corona discharge is more intense, pre-breakdown streamers called *brush discharges* occur. These appear as random filaments of light that make faint hissing or frying sounds. Brush discharges that originate on needlelike tips with radii smaller than 1 mm (0.04 in.) do not, in general, lead to ignition. Discharges from blades, however, can ignite mixtures that have very low ignition energies, such as hydrogen–air or carbon disulfide–air mixtures. Gas–air and vapor–air mixtures can be ignited if brush discharges originate from elements with edge diameters greater than 5 mm (0.20 in.) or from a rod with a hemispherical end, such as a human finger. (See Figure 5.5.2.1.)

5.5.2.2 Sharp edges, corners, and projections [e.g., those with an edge diameter of 5 mm (0.20 in.) or less] that point toward charged surfaces need to be identified because they can concentrate the charge, providing intense, localized stresses that can lead to electrical corona and sparks.

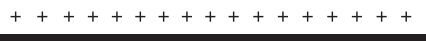
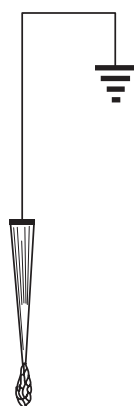


FIGURE 5.5.2 Corona Discharge. (Source: T. H. Pratt, *Electrostatic Ignitions of Fires and Explosions*, p. 32.)

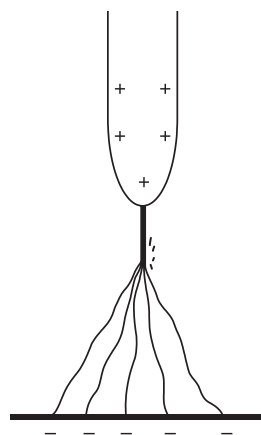


FIGURE 5.5.2.1 Brush Discharge. (Adapted from H. L. Walmsley, "Avoidance of Electrostatic Hazards in the Petroleum Industry," p. 27.)

5.5.3 Sparks Between Conductors.

5.5.3.1 Sparks from ungrounded charged conductors, including the human body, are responsible for most fires and explosions ignited by static electricity. Sparks are typically intense capacitive discharges that occur in the gap between two charged conducting bodies, usually metal. The energy of a spark discharge is highly concentrated in space and in time.

5.5.3.2 The ability of a spark to produce ignition is governed largely by its energy, which is some fraction of the total energy stored in the system.

5.5.3.3 The energy of a spark can be determined from the capacitance of the conductive system and the electrical potential or from the quantity of charge separated from the conductors. This determination is expressed by the equations that follow, and the relationships are shown graphically in Figure 5.5.3.3.



[5.5.3.3a]

$$W = \frac{1}{2} CV^2$$

where:

W = energy (joules)

C = capacitance (farads)

V = potential difference (volts)

[5.5.3.3b]

$$W = \frac{1}{2} QV$$

where:

Q = charge (coulombs)

[5.5.3.3c]

$$W = \frac{1}{2} \left(\frac{Q^2}{C} \right)$$

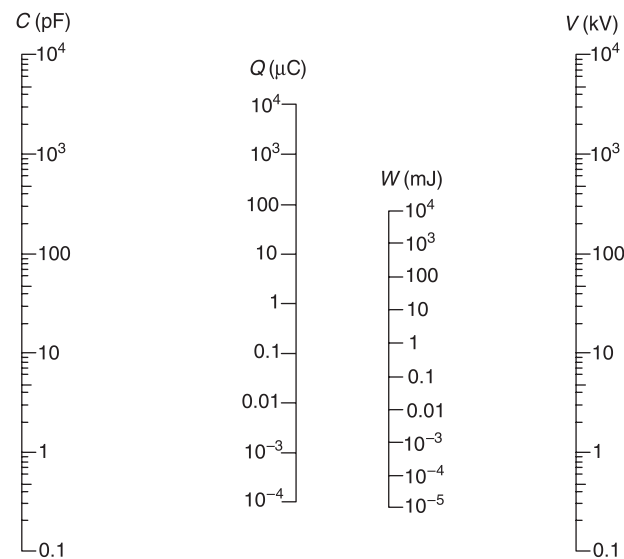
[5.5.3.3d]

$$Q = CV$$

5.5.3.4* To be capable of causing ignition, the energy released in the discharge must be at least equal to the minimum ignition energy (MIE) of the ignitable mixture. Other factors, such as the shape of the charged electrodes and the form of discharge, influence conditions for the static electric discharge and its likelihood of causing ignition.

5.5.3.5 Most gases and vapors of hydrocarbons require about 0.25 mJ of energy for spark discharge ignition, assuming optimum mixtures with air. There are some that require less energy for ignition. Discussion of the minimum ignition energy for specific materials can be found in 9.2.3, 9.2.4, and 15.10.1. (See Table B.1.)

5.5.3.6 Mists, dusts, and fibers usually require an MIE that is one or two orders of magnitude greater than that for gases and vapors. It should be noted that, for any given particulate material, the MIE diminishes rapidly with decreasing particle size.



Note: One straight line through the scales simultaneously solves the relationships:
 $W = \frac{1}{2}CV^2$ $W = \frac{1}{2}QV$ $W = \frac{1}{2}Q^2/C$ $Q = CV$

▲ FIGURE 5.5.3.3 Nomograph for Estimating Energy in a Capacitive Spark Discharge. (Source: T. H. Pratt, *Electrostatic Ignitions of Fires and Explosions*, p. 113.)

5.5.3.7 The ignition energies for gases, vapors, and dusts are reduced by an increase in the oxygen concentration relative to that for air. Likewise, ignition energies are increased by a decrease in oxygen concentration.

5.5.4 Hybrid Mixtures. Where two or more flammable materials of different phases (e.g., a dust and a vapor) are present in the same mixture, the mixture is referred to as a *hybrid*. Tests have shown that adding a flammable gas to a dust suspension can greatly lower the ignition energy of the dust. This phenomenon is especially true where the gas is present at a concentration below its lower flammable limit (LFL) or the dust is below its minimum explosible concentration (MEC). Such hybrid mixtures can sometimes be ignited even if both components are below their lower limits. A hybrid mixture can be formed by the following:

- (1) Vapor desorption from particulates (such as in resin product receivers)
- (2) Reaction of particulates with atmospheric moisture that produces a flammable gas
- (3) Introduction of a dust into a flammable vapor atmosphere [such as adding a dust or powder to a flammable liquid (Class I liquid, as designated by NFPA 30)]

5.5.5 Static Electric Discharge from the Human Body.

5.5.5.1 The human body is a good electrical conductor and has been responsible for numerous incidents of static electric discharge.

