551.563 GOL V.1

CONTENTS

Page

1. Lightning in History

1. Introduction 1
2. Mythological symbols and rites 1
3. Learned opinions and curiosities of antiquity 5
4. Sparks and lightning 6
5. Lightning experiments 9
6. Kites, balloons, mortars and rockets 12
7. Protection against lightning 14
8. Simulating lightning 16
9. Epilogue 20

References 20

2. Benjamin Franklin

1. Introduction 23
2. Points and clouds 23
3. 'Experiments and observations' 28
4. The sentry-box and Marly experiments 30
5. The kite 34
6. The lightning rod 37
7. The lightning rod in Europe 43

References 48

3. The Thundercloud

1. Introduction 51
2. Thunderstorm occurrence 52
3. Developments of thunderclouds 54
   - 3.1 Convection 54
   - 3.2 Precipitation 63
   - 3.3 Electrification 70
4. Electrical conditions around thunderclouds 73
   - 4.1 Conduction 73
   - 4.2 Point-discharge currents 78
   - 4.3 Charge transported by precipitation 79
   - 4.4 Charge distribution in thunderclouds 80
   - 4.5 The electric field intensities necessary to produce lightning 84
5. Cloud electrification mechanisms 85
   - 5.1 Precipitation-powered processes 85
   - 5.2 Convective electrification mechanism 87
   - 5.3 Explanations based on the contact differences of potential 88
   - 5.4 Requirements for a satisfactory explanation of cloud electrification 89
6. Modification of thunderclouds 90
7. Summary 92

Acknowledgements 92

References 93

4. Point-discharge

1. Introduction 99
2. The mechanism of point-discharge 100
3. Point-discharge from artificial points 101
4. Point-discharge at the ground 103
5. Corona at the ocean surface 107
6. Corona discharges within thunderclouds 111

References 115

5. The Earth Flash

1. Early investigation 119

1.1 Magnetic-link measurements 119
1.2 The fulchronograph 120
1.3 The klydonograph 120
1.4 The cathode-ray oscillograph 120
2. Lightning recording at a distance 121
2.1 General 121
2.2 Temporal characteristics of lightning flashes 128
3. Types of lightning discharge 134
3.1 Definitions 134
3.2 Description of lightning types 134
4. Results of lightning research and recording stations 138
4.1 Methods of recording lightning currents 138
4.2 The Empire State Building 139
4.3 Mount San Salvatore 140
4.4 Other recording stations 165
5. Physical picture of the earth flash 167
5.1 Charge distribution in a thundercloud 167
5.2 Point-discharge 168
5.3 Transition from corona to leader arc 169
5.4 The stepped leader 173
5.5 Transition from leader to return stroke 175
5.6 The first return stroke 178
5.7 The multiple flash 181
5.8 Subsequent strokes 182
5.9 Discharge of positive clouds 183
5.10 Stroke potential and energy in lightning flash 184
6. Outlook 186
References 187

6. The Cloud Discharge
1. Introduction 191
1.1 General remarks 191
1.2 Methods of investigation 192
2. The electric field and charge distribution 193
2.1 Observed fields 193
2.2 The electric field produced by simple charge distributions 195
3. Electric field-changes 196
3.1 Observed data 196
3.2 The cloud flash model 197
3.3 Heights of the charges 199
3.4 Values of charge and moment change 201
4. Initial cloud-discharge streamer 206
4.1 Classification of electric field-change patterns 206
4.2 The initial streamer 207
4.3 Multistation measurements 213
4.4 Tilted streamer 213
5. K changes 217
5.1 Observation 217
5.2 Characteristics of the K changes 219
6. Photographic analyses 220
7. Radiation from cloud flashes 222
8. Summary and conclusions 226
References 228

7. The Long Spark
1. Introduction 231
2. Sparkover under unipolar lightning impulse voltages and switching impulse voltages 233
2.1 General description of breakdown characteristics 233

2.2 Sparkover of rod/plane, rod/rod and sphere/plane gaps under lightning impulse voltages 234
2.3 Sparkover under switching impulses 237
2.4 Breakdown of a “window” gap surrounding a transmission line 244
2.5 Sparkover between two phase conductors separately stressed 245
2.6 Effect of air density and humidity 245
2.7 Time-lags, standard deviations and withstand voltages 247
3. Sparkover under alternating and constant voltages 248
4. Physical mechanism of spark formation 249
4.1 The leader stroke/main stroke mechanism 249
4.2 The positive leader stroke 257
4.3 The rod/plane discharge of negative polarity 269
4.4 The sphere/plane discharge 271
5. Future problems 271
References 275

