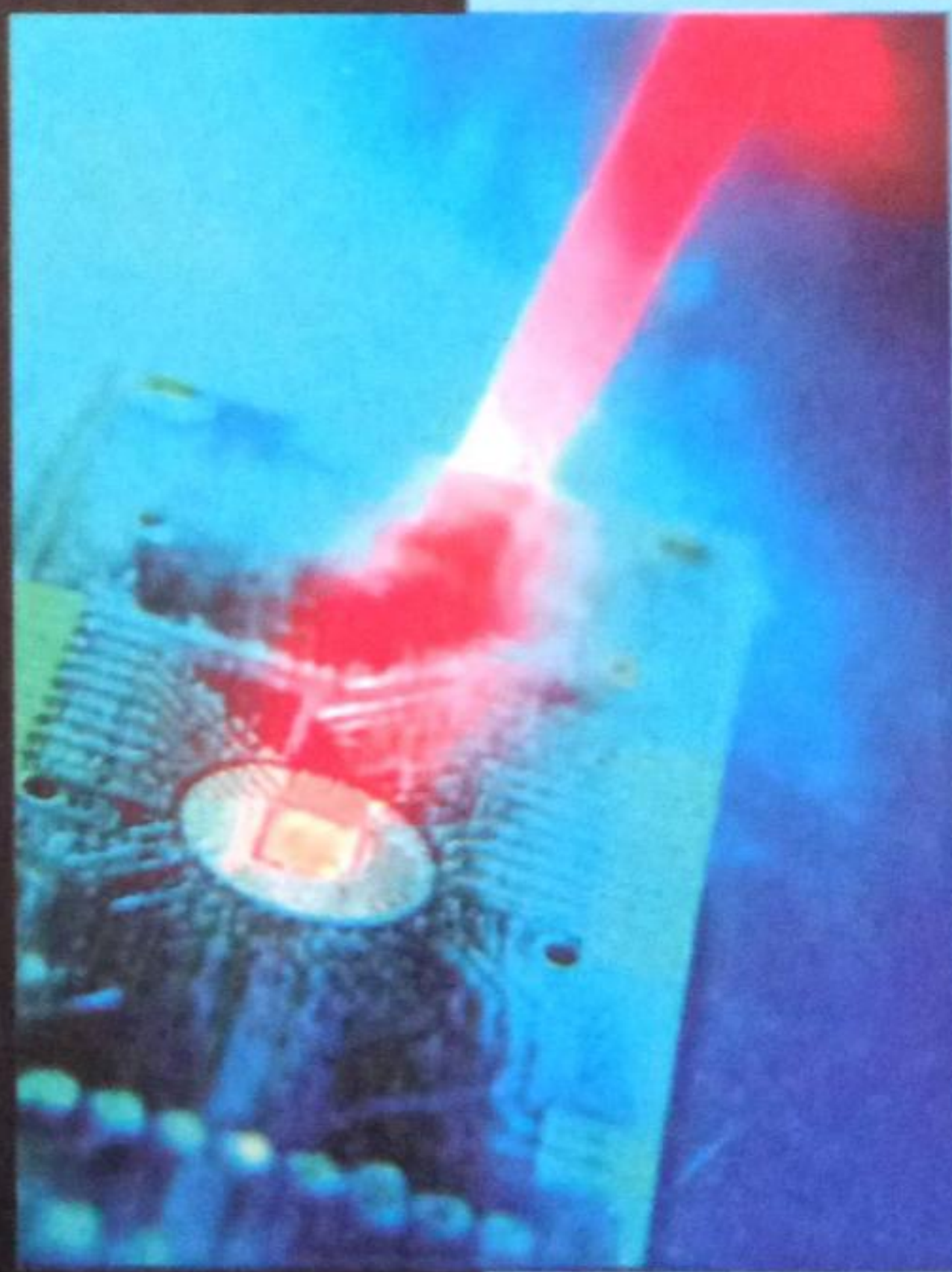




# ADVANCED EXPERIMENTAL TECHNIQUES IN MODERN PHYSICS

- K. MURALEEDHARA VARIER
- ANTONY JODRPH
- P. P. PRADYUMNAN



*A Pragati Edition*



# CONTENTS

## CHAPTER I - VACUUM TECHNIQUES

1-49

- 1.1 Introduction 1
- 1.2 Brief History 2
- 1.3 Important Areas of Application 3
- 1.4 Units Used in Vacuum Measurements 4
- 1.5 Basic Definitions of Vacuum Technology 4
  - 1.5.1 Pumping Speed 4
  - 1.5.2 Throughput 6
  - 1.5.3 Pump Compression Ratio 6
  - 1.5.4 Pumpdown Time 6
  - 1.5.5 Physical Characteristics Dependent on the Degree of Vacuum 7
- 1.6 Vacuum Pumps 9
- 1.7 Roughing Pumps 10
  - 1.7.1 Oil Sealed Rotary-vane Pump 10
  - 1.7.2 Sorption Pump 13
- 1.8 High Vacuum Pumps 15
  - 1.8.1 Kinetic Vacuum Pumps 15
    - 1.8.1.1 Oil Vapour Booster Pump 15
    - 1.8.1.2 Diffusion Pump 16
    - 1.8.1.3 Turbomolecular Pump 19
  - 1.8.2 Ion Pumps 22
    - 1.8.2.1 Sputter Ion Pump 22
    - 1.8.2.2 Getter Ion Pump 26
  - 1.8.3 Cryogenic Pump 26
- 1.9 Vacuum Gauges 30
  - 1.9.1 Direct Reading Vacuum Gauges 30
    - 1.9.1.1 Liquid Column Manometer 30
    - 1.9.1.2 McLeod Gauge 31
  - 1.9.2 Indirect Reading Vacuum Gauges 32
    - 1.9.2.1 Capsule Type Gauges-Bourdon Gauge 32
    - 1.9.2.2 Capacitance Manometer (Capacitance Diaphragm Gauge) 33
    - 1.9.2.3 Pirani Gauge 34
    - 1.9.2.4 Thermocouple Gauge 35
    - 1.9.2.5 Ionization Gauges 36
      - (a) Penning Gauge (Cold Cathode Ionization gauge) 36
      - (b) Hot Filament Ionization Gauge 37
- 1.10 Vacuum Accessories 38
  - 1.10.1 Vacuum Valves 38
    - 1.10.1.1 Diaphragm Valve (Saunders Type) 38
    - 1.10.1.2 Gate Valve 39
    - 1.10.1.3 Butterfly Valve 39
    - 1.10.1.4 Baffle Valve 39
