

## Index

### a

absorption method 84  
 active corona 97  
 act with relevant experience 219–220  
 additive-depleted surface 50–51  
 adhesion of an insert on a variable  
   base 227–229  
 adhesive bonding-blocking 226–227  
 adhesive replacement 226  
 adiabatic compression and shock  
   waves 11  
 aerials 94  
 aerosol 234–236, 239–240  
 air boundary layers 242  
 alcohol cup 173  
 antistatic 45  
 antistatic packaging 182  
 application of liquid media 234–236  
 application of water, use of charging  
   during 236  
 asymmetrical rubbing 24  
 ATEX certification 240  
 atmosphere exchange 236

### b

back discharge 160  
 balun 94  
 bang effect 144, 156  
 basics of fire and explosion  
   danger triangle 2  
   exothermic reaction of fuel 1  
   explosion-endangered areas and  
   permissible equipment 7  
   explosive atmosphere  
     limits with combustible dusts 6

    limits with flammable liquids 3–6  
     metal dusts 6  
 flammable liquids 15–18  
 fuel 2  
 heat 2–3  
   vs. oxygen 3  
 hybrid mixtures 6–7  
 ignition sources  
   adiabatic compression and shock  
     waves 11  
   cathodic protection 10  
   chemical reactions 11  
   electrical apparatus 10  
   electromagnetic field 10  
   electromagnetic radiation 10  
   flames and hot gases 9  
   hot surfaces 9  
   ionizing radiation 10  
   lightning 10  
   mechanically generated sparks 10  
   static electricity 10  
   ultrasonics 11  
 inerting process 3  
 minimum ignition energy 11–15  
 oxygen 3  
 permissible equipment 7–9  
 big storage tanks, two  
   explosions 189–192  
 bipolar charge layers 124  
 blocking effect 230  
 blocking of newspapers 226  
 blow trunk 190  
 breakdown voltage of a discharge  
   gap 267  
 Brownian molecular movement 28

*Static Electricity: Understanding, Controlling, Applying*, First Edition.

Günter Lüttgens, Sylvia Lüttgens, and Wolfgang Schubert.

© 2017 Wiley-VCH Verlag GmbH & Co. KGaA. Published 2017 by Wiley-VCH Verlag GmbH & Co. KGaA.

- brush discharges 97–98, 104–108, 162
  - bulk materials 52, 74–75, 130, 132
  - burning handkerchief does not burn up 174
- C**
- capacitance 38, 259–261
    - charge decay measurements 79–81
    - coaxial cable/cylinder
      - capacitance 260
    - conductive sphere in space 260
    - measurement 77–78
    - permittivity value 78–79
    - plate capacitor 261
    - rod (wire) across a conductive area 259
    - series of single capacitors 261
    - shunt of single capacitors 261
    - sphere across a conductive area 260
  - capacitive current limit 136
  - capacitive hygrometer 86
  - capacitor 38, 135
  - carbon fiber brush 136
  - carriers 19
  - cast film process 230
  - cathodic protection 10
  - charge 263–264. *see also* targeted use of charges
    - caused by separating process 149–150
    - conservation 223, 225
    - decay measurements 79–81
    - dissipation 20
    - of electron beam 263
    - mass charge density 264
    - measurement 54–56
    - moved charge 263
    - relaxation with liquids 30–31
    - surface charge density 263–264
    - volume charge density 264
  - charge decay measuring device QUMAT<sup>®</sup>-528 80
  - charge-emitting discharge electrode 114
  - charging
    - bars 223
    - behavior 41
      - by gases 31–33
      - of liquids 28–31
      - of particles
        - many 152–153
        - single 150–152
      - by separation 160
  - chemical reactions 11
  - chill roll 230–231
  - circular frequency 258
  - classification for flammable liquids 5–6
  - clean surfaces 128
  - climate 81–82
  - coating machine 237–241
  - coating process 241–243
  - coaxial cable/cylinder capacitance 260
  - “CombiCleaner” operating principle 128–129
  - combustible organic dusts 6
  - composite materials 125–127
  - conductance 269
  - conductive layers 125, 126
  - conductive sphere in space 260
  - conductive surfaces 135
  - conductivity 30, 51, 269
  - cone discharges 98
  - contact and separation 120
  - core dummy charge 232–233
  - corona discharges 96–97, 104, 161–162
  - corona effect 114
  - corona systems 248–251
  - Coulomb forces 144, 224
  - Coulomb meter 66–67
  - cracks 193
  - current density 240
  - current limiter 134
- d**
- danger triangle 2
  - “decanting” of gasoline vapors 171–172
  - description of demonstration experiments
    - charges caused by separating process 149–150
    - charging by separation 160

