

CONTENTS

CHAPTER I

DEFLECTIONAL INSTRUMENTS

1.1.1.	Introduction	
1.2.	Classification of Instruments	2
1.3.	Scale Shapes	2

MOVING-COIL INSTRUMENTS

1.2.1.	General Construction	3
2.2.	Torque Equation	4
2.3.	Movements and Magnet Systems	4
2.4.	Typical Operating Details	8

MOVING-IRON INSTRUMENTS

1.3.1.	Moving-iron Movements.	8
3.2.	Torque Equation	11
3.3.	Scale Shape	12
3.4.	Current Range and Impedance.	13

ELECTRODYNAMIC INSTRUMENTS—AIR-CORED TYPE

1.4.1.	General Construction	14
4.2.	Torque Equation	14
4.3.	Connections and Applications	16
4.4.	Scale Shape	17

ELECTRODYNAMIC INSTRUMENTS—IRON-CORED TYPE

1.5.1.	General	18
--------	-------------------	----

INDUCTION INSTRUMENTS

1.6.1.	Operation	19
6.2.	Torque Equation	21
6.3.	Magnet Systems	21
6.4.	The Shaded Pole	22
6.5.	Construction	23

ELECTROSTATIC INSTRUMENTS

1.7.1.	Construction and Operation	24
7.2.	Force and Torque Equations	27
7.3.	The Quadrant Electrometer	29
7.4.	Torque of Quadrant Electrometer	29
7.5.	The Wattmeter Connection	30

THERMAL INSTRUMENTS

1.8.1.	Hot-wire Type	30
8.2.	Bi-metallic Strip Type	32
8.3.	Thermo-junction Type	32

MOVING-COIL INSTRUMENTS WITH ADAPTORS

1.9.1.	Thermo-couples	
9.2.	Rectifiers	

INSTRUMENTS FOR SPECIAL PURPOSES

1.10.	Frequency Meters	36
10.1.	General	36
10.2.	Reed Type	37
10.3.	Moving-coil Types	38
10.4.	Moving-iron Types	39
1.11.	Power Factor Meters	41
11.1.	Moving-coil Types	42
11.2.	Moving-iron Types	44

RECORDING

1.12.	Recording Instruments	46
-------	---------------------------------	----

DAMPING

1.13.1.	Eddy-current Damping	46
13.2.	Air Damping	48
13.3.	Damping by Oil Dashpot	49

OTHER CONSTRUCTIONAL DETAILS

1.14.	Pointers	49
1.15.	Control Springs	50
1.16.	Instrument Bearings	50

CHAPTER 2

DEFLECTIONAL METHODS

2.1.1.	Current Measurement	52
1.2.	Instrument Shunts	53
2.2.1.	Voltage Measurement	53
2.2.	Current-operated Voltmeters	54
2.3.	Voltage-operated Instruments	54
2.3.1.	Multi-test Instruments	55
3.2.	Measurement of Mean Values	56
3.3.	Measurement of Peak Values	56
2.4.1.	Measurement of Power	56
4.2.	Three-Voltmeter Method	57
4.3.	Three-Ammeter Method	58
4.4.	Electrostatic Wattmeter	58
4.5.	Thermal and Thermionic Valve Type Wattmeters	59
4.6.	Power Measurement at Low Power Factors	60
4.7.	Power in Polyphase Systems	62
4.8.	Measurement of Power in Three-Phase Systems	63
2.5.	Measurement of Reactive Volt-Amperes	66

CONTENTS

xi

2.6.1.	Measurement of Power Factor and Phase Angle	68
6.2.	Three-Voltmeter Method and Three-Ammeter Method	68
6.3.	Wattmeter with Reactive Component Meter	69
6.4.	Electrodynanic Wattmeter with Modified Voltage Circuit	69
6.5.	Use of a Phase Shifter in a Null Method	69
6.6.	Wattmeter with Rectifiers	70
6.7.	Electronic Methods	72
6.8.	Power Factor of Polyphase Systems	72
2.7.1.	Measurement of Low and Medium Resistances	72
7.2.	Measurement of High Resistances	74
7.3.	Ohmmeters	76
7.4.	Testing Instruments for Low and Medium Resistances	77
7.5.	Insulation Testers—the 'Megger'	77
7.6.	Bridge Testing Sets	78