5.5.5.2 A person insulated from ground can accumulate a significant charge by walking on an insulating surface, by touching a charged object, by brushing surfaces while wearing nonconductive clothing, or by momentarily touching a grounded object in the presence of charges in the environment. During normal activity, the potential of the human body can reach 10 kV to 15 kV. At a capacitance of 200 pF (see Table

A.3.3.5), the accumulated energy available for a spark can reach 10 to 22.5 mJ. A comparison of these values to the MIEs of gases or vapors makes the hazard readily apparent.

5.5.6 Discharges Between Conductors and Insulators.

5.5.6.1 Sparks often occur between conductors and insulators. Examples of such occurrences include situations in which plastic parts and structures, insulating films and webs, liquids, and particulate material are handled. The charging of these materials can result in surface discharges and sparks, depending on the accumulated charge and the shape of nearby conductive surfaces. The variable charge density (both in magnitude and polarity) observed on insulating surfaces is the effect of these discharges spreading over a limited part of the insulating surface.

5.5.6.2 Even with the use of static electricity neutralizers, some charges will remain in certain areas but typically are not hazardous if there is no mechanism by which they can accumulate. However, a dangerous (i.e., ignition-capable) static electric charge can result because of concentration of individual charges. Examples of how such concentration of charge can occur include stacking or nesting of empty plastic containers, winding film onto a roll or drum, and filling a vessel with a nonconductive liquid or powder.

5.5.7 Discharge on the Surface of an Insulator Backed by a Conductor. A surface coated with a thin [less than 8 mm (0.31 in.)] layer of an insulating material will act as a capacitor to store charge. At sufficiently high charge levels (i.e., greater than 250 μC/m²), a branching discharge will be observed on the surface of the coating. This branching discharge is referred to as a *propagating brush discharge*. Alternatively, an electrical breakdown through the layer can occur. The energy stored in the coating can be as high as several joules per square meter, so the energy of the discharge, however distributed in space, can be sufficient to ignite gas-air, vapor-air, and dust-air mixtures. (See Figure 5.5.7.)

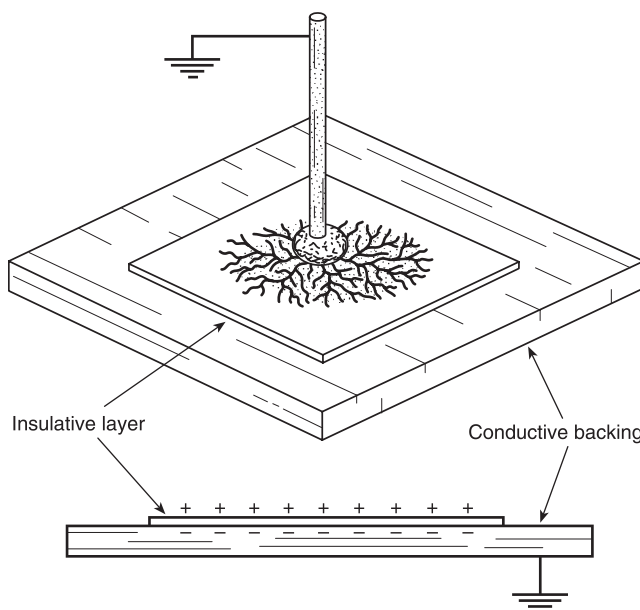


FIGURE 5.5.7 Propagating Brush Discharge. (Source: T. H. Pratt, *Electrostatic Ignitions of Fires and Explosions*, p. 35.)

Chapter 6 Evaluating Static Electricity Hazards

6.1 General.

6.1.1 The two basic steps in evaluating static electricity hazards are as follows:

- (1) Identification of locations where charge separates and accumulates
- (2) Assessment of the ignition hazards at the locations where charge separates and accumulates

6.1.2 The evaluation process specified in 6.1.1 is outlined in Figure 6.1.2.

6.1.3 On-site evaluation or survey of the process should be done to identify any ungrounded conductive objects, including personnel, and any materials that could serve as electrical insulators and interfere with proper bonding and grounding.

6.1.3.1 The survey should identify those locations that might pose a static electricity hazard, even if there is no evidence of accumulation of charge at the time of the evaluation.

6.1.3.2 Special attention should be given to insulating materials that are handled or processed, including insulating materials that might be worn by personnel.

6.1.3.2.1* Each process operation should be considered separately, with attention given to the likely range of exposure of the materials to external influences.

6.1.3.3 A design review of the operation, process, equipment, materials, and operator interaction, including a visual survey of the area, should be completed first. On-site testing should be conducted during normal and foreseeable operating conditions and process upsets to determine the nature and magnitude of any static electricity hazards present.

Note 1: Does process include

- Moving, pouring, sliding, flowing or spraying of materials or liquids?
- Agitation or atomization?
- Liquids, powders or solids?
- Interaction with personnel?
- Filtration?
- Settling?
- Bubbles rising?
- Deliberate or intentional generation of electrostatic charge, e.g., an electrostatic coating process?
- Moving parts (gears, belts, pulleys, shafts)?