- charging of particles
  - many 152–153
  - single 150–152
- dissipating properties 157–158
- electric induction
  - basic experiment 153–154
  - chimes 154–155
  - isolated conductive
    - parts 155–157
- electrostatic charging of a
  - person 158–159
- electrostatic force effects 144–145
  - electrical field lines 148
  - electroscope 147–148
  - hovering pipes 146–147
  - rolling pipes 145–146
- electrotechnical ideas 139
- explosion tube 142–144
- field meter 57, 142
- fire and explosion dangers
  - burning handkerchief does not
    - burn up 174
  - “decanting” of gasoline
    - vapors 171–172
  - effects with large surfaces 168–169
  - extinguishing with
    - water 173–174
  - flash point 168
  - inflaming solid
    - combustibles 174–175
    - oxygen demand 172–173
    - progressive flame front 170–171
    - rich mixture 169–170
- gas discharges
  - brush discharges 162
  - corona discharges 161–162
  - evidence of ion wind 163–164
  - ignition by brush
    - discharges 162–163
  - propagating brush
    - discharges 164–167
  - spark discharges 160–161
  - super brush discharges 163
- ignition voltage 159–160
- preliminary remarks 140–141
- static voltmeter 141
- Van de Graaff generator 142–143
  - visualization 139
- dew point hygrometry 83–84
- dielectric strength 117–118
- direct charge 232
- dirty discharge electrodes 135
- discharge electrodes 114
- discharges, gas 89
  - avoidable 103–111
  - brush discharge 97–98
  - cone discharges 98
  - consequences of 102
  - corona discharge 96–97
  - electrostatic 90–94
  - mechanisms of 89–90
  - propagating brush
    - discharge 98–102
  - spark discharge 94–95
  - traces caused by gas 102–103
- discharges without electrodes 94
- discharging charged
  - surfaces 118–119
- granules and similar
  - particles 129–133
- material webs
  - behavior of composite
    - materials 125–127
  - bipolar layers of equal field
    - strength 124
  - double-sided
    - discharging 123–124
  - electric potential 123
  - friction 120
  - nonporous materials 122
  - optimal discharging setup 120, 121
  - optimal placement of discharge
    - bars 122
  - rerolling process 120–121
  - single-sided discharging 123
  - static electric shocks 119
  - triboelectric effect 120
- other objects 127–129
- sheets 127–128
- discharging granules 129–133
- discharging of sheets 127–128
- disruptive discharge 117
- dissipating property 41, 157–158

- drying 236–237
  - of fast moving substrates 236–237
- dust explosion 130
- e**
- effects with large surfaces 168–169
- electrical apparatus 10
- electrical breakdown 90
- electrical charge 230
  - coverage 117, 118
- electrical field lines 148, 235
- electrical resistance 45
- electric field 33–36
- electric induction 156, 224, 225
  - basic experiment 153–154
  - chimes 154–155
  - image charge 37–38
  - isolated conductive parts 155–157
  - specification of 36–37
- electric induction field meter 67
- electroadhesion 247–248
- electromagnetic field 10
- electromagnetic radiation 10
- electrometer amplifier 54
- electron density 247
- electron work function 21
- electroscope 147–148
- electrostatic application 223
- electrostatic charging
  - with fluids 75–76
  - of liquids 28–30
    - charge relaxation with liquids 30–31
    - charging by gases 31–33
  - of a person 158–159
  - of powdery bulk materials 74–75
- electrostatic discharge 89, 180
- electrostatic disturbances prevention
  - alternating current voltage 114
  - charge-emitting discharge
    - electrode 114
  - clean and corroded points 115
  - dielectric strength 117–118
  - discharging charged surfaces 113, 118–119
    - granules and similar particles 129–133
    - material webs 119–127
    - other objects 127–129
    - sheets 127–128
- empty space 115
- field line concentration 116–117
- intentionally charging surfaces 113
- ionizing electrodes 114
- passive ionizer 116
- potential hazards posed by discharge
  - electrodes 134–136
- electrostatic effect 236
- electrostatic force effects 144–145
  - electrical field lines 148
  - electroscope 147–148
  - hovering pipes 146–147
  - rolling pipes 145–146
- electrostatic ignitions, doubts with
  - burst of a glass pipe 218–219
  - fire in a polyethylene drum 213–215
  - fire in a solvent cleaning area 215–217
- electrostatic safety measures 44
- electrostatic separation 245
- electrostatic shock 111
- electrostatic voltmeters 53–54
- electro-technical explosion
  - protection 178
- energy  $W$  of a capacitance 255–256
- “equipment protection levels” (EPLs) 8–9
- equipotential lines 34
- equipotential surface 34
- evidence of ion wind 163–164
- explosion 1
  - disaster near Bitburg 190–192
  - in a floating roof tank followed by fire 189–190
  - in a mixing silo for plastic granules 202
  - in a railcar bulk container 192–193
  - during rotational molding 201–202
- explosion dangers, fire and burning handkerchief does not burn up 174
- “decanting” of gasoline vapors 171–172
- effects with large surfaces 168–169

