

# Contents

Introduction. By S. Bashkin .....	1
1. Experimental Methods. By S. Bashkin .....	5
1.1 Accelerators .....	5
1.2 Ion Sources .....	6
1.3 Beam Requirements and Limitations .....	8
1.4 Mass Analyzers .....	9
1.5 Target Chambers .....	12
1.6 Targets .....	14
1.7 Analytical Devices .....	17
1.8 Detectors .....	19
1.9 Detection Geometry and Line Width .....	22
1.10 Beam Monitors .....	25
1.11 External Fields .....	28
1.12 Concluding Remarks .....	29
References .....	29
2. Studies of Atomic Spectra by the Beam-Foil Method. By I. Martinson .....	33
2.1 Experimental Methods .....	33
2.2 Results of Spectral Studies .....	38
2.2.1 Previously Incompletely-Studied Systems .....	39
2.2.2 Hydrogen-Like Levels .....	43
2.2.3 Displaced Terms .....	48
2.2.4 Multiply-Excited States .....	50
References .....	57
3. Lifetime Measurements. By L. J. Curtis .....	63
3.1 Lifetime Studies as a Basic Area of Atomic Physics .....	64
3.1.1 The Need for Lifetime Measurements .....	65
3.1.2 Lifetime Measurements Prior to the Development of the Beam-Foil Technique .....	66
3.2 Definitions of Basic Quantities .....	68
3.2.1 Instantaneous Populations .....	68
3.2.2 Transition Probabilities and Oscillator Strengths .....	69

3.3	Measurement of Beam-Foil-Excited Decay Curves .....	70
3.3.1	Strengths and Limitations of the Beam-Foil Technique .....	70
3.3.2	Details of Beam-Foil Apparatus and Measurement Procedures .....	72
3.3.3	Cascade Repopulation - A Tractable Problem .....	76
3.4	Time Dependence of the Measured Decay Curves .....	79
3.4.1	Solution of the Driven Coupled Linear Rate Equations .....	79
3.4.2	A Quantitative Indicator of Level Repopulation - The Replenishment Ratio .....	83
3.4.3	Intensity Relationships for an Aligned Source .....	83
3.4.4	Distortions Which Preserve the Mean-Life Content of a Decay Curve .....	85
3.5	Mean-Life Extraction by Exponential Fits to Individual Decay Curves .....	87
3.5.1	Maximum Likelihood Method .....	87
3.5.2	Non-Linear Least Squares Method .....	88
3.5.3	Differentiation and Integration of Decay Curves .....	90
3.5.4	Expansion About a Close-Lying Mean Life .....	91
3.5.5	Fourier-Transform Methods .....	92
3.5.6	Method of Moments .....	92
3.6	Mean-Life Extraction by Joint Analysis of Cascade-Related Decay Curves .....	93
3.6.1	Ambiguities in the Assignment of Fitted Mean Lives .....	93
3.6.2	Constrained Fits .....	96
3.6.3	Linearly-Fitted Normalizations of Cascade-Related Decay Curves .....	96
3.7	Cascade-Free Methods .....	100
3.7.1	Beam-Foil Coincidence Techniques .....	100
3.7.2	Use of Alignment to Discriminate Against Cascades .....	100
3.7.3	Laser Excitation .....	102
3.8	Concluding Remarks .....	104
	References .....	104
4.	Theoretical Oscillator Strengths of Neutral, Singly-Ionized, and Multiply-Ionized Atoms: The Theory, Comparisons with Experiment, and Critically-Evaluated Tables with New Results. By Oktay Sinanoğlu .....	111
4.1	The Non-Closed-Shell Many-Electron Theory .....	114
4.2	A Spectroscopic Interpretation of the Charge Wave Function .....	118
4.3	NCMET Calculations .....	120
4.3.1	The $L^2$ , $S^2$ Symmetry of $\psi_c$ .....	123
4.3.2	Dipole Length vs. Dipole Velocity .....	124
4.3.3	Semi-Internal Orbital Variations (Type A, Lowest-of-Symmetry, States) .....	125