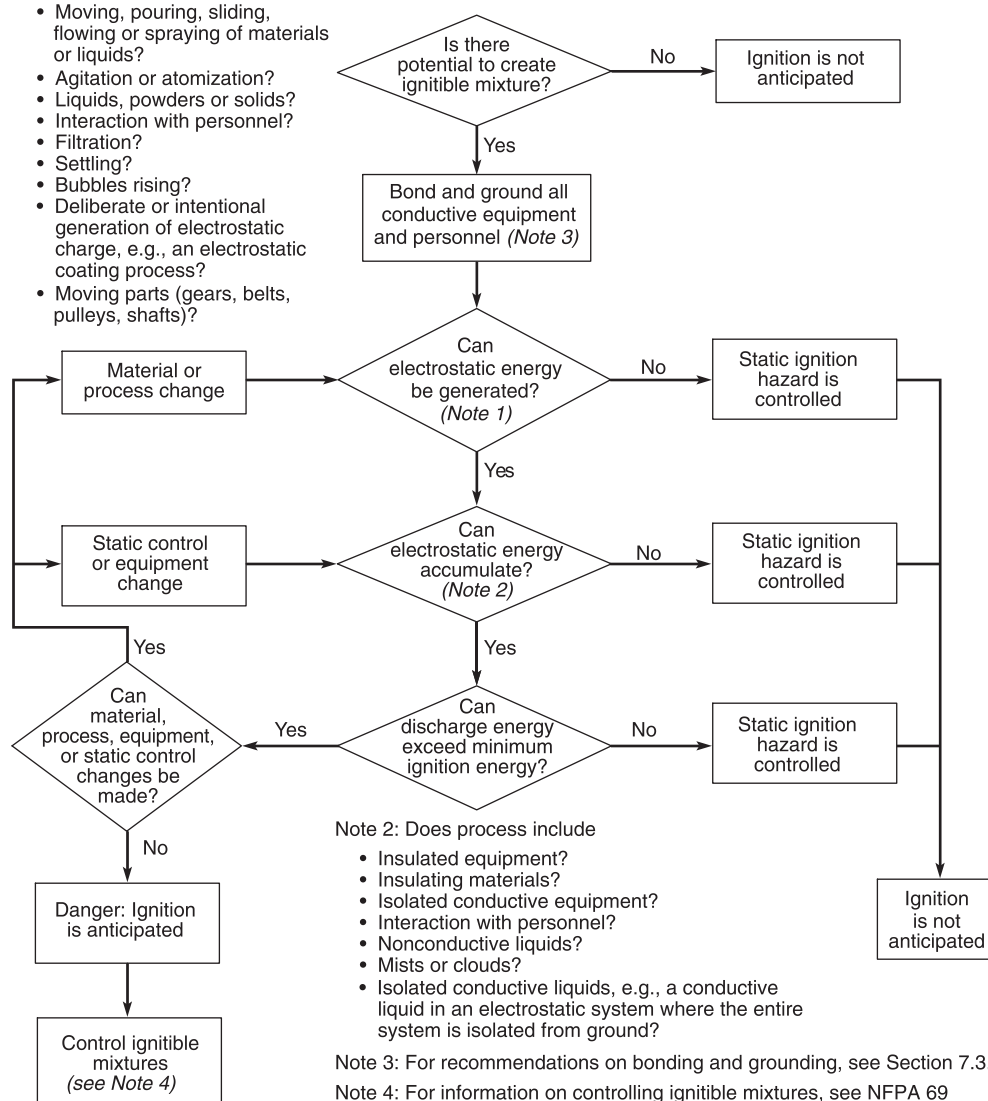


FIGURE 6.1.2 Flow Chart for Determining Static Electric Ignition Hazard.

WARNING: During the on-site review and testing, precautions should be taken to avoid creating a static electric discharge and any testing should be conducted in a safe manner to avoid ignition of a flammable atmosphere. All test equipment should be suitable for the application, for the area in which it is used, and for the type of object being evaluated. The primary ignition hazard comes from introducing a grounded electrode, such as the housing of an electrostatic field meter (see Section 6.4), into the vicinity of a charged surface, thus providing a route for a static electric discharge. The surface of objects being measured should always be approached slowly during observation of the meter's response. Extreme care should be taken so that neither instruments nor testing techniques cause ignition of flammable atmospheres. Appropriate safe work practices should be employed where measurements are being taken in and around hazards including, but not limited to, live electrical circuits, hot surfaces, lasers, and moving parts.

6.2 Measuring a Static Electric Charge. A meaningful evaluation should be done using an appropriate instrument, using the instrument according to the manufacturer's instructions, maintaining calibration of the instrument, and interpreting the measurements according to the manufacturer's recommendations.

6.3 Measuring the Charge on a Conductor.

6.3.1 The voltage on a conductor is proportional to the charge it supports and is expressed by the following equation:

[6.3.1]

$$V = \frac{Q}{C}$$

where:

V = potential difference (volts)

Q = charge supported by the conductor (coulombs)

C = capacitance of the conductor (farads)

6.3.2 The voltage on a conductor can be measured by direct contact using a voltmeter if the impedance of the voltmeter is high enough so that it does not discharge the conductor and the capacitance is small enough so that it does not collect a significant charge from the conductor. An electrostatic voltmeter with input impedance greater than 1×10^{12} ohms can be used for measuring voltages on most ungrounded conductors. Because conductors have the same voltage at every point on their surface, the location at which the test probe of the voltmeter touches the surface of the conductor is not important.

6.4 Measuring the Charge on a Nonconductor.

6.4.1 Because the charge on a nonconductor cannot be measured using a direct contact electrostatic voltmeter, a noncontact electrostatic voltmeter or an electrostatic field meter should be used.

N 6.4.2 A noncontact electrostatic voltmeter senses the strength of the static electric field from the net charge on or in the nonconductor. The field strength, which is proportional to the static electric force per unit charge, describes the electric forces present near a charged object. For practical purposes, an electric field is the force that a person experiences or measures around a charged object.

6.4.3 Electrostatic field meters measure the force between the induced charges in a sensor and the charge present on the surface of an object and are calibrated to measure the electric field in units of volts per unit distance, typically kilovolts per meter. In most cases, the measurements are proportional to the net static electric charge on the object being measured. Electrostatic field meters are sometimes referred to as *field mills*, *static meters*, *static locators*, or *charge locators*. Because the charge density on or in a nonconductor typically is not uniform, measurements should be taken at several locations.

6.4.4 Charged nonconductors exist in many forms, such as sheets, films, webs, powders, liquids, process rolls, and extrusions. Charges on these materials and objects might produce electric fields that are influenced by the test instrument, by the individual conducting the test, and by other nearby conductive, semiconductive, or insulating materials. As a result, the electrostatic field measured by the instrument generally is different from the electrostatic field present before the instrument was introduced. This phenomenon is due to a change in capacitance of the nonconductor being tested.

6.4.5 The forces between electric charges exhibit themselves at a distance. For that reason, the effects of accumulated charge can be observed as the charged objects are approached. For example, the hands and arms of a person who approaches a highly charged object will tingle and might even draw a spark as the surface of the skin and the hair become "charged." Sometimes these observations and sparks provide the first indication that a potentially hazardous condition exists. Charging of the human body can happen even if the person is well grounded.

6.5 General Practices.

Δ 6.5.1 The primary instrument for locating a charge on either a conductor or a nonconductor is the noncontact voltmeter or the electrostatic field meter. The instrument does not contact the charged surface directly. Rather, it senses the magnitude and the polarity of the electric field that exists at its sensing aperture. The instrument and its sensing aperture might disturb the electric field around the charge to be measured, so the meter reading might not accurately indicate the actual magnitude of the field where the meter is not present. Aside from this issue, the meters are effective tools for locating a static electric charge.