extinguishing with water 173–174  
 flash point 168  
 inflaming solid  
   combustibles 174–175  
   oxygen demand 172–173  
   progressive flame front 170–171  
   rich mixture 169–170  
 explosion range 4  
 explosion tube 142–144  
 explosive atmosphere  
   limits with combustible dusts 6  
   limits with flammable liquids 3–6  
   metal dusts 6  
 extinguishing with water 173–174

**f**

Faraday cage 55  
 Faraday pail 55  
 feeder bowls 133  
 fiberglass fabric 169  
 field  
   field of point charge 256  
   field of rod (wire) charge 257  
   homogeneous field between plane  
     plates 256  
   lines 33, 34  
   meter 142  
   permittivity 257  
   strength (*see* field)  
 fire 1  
 fire extinguishing installation 189–191  
 fixing coverings 227  
 fixing of thin materials 226  
 flames and hot gases 9  
 flammable liquids 15–18  
 flash point 4, 168  
 fluida 20  
 flux density 257  
 force 262  
   between 2 point charges 262  
 free-falling objects 55–56  
 frequency  
   circular frequency 258  
   wavelength 258  
 frictional electrification 22  
 fuel 2  
 fuel/oxygen mixture 1–2

**g**

gas discharges 89  
   avoidable 103–111  
   brush discharges 97–98, 162  
   cone discharges 98  
   consequences of 102  
   corona discharges 96–97, 161–162  
   electrostatic 90–94  
   evidence of ion wind 163–164  
   ignition by brush  
     discharges 162–163  
   mechanisms of 89–90  
   propagating brush  
     discharges 98–102, 164–167  
   spark discharges 94–95, 160–161  
   super brush discharges 163  
   traces caused by gas 102–103  
 gasification process with  
   wood 174–175  
 gas stream 246  
 glass fiber fabric, impregnation  
   of 186–187  
 Globally Harmonized System  
   (GHS) 5  
 gravure printing 237–241  
 grounded emitter 93  
 guard ring circuit 47–49

**h**

hair hygrometer 84  
 Helmholtz double-layer effect 38  
 homogeneous field between plane  
   plates 256  
 hose filter 208–209  
 hot surfaces 9  
 hovering pipes 146–147  
 humidity 81  
 hybrid mixtures 6–7  
 hygrometers 86–87

**i**

ignitability of brush discharges 109  
 ignition by brush  
   discharges 162–163  
 ignition caused by cone  
   discharges 212–213  
 ignition of dust 165–166

