

CONTENTS

20. RECOMBINATION

1. Introduction	2115
2. Electron-ion recombination	2116
2.1. Radiative recombination	2117
2.2. Recombination through inverse autoionization	2118
2.2.1. Dielectronic recombination	2119
2.2.2. Dissociative recombination	2122
2.3. Electronic collisional-radiative recombination	2126
2.3.1. Simplified theory	2126
2.3.2. Detailed theory	2130
2.3.3. Effect of optical thickness	2134
2.3.4. Recombination to multiply-charged bare ions	2136
2.3.5. Recombination to other ions	2136
2.3.6. Inclusion of dielectronic recombination	2136
2.3.7. The energy balance in a decaying plasma	2140
2.3.8. Collisional-dissociative recombination	2147
2.4. Neutral collisional-radiative recombination	2149
3. Experimental methods for investigating electron-ion recombination	2155
3.1. Recombination in plasmas with low electron concentration and ordinary neutral-gas temperature	2156
3.1.1. Microwave probing methods—general principles	2156
3.1.2. Microwave probing methods—typical experiments	2163
3.1.3. Use of single Langmuir probes	2167
3.1.4. Use of a double probe	2169
3.1.5. Study of afterglows in shock-excited gas	2174
3.1.6. Measurement of relaxation times in caesium-seeded plasmas	2178
3.1.7. Optical experiments	2179
3.1.7.1. Spectroscopic study of line and band emission in flowing afterglows	2180
3.1.7.2. Spectroscopic study of line and band emission in static afterglows	2182
3.1.7.3. Experiments with an arc-jet plasma	2184
3.1.7.4. Interferometric study of the widths and profiles of afterglow lines	2186
3.1.8. Recombination in flames	2190
3.1.9. Merging-beam methods	2194

4. Discussion of experimental results for electron-ion recombination	2196
4.1. Historical account	2196
4.2. Recombination in helium	2201
4.2.1. Experiments in dense plasmas	2204
4.2.2. The origin of the He_2 band emission in an afterglow	2213
4.2.3. Recombination in helium at higher pressures—possible contribution from He_3^+	2220
4.2.4. Concluding remarks—the He_2 potential-energy curves	2222
4.3. Recombination in the heavier rare gases	2223
4.3.1. Neon	2223
4.3.1.1. Temperature variation of the recombination coefficient	2231
4.3.2. Argon	2233
4.3.3. Krypton and xenon	2235
4.4. Recombination in caesium and caesium-seeded plasmas	2237
4.5. Recombination in nitrogen	2241
4.6. Recombination in oxygen	2248
4.7. Recombination in nitric oxide	2251
4.8. Recombination in hydrogen	2254
4.9. Recombination in carbon dioxide	2256
4.10. Neutral collisional-radiative recombination in flames	2257
5. Recombination between positive and negative ions	2259
5.1. Summary of possibilities	2259
5.2. Radiative recombination	2259
5.3. Mutual neutralization	2259
5.4. Three-body recombination	2266
5.4.1. J. J. Thomson's theory	2267
5.4.2. Application of collisional-recombination theory	2270
5.4.3. Langevin's theory	2275
5.5. Experimental study of three-body recombination of ions	2276
5.5.1. The medium-pressure range	2276
5.5.2. The high-pressure region	2280
5.6. Measurement of ion-ion recombination coefficients at low pressures	2281
5.6.1. Experiments using a photoionization source	2281
5.6.2. Measurement of mutual neutralization rates using the dielectric-constant method	2286
5.6.3. Application of the merging-beam technique to the measurement of rates of mutual neutralization	2289
6. Electronic and ionic reaction rates and the ionosphere	2292
6.1. Introduction—the ionosphere	2292
6.2. Observational methods for exploring the ionosphere and the data obtained	2294