6.5.2 In some cases, primarily cases involving flowing liquids and flowing bulk solids, it is easier to collect a sample of the charged material in an isolated vessel or cup, referred to as a *Faraday cup*, and to use an electrometer to measure the streaming current or net charge flowing to the cup receiving the charged material.

6.6 Measuring the Accumulation and Relaxation of Charge.

6.6.1 Measuring the rate of accumulation and relaxation of static electric charge involves measuring changing potential differences or currents.

6.6.2 Electrostatic field meters and dedicated charge decay monitors can be used to observe charge relaxation on conductors and nonconductors under conditions of prescribed initial voltages.

6.6.3 Leakage currents down to about 1×10^{-13} amperes can be measured from isolated conductors using commercially available electrometers. The isolated conductor can be a Faraday cup containing a bulk solid or fluid.

6.7 Measuring the Resistivity of Materials.

6.7.1 Electrical resistivity of materials often consists of volume (bulk) and surface components. In electrostatic processes, the approximate ranges of resistivities that define materials as insulating, semiconductive (antistatic), or conductive are summarized in Figure 6.7.1.

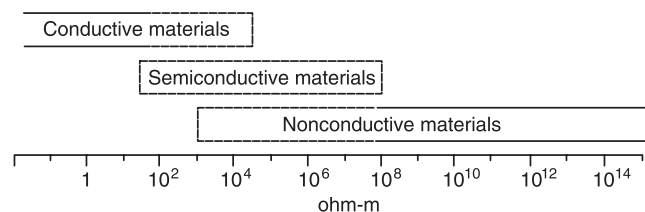
6.7.1.1 Note that there are overlapping ranges in Figure 6.7.1. Dissipating electrical charge is one effective way to mitigate static ignition risks. Often, charge dissipates exponentially with a time constant τ known as the charge relaxation time in Equations 5.4.6 and 5.4.7 that is proportional to the volumetric resistivity.

6.7.1.2 The maximum volumetric resistivity needed to mitigate static discharge risks depends greatly on the speed of the process. Volume resistivities less than the maximum are considered conductive. Mitigating static risks in tens of seconds may be appropriate for a slow process, such as filling a large storage tank, while mitigating the risk in milliseconds is required for a fast process such as a printing operation.

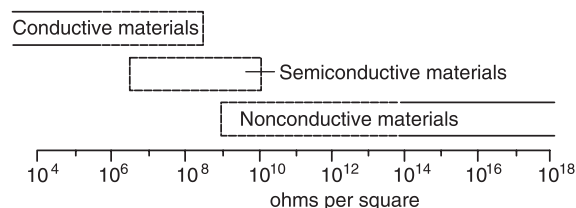
6.7.2 Electric charges can be conducted from a solid, liquid, or powder, either across the surface or through the material.

6.7.3 The volumetric resistivity of a material can be determined by applying a potential difference across a sample of known cross section and monitoring the current through the cross section.

6.7.4 Adsorbed material, particularly water vapor, and compaction of materials are known to lower the resistivity of materials. The resistivity of many materials also has been found to vary with the applied potential difference and with the duration of the test. Various designs of cells used to measure resistivity



(a) Volume resistivity



(b) Surface resistivity

FIGURE 6.7.1 Ranges of Volume and Surface Resistivities.
(Source: H. L. Walmsley, "Avoidance of Electrostatic Hazards in the Petroleum Industry," p. 138.)

ity have been developed into standard test configurations that are applicable to specific kinds of samples. Appropriate test procedures include the following:

- (1) ASTM D257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*
- (2) ISO/IEC 80079-20-2, *Explosive atmospheres — Part 20-2: Material characteristics — Combustible dusts test methods*
- (3) JIS B 9915, *Measuring Methods for Dust Resistivity (with Parallel Electrodes)*

6.8 Assessment of Conduction Paths.

6.8.1 As defined in 3.3.2, *bonding* is a process whereby two or more conductive objects are connected by means of a conductor so that they are at the same electrical potential; that is, the voltage difference between the objects is zero. The objects might or might not be at the same potential as the earth. In fact, a considerable potential difference between the objects and the earth could exist.

6.8.2 As defined in 3.3.23, *grounding* is the process of bonding one or more conductive objects to the earth so that they are all at zero electrical potential.

6.8.3 The purpose of bonding and grounding is to eliminate the occurrence of a static electric spark.

6.8.4 An evaluation and on-site survey of the area should be done to identify conductive objects and verify they are properly bonded and grounded. Periodic inspection and testing of bonding and grounding systems are equally important to ensure that the accumulation of static electric charges are minimized. Self-testing bonding clamps can be used to continuously test the resistance to ground and verify acceptable levels in bonding and grounding installations that are subject to movement, have insulating coatings, or are prone to corrosion.

6.8.5 The resistance to ground of the bonding or grounding path is important not only to ensure relaxation of the static electric charge but also to maintain worker safety and satisfy other purposes, such as for lightning protection and electrical system shock protection. Practices that constitute proper resistance to ground vary from application to application. Chapters 7 through 16 provide examples of acceptable grounding practices.

6.8.6 The resistance to ground is measured with an ohmmeter or a megohmmeter. Care should always be taken to avoid ignition of a flammable atmosphere. The test equipment should be suitable for the application, for the classification of the area in which it is used, and for the type of object being evaluated.

6.9 Measuring Spark Discharge Energies.

6.9.1 The spark discharge energy for conductors is determined from the voltage on the conductor and its capacitance and is expressed by the following equations (which were also given in 5.5.3.3):

[6.9.1]

$$W = \frac{1}{2} CV^2$$

$$W = \frac{1}{2} \left(\frac{Q^2}{C} \right)$$

where:

W = energy (joules)

C = capacitance (farads)

V = potential difference (volts)

Q = charge (coulombs)

6.9.2 A capacitance meter often can be used to measure electrostatic charge storage capacity where the charge is stored on a conductive element. Care should always be taken to avoid ignition of a flammable atmosphere. The test equipment should be suitable for the application, for the classification of the area in which it is used, and for the type of object being evaluated.

6.10 Measuring Ignition Energies.

6.10.1 Any combustible solid (dust), liquid (vapor), or gas should be evaluated for its potential as an ignitable atmosphere in the presence of discharges of static electricity. This evaluation requires determining the MIE of the material. (See Table B.1 for the MIEs of typical gases and vapors.)