- ignitions due to brush discharges
    - filling pipe blocked with sulfur
      - leading to ignition of methanol 187–188
    - ignition caused by an antistatic PE bag 182–183
    - impregnation of a glass fiber fabric 186–187
    - ion exchanger resin in toluene 188–189
    - PE liner slipping out of paper bag 181–182
    - pouring flaked product into an agitator vessel 180–181
    - pumping polluted toluene 185–186
    - shaking fine dust out of a PE bag 183–185
    - two explosions in big storage tanks 189–192
  - ignition sources 2, 9–11, 178
    - adiabatic compression and shock waves 11
    - cathodic protection 10
    - chemical reactions 11
    - electrical apparatus 10
    - electromagnetic field 10
    - electromagnetic radiation 10
    - flames and hot gases 9
    - hot surfaces 9
    - ionizing radiation 10
    - lightning 10
    - mechanically generated sparks 10
    - static electricity 10
    - ultrasonics 11
  - ignition voltage 159–160
  - image charge 37–38
  - impedance
    - of a capacitance 271
    - of an inductance 271–273
  - impression roller 237
  - indirect charge 233–234
  - inductance, of an air coil 259
  - induction electric field meters 56–58
  - induction field meter 56
  - inerting process 3
  - inflaming
    - a dust heap 175
    - solid combustibles 174–175
  - ink particles 239
  - in-mold-decoration (IMD) 232–234
  - in-mold-labeling (IML) 232–234
  - intermediate layers 227
  - investigation, strategy of 177–178
    - general approach 179
    - hasty consequence 179–180
    - ignition sources 178–179
  - ion exchanger resin in toluene 188–189
  - ionization 89–91
  - ionizing electrodes 114
  - ionizing radiation 10
  - ions 89–91
  - ion wind 97
- k**
- Kasuga Denki KSD System 61–62
  - Kirchhoff's junction rule 266
  - Kirchhoff's loop rule 266
- l**
- laminar air boundary layers 234
  - laminar airflow 234–237
  - laminar airflow boundary layer 236
  - leakage current 240
  - leakage resistance 269
  - Lewis acidic surfaces 119
  - Lewis base surface 119
  - Lichtenberg discharges 98
  - lightning 10
  - lithium-chloride hygrometer 85–86
  - lower explosion limit 4
- m**
- mass charge density 264
  - material separation 246
  - maximum allowable capacitance 104
  - maximum allowed surface area 105
  - measurement methods. *see also* metrology
    - electrical resistance 45
    - realization of resistance measurements 46–49
  - measuring area E-field meter 64
  - measuring area piezo sensor 65

mechanically generated sparks  
 (MGSS) 10  
 mechanism of charging 19  
 metallic dust 6  
 metrology  
 additive-depleted surface 50–51  
 applications of induction electric field  
 meters 65–67  
 bulk materials 52  
 capacitance 77–81  
 conductivity of liquids 51  
 discharge capacity 71–73  
 electrostatic charges in chemical  
 production 76–77  
 electrostatic charging of powdery  
 bulk materials 74–75  
 electrostatic charging with  
 fluids 75–76  
 electrostatic safety measures 44  
 electrostatics/electrical  
 engineering 44–45  
 electrostatic voltmeters 53–54  
 errors when measuring field  
 strength 58–61  
 Faraday pail 54–56  
 induction electric field  
 meters 56–58  
 measurement methods  
 electrical resistance 45  
 realization of resistance  
 measurements 46–49  
 protective textile clothing 68–71  
 surface charge on moving webs 68  
 test procedure for paper 73–74  
 themes around air  
 humidity 81–87  
 types of electric field  
 meters 61–65  
 use of insulating material in  
 endangered areas 52  
 walking test 41–43  
 microampere meter 161  
 micronizer jet mill, ignition in a 200  
 minimum ignition energy  
 (MIE) 11–15  
 miraculous earthing clamp 212  
 modified ball electrode 67

modified induction electric field meter 66  
 moved charge 263  
 mutual binding effect 99

**n**

n-hexane 207–208

**o**

oil application 234  
 oil suction granules 168, 169  
 one-electrode discharges 95  
 opposite- and similar-poled  
 charges 224  
 Optical-Web-Tension-Profile-  
 Scanner 244  
 oxygen 3  
 oxygen demand 172–173

**p**

paper ribbon 230  
 particle mist 241–243  
 passive corona 97  
 passive discharge electrode 136  
 passive ionizer 116, 240  
 permittivity 257  
 permittivity value 78–79  
 Perspex<sup>®</sup> tube 142  
 Picoampere meter 67  
 pinch effect 91  
 pipe ionization 131  
 plasma 92  
 plate capacitor 261  
 polluted toluene pumping 185–186  
 potential 264  
 powder heap discharge 98. *see also*  
 cone discharges  
 print cylinder 237  
 progressive flame front 170–171  
 propagating brush discharges 98–100,  
 118  
 corona needle 164  
 curiosity during outflow of liquid  
 from a metal pipe 202–204  
 explosion during rotational  
 molding 201–202  
 explosion in a mixing silo for plastic  
 granules 202

propagating brush discharges (*contd.*)  
 explosion in a railcar bulk  
 container 192–193  
 failed attempt to eliminate  
 electrostatic  
 nuisances 195–197  
 fire in a spray-bed dryer 197–200  
 ignition in a micronizer jet  
 mill 200  
 ignition of dust 165–166  
 metal drum with inner  
 liner 193–195  
 plastic drum with inner liner 195  
 short circuit of a double-layer  
 charge 166–167  
 protective textile clothing  
 test procedures with electrostatic  
 influence 69–71  
 triboelectric test procedure 69  
 psychrometer 84–85