ERRORS IN INDICATING INSTRUMENTS

2.8.	Errors due to Temperature Change	78
8.1.	Changes in Magnetic Circuits	79
8.2.	Changes in Physical Dimensions	79
8.3.	Changes in Elastic Properties	79
8.4.	Change of Resistance	79
8.5.	Thermo-electric E.m.fs.	80
8.6.	Resistance-Temperature Errors in Ammeters	81
8.7.	Resistance-Temperature Errors in Voltmeters	82
8.8.	Resistance-Temperature Errors in Wattmeters	84
8.9.	Temperature Effects in Rectifier and Thermal Convertors	84
8.10.	Permissible Variations in Indication caused by Temperature Change	85
2.9.	Errors due to Connection of Instruments	85
2.10.	Frequency Errors	88
10.1.	Effects of Inductance	88
10.2.	Frequency Characteristics of Induction Instruments	88
10.3.	Permissible Variations in Indication due to Frequency changes	94

EFFECTS OF STRAY FIELDS

2.11.1.	Stray Magnetic Fields	94
11.2.	Interference Effects in Polyphase Wattmeters	95
11.3.	Permissible Variations due to External Magnetic Fields	96
11.4.	Stray Electrostatic Fields.	96

EFFECT OF NON-SINUSOIDAL WAVEFORMS

2.12.1.	Harmonics and R.M.S. Values.	97
12.2.	Harmonics and Mean Values	97

INSTRUMENT CALIBRATION AND TESTING

2.13.	Recognised Accuracies	98
2.14.	Calibration	99
14.1.	Direct Comparison.	100
14.2.	Sources of Supply	100
14.3.	Use of Phantom Loads	100

CHAPTER 3

POTENTIOMETER MEASUREMENTS

THE DIRECT CURRENT POTENTIOMETER

3.1.1.	Principle of the Potentiometer	102
1.2.	The Standard Cell	103
1.3.	Uses of the Potentiometer	104
3.2.	Developments of the D.C. Potentiometer	106
2.1.	Use of a Stud Switch and Slide Wire	106
2.2.	Low-Voltage Ranges	107
2.3.	Separate Checking Circuit for the Standard Cell	107
2.4.	Provision of True Zero and Small Negative Values	109
2.5.	The Varley Vernier Dial	109
2.6.	Dial Switches with Large Numbers of Studs	110
2.7.	Difficulties in Measuring Very Low Voltages and in Very Precise Measurements	110
2.8.	The Diesselhorst Potentiometer	110

THE ALTERNATING CURRENT POTENTIOMETER

3.3.1.	General	
--------	-------------------	--

POLAR TYPE POTENTIOMETER

3.4.1.	The Drysdale Potentiometer	113
4.2.	Obtaining the Balance	114

CO-ORDINATE TYPE A.C. POTENTIOMETERS

3.5.1.	Principle of Gall Potentiometer	116
5.2.	Phase Splitter for Gall Potentiometer	117
5.3.	Operation of Gall Type Potentiometer	118
3.6.1.	Simple Larsen Potentiometer	118
6.2.	The Campbell-Larsen Potentiometer	119
3.7.1.	The Pedersen Potentiometer	120

TRANSFER INSTRUMENTS

3.8.1.	General	121
8.2.	Suspended Reflecting Electrodynamic Instrument	122
8.3.	Campbell's Thermal Current Balance	123

GALVANOMETERS

3.9.	D.C. Galvanometers	124
9.1.	D'Arsonval Galvanometer	124
9.2.	Sensitivity of Moving-coil Galvanometers	125
9.3.	Moving-magnet Galvanometers	126
9.4.	The Galvanometer and the Circuit	127
3.10.	Vibration Galvanometers	128
10.1.	Moving-magnet Types	129
10.2.	Moving-coil Types	130