6.10.2 Standardized test equipment and procedures have been developed for measuring the MIEs of particulate and gaseous materials. The equipment is highly specialized and requires trained technicians for its operation. Typically, the equipment is operated and maintained by specialized testing firms.

Chapter 7 Control of Static Electricity and Its Hazards by Process Modification and Grounding

7.1 General.

7.1.1* The objective of controlling a static electric hazard is to provide a means whereby separated charges can dissipate before harmful discharges can occur.

7.1.2 Ignition hazards from static electricity can be controlled by the following methods:

- (1) Removing the ignitable mixture from the area where static electricity could cause an ignition-capable discharge
- (2) Neutralizing the charges, the primary methods of which are grounding isolated conductors and air ionization
- (3) Reducing charge generation, charge accumulation, or both by means of process or product modifications
- (4) Operating outside the flammable range, which could include diluting or inerting the mixture

7.2 Relocation. Where equipment that can accumulate a static electric charge is unnecessarily located in a hazardous area, it should be moved to a safe location rather than rely on another means of hazard control.

7.3* Charge Dissipation.

7.3.1 Bonding and Grounding. Bonding is used to minimize the potential difference between conductive objects, even where the resulting system is not grounded. Grounding (i.e., earthing), on the other hand, equalizes the potential difference between the objects and the earth. See Chapter 3 for the definitions of *bonding*, *verified ground point*, *grounding*, and *grounding electrode conductor*. Examples of bonding and grounding are illustrated in Figure 7.3.1.

7.3.1.1 A grounding conductor connects the grounding electrode system to conductive objects.

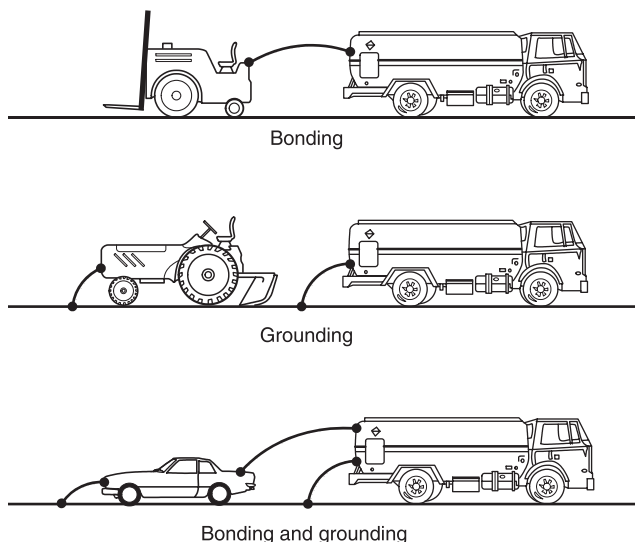


FIGURE 7.3.1 Bonding and Grounding.

7.3.1.2 A bonding conductor connects equipment to other conductive objects.

7.3.1.3 An active bond monitoring system provides a low resistance monitored bond connection between the object and the verified ground point.

7.3.1.4 A conductive object can be grounded by a direct conductive path to earth or by bonding it to another conductive object that is already connected to the ground. Some objects are inherently bonded or inherently grounded because of their contact with the ground. Examples of inherently grounded objects are underground metal piping and large metal storage tanks resting on the ground.

7.3.1.5* The total resistance between a grounded object and the soil is the sum of the individual resistances of the ground wire, its connectors, other conductive materials along the intended grounding path, and the resistance of the ground electrode (i.e., ground rod) to the soil. Most of the resistance in a ground connection exists between the ground electrode and the soil. This ground resistance is quite variable because it depends on the area of contact, the resistivity of the soil, and the amount of moisture present in the soil.

7.3.1.6* To prevent the accumulation of static electricity in conductive equipment, the total resistance of the ground path to earth should be sufficient to dissipate charges that are otherwise likely to be present. A resistance of 1 megohm (1×10^6 ohms) or less is considered adequate for fixed equipment installations. For fluids with very low conductivity (< 45 pS/m), such as heptane, a time period for relaxation of the charges should be in place (see 5.4.7).

7.3.1.6.1 Where the bonding/grounding system is all metal, resistance in continuous ground paths is measured to verify mechanical integrity. (See A.3.3.2.) Such systems include those having multiple components. Greater resistance usually indicates that the metal path is not continuous, usually because of loose connections or corrosion. A permanent or fixed grounding system that is acceptable for power circuits or for lightning protection is more than adequate for a static electricity ground-

ing system. Static grounds should be made to the building steel, if possible. Grounding to power grounds or lightning protection systems is not recommended.

7.3.1.6.1.1 In field-based situations such as HAZMAT response operations or flammable/combustible material spill control and transfer, it might be necessary to establish a temporary or emergency grounding system in a remote location in order to dissipate electrostatic charges. In such situations, various types of conductive grounding electrodes can be used, such as rods, plates, and wires, which are sometimes used in combination to increase surface area contact with the earth. If the purpose of the temporary grounding system is to dissipate static electricity, a total resistance of up to 1 Kilohm (1000 ohms) in the ground path to earth is considered adequate. This can be measured using standard ground resistance testing instruments and is realistically and quickly achievable in most types of terrain and weather conditions.

7.3.1.6.2 Annex G contains diagrams of various bonding and grounding devices, connections, and equipment.

7.3.1.7 Where wire conductors are used, the minimum size of the bonding or grounding wire is dictated by mechanical strength, not by its current-carrying capacity. Stranded or braided wires should be used for bonding wires that will be connected and disconnected frequently. (See Annex G for additional information.)

7.3.1.8 Although grounding conductors can be insulated (e.g., a jacketed or plastic-coated cable) or uninsulated (i.e., bare conductors), uninsulated conductors should be used because defects are easier to detect.

7.3.1.9 Permanent bonding or grounding connections can be made by brazing or welding. Temporary connections can be made using bolts, pressure-type bonding clamps, bonding balls, or other special clamps or means of connection. Pressure-type bonding clamps should have sufficient pressure to penetrate any protective coating, rust, or spilled material to ensure contact with the base metal. When making connections through any surface that is compromised (e.g., by debris, by corrosion), the connection should be verified with a low voltage ohmmeter or similar device (see A.3.3.2).

7.3.1.10 Workers should be grounded only through a resistance that limits the current to ground to less than 3 mA for the range of voltages experienced in the area. This method, referred to as *soft grounding*, is used to prevent injury from an electric shock from line voltages or stray currents.