    - 1.10.1.5 Adjustable Valves-The Needle Valve 40
    - 1.10.1.6 Isolation-cum-air-admittance Valve 40
    - 1.10.1.7 Air Inlet Valves 41
  - 1.10.2 Flanges 42
  - 1.10.3 Gaskets and "O" Rings 42
  - 1.10.4 Bellows 43
  - 1.10.5 Wilson's Seal 44
  - 1.10.6 Vacuum Traps 45
    - 1.10.6.1 Liquid Nitrogen Trap 45
      - (a) Re-entrant Trap 45
      - (b) High Conductance- High Vacuum Trap 45
    - 1.10.6.2 Refrigerated Chevron Baffle Assembly 46
    - 1.10.6.3 Sorption Traps 47
  - 1.10.7 Conflat Couplings (KF and QF Couplings) 48
- 1.11 General Layout of a Complete Vacuum System 48

## CHAPTER II - THIN FILM TECHNIQUES

50-80

- 2.1 Introduction 50
- 2.2 Fabrication of Thin Films 51



- 2.2.1 Thermal Evaporation Techniques 51
  - 2.2.1.1 Resistive Heating 53
  - 2.2.1.2 Flash Evaporation 54
  - 2.2.1.3 Exploding Wire Technique 55
  - 2.2.1.4 Electron Beam Evaporation 55
  - 2.2.1.5 Laser Evaporation Technique 58
  - 2.2.1.6 Arc Evaporation 59
  - 2.2.1.7 RF Heating 60
- 2.2.2 Sputter Deposition 61
  - 2.2.2.1 Basic Concepts of Sputtering - Ion Surface Interaction 61
  - 2.2.2.2 Sputtering Yield 62
  - 2.2.2.3 Glow Discharge Sputtering 65
- 2.3 Thickness Measurement 67
  - 2.3.1 Electrical Techniques for Thickness Measurement 67
    - 2.3.1.1 Resistance Measurements 67
    - 2.3.1.2 Film Resistance by Wheatstone Bridge Method 69
  - 2.3.2 Quartz Crystal Monitor 69
  - 2.3.3 Optical Interference Method 71
    - 2.3.3.1 Fizeau Fringes of Equal Thickness 71
    - 2.3.3.2 Fizeau Interferometer with Beam Splitter 72
  - 2.3.4 Spectrometric Method 74
- 2.5 Thin Film Optics 74
- 2.6 Interference Filters 77
  - 2.6.1 Multilayer Optical Filters 77
- 2.7 Thermoelectric Power of Thin Films 78