8. Lightning Spectroscopy
1 History 281
2. Experimental techniques and qualitative results 283
2.1 Slit spectrometers 283
2.2 Slitless spectrometers 284
2.3 Spectrometers using photoelectric detertors 292
2.4 Calibration techniques 293
3. Quantitative analyses 294
3.1 Introductory remarks 294
3.2 Theory 294
3.3 Results of stroke-resolved spectroscopy 298
4. Future experiments 305
References 306

9. Lightning Currents and Related Parameters
1. Historical survey 309
1.1 General 309
1.2 Early estimates 310
2. Time resolution of lightning current 312
3. Current amplitude 314
3.1 Introductory remarks 314
3.2 Downward discharge 315
3.3 Upward discharge 323
4. Current wave-shape 324
4.1 Downward discharge 324
4.2 Upward discharge 335
5. Related parameters 336
5.1 Charge 336
5.2 Electric moment 340
5.3 Action integral and energy 341
6. Correlation of parameters 343
7. Outlook 344
Acknowledgements 344
References 345

10. Atmospherics and Radio Noise
1. Definitions and introduction 351
2. Atmospherics due to lightning 352
2.1 General 352
3. Atmospherics due to lightning—source effects 353
3.1 General 353
3.2 Signals at frequencies less than 300 kHz 357
3.3 Signals at frequencies exceeding 300 kHz 363
4. Atmospherics due to lightning—propagation effects 364
4.1 Propagation at frequencies of less than 300 kHz 364
4.2 Propagation at frequencies exceeding 300 kHz 367

4.3 Summary 367
5. The location of distant thunderstorms 369
5.1 Introduction 369
5.2 Multistation systems 370
5.3 Single-station methods 371
5.4 Summary 373
6. Radio noise and special topics 373
6.1 Radio noise—general 373
6.2 Whistlers 376
6.3 Satelite measurements 377
6.4 Schumann resonances 379
6.5 Special noise sources 380
6.6 The electromagnetic pulse 380
Acknowledgements 381
References 381

11. Thunder
1. Introduction 385
2. Experimental techniques and observations 386
2.1 Techniques prior to 1960 386
2.2 Techniques after 1960 387
2.3 Most recent techniques and results 388
3. Theories of thunder 393
3.1 General concepts 393
3.2 Lightning channel theory of thunder generation 393
3.3 Generation of thunder 395
4. Infra-sound 401
4.1 Observations 401
4.2 Theories of infra-sound generation 403
5. Other topics associated with thunder 405
Acknowledgements 405
References 406

12. Ball Lightning
1. Properties 409
2. Theories 412
3. Scepticism toward ball lightning 414
3.1 General considerations 414
3.2 Photographic evidence 415
3.3 Optical illusions 417
3.4 Ball lightning versus other atmospheric phenomena 418
4. Recent studies of ball lightning theories 420
4.1 General survey 420
4.2 Kapitsa’s radio-frequency theory 420
4.3 Plasma properties 423
4.4 Nuclear theories 425
4.5 Miscellaneous characteristics 428
4.6 Coherent radiation theories 428
4.7 Formation of ball lightning by an earth flash 429
5. Outlook 433
Acknowledgements 433
References 433

13. Measuring Techniques
1. Introduction 437
2. The electric field 437
2.1 Principle of measurement 437
2.2 Electrostatic field strength measurements 438
3. The electric field-change 448
3.1 The electrostatic field-change 448
3.2 The electromagnetic field-change 452

4. Wave-shapes of lightning currents 455
5. Lightning flash density 457
5.1 Spherics 457
5.2 Lightning flash counters 458
6. Conclusions 461
Acknowledgements 461
References 462

14. Frequency of Lightning Discharges
1. Introduction 465
2. Lightning incidence in space and time 466
2.1 General 466
2.2 Methods of determination of lightning incidence 469
2.3 Data on lightning incidence 471
2.4 Discussion 477
3. Relationships between lightning incidence and other parameters 480
3.1 General 480
3.2 Lightning incidence and thunderstorm statistics 480
3.3 Lightning incidence and geographic latitude 482
3.4 Lightning incidence and precipitation 484
3.5 Discussion 485
4. Ratio of cloud flashes to ground flashes 485
4.1 General 485
4.2 Fundamental considerations 485
4.3 Estimates of ratio 486
4.4 Empirical relationships 486
4.5 Discussion 488
5. Effect of height of object and terrain on incidence of ground flashes 488
6. Deficiencies in knowledge 491
References 492

AUTHOR INDEX **i**

SUBJECT INDEX **xvii**