CHAPTER 4

SYSTEMS, DIMENSIONS, AND STANDARDS

4.1.1	Introduction	131
1.2	The Metric System	131
DIMENSIONS		
4.2.1.	Introduction	131
2.2.	Dimensions in the Electrostatic System	132
2.3.	Dimensions in the Electromagnetic System	133
2.4.	Dimensional Equations	133
SYSTEMS OF UNITS		
4.3.1.	Absolute Electrostatic System of Units (e.s.u.)	135
3.2.	Absolute Electromagnetic System of Units (e.m.u.)	135
3.3.	The Practical Units	136
3.4.	Relations between the Electrostatic and Electromagnetic Systems	137
3.5.	Modifications to the Classical Systems	137
3.6.	The Rationalised m.k.s. System	139
STANDARDS OF MEASUREMENT		
4.4.1.	General	144
4.2.	International Standards	145
4.3.	Reference Standards for Resistance	145
4.4.	Reference Standards for Potential Difference	146
4.5.	Reference Standards for Current	147
4.6.	Reference Standards for Inductance and Capacitance	147
ABSOLUTE MEASUREMENTS		
4.5.1.	General	147
5.2.	Mutual Inductance	148
5.3.	Resistance	152
5.4.	Current	154
RESISTANCE BOXES AND SHUNTS		
4.6.1.	Materials	156
6.2.	Resistance Boxes	157
6.3.	Low Resistance Windings	158
6.4.	Medium Resistance Windings	158
6.5.	High Resistance Windings	159
6.6.	Shunts for D.C. Circuits	160
6.7.	Low Resistances for A.C. Circuits	161
6.8.	Screening of Resistances	161
FIXED AND VARIABLE CAPACITORS		
4.7.1.	Fixed Standards with Solid Dielectric	162
7.2.	Fixed Standards with Air Dielectric	163
7.3.	Variable Air Dielectric Capacitors	163
7.4.	Screening of Capacitors	165

STANDARDS OF INDUCTANCE		
4.8.1.	Formers	166
8.2.	Resistance-to-Inductance Ratio	166
8.3.	Variable Inductances	167
8.4.	Fixed Standards of Mutual Inductance	168
8.5.	Adjustable Standards of Mutual Inductance	168
8.6.	Comparison of L, M and C as Standards	169

ERRORS IN MEASUREMENTS		
4.9.1.	Relative Error	171
9.2.	Systematic Errors	171
9.3.	Calculation of Maximum Systematic Error	173
9.4.	Random Errors	178
9.5.	Appraisal of the Results	180

CHAPTER 5

BRIDGE METHODS

5.1.1.	D.C. Bridge Methods	184
1.2.	Extension of Bridge Methods	184

D.C. BRIDGES

5.2.1	The Wheatstone Bridge	185
2.2.	Constructional Features	186
2.3.	Operating Features	186
2.4.	Sensitivity	187
5.3.1.	Precise Comparisons of Medium Resistances	189
3.2.	The Carey Foster Slide-wire Bridge	190
5.4.1.	The Kelvin Double Bridge	191

A.C. BRIDGES

5.5.1.	General	193
5.6.1.	The Four Arm A.C. Bridge Network	194
6.2.	Maxwell's Method for Comparing Inductances	195
6.3.	Balance Adjustment of A.C. Bridges	196
6.4.	Maxwell's Method for Comparing Inductance with Capacitance	197
6.5.	Hay's Bridge for Coils of Large Time-constant	198
6.6.	Owen's Bridge	199
6.7.	The Resonance Bridge	200
5.7.1.	Some Modified Bridge Networks	201
7.2.	Anderson's Bridge	201
7.3.	The Heaviside Bridge	203
7.4.	The Heaviside Bridge with Balancing Coil	204
7.5.	The Heaviside Campbell Equal Ratio Bridge	205
7.6.	The Modified Carey Foster Bridge	207
5.8.1.	Bridges for Measurement of Capacitance	208
8.2.	The Series and Parallel Resistance Methods	209
8.3.	The Wien Bridge	211
8.4.	The Schering Bridge	212
8.5.	High-Voltage Schering Bridge	213
8.6.	Measurements on Insulating Materials by Low-Voltage Schering Bridge	214

ERRORS AND PRECAUTIONS

5.9.1.	Sensitivity	217
9.2.	Electromagnetic Induction	217
9.3.	Electric Induction and Stray Capacitance	218
9.4.	Use of Screened and Balanced Transformers	219
9.5.	The Wagner Earth	220
9.6.	Bridge with Screening	221
9.7.	Substitution Methods	222

SOME DEVELOPMENTS IN BRIDGE NETWORKS

5.10.1.	Bridge with Coupled Inductive Ratio Arms	223
10.2.	Mutual Admittance Bridges	224
10.3.	Adjustable Coupled Inductive Ratio Arms	225
10.4.	A Radio Frequency Admittance Bridge	226
10.5.	The Parallel-T Network	228
10.6.	The Bridged-T Network	230