6.3. Observational methods for observing solar radiation and atmospheric composition	2295
6.4. Determination of relevant reaction rates	2297
6.5. Application to the ionosphere in the E and F ₁ regions	2298
6.6. The F ₂ region	2301
6.7. The exosphere	2302
6.8. The lower ionosphere	2303
 21. COLLISION PROCESSES INVOLVING ENERGETIC IONIZED AND NEUTRAL BEAMS OF ATOMS AND MOLECULES—INTRODUCTION	
1. Experiments with ionized atomic beams	2307
2. Relative (C.M.) and laboratory coordinates	2310
3. Notation for cross-sections	2311
4. Sources of homogeneous ionic and atomic beams	2312
4.1. Ion sources	2312
4.2. Neutral atom sources	2322
5. Detection of fast heavy-particle beams	2324
5.1. The Faraday cage	2324
5.2. Thermal detectors	2325
5.3. Secondary emission detectors	2326
5.4. Scintillation counters	2327
5.5. Proportional counters	2328
5.6. Solid-state counters	2328
6. Detection of photons	2329
6.1. Photon detectors	2329
6.2. Calibration of photon detectors	2331
7. Determination of the effective target thickness in collision experiments	2333
7.1. Beam and static gas target configuration	2333
7.2. Intersecting beams	2335
 22. ELASTIC COLLISIONS BETWEEN PARTICLE BEAMS AND NEUTRAL ATOMS AND MOLECULES	
1. Introductory remarks	2337
2. The principles involved in the measurement of 'total' scattering and the analysis of the data obtained	2340
3. Collisions between neutral systems	2346
3.1. The experimental arrangements	2346
3.2. Results obtained and their analysis	2353
3.2.1. He-He collisions	2353
3.2.2. Collisions between other neutral atoms in their ground states	2358
3.2.3. Collisions involving diatomic or polyatomic molecules	2362

4. Collisions between ionized and neutral systems	2367
4.1. The experimental arrangements	2367
4.1.1. The measurement of 'total' cross-sections	2368
4.1.2. The measurement of differential cross-sections	2373
4.2. Theoretical analysis of data on differential cross-sections	2381
4.2.1. The interaction potential in the ground state	2381
4.2.2. The inversion problem	2384
4.2.3. Use of impact expansions	2386
4.2.4. Interaction between elastic and inelastic collisions— perturbation due to curve crossing	2388
4.2.5. The inelastic scattering due to a pseudo-curve crossing	2392
4.2.6. Estimation of the interaction at the pseudo-crossing	2395
4.2.7. Summary of possibilities arising from analysis of perturbations	2395
4.3. Experimental results and their analysis	2396
4.3.1. He ⁺ -Ne collisions	2396
4.3.1.1. Determination of V_I^d	2399
4.3.1.2. Pseudo-crossing perturbations	2399
4.3.2. Ne ⁺ -He collisions	2405
4.3.3. He ⁺ -Ar collisions	2406
4.3.4. He ⁺ -Kr and He ⁺ -Xe collisions	2410
4.3.5. H ⁺ collisions with Ar, Kr, and Xe	2412
4.3.6. Li ⁺ -He collisions	2413
4.3.7. Li ⁺ collisions with H ₂ , N ₂ , and O ₂	2417
4.3.8. Other collisions between ions and neutral atoms or molecules	2418
 23. INELASTIC COLLISIONS BETWEEN ATOMIC SYSTEMS— THEORETICAL CONSIDERATIONS	
1. Introduction	2419
2. Fast collisions. Born's approximation for excitation and ionization	2420
2.1. Excitation by bare positive ions	2420
2.1.1. Summary of formulae	2420
2.1.2. Excitation and ionization of H atoms	2423
2.1.3. Excitation and ionization of helium atoms	2423
2.1.4. Ionization of outer shells of complex atoms	2429
2.1.5. Inner shell ionization	2430
2.2. Collisions between systems both possessing electronic structure	2434
2.2.1. Collisions between normal H atoms	2434
2.2.2. Ionization of excited H atoms by impact with normal H atoms	2440
2.2.3. He ⁺ -H collisions	2440
2.2.4. H-He collisions	2442

