AMERICAN VACUUM SOCIETY CLASSICS

THE PHYSICAL BASIS OF ULTRAHIGH VACUUM

P. A. Redhead

J. P. Hobson

E. V. Kornelsen

Radio & Electrical Engineering Division National Research Council Ottawa, Canada

> Fachbereich Materialwissenschaft der Techn. Hochschule Darmstadt

Inv.-Nr.: 1(





CONTENTS

	Acknowledgements pag	e vi
1	INTRODUCTION	1
	Index of Symbols	4
	PART A: PHYSICAL PROCESSES	
2	MOLECULE-MOLECULE AND MOLECULE- SURFACE INTERACTIONS	11
	 2.1 Energies between Molecules 2.1.1 Van der Waals Energies and Valence Energies, 12 2.1.2 Induction Energies and Electrostatic Energies, 16 	11
	 2.2 Intermolecular Collisions 2.3 Energies between a Molecule and a Surface 2.3.1 Energies of Physisorption, 22 2.3.2 Energies of Chemisorption, 29 	18 22
	 2.4 Dynamic Interactions between a Molecule and a Surface 2.4.1 Vapour Pressure, 37 2.4.2 Adsorption Isotherms, 39 2.4.3 Impact between a Molecule and a Surface: Accommodation, Condensation and Sticking, 54 2.4.4 Desorption of a Molecule from a Surface, 73 2.4.5 Adsorption of Mixtures, Cryotrapping and Replacement, 83 	37
	 2.5 Diffusion, Solution and Permeation of Gases in Solids 2.5.1 Solution and De-solution of Gas from a Semi-infinite Solid, a Slab, a Cylinder, and a Sphere, 92 2.5.2 De-solution of Gas from Vacuum Chamber Wall and Permeation, 99 2.5.3 Modifications to Idealized Solutions for Diffusion, 100 2.5.4 Specific Examples of Diffusion Mechanisms in Ultrahigh Vacuum Practice, 105 	88
3	COLLISION PROCESSES IN GASES	110
	3.1 Elastic Collisions of Electrons with Atoms (e0/e0)	111

3.2 Inelastic Electron-Atom Collisions	114
3.2.1 Ionization, 114 3.2.2 Excitation, 117	
3.3 Elastic Atom-Atom and Ion-Atom Collisions (00/00, 10/10) 3.4 Inelastic Effects in Ion-Atom Collisions 3.4.1 Charge Transfer (10/01), 123 3.4.2 Excitation (10/10), 125 3.4.3 Ionization (10/11), 125	120 123
3.5 Photo-absorption and Photo-ionization	128
3.6 Positive Ion Recombination	131
4 INTERACTION OF CHARGED PARTICLES WITH SURFACES	134
 4.1 Electron Scattering from Surfaces 4.1.1 The Energies of Scattered Electrons, 134 4.1.2 Elastic Reflection of Electrons, 135 4.1.3 Characteristic Energy Losses and Rediffused Electrons, 152 4.1.4 Secondary Electron Emission, 159 	134
4.2 Electron-Impact Desorption	167
 4.2.1 Electron-Impact Desorption from Adsorbed Layers, 168 4.2.2 Electron-Impact Desorption from Thick Layers, 172 4.2.3 Electron-Impact Desorption from Surfaces of Unknown State, 174 4.2.4 Theory of Electron-Impact Desorption, 176 	ı
 4.3 Impact of Energetic Atoms and Ions on Surfaces 4.3.1 Back-Scattering, 188 4.3.2 Sputtering, 192 4.3.3 Radiation Damage, 204 4.3.4 Entrapment and Re-emission, 209 4.3.5 Penetration and Channelling, 216 4.3.6 Electron Ejection, 222 	181
4.4 Emission of Ions from Hot Surfaces4.4.1 Thermionic Emission of Ions, 2294.4.2 Surface Ionization, 230	229
5 INTERACTION OF RADIATION WITH SURFACES	234
5.1 Photo-electric Emission	234
5.2 Interaction of Photons with Adsorbed Gases	239
6 MECHANICAL PROPERTIES OF MATERIALS AT VERY LOW PRESSURES	243
6.1 Adhesion or Cold Welding	243
6.2 Friction, Lubrication and Wear	240
6.3 Creep. Fatigue and Fracture	248