### CHAPTER III CRYOGENIC TECHNIQUES

81-129

- 3.1 Introduction 81
- 3.2 Brief History 82
- 3.3 Liquefaction of Gases 84
  - 3.3.1 Internal Work Method 85
  - 3.3.2 External Work Method 87
  - 3.3.3 Hampson's / Linde's Process for Liquefaction of Air 90
  - 3.3.4 Air Liquefier Using External Work Technique (Claude Process) 91
  - 3.3.5 Hydrogen Liquefier 92
  - 3.3.6 Heylandt Air Liquefier 92
  - 3.3.7 Helium Liquefier (Kammerlingh Onne's Method) 93
  - 3.3.8 Kapitza Helium Liquefier 94
  - 3.3.9 Simon Helium Liquefier 94
- 3.4 Manipulation of Liquefied Gases and Maintenance of Low Temperatures 95
  - 3.4.1 Henning Cryostat 96
  - 3.4.2 Hydrogen Vapour Cryostat (Kammerlingh Onnes and Crommelin) 97
- 3.5 Liquids Boiling under Reduced Pressure 98
- 3.6 Special Properties of Helium 99
- 3.7 Production of Temperatures Below 1 K 102
  - 3.7.1 Adiabatic Demagnetization of a Paramagnetic Salt 102
  - 3.7.2 Magnetic Refrigerator 106
- 3.8 Other Possible Methods for Production of Low Temperatures 107
  - 3.8.1 Simon Desorption Method 107
  - 3.8.2 Adiabatic Magnetization of a Superconductor 108
  - 3.8.3 Passage of Liquid Helium Through a Porous Plug 108
  - 3.8.4 Dilution Refrigerator 108
  - 3.8.5 Pomeranchuk Cooling 113
- 3.9 Temperatures Below  $10^6$  K 115
  - 3.9.1 The Nuclear Refrigerator 115
- 3.10 Measurements of Low Temperatures 116
  - 3.10.1 Primary Thermometers 118
    - 3.10.1.1 Gas Thermometry 118
  - 3.10.2 Secondary Thermometers 121
    - 3.10.2.1 Resistance Thermometers 121
    - 3.10.2.2 Vapour Pressure Thermometry 124
    - 3.10.2.3 Thermoelectric Thermometers 125
    - 3.10.2.4 Magnetic Thermometers 126
- 3.11 Applications of Cryogenics 128