2.2.5. He^+ -He collisions	2447
2.2.6. He-He collisions	2448
2.2.7. Detachment of electrons from H^-	2448
2.2.8. Other collisions	2449
3. Fast collisions—electron transfer reactions	2451
3.1. The single electron problem	2452
3.1.1. Born's approximation	2452
3.1.2. The non-orthogonality problem—Bates's approximation	2454
3.1.3. Behaviour of the cross-section for symmetrical charge exchange at very high energy	2458
3.1.4. The impulse approximation	2462
3.2. Applications to individual collisions	2466
3.2.1. H^+ -H collisions	2466
3.2.2. He^{++} -H collisions	2467
3.2.3. H^+ -He collisions	2467
3.2.4. H^+ -O and H^+ -N collisions	2470
3.2.5. Semi-empirical theory of the capture of electrons by protons from many-electron atoms	2473
3.2.6. Relation of capture cross-sections from molecules to those for the constituent atoms	2474
3.2.7. H-H collisions	2477
3.2.8. He^+ -He collisions	2478
3.2.9. He^{++} -He collisions	2479
3.3. Excitation of triplet states of helium by hydrogen atom impact	2479
3.4. Effect of electron exchange on excitation of singlet states	2483
3.5. 'Capture' into continuum states	2483
4. Fast collisions—classical approximations	2485
4.1. Introduction	2485
4.2. Ionization and charge transfer collisions between protons and hydrogen atoms	2485
4.2.1. Application of the Monte Carlo method	2485
4.2.2. The classical impulse approximation—conditions for validity	2488
4.2.3. The classical impulse approximation—application to H^+ -H collisions	2491
4.3. The classical impulse approximation in general	2494
4.3.1. Some classical dynamical formulae	2494
4.3.2. Application to electron loss by neutral atoms in passing through gases	2498
4.3.3. Application to detachment of electrons from H^- ions in passing through gases	2503
4.4. Classical treatment of charge transfer in terms of binary encounters	2504
4.4.1. High velocity encounters	2505
4.4.2. Electron capture by protons from heavy atoms	2507

5. Fast collisions—break-up of molecular ions on impact—ionic reactions	2510
5.1. Impact dissociation of H_2^+	2510
5.1.1. By proton impact	2510
5.1.2. By impact with other atoms and molecules—total cross-sections	2514
5.1.3. By impact with other atoms and molecules—angular distributions of dissociation products	2517
5.2. Collisions involving complex ions and molecules	2521
6. Slow collisions—symmetrical charge transfer	2526
6.1. H^+ – H collisions	2527
6.1.1. Introductory theory—the total cross-section for charge transfer	2527
6.1.2. The differential cross-sections for elastic scattering and charge transfer	2530
6.1.3. The effect of nuclear symmetry	2533
6.1.4. The effect of the transfer of the electron momentum	2534
6.1.5. The effect of transitions to states which dissociate into excited H atoms	2537
6.1.6. Results of calculations—the total cross-section for charge transfer	2541
6.1.7. Results of calculations—differential cross-sections	2543
6.2. He^+ – He collisions	2546
6.2.1. The interactions effective in producing charge exchange	2546
6.2.2. Angular distribution of scattered He^+ ions	2549
6.3. He^{++} – He collisions	2560
6.4. Ne^+ – Ne and Ar^+ – Ar	2564
6.5. Li^+ – Li	2573
6.6. Hg^+ – Hg	2576
6.7. H^- – H	2577
6.8. H^+ – H^* collisions	2579
6.9. H_2^+ – H_2 collisions	2579
6.10. Semi-empirical formulae—relation of charge transfer cross-section to ionic mobility	2581
6.11. Classical theory and slow, symmetrical, charge transfer collisions	2583
7. Slow collisions—non-symmetric charge transfer	2585
7.1. The perturbed stationary state method	2585
7.1.1. Wave formulation	2585
7.1.2. Impact parameter formulation	2590
7.1.3. Born and distorted wave approximations	2591
7.2. Strong coupling without distortion—schematic model	2592
7.3. Application of other methods for solving the coupled equations	2595
7.4. Charge transfer between multiply-charged ions and atoms—long range crossing	2597

8. Inelastic cross-sections at intermediate energies	2601
8.1. Introduction—classification of approximations	2601
8.2. H^+-H collisions	2607
8.2.1. Description of methods used	2608
8.2.1.1. Inclusion of distortion	2608
8.2.1.2. 4-state approximation	2609
8.2.1.3. Harmonic expansion method	2609
8.2.1.4. Four-state binuclear approximation with momentum transfer	2611
8.2.1.5. Use of Sturmian expansion	2611
8.2.1.6. Back coupling and coupling through intermediate states—use of a time-dependent effective nuclear charge	2612
8.2.1.7. Use of a pseudo-state expansion	2613
8.2.2. Results and discussion	2615
8.2.2.1. Symmetrical charge transfer	2615
8.2.2.2. $2s$ and $2p$ excitations with and without charge transfer	2616
8.3. He^+-He collisions	2621
8.4. H^+-He collisions	2621
8.4.1. Excitation	2621
8.4.2. Charge transfer	2625
8.5. $He^{++}-H$ collisions	2629
8.6. $H-H$ collisions	2631
8.6.1. Calculations ignoring electron exchange	2631
8.6.2. Inclusion of electron exchange	2634
8.7. $H-He$ collisions	2636
8.8. $H-Ne$, $H-Ar$, and $H-Kr$ collisions	2637
9. Ionizing collisions between atomic systems at slow to intermediate energies	2637
 24. CHARGE-CHANGING AND IONIZING COLLISIONS— EXPERIMENTAL METHODS AND RESULTS INCLUDING THEORETICAL ANALYSIS	
1. Experimental methods	2642
1.1. Measurement of the energy and angular distributions of the collision products	2643
1.1.1. Primary particles	2643
1.1.2. Secondary ions	2645
1.1.3. Electrons	2647
1.1.4. Coincidence studies	2650
1.2. The measurement of charge-changing and ionization cross- sections	2654