**q**

quenching distance 95

**r**

recombination 114  
 relaxation time 235  
 resistance 267  
 conductance 269  
 conductivity 269  
 impedance of a capacitance 271  
 impedance of an inductance 271–273  
 leakage resistance 269  
 measurements 46–49  
 resistivity of a conductor 268  
 series 270  
 shunt 270  
 surface resistivity 268  
 volume resistivity 268  
 resistive/capacitive coupling 134  
 resistive hygrometer 86  
 resistivity of a conductor 268  
 ribbon tacking 230  
 rich mixture 169–170  
 rod (wire) across a conductive  
 area 259  
 rolling pipes 145–146

**s**

sawtooth sequence 162  
 semiconductive rollers 230  
 separation of pollutants 246  
 series of single capacitors 261  
 series resistance 270  
 short-circuit effect 92  
 short circuit of a double-layer  
 charge 166–167  
 shunt of single capacitors 261  
 shunt resistance 270  
 sliding discharges 100  
 space charge clouds 114  
 spark discharges 94–95, 104, 135,  
 160–161  
 alternative restrictions on insulating  
 solid materials 219–220  
 dust removal from pharmaceutical  
 pills 205–206  
 filling n-hexane into metal  
 drums 207–208  
 hose filter 208–209  
 lost and found 211–212  
 miraculous earthing clamp 212  
 powder explosion in a metal  
 drum 204–205  
 sparks at a throttle valve 206–207  
 water flowing through PVC  
 hose 210–211  
 spark-gap transmitters 92  
 sphere across a conductive area 260  
 spray-bed dryer, fire in a 197–200  
 static electricity 10  
 basics 19–21  
 capacitance and capacitor 38  
 electric field 33–36  
 electric induction  
 image charge 37–38  
 specification of 36–37  
 electrostatic charging of  
 liquids 28–30  
 charge relaxation with  
 liquids 30–31  
 charging by gases 31–33  
 electrostatic charging of  
 solids 21–23  
 surface resistivity 24–28



- influence of surface texture on
  - static charging 28
- triboelectric series 24
- static voltmeters 53–54, 141
- stoichiometric value 12
- stored electrical energy 44
- super brush discharges 98, 104–106, 163
- supercapacitors 38
- surface charge density 263–264
- surface resistance 48
- surface resistivity 24–28, 48, 268
- surface texture 28
- surface treatment with corona
  - systems 248–251

**t**

- targeted use of charges
  - adhesion of a melt layer on the chill roll 230–231
  - adhesion of an insert on a variable base 227–229
- adhesive
  - bonding - blocking 226–227
- application of liquid media on fast moving webs 234–236
- applications 223–225
- avoiding telescoping when winding 231–232
- blocking a number of paper webs or film webs in one ribbon 229–230
- drying of fast moving
  - substrates 236–237
- electroadhesion 247–248
- gravure printing and coating machine 237–241
- in-mold-labeling-in-mold-decoration 232–234
- oil application on metal sheets 234
- precipitation of mixed substances 244–247
- reduction of particle mist in the coating process 241–243
- surface treatment with corona
  - systems 248–251

- use of charging for technical
  - measurement
  - processes 243–244
- telescoping 231–232
- thin laminates 226
- time constant 266
- traces caused by gas
  - discharges 102–103
- Trek contact voltmeter 64
- triboelectric series 24, 150
- triboelectric test procedure 69
- two-electrode discharges 94

**u**

- ultrasonics 11
- upper explosion limits 4

**v**

- Van de Graaff generator 142–143
- vibratory conveyors 133
- voltage 265–267
  - breakdown voltage of a discharge gap 267
  - in a homogeneous electric field 265
  - Kirchhoff's junction rule 266
  - Kirchhoff's loop rule 266
  - time constant 266
  - voltage gradient when charging a capacitor 265
  - voltage gradient when discharging a capacitor 265
- voltage/current principle 46
- voltage gradient
  - when charging a capacitor 265
  - when discharging a capacitor 265
- voltmeters 53–54
- volume charge density 264
- volume resistance 46–47
- volume resistivity 46–47, 268

**w**

- Walking Test 41–43
- wavelength 258
- web tension profile 243

**z**

- zones 7