7.4 Control of Generation of Static Electric Charge. Electric charges separate where materials are placed in contact and then pulled apart. Reducing process speeds and flow rates reduces the rate of charge generation. Such charge separation is found where plastic parts and structures, insulating films and webs, liquids, and particulate material are handled. If the material flows at a slow enough rate, a hazardous level of excess charge does not normally accumulate. This means of static electricity control might not be practical due to processing requirements. (See Chapters 9 through 16 for recommended practices in specific applications.)

7.4.1 Humidification.

7.4.1.1 The surface resistivity of many materials can be controlled by the humidity of the surroundings. At humidities of 65 percent and higher, the surfaces of some materials adsorb

enough moisture to ensure a surface conductivity sufficient to prevent accumulation of static electricity. When humidity falls below 30 percent, these same materials could become good insulators, in which case accumulation of charge occurs.

7.4.1.2 While humidification does increase the surface conductivity of the material, the charge will dissipate only if there is a conductive path to ground.

7.4.1.3 Humidification is not a cure-all for static electricity problems. Some insulators do not adsorb moisture from the air; therefore, high humidity will not noticeably decrease their surface resistivity. Examples of such insulators are uncontaminated surfaces of some polymeric materials, such as plastic piping, containers, and films, and the surfaces of petroleum liquids. These surfaces can accumulate a static electric charge even when the atmosphere has a humidity of 100 percent.

7.4.2 Charge Relaxation and Antistatic Treatments.

7.4.2.1 Based on their properties, liquid and solid materials carrying a static electric charge need time to dissipate, or “relax,” the charge. In some cases, the materials can be allowed sufficient time for the charges to relax before being moved and used in a hazardous area or process.

7.4.2.2 Charge relaxation can occur only if a path to ground for conduction of the charge is available. Increasing the conductivity of the material will not eliminate hazards if the material remains isolated from ground.

7.4.2.3 A nonconductive material often can be made sufficiently conductive to dissipate static electric charge, either by adding conductive ingredients to its composition or by applying hygroscopic agents to its surface to attract atmospheric moisture.

7.4.2.4 Carbon black can be added to some plastics or rubbers to increase conductivity. Carbon-filled plastics and rubber articles are sometimes sufficiently conductive to be grounded like metal objects. However, a material being black due to carbon loading does not necessarily mean it is conductive. Antistatic additives can also be mixed with liquid and particulate streams to foster charge relaxation.

7.4.2.5 In some cases, particularly with plastic films or sheeting, a material is added to attract atmospheric moisture to the surface, thus increasing surface conductivity. Care should be taken where antistatic plastic film or sheeting is used in low-humidity conditions. In environments with less than 30 percent humidity, film or sheeting can become nonconductive and accumulate static electric charge. These materials have a finite shelf life and can be impacted by solvents, sunlight, or UV exposure or otherwise lose effectiveness overtime.

7.4.2.6 Topical hygroscopic coatings attract atmospheric moisture and make the surface of the coated material conductive. However, such coatings can be easily washed away or rubbed off or can lose effectiveness over time. This type of coating should be considered only as a temporary measure to reduce accumulation of static electric charge.

7.4.2.7 Conductive polymers, laminates with conductive elements, and metallized films, along with permanent, inherently dissipative polymer (IDP) additives that do not depend on moisture to impart dissipative properties, have been developed for improved dissipation of static electric charge.

7.5 Control of Ignitable Mixtures in Equipment.

▲ **7.5.1 General.** Despite efforts to prevent accumulation of static electric charges through good design, many operations that involve the handling of nonconductive materials or nonconductive equipment do not lend themselves to engineered solutions. It then becomes desirable or essential, depending on the nature of the materials involved, to provide other measures, such as one of the following:

- (1) Inerting of the equipment
- (2) Ventilation of the equipment or the area in which it is located

7.5.2 Inerting.

7.5.2.1* Where an ignitable mixture is contained, such as in a processing vessel, the atmosphere should be made oxygen deficient by introducing enough inert gas (e.g., nitrogen, combustion flue gas) to make the mixture nonignitable. This technique is known as *inerting*. (See NFPA 69 for more information on inerting systems.)

7.5.2.2 Where operations are normally conducted in an atmosphere containing a mixture above the upper flammable limit (UFL), it might be practical to introduce the inert gas only during those periods when the mixture passes through its flammable range.

7.5.3 Ventilation. Mechanical ventilation can be used to dilute the concentration of a combustible material to a point well below its lower flammable limit (LFL), in the case of a gas or vapor, or below its minimum explosible concentration (MEC), in the case of a dust. Usually, such a reduction means dilution to a concentration at or below 25 percent of the lower limit. Also, by properly directing the air movement, it might be practical to prevent the material from approaching an area of operation where an otherwise uncontrollable static electricity hazard exists.

Chapter 8 Control of Static Electricity and Its Hazards by Static Eliminators and Personnel Factors

8.1 Charge Neutralization by Ionization of Air.

8.1.1 General. Charges on nonconductive surfaces can be neutralized by devices that produce oppositely charged air ions via corona discharge. If such air ionizers are used, certain factors influence their effectiveness and must be considered. These factors might be environmental conditions (e.g., dust and temperature) and positioning of the device in relation to the material processed, machine parts, and personnel. It is important to note that these control devices do not prevent the generation of static electric charge. They provide ions of opposite polarity to neutralize the generated static electric charge.

8.1.2 Inductive Neutralizers.

8.1.2.1 Inductive neutralizers include the following:

- (1) Needle bars, which are metal bars equipped with a series of needlelike emitters
- (2) Metal tubes wrapped with metal tinsel
- (3) Conductive string
- (4) Brushes made with metal fibers or conductive fibers

8.1.2.2 The design of each type of inductive neutralizer is based on or consists of sharply pointed elements arranged for placement in the static electric field near the charged surfaces.

8.1.2.3 A charge drawn from ground to the needlelike tips of an inductive neutralizer produces a concentrated electric field at the tips. If the tips are sharply pointed, the electrical field will be sufficient [i.e., greater than 3 kV/mm (76 kV/in.)] to produce a localized electrical breakdown of the air. This electrical breakdown, known as corona, injects ions into the air that are free to move to distant charges of opposite polarity. The flow of ions produced in corona constitutes a neutralizing current. (See Figure 8.1.2.3.)

8.1.2.4 Although inexpensive and easy to install, inductive neutralizers require a minimum potential difference between the object and the needle tip to initiate corona and the neutralizing process. In the absence of this minimum charge, neutralization will not occur, and a residual potential of a few thousand volts will be left on the material where sharp inductive points are within about 12 mm (0.47 in.) of the surface.