1.2.1. Methods based on collection of the slow collision products produced during the passage of a heavy particle beam through a static gas target	2654
1.2.1.1. Basis of the experimental approach	2654
1.2.1.2. The condenser plate method	2656
1.2.1.3. Methods used in collisions involving low energy ion beams	2663
1.2.1.4. Mass spectrometric methods	2668
1.2.1.4.1. Measurements at keV energies	2668
1.2.1.4.2. Measurements at low impact energies	2674
1.2.2. Methods based on studies of the attenuation and change of composition of heavy particle beams during passage through a static gas target	2680
1.2.2.1. Single collision methods	2680
1.2.2.2. Charge equilibration of fast particle beams in thick gaseous targets	2692
1.2.2.3. Beam attenuation studies	2698
1.2.2.4. Growth curve methods	2703
1.2.2.5. The Aston band method	2704
1.2.3. Studies of the effect of an excited state population in the primary beam	2707
1.2.4. Intersecting beam methods	2712
1.2.4.1. Crossed beams	2712
1.2.4.2. Merging beams	2718
1.2.4.3. Inclined beams	2722
1.3. The measurement of inner shell ionization cross-sections	2725
1.3.1. Introduction	2725
1.3.2. Measurement of characteristic X-ray production	2726
1.3.2.1. Experimental arrangements	2726
1.3.2.2. Derivation of the inner shell ionization cross-section	2729
1.3.3. Measurement from observation of Auger electron emission	2730
2. Experimental results and their analysis in relation to theory	2732
2.1. Energy and angular distribution of collision products	2732
2.1.1. Primary and secondary collision products—general description	2732
2.1.2. Angular distribution of scattered primary particles	2733
2.1.3. Energy and angular distribution of the scattered secondary ions	2739
2.1.4. Coincidence studies and inelastic energy loss	2741
2.1.5. Energy and angular distribution of the electrons emitted in inelastic collisions	2756

2.2. Charge-changing collisions	2767
2.2.1. Simple charge transfer at low impact energies—total cross-sections—introduction	2767
2.2.2. Simple charge transfer—symmetrical resonance—total cross-sections	2767
2.2.2.1. H^+-H	2767
2.2.2.2. $H^- - H$	2770
2.2.2.3. Reactions involving neutral and singly ionized rare-gas atoms	2770
2.2.2.4. Hg^+-Hg	2774
2.2.2.5. Reactions involving alkali-metal atoms	2774
2.2.2.6. Reactions involving O, N, and C atoms	2779
2.2.2.7. Reactions involving doubly and triply ionized rare-gas atoms	2781
2.2.2.8. $H_2^+-H_2$	2782
2.2.2.9. Reactions involving other molecules	2784
2.2.3. Simple charge transfer—accidental resonance	2784
2.2.4. Simple charge transfer at low impact energies—non-resonant cases—total cross-sections	2788
2.2.4.1. Charge transfer reactions involving H^+	2789
2.2.4.2. Charge transfer reactions involving He^+	2792
2.2.4.3. Charge transfer reactions involving heavier rare-gas ions	2795
2.2.4.4. Charge transfer reactions involving alkali-metal ions and atoms	2796
2.2.4.5. Charge transfer reactions involving ions of period V of the periodic table	2799
2.2.4.6. Other single electron capture reactions involving singly-charged positive ions	2799
2.2.4.7. Charge transfer involving doubly-charged positive ions	2800
2.2.4.8. Charge transfer reactions involving negative ions	2800
2.2.5. Simple charge transfer at low impact energies—mutual neutralization	2804
2.2.6. Electron detachment processes	2805
2.2.6.1. Total cross-sections	2805
2.2.6.2. Energy distribution of detached electrons	2811
2.2.7. Ion-atom interchange	2814
2.2.8. Charge-changing collisions involving fast hydrogen beams	2823
2.2.8.1. Collisions in atomic hydrogen	2823
2.2.8.2. Collisions in other gases	2827
2.2.8.3. H^- formation	2836
2.2.8.4. Collisional destruction of $H(2s)$ atoms	2837