CHAPTER 6

OSCILLATIONS AND VIBRATIONS

6.1.1.	The Vibration Equation and its Solution	232
1.2.	The Arbitrary Constants in the Complementary Function	233
1.3.	Forms of the Transient Solution	233
1.4.	Verification of the Complementary Solution	234

TRANSIENTS IN ELECTRICAL CIRCUITS

6.2.1.	Introduction	235
2.2.	Circuit with Resistance and Inductance	236
2.3.	Application of a Short Circuit	238
2.4.	Circuit Containing Resistance and Capacitance	240
2.5.	Series Circuit with Resistance, Inductance and Capacitance	243

APPLICATIONS TO PERMANENT-MAGNET MOVING-COIL INSTRUMENTS

6.3.1.	Electromagnetic Damping	247
3.2.	Behaviour of Damped Movements	248
3.3.	Theory of the Ballistic Galvanometer	252
3.4.	The Ballistic Galvanometer with Moderate Damping	256
3.5.	Theory of the Grassot Fluxmeter	257
6.4.	The Vibration Galvanometer	259

WAVEFORM AND ITS DETERMINATION

6.5.	Waveform	262
6.6.	Oscillographs and Oscilloscopes	263

THE DUDELL OSCILLOGRAPH

6.7.1.	Principle and Operation	264
7.2.	Theory	266
7.3.	Extension of Frequency Range	272
7.4.	Construction	273
6.8.	The Electrostatic Oscillograph	274

THE CATHODE RAY OSCILLOGRAPH

6.9.1.	Principle of the Cathode Ray Oscillograph.	276
9.2.	Types of Cathode Ray Tubes	277
9.3.	Spot Brilliance and Screens	278
9.4.	Focusing	279
9.5.	Gas Focusing	280
9.6.	Magnetic Focusing	281
9.7.	Electrostatic Focusing	284
9.8.	Magnetic Deflection	287
9.9.	Electrostatic Deflection	288
9.10.	Asymmetric and Push-pull Deflection	290
9.11.	Obtaining Multiple Traces	292

TIME BASES FOR THE CATHODE RAY OSCILLOGRAPH

6.10.1.	Simple Linear Time Base	293
10.2.	Time Base with Gas-filled Discharge Valve	297
10.3.	Puckle Hard Valve Time Base	299
10.4.	Other Types of Time Base	300

USING THE CATHODE RAY OSCILLOGRAPH

6.11.1.	Screening, Earthing, and Precautions	301
11.2.	Voltage and Current Waveforms	302
11.3.	Time Measurement with Linear Time Bases	303
11.4.	Voltage and Current Deflections in Two Dimensions	304
11.5.	B-H Loop for Magnetic Material	305
11.6.	Dielectric Loss	306
11.7.	Applications to Mechanical Problems	308
11.8.	Frequency Comparisons	308
11.9.	The Cold Cathode, Continuously Evacuated Tube	312

CHAPTER 7

METHODS USING THERMIONIC VALVES

7.1.1.	Introduction	315
1.2.	Thermionic Emitters	315
1.3.	The Diode Valve	315
1.4.	The Triode Valve	317
1.5.	Multielectrode Valves	318

TRIODE AMPLIFIERS AND OSCILLATORS

7.2.1.	The Triode Amplifier	320
2.2.	Amplifiers with Negative Feed back	322
2.3.	Principle of the Triode Oscillator	324
2.4.	Oscillator Frequency Stability	325
2.5.	Other Oscillator Circuits	326

VALVE VOLTMETERS

7.3.1.	General Considerations	328
3.2.	The Slide Back Method	330

7.3.3.	Diode Mean Type Voltmeter	333
3.4.	Diode Peak Type Voltmeter	336
3.5.	Waveform and Frequency Errors; Stability	337
3.6.	Standing Current and Permanence of Calibration	338
3.7.	Input Impedance	338
3.8.	Developments of the Diode Peak Voltmeter	340

TRIODE VALVE VOLTMETERS

7.4.1.	The Anode Bend Valve Voltmeter	342
4.2.	The Moullin Voltmeter	343
4.3.	The Reflex Voltmeter	344
4.4.	A Valve Millivoltmeter	344