PART B: PRESSURE MEASUREMENT

7 GENERAL CONSIDERATIONS OF PRESSURE MEASUREMENT	253
7.1 Calibration of UHV Gauges	253
7.1.1 Absolute Pressure Measurement, 253 7.1.2 The McLeod Gauge, 254 7.1.3 Extensions to Lower Pressure, 257 7.1.4 Relative Sensitivity for Different Gases, 262	200
7.2 Measuring Systems as Sinks and Sources	263
7.2.1 Pumping and Re-emission in Gauges, 2637.2.2 Gas Interactions at Hot Surfaces, 2757.2.3 Sinks and Sources in Tubing (Blears effect), 280	
7.3 Pressure Measurements in Non-Uniform Environments	281
7.4 Residual Currents	287
7.4.1 Soft X-ray Photo-emission, 287 7.4.2 Electron-Impact Desorption, 290	
7.5 Methods of Current Measurement	294
 7.5.1 General Problems of Current Collection in UHV, 294 7.5.2 Measurement with dc Amplifiers, 295 7.5.3 Electron Multipliers, 295 7.5.4 Conversion-Scintillation Detectors, 298 	
7.6 Cathodes and Cathode Effects	299
S TOTAL PRESSURE GAUGES	304
8.1 Hot-Cathode Gauges	304
 8.1.1 The Bayard-Alpert Gauge, 305 8.1.2 Suppressor Gauge, 313 8.1.3 Extractor Gauge, 315 8.1.4 Orbitron Gauge, 317 8.1.5 Hot-Cathode Gauges with Magnetic Field, 319 8.1.6 Other Hot-Cathode Gauges, 322 8.1.7 Measurement of Residual Currents, 323 	
8.2 Crossed-Field, Cold-Cathode Gauges	329
 8.2.1 Penning Gauge, 329 8.2.2 Magnetron Gauge, 331 8.2.3 Inverted-Magnetron Gauge, 333 8.2.4 Current-Pressure Characteristics and Oscillatory Behaviour, 334 	
8.3 Comparison of Total Pressure Gauges	336

9 PARTIAL PRESSURE GAUGES	340
 9.1 Mass-Spectrometers 9.1.1 General Characteristics, 342 9.1.2 Examples of Ultrahigh Vacuum Mass-Spectrometers, 345 9.1.3 Measurement Problems in Partial Pressure Analysis, 352 9.1.4 Mass Numbers Typically Observed, 354 	340
9.2 Desorption Spectrometers9.2.1 Chemical Desorption Spectrometers, 3559.2.2 Physical Desorption Spectrometers, 361	355
9.3 Gauges using Field Emission or Work-Function Changes	365
PART C: PRODUCTION OF ULTRAHIGH VACU	UM
10 PROCESSING TECHNIQUES FOR ULTRAHIGH VACUUM	369
10.1 Pre-treatment of Materials10.2 Baking Procedures10.3 Degassing Procedures after Baking	371 373 378
111 PUMPS FOR ULTRAHIGH VACUUM	379
 11.1 Molecular Drag and Turbo-Molecular Pumps 11.2 Diffusion Pumps 11.3 Cryopumps 11.3.1 Cryosorption Pumps, 385 11.3.2 Cryogenic Pumps, 391 	379 380 383
11.4 Getter Pumps 11.4.1 Getter Materials, 399 11.4.2 Types of Getter Pumps, 403	399
11.5 Ion Pumps 11.5.1 Sputter-Ion Pumps, 406 11.5.2 Getter-Ion Pumps, 411	404
11.6 Comparison of Properties of UHV Pumps	416
12 EXAMPLES OF ULTRAHIGH VACUUM SYSTEMS	417
12.1 Small Glass and Metal Systems 12.1.1 Apparatus, 417 12.1.2 Residual Conditions Achieved, 417 12.1.3 Residual Processes, 420 12.1.4 Admission of Gas, 427	417

12.2 Large UHV Systems	430
12.2.1 Conventional Systems of Moderate Size, 431	
12.2.2 Cryogenic Systems, 432	
12.2.3 Accelerator Vacuum Systems, 433	
12.2.4 Systems for Plasma Physics Research, 433	
12.2.5 Space Simulators, 434	
References	435
Appendix A. Recent References	
Subject Index	477
Author Index	485