2.2.9. Charge-changing collisions involving fast helium beams	2841
2.2.9.1. He^+ beams	2842
2.2.9.2. He^0 beams	2846
2.2.9.3. He^{++} beams	2848
2.2.9.4. He^- production	2850
2.2.10. Charge-changing collisions involving other fast atomic beams	2852
2.2.10.1. Atoms of the first long row of the periodic table	2852
2.2.10.2. Heavy metal atoms and ions	2861
2.2.10.3. Bromine and iodine atoms and ions	2863
2.2.10.4. Production of long-lived excited ions	2866
2.2.10.5. Comparison of data for ionization of neutral atom beams with semi-classical statistical theory	2871
2.2.11. Differential scattering in charge-changing collisions—the probability of charge transfer in symmetrical cases	2871
2.2.11.1. Introduction	2871
2.2.11.2. $\text{H}^+ - \text{H}$ collisions	2875
2.2.11.3. $\text{He}^+ - \text{He}$ collisions	2880
2.2.11.4. $\text{Ne}^+ - \text{Ne}$ collisions	2886
2.2.11.5. $\text{Ar}^+ - \text{Ar}$ collisions	2891
2.2.11.6. Other symmetrical collisions involving singly-charged positive ions	2892
2.2.11.7. $\text{He}^{++} - \text{He}$ collisions	2893
2.2.11.8. $\text{H}^- - \text{H}$ collisions	2895
2.2.12. Differential scattering in charge-changing collisions—probability of charge transfer in non-symmetrical cases	2896
2.2.12.1. $\text{He}^+ - \text{He}$ collisions	2897
2.2.12.2. $\text{He}^+ - \text{H}$ collisions;	2897
2.2.12.3. Other collisions involving H^+	2898
2.2.12.4. Other collisions involving He^+	2898
2.2.12.5. Collisions involving other singly-charged ions	2899
2.2.12.6. $\text{H} - \text{H}$ and $\text{H} - \text{H}_2$ collisions	2901
2.2.12.7. $\text{He}^{++} - \text{H}$ collisions	2902
2.2.12.8. Collisions involving other multiply-charged ions	2903
2.2.13. Collisional dissociation of fast molecular species	2909
2.2.13.1. Dissociation of H_2^+ —total cross-sections	2909
2.2.13.2. Dissociation of H_2^+ —energy and angular distribution of product protons	2916
2.2.13.3. Dissociation of other fast molecular ions	2934

2.3. Ionization	2936
2.3.1. The gross yield of electrons and slow ions	2936
2.3.1.1. Ionization by fast hydrogen beams	2936
2.3.1.2. Ionization by fast helium beams	2941
2.3.1.3. Ionization by fast beams of species other than hydrogen or helium	2947
2.3.1.4. Ionization at low impact energies	2951
2.3.2. Mass spectrometric analysis of the secondary ions	2957
2.3.2.1. Multiple ionization of atomic targets	2957
2.3.2.2. Ionization and fragmentation of molecular targets	2960
2.3.3. Results of the measurement of characteristic X-ray production by positive ions	2966
2.3.3.1. Ionization by protons	2966
2.3.3.2. Ionization by He^+ ions	2966
2.3.3.3. Dependence of inner shell ionization cross-sections on the atomic number of the target	2972
2.3.3.4. Ionization by heavier ions	2973
2.3.3.5. Dependence of inner shell ionization cross-section on impact parameter in the ionizing collision	2975
2.3.3.6. Results obtained from observations of Auger emission	2978
2.3.3.7. Comparison with theory	2980
2.3.3.8. Interpretation of anomalous inner shell excitation by heavy incident ions	2982
3. Comparison of theory and experiment for charge-changing and ionizing collisions—summary account	2985
3.1. One-electron cases	2986
3.1.1. H^+-H collisions	2986
3.1.2. $\text{He}^{++}-\text{H}$ collisions	2988
3.2. Two-electron cases	2989
3.2.1. $\text{H}(1s)-\text{H}(1s)$ and H^+-H^- collisions	2989
3.2.2. $\text{H}(2s)-\text{H}(1s)$ collisions	2990
3.2.3. H^+-He and He^+-H collisions	2990
3.2.4. $\text{He}^{++}-\text{He}$ collisions	2991
3.3. Three-electron cases	2992
3.3.1. He^+-He collisions	2992
3.3.2. H^--H collisions	2993
3.3.3. H^--He^+ collisions	2994
3.3.4. $\text{H}(1s)-\text{He}(1^1S)$ collisions	2994
3.3.5. $\text{H}(2s)-\text{He}(1^1S)$ and $\text{He}(2^3S)-\text{H}(1s)$ collisions	2995
3.4. Four-electron cases	2995
3.4.1. Collisions between neutral helium atoms	2995
3.4.2. H^--He collisions	2995