MISCELLANEOUS METHODS

7.5.1.	Small Direct Voltages and Currents	345
5.2.	The Electrometer Valve	347
5.3.	Measurement of High Resistance	348
5.4.	A Valve Ammeter	349
5.5.	A Valve Wattmeter	350
5.6.	A Valve Frequency Meter	351

CHAPTER 8

RESONANCE AND HETERODYNE METHODS

INTRODUCTION TO RESONANCE METHODS

8.1.1.	The Resonant Circuit	353
1.2.	Thermal versus Valve Indicators	354
1.3.	Reaction of Circuit on Source	354

RESONANCE WAVEMETERS

8.2.1.	Wavemeter with Current Indication	355
2.2.	Wavemeter with Voltage Indication	357
2.3.	The Absorption Wavemeter	358

RESONANCE METHODS FOR CIRCUIT CONSTANTS

8.3.1.	Capacitance	359
3.2.	Inductance	359
3.3.	Inductance and Self-Capacitance of a Coil	360
3.4.	Frequency Variation Method (Current Indication)	361
3.5.	Frequency Variation Method (Voltage Indication)	365
3.6.	Reactance Variation Method	366
3.7.	Resistance Variation Method	366
3.8.	Effect of Valve Voltmeter on Measurement of Resistance	368
3.9.	Magnification Factor—or 'Q'-Meter	369

MECHANICAL RESONATORS

8.4.1.	Electro-Mechanical Resonator	370
4.2.	Tuning Fork Oscillator	371
4.3.	The Quartz Crystal	372
4.4.	The Quartz Crystal as a Passive Standard	373
4.5.	The Quartz Crvstal as a Generating Standard	374

HETERODYNE METHODS

8.5.1.	Introduction	376
5.2.	The Heterodyne Wavemeter	378
5.3.	The Double Beat Method	379
5.4.	Capacitance Measurement by the Double Beat Method	380
5.5.	A Secondary Frequency Standard (Radio Frequencies)	381
5.6.	The Absolute Determination of Frequency	383

MEASUREMENT OF HARMONICS

8.6.1.	Resonance Method for Harmonics	384
6.2.	Distortion Factor Meter	385
6.3.	Heterodyne Methods of Harmonic Analysis	386
6.4.	Superheterodyne Wave Analyser	387
6.5.	Selective Amplifier Type of Analyser	388
6.6.	Determination of Phase of Harmonics	389

CHAPTER 9

POWER SYSTEM MEASUREMENTS

SYMMETRICAL COMPONENTS

9.1.	Unbalanced Systems	390
9.2.	Symmetrical Component Theory	391
2.1.	Positive, Negative and Zero Sequence Components	391
2.2.	Determination of Symmetrical Components	392
2.3.	Direct Graphical Determination of Symmetrical Components	393
2.4.	Three-Phase Systems without Residue	394
2.5.	Positive, Negative and Zero Sequence Power	395
9.3.	Measurement of Symmetrical Components	396
3.1.	Zero Sequence Currents	397
3.2.	Zero Sequence Voltages	397
3.3.	Positive and Negative Sequence Currents	399
3.4.	Suppression of Zero Sequence Currents	401
3.5.	Positive and Negative Sequence Voltages	402
3.6.	Power Components	404

LOCATION OF CABLE FAULTS

9.4.	Classification of Tests	405
9.5.	Terminal Tests	405
5.1.	Location of Earth and Inter-core Faults	406
5.2.	The Murray Loop	406
5.3.	The Overlap Method (Werren)	407
5.4.	Fall of Potential Tests	408
5.5.	Tests for Severed Cores	409
5.6.	Tests for Flashing Faults	411
5.7.	Pulsing Methods	412
6.6.	Local Tests	413

CONTENTS

HIGH VOLTAGE MEASUREMENT

9.7.	General Considerations	414
9.8.	Voltmeters for Measurement of R.M.S. Values	415
8.1.	The Attracted-disc Voltmeter	415
8.2.	The Ellipsoid Voltmeter	416
8.3.	Measurement of Charging Current	417
8.4.	The Use of Potential Dividers	418
8.5.	Compensated Capacitance Dividers	419
8.6.	The Use of Instrument Transformers	420
9.9.	Voltmeters for Measurement of Peak Values	420
9.1.	The Sphere Gap	420
9.2.	Condenser-Rectifier Methods	421
9.3.	Ionisation Voltmeters	423
9.10.	Instruments for Instantaneous Voltage Measurement	425
9.11.	The Measurement of High D.C. Voltages	425
11.1.	Generating Voltmeters	425