4.4	States Not Lowest of Their Symmetry .....	126
4.4.1	Neutral and Singly-Ionized Atoms .....	127
4.4.2	Variational Collapse and Its Avoidance .....	129
4.5	New Oscillator Strengths for Intershell ( $KL \rightarrow KL'[M]$ ) Transitions to Pre-Rydberg Levels ( $\bar{V} \rightarrow pR$ ) .....	134
4.6	Further Examination of Remaining Correlation Effects on Oscillator Strengths with NCMET .....	136
4.7	Conclusion .....	141
	References .....	142
5.	Regularities of Atomic Oscillator Strengths in Isoelectronic Sequences. By Wolfgang Wiese .....	147
5.1	Theoretical Basis .....	149
5.1.1	Definitions .....	149
5.1.2	Nuclear Charge-Dependence of the f-Value .....	150
5.1.3	Investigation of $\lim 1/Z \rightarrow 0$ .....	152
5.2	Discussion of Established Trends .....	153
5.2.1	Basic Trends .....	155
5.2.2	Curves With a Maximum .....	156
5.2.3	Curves With a Minimum .....	164
5.2.4	Anomalous Curves .....	166
5.3	Oscillator-Strength Distributions in a Spectral Series Along an Isoelectronic Sequence .....	167
5.4	Relativistic Effects and Corrections .....	169
5.5	Summary .....	174
	References .....	175
6.	Applications to Astrophysics: Absorption Spectra. By Ward Whaling .....	179
6.1	Branching Ratios .....	180
6.1.1	Light Sources .....	181
6.1.2	Spectrometers .....	182
6.1.3	Spectrometer Calibration .....	183
6.1.4	Selection of Branches to be Measured .....	184
6.2	Curve-of-Growth Analysis .....	185
6.2.1	Construction of a Curve-of-Growth .....	186
6.2.2	Internal-Consistency Test .....	187
6.2.3	Comparison of Transition Probabilities for Different Transitions .....	188
6.2.4	Solar-Abundance Determination .....	188
6.3	Beam-Foil-Spectroscopy Measurements Needed for Astrophysical Applications .....	189
	References .....	190

7.	Applications of Beam-Foil Spectroscopy to the Solar Ultraviolet Emission Spectrum. By Leon Heroux .....	193
7.1	Ionization Balance in the Chromosphere and Corona .....	196
7.2	Excitation Balance in the Chromosphere and Corona .....	196
7.3	Line-Ratio Measurements of Electron Temperature .....	198
7.4	Line-Ratio Measurements of Electron Density .....	203
7.5	The Determination of Chromospheric-Coronal Abundances .....	204
7.6	Beam-Foil Measurements Needed for Diagnostic Methods .....	206
	References .....	207
8.	Studies of Hydrogen-Like and Helium-Like Ions of High Z. By Richard Marrus .....	209
8.1	The Lamb Shift in the One-Electron System .....	209
8.1.1	Quenching Measurements on Fast Ion Beams of High Z .....	212
8.1.2	Lamb Shift in Hydrogen Using Separated Oscillating Fields ....	214
8.2	Lamb Shift in Two-Electron Systems .....	215
8.3	Radiative Decay of the $2S_{1/2}$ Metastable State of the One-Electron System .....	216
8.3.1	Theory .....	217
8.3.2	Experiments .....	220
8.4	Forbidden Radiative Decay in the $n=2$ State of the Two-Electron System .....	224
8.4.1	Radiative Decay from $2^1S_0$ .....	224
8.4.2	Radiative Decay from $2^3S_1$ .....	227
8.4.3	Radiative Decay from $2^3P_2$ .....	229
8.4.4	Radiative Decay from $2^3P_1$ .....	231
8.5	Study of Doubly-Excited Configurations in the Two-Electron System .....	232
	References .....	233
9.	Coherence, Alignment, and Orientation Phenomena in the Beam-Foil Light Source. By J. Macek and D. Burns .....	237
9.1	General Theoretical Considerations .....	239
9.1.1	The Emission Process .....	239
9.1.2	Symmetry Considerations .....	243
9.2	Alignment and Linear Polarization .....	246
9.2.1	Zero-Field Measurements .....	246
9.2.2	Electric Field .....	253
9.2.3	Magnetic Field .....	257
9.3	Orientation and Circular Polarization .....	260
9.3.1	Zero Field .....	260
9.3.2	Magnetic Field Measurements .....	261
9.3.3	The Quadratic Stark Effect .....	262
	References .....	263

10. The Measurement of Autoionizing Ion Levels and Lifetimes by Fast Projectile Electron Spectroscopy. By Ivan A. Sellin.....	265
10.1 The Fast-Projectile Electron Spectroscopy (FPES) Method .....	269
10.1.1 Choice of an Analyzer .....	270
10.1.2 Properties of a Cylindrical-Mirror Analyzer Suitable for FPES .....	271
10.1.3 Kinematic Modification of Analyzer Optimization Criteria .....	274
10.1.4 Relativistic Corrections to Analyzer Performance .....	275
10.1.5 Broadening from Transverse Velocity Spread .....	276
10.1.6 Further Kinematic Considerations: Sample Estimates of Net Line Widths Observed in FPES .....	277
10.1.7 Summary of the Advantages of FPES .....	279
10.2 Examples of FPES .....	280
10.2.1 Spectra of Long-Lived States of the Li-Like, Be-Like, and B-Like Ions .....	280
10.2.2 Spectra of Long-Lived Core-Excited States of Sodium-Like Chlorine .....	282
10.2.3 Core-Excited States of the Neutral and Nearly-Neutral Alkali Metals .....	283
10.2.4 Electron Background in FPES with Foil Targets .....	286
10.2.5 Electron Background in FPES with Gas Targets .....	287
10.3 The Measurement of Auger Lifetimes by FPES .....	290
10.3.1 Auger Lifetimes of Metastable Lithium-Like Ions .....	290
10.3.2 Examples of Lifetimes from Optical Decay Channels of Auger-Emitting Levels .....	294
References .....	295
APPENDIX (Up-dated bibliography) .....	299
SUBJECT INDEX.....	311