8.1.2.5 It is critically important that inductive neutralizers are connected to a secure ground. If the inductive neutralizer is not grounded, sparks from the induction bar can occur.

8.1.3 Active Electric Static Neutralizers.

8.1.3.1 Electrically powered electrostatic charge neutralizers use a high-voltage power supply to produce corona from sharp electrodes. The charge on any object near the device attracts oppositely charged air ions produced by the device to achieve neutralization. The use of a high-voltage power supply eliminates the limitation of inductive neutralizers in control of charges having fields below the corona onset threshold.

8.1.3.2 An electrically powered static neutralizer can create sparks and must be approved for the location in which it is used. It must not constitute a source of ignition. For example, when not energized or in case of failure, it can be designed to function as an induction neutralizer.

8.1.3.3 Electrically powered static neutralizers using alternating current use a high-voltage power supply to energize the corona electrodes at 50 Hz to 60 Hz. The use of an alternating field stresses the electrodes to produce both positive and negative ions for use in the neutralizing process. Current from the power supply is capacitive-coupled to each or to several of the sharp electrodes to limit spark energy in the event of a short circuit. An electric static neutralizer must be suitable for the location in which it is used and must not constitute a source of ignition.

8.1.3.4 Electric static neutralizers that use pulsed or steady-state double-polarity direct current use a pulsed or steady field to stress the electrodes to produce ions for use in the neutralization.

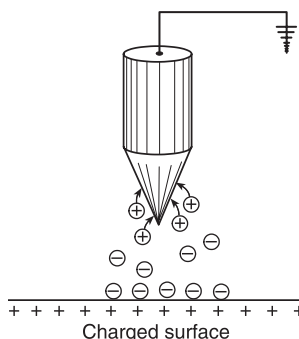


FIGURE 8.1.2.3 Example of an Induction Needle.

ing process. In the event of a short circuit, the spark energy is controlled by current-limiting resistors. Pulsed or double-polarity dc ionizers must be suitable for the location in which they are used and must not constitute a source of ignition.

8.1.4* Active Radioactive Static Neutralizers. Radioactive (nuclear) ionizers use ionizing radiation to produce ions for neutralization of static electric charges. The most common radioactive ionizers depend on alpha particle generation from the decay of polonium-210 (^{210}Po).

8.1.4.1 Performance of radioactive ionizers deteriorates with the decay of the radioactive material. The neutralizers must be registered and installed in accordance with Nuclear Regulatory Commission regulations and replaced periodically (at least annually), because ionization capability diminishes with radioactive decay. Radioactive ionizers are often used in conjunction with inductive neutralizers to control high charge densities.

8.1.4.2 Although cost and regulatory compliance issues are associated with radioactive ionizers, they are nonincendive, require no wiring, and can reduce static electric charges to the lowest levels.

8.2* Control of Static Electric Charge on Personnel. The human body is an electrical conductor and can accumulate a static charge if insulated from ground. This charge can be generated by contact and separation of footwear with floor coverings, by induction, or by participation in various manufacturing operations. Where ignitable mixtures exist, the potential for ignition from the charged human body exists, and means to prevent accumulation of static electric charge on the human body might be necessary.

8.2.1 Prevention of Charge Accumulation. Steps to prevent charge accumulation include use of the following:

- (1) Conductive or static dissipative flooring and footwear
- (2) Personnel-grounding devices
- (3) Antistatic or conductive clothing

8.2.2 Conductive and Static Dissipative Flooring and Footwear.

8.2.2.1 Conductive or static dissipative flooring can provide effective dissipation of static electricity from personnel who are adequately bonded to the floor. Materials can be solid or can be coatings that are selected on the basis of wear characteristics, chemical resistance, and the floor area that needs to be covered. Small areas can be handled with a grounded metal plate. Resistance to ground for flooring systems should be less than 1×10^8 ohms. Clean uncoated concrete floors typically have a resistance to ground of 1×10^6 to 1×10^8 ohms. If static protection is dependent on the resistance to ground of the flooring, the flooring should be measured regularly per ASTM F150, *Standard Test Method for Electrical Resistance of Conductive and Static Dissipative Resilient Flooring*. Accumulation of debris, wax, and other high-resistivity materials will compromise the conductivity of the floor. Floors should be routinely measured to confirm that they have acceptable resistance to ground.

8.2.2.2* Static dissipative (SD) footwear used in conjunction with conductive or static dissipative flooring provides a means to control and dissipate static electric charges from the human body. Resistance to earth through static dissipative footwear and conductive or static dissipative flooring should be between 1×10^6 ohms and 1×10^8 ohms. For materials with very low ignition energies, the resistance to earth through footwear and flooring should be less than 1×10^6 ohms. Resistance should be

measured with commercially available footwear conductivity testers.

8.2.2.3 Resistance of footwear can increase with accumulation of debris such as wax or other nonconductive deposits on the sole of the footwear or on the flooring itself, the use of orthopedic foot beds or orthotic devices, and reduced floor contact area. Resistance of footwear should be tested on a periodic basis to confirm functionality.

8.2.2.4 Conductive footwear is footwear designed to have a resistance to ground through the footwear and the floor of less than 1×10^6 ohms. It is typically used where materials of low ignition energy, such as explosives and propellants, are handled. Conductive footwear should not be used where a possibility for electrocution by line voltages exists.

8.2.3* Personnel Grounding Devices.

8.2.3.1 Where static dissipative footwear will not provide adequate personnel grounding, supplementary devices should be used. Such devices include wrist straps, heel/toe grounders, and conductive overshoes.

8.2.3.2 Supplementary devices should be selected so that accumulation of hazardous static electric charge is prevented, while the risk of electrocution is not increased. In most practical situations, grounding of personnel is achieved by ensuring that the resistance from the skin to ground is approximately 1×10^8 ohms or less. The need to protect against electrocution via a grounding device imposes a minimum resistance from skin to ground of 1×10^6 ohms. Based on skin contact and contact with the floor, especially during activities where the entire sole of the footwear is not in contact with the floor (e.g., kneeling), effectiveness can be compromised.

8.2.3.3 The simplest type of commercial device is a grounding bracelet with a built-in resistor typically giving a resistance to ground of about 1×10^6 ohms for shock protection. Wrist straps of this type have the greatest utility at ventilation hoods and at other locations where limitation on the operator's mobility can be tolerated. Breakaway wrist tether systems could be necessary where emergency egress is needed. A hood can be equipped with two external coiled grounding cords with cuff attachments that can be removed and kept by individual users.