CHAPTER 10

INTEGRATING METERS

10.1.	Energy Measurement	428
10.2.	Braking.	428

DIRECT CURRENT METERS

10.3.	Electrolytic Meters.	429
10.4.	Mercury Motor Meters	431
4.1.	Ampere-hour Type	432
4.2.	Watt-hour Type	434
4.3.	Typical Operating Details	436
10.5.	Clock Meters.	436

ALTERNATING CURRENT METERS

10.6.	Induction Energy Meters.	439
6.1.	Torque and Vector Diagram	439
6.2.	Compensation of Errors	441
6.3.	Effects of Frequency Variations	444
6.4.	Adjustment of Induction Energy Meters	445
10.7.	Polyphase Metering	446
7.1.	Types of Polyphase Meters	447
7.2.	Adjustments of Polyphase Meters	447
7.3.	Errors of Polyphase Meters	448
7.4.	Typical Operating Details	448
10.8.	Bearings for Integrating Meters	449
10.9.	Prepayment Meters	451
10.10.	Maximum Demand Indicators	452

CHAPTER 12

MAGNETIC MEASUREMENTS

INTRODUCTION

12.1.1.	Requirements	520
1.2.	Effects of Magnetic Fields	521
1.3.	Magnetic Units	521

MEASUREMENT OF MAGNETIC FIELDS IN AIR

12.2.1.	Deflectional Method	523
2.2.	Method of Oscillations	523
2.3.	Absolute Values for Magnetic Moment and Magnetic Field	524
2.4.	Use of Ballistic Galvanometer	526
2.5.	The Grassot Fluxmeter	529
2.6.	Modifications in the Construction and Use of the Fluxmeter	529
2.7.	Other Methods of Measurement	531
2.8.	The Earth's Field	533
2.9.	The Chattock Magnetic Potentiometer	534
2.10.	Some Applications of the Magnetic Potentiometer	535

MEASUREMENT OF THE B-H CHARACTERISTIC FOR IRON

12.3.1.	The Reversals or Normal Induction Curve	536
3.2.	Measurement on a Ring Specimen	538
3.3.	Bar and Yoke Methods	540
3.4.	The Illiovisi Permeameter	540
3.5.	Dr. Hughes' Permeameter	542
3.6.	Fahy Simplex Permeameter	543
3.7.	National Physical Laboratory Permeameter	544
3.8.	Other Methods of Measurement	545
3.9.	Determination of the Hysteresis Loop	546

ALTERNATING CURRENT METHODS OF TESTING

12.4.1.	The Problem	
4.2.	Permeability and Core-Loss Measurements on a Ring Specimen	551
4.3.	Use of the A.C. Potentiometer	553
4.4.	Use of A.C. Bridge Methods	553
4.5.	A Calorimetric Method	554
4.6.	Magnetic Squares	555
4.7.	Wattmeter Method	556
4.8.	Separation of Eddy-Current and Hysteresis Losses	557

INCREMENTAL PERMEABILITY AND INDUCTANCE

12.5.1.	Incremental Permeability	559
5.2.	The Voltmeter Method	560
5.3.	Bridge Methods	561

PERMANENT MAGNETS

12.6.1.	Theory of Permanent Magnets.	563
6.2.	Testing Permanent Magnets .	567
6.3.	The Betteridge Apparatus .	569
12.7.	Magnetostriction	570

CHAPTER 13

MEASUREMENT OF
SOME NON-ELECTRICAL QUANTITIES

13.1.	General	571
13.2.	✓ Mechanical Quantities	572
2.1.	✓ Displacement.	572
2.2.	Telemetry.	574
✓ 2.3.	Strain	577
2.4.	Pressure	579
2.5.	Speed of Rotation	580
13.3.	Measurement of Temperature	582
3.1.	Resistance Pyrometers	582
3.2.	Thermo-couple Pyrometers	583
3.3.	Radiation Pyrometers	584
3.4.	Optical Pyrometers	585
13.4.	Measurement of Hydrogen Ion Concentration (pH values)	586
13.5.	Gas Analysis	587
5.1.	CO ₂ Meter	587
5.2.	CO and H ₂ Meter	588
13.6.	Measurement of Humidity	588
13.7.	Electrical Counting.	590