<b>CHAPTER IV TECHNIQUES FOR PARTICLE ACCELERATION</b>	<b>130-166</b>
4.1 Introduction	130
4.2 Brief History	131
4.3 Linear Electrostatic Accelerators	134
4.3.1 Cascade Accelerator (Cock-Croft Walton Accelerator)	134
4.3.2 Van de Graaff Accelerator	135
4.3.3 Tandem Van de Graaff Accelerator (Pelletron)	137
4.4 Linear Radio Frequency Accelerators	138
4.5 Cyclic Accelerators	140
4.5.1 Cyclotron	141
4.5.2 Sector Focussed Cyclotron	144
4.5.3 Betatron	145
4.5.4 Electron Synchrotron	147
4.5.5 Proton Synchrotron	149
4.5.6 Heavy Ion Synchrotrons	151
4.6 Ion Sources	151
4.6.1 Ionization Processes	151
4.6.1.1 Electron Impact Ionization	151
4.6.1.2 Thermionic Emission	152
4.6.1.3 Spark Discharge	152
4.6.1.4 Thermal Ionization	153
4.6.1.5 Surface Ionization	153
4.6.1.6 Ion Impact Ionization	153
4.6.1.7 Ion Beam Sputtering	153
4.6.1.8 Photo Ionization	153
4.6.1.9 Charge Exchange	153
4.6.1.10 Electron Attachment / Detachment	154
4.6.2 Simple Ion Source	154
4.6.3 Ion Plasma Source	155
4.6.4 RF Ion Source	156
4.7 Important Applications of Accelerators	158
4.8 Ion Implantation	158
4.8.1 The Process	159
4.8.2 Techniques for Ion Implantation	160
4.8.3 Ion Implantation Profiles	161
4.8.4 Methods for Profile Measurement	163
4.8.4.1 Radiotracer Method	163
4.8.4.2 Differential Hall Measurement	163
4.8.4.3 Capacitance Voltage Measurement	163
4.8.4.4 Rutherford Backscattering or Nuclear Reaction Technique	163
4.8.5 Advantages and Limitations of Ion Implantation Technique	163
4.9 Ion Beam Sputtering	164
4.9.1 Principle	164
4.9.2 Applications of Ion Beam Sputtering	165
<b>CHAPTER V- NUCLEAR TECHNIQUES FOR MATERIALS ANALYSIS</b>	<b>167-180</b>
5.1 Introduction	167
5.2 Brief History	168
5.3 Basic Principle of Elemental Analysis	169
5.4 Basic Requirements for Any Technique for Elemental Analysis	170
5.5 Nuclear Techniques for Elemental Analysis	171
5.6 General Experimental Setup	172
5.6.1 Source	172
5.6.2 Sample (Target)	172
5.6.3 Detectors	173
5.6.4 Electronics	175
5.7 Main Nuclear Processes Useful for Materials Analysis	176
5.7.1 Elastic Scattering	176
5.7.2 Inelastic Scattering	176
5.7.3 Nuclear Reactions	176
5.8 Mathematical Basis of the Quantitative Estimate	176
5.9 Nuclear Reaction Kinematics	178
<b>CHAPTER VI - RUTHERFORD BACKSCATTERING</b>	<b>181-192</b>
6.1 Introduction	181



- 6.2 Theoretical Background 183
  - 6.2.1 Cross Section for Rutherford Scattering 185
    - 6.2.1.1 Classical Theory 185
    - 6.2.1.2 Quantum Mechanical Treatment (Partial Wave Analysis) 185
- 6.3 Experimental Setup 187
- 6.4 Energy Straggling 189
- 6.5 Applications of Rutherford Backscattering Technique 190
- 6.6 Elastic Recoil Detection Analysis 190

## CHAPTER VII - NUCLEAR REACTION ANALYSIS

- 7.1 Introduction 193
- 7.2 Principle of the Nuclear Reaction Analysis Technique 193
- 7.3 Instrumentation for Nuclear Reaction Analysis 195
- 7.4 Resonance Nuclear Reactions—Possibility of Depth Profiling 197
- 7.5 Specific Nuclear Reactions Suitable for NRA 198
  - 7.5.1 Hydrogen 199
  - 7.5.2 Helium 199
  - 7.5.3 Lithium 200
  - 7.5.4 Beryllium 200
  - 7.5.5 Boron 200
  - 7.5.6 Carbon 200
  - 7.5.7 Nitrogen 201
  - 7.5.8 Oxygen 201
- 7.6 Applications of Nuclear Reaction Analysis 202

## CHAPTER VIII - NEUTRON ACTIVATION ANALYSIS

- 8.1 Introduction 203
- 8.2 Principle of the Technique 203
- 8.3 Instrumentation for Neutron Activation Analysis 204
- 8.4 Sources of Neutrons 205
- 8.5 Applications of Neutron Activation Analysis 208
  - 8.5.1 14 MeV Neutrons 208
  - 8.5.2 Fossil Fuels 209

## CHAPTER IX - PROTON INDUCED X-RAY EMISSION TECHNIQUE

- 9.1 Introduction 210
- 9.2 Principle of the PIXE Technique 211
- 9.3 Brief Theoretical Considerations 212
- 9.4 Experimental Details 213
- 9.5 Applications of PIXE 217
  - 9.5.1 Water Samples 217
  - 9.5.2 Human Hair Samples 217
  - 9.5.3 Forensic Samples 218
  - 9.5.4 Aerosol Samples 219
  - 9.5.5 Biological and Medical Samples 220
- 9.6 Other Samples 220
- 9.7 Limitations of PIXE Technique 220
- 9.8 X-ray Resonance Fluorescence Technique 221

## Review Questions and Problems

## APPENDIX A- Centre of Mass Co-ordinate System & Laboratory Co-ordinate System

## APPENDIX B - Some Useful Data for Cryogenics

## BIBLIOGRAPHY

## INDEX

223-237

238-242

243-244

245-246

247-248