8.2.3.4 Personnel resistance to ground should be checked periodically to ensure it meets the manufacturer's specified limits. The chosen testing instrument should be capable of measuring an order of magnitude greater than the limit value.

8.2.4 Antistatic or Conductive Clothing.

8.2.4.1 Although silk and most synthetic fibers are excellent insulators and undergarments made from these materials exhibit electrostatic phenomena, no conclusive evidence exists to indicate that wearing such undergarments constitutes a hazard. However, removal of outer garments is particularly hazardous in work areas, such as in hospital operating rooms, explosives manufacturing facilities, and similar occupancies and where clothing is contaminated by flammable liquids (Class I liquids, as designated by NFPA 30). Outer garments used in such areas should be suitable for the work area and should be antistatic.

8.2.4.2* Although the likelihood of ignition by a grounded person due to any type of clothing is usually very low, the charging of personnel (e.g., where personnel are getting out of a

forklift truck) is greatly increased by clothing that has high resistivity.

8.2.4.3* In oxygen-enriched atmospheres, such as those that could be present in liquid oxygen filling plants, vapor from the cooled gas can permeate an employee's clothing, increasing its combustibility. A static electric charge that accumulates on the employee and then suddenly discharges can ignite the clothing.

8.2.5 Gloves. Gloves should be antistatic or conductive with the same resistivity as prescribed for footwear. Gloves should be tested in conjunction with the footwear.

8.2.6 Cleaning or Wiping Cloths.

8.2.6.1 Synthetic fabrics used in cleaning or wiping cloths can develop sufficient static electric charge to produce discharges capable of igniting solvent vapors. Ignitable (flammable and combustible) liquids used at temperatures above their flash points, where used with synthetic cleaning or wiping cloths, increase the risk of fire. Typically, charge generation increases with the speed and vigor of the wiping action. The material being cleaned or wiped, if nonconductive, also can accumulate a charge, which might be capable of causing ignition.

8.2.6.2 Cotton or synthetic fabric treated with an antistatic compound should be used if static electric charge generation needs to be controlled, especially if flammable liquid (Class I liquid, as designated by NFPA 30) solvents are used for cleaning or wiping. Conductive solvents should be used.

8.3 Maintenance and Testing. All provisions for control of personnel static electricity should be maintained and tested to remain effective.

8.4 Discomfort and Injury. Electrostatic shock can result in discomfort and, under some circumstances, injury. While the discharge itself typically is not dangerous to humans, it can cause an involuntary reaction that results in a fall or entanglement with moving machinery. If charge accumulation cannot be avoided and no flammable gases or vapors are present, consideration should be given to the various methods by which contact with metal parts can be eliminated. Such methods include use of nonmetal handrails, insulated doorknobs, and other nonconductive shields. Any spark or shock to personnel should be investigated.

Chapter 9 Ignitable (Flammable and Combustible) Liquids and Their Vapors

9.1 General. This chapter discusses the assessment and control of static electricity hazards involved with the storage, handling, and use of ignitable (flammable and combustible) liquids and their vapors and mists. While focused on ignitable (flammable and combustible) liquids, the principles of this chapter also apply to noncombustible liquids and vapors (e.g., wet steam) where their storage, use, and handling can cause a static electricity ignition hazard. The chapter begins with a discussion of the combustion characteristics of liquids and their vapors and mists, followed by a discussion of charge generation and dissipation in liquids. Emphasis is then given to processes involving the following:

- (1) Flow in pipe, hose, and tubing
- (2) Storage tanks
- (3) Loading and unloading of tank vehicles

- (4) Vacuum trucks
- (5) Railroad tank cars
- (6) Marine vessel and barge cargo tanks
- (7) Process vessels
- (8) Gauging and sampling
- (9) Tank cleaning
- (10) Portable tanks and containers
- (11) Vacuum cleaning

Δ 9.1.1 Static control measures need to be taken wherever ignitable mixtures might present. Conversely, if ignitable mixtures can be ruled out, these measures are not required. However, careful evaluation is required to rule out the possibility of ignitable mixtures under all conditions (see Section 9.2). Grounding and bonding should correct problems with electrostatic shock, which can result in discomfort and, under some circumstances, injury (see Section 8.4).

9.2 Combustion Characteristics of Liquids, Vapors, and Mists.

The following combustion properties of liquids need to be understood to properly assess the static electricity ignition hazard:

- (1) Flash point
- (2) Flammable limit and vapor pressure
- (3) Ignition energy
- (4) Oxidant concentration

9.2.1 Flash Point.

9.2.1.1* Flash point is the minimum temperature at which a liquid gives off sufficient vapor to form an ignitable mixture with air near the surface of the liquid, as determined using standard flash point apparatus described in ASTM E502, *Standard Test Method for Selection and Use of ASTM Standards for the Determination of Flash Point of Chemicals by Closed Cup Methods*. Selection of test procedures and apparatus depends on other physical characteristics of the liquid. For reasons discussed in A.9.2.1.2, ignition might occur at temperatures lower than the reported flash point.

9.2.1.2* If the flash point of a liquid is at or below typical ambient temperatures, it is likely to evolve an ignitable vapor. The lower the flash point, the higher the vapor pressure and the more likely that an ignitable vapor concentration will be present. Because of the inherent errors in standard flash point measurements, an allowance of at least 5°C to 11°C (9°F to 20°F) below the published flash point should be made in the evaluation of an ignition hazard. A minimum safety factor of 5°C (9°F) is appropriate for single-component liquids having well-defined flash points. The higher minimum safety factor of 11°C (20°F) is appropriate for mixed liquids of less certain composition, such as fuels.

N 9.2.1.3 Processing and handling of combustible liquids (Class II and Class III liquids, as designated by NFPA 30) heated at or above their flash point should follow the requirements for flammable liquids (Class I liquids, as designated by NFPA 30), unless an engineering evaluation justifies following the requirements for some other liquid class.

9.2.1.4 Operations at high elevations, such as mining operations, require an additional safety factor, depending on the elevation. The recommended additional safety factor for each 1000 m (3280 ft) above sea level is 2.6°C (4.7°F) for complex fuels, such as diesel fuels, and 1.9°C (3.4°F), for pure liquids, such as toluene and ethanol. Elevations below 1000 m (3280 ft) can be neglected, because the additional correction factor is no