3.5. Collisions between more complex systems and general summary	2995
3.5.1. Ionization and detachment	2996
3.5.2. Charge transfer and elastic scattering	2998
3.5.3. Collisions involving molecules	3001
3.6. Concluding remarks	3001
25. COLLISIONS INVOLVING EXCITATION— EXPERIMENTAL METHODS AND DISCUSSION OF RESULTS OBTAINED	
1. Introduction	3003
1.1. Methods based on the spectroscopic analysis of radiation emitted during the passage of particle beams through gases	3003
1.1.1. Basis of the experimental approach	3003
1.1.2. General experimental requirements for the accurate determination of emission functions	3004
1.1.3. Measurements with static gas targets	3007
1.1.4. Crossed beam measurements	3010
1.1.5. The photon-coincidence method	3013
1.2. Methods based on the post-collision analysis of fast excited beams	3015
1.2.1. The decay curve method	3015
1.2.2. Metastable states—the beam attenuation technique	3016
1.2.3. Metastable states—analysis by electric field quenching	3017
1.2.4. Highly excited states—field ionization methods	3020
1.3. Measurement of differential cross-sections for inelastic collisions	3023
2. Experimental results and their comparison with theory	3023
2.1. Introduction—the earlier observations	3023
2.2. Excitation in collisions involving hydrogen and helium beams	3027
2.2.1. Collisions involving the emission of Lyman α radiation	3027
2.2.1.1. Emission due to excitation of H atoms in a beam	3027
2.2.1.2. Emission due to impact by protons in atomic gases	3033
2.2.1.3. Emission due to impact by protons on molecular gases	3041
2.2.1.4. Emission in $\text{He}^+\text{-H}$ impacts	3045
2.2.1.5. Emission due to impact of He^+ and H_2^+ ions in H_2	3046
2.2.1.6. Emission due to impact of H_2^+ and D_2^+ ions with rare gases	3046
2.2.2. Excitation of helium	3048
2.2.2.1. Excitation by proton beams	3048
2.2.2.2. Excitation by H atom beams	3057
2.2.2.3. Excitation by He^+ ion beams	3060
2.2.3. Excitation of the heavier rare gases	3065

2.2.4. Excitation of molecular gases	3069
2.2.4.1. Excitation of H_2	3070
2.2.4.2. Excitation of N_2	3073
2.2.4.3. Excitation of O_2	3085
2.2.4.4. Excitation of CO	3086
2.2.5. Excitation of hydrogen (other than $H(2s)$ or $H(2p)$) and helium beams	3087
2.3. Excitation in collisions involving beams other than of hydrogen or helium	3098
2.3.1. Excitation in collisions between rare-gas ion beams and rare-gas atoms	3098
2.3.2. Excitation of N_2	3100
2.3.3. Excitation of O_2 and CO	3104
2.4. Differential cross-sections for inelastic collisions	3104
2.4.1. Collisions with He	3105
2.4.2. Collisions with Ne	3108
2.4.3. Collisions with Ar, Kr, and Xe	3110
2.4.4. Collisions of Li^+ with N_2 and O_2	3110
3. Comparison of theory and experiment for collisions including excitation—a summary account	3114
3.1. One-electron cases—excitation in H^+-H collisions	3115
3.1.1. Correlation with evidence from charge-changing and ionizing collisions	3117
3.2. Two-electron cases—excitation in H^+-He collisions	3118
3.2.1. Excitation of He	3118
3.2.2. Charge transfer to excited states of H	3118
3.2.3. Comparison with data on total cross-sections for ionization and charge transfer	3119
3.3. Two-electron cases—excitation in $H-He^+$ collisions	3119
3.4. Three-electron cases—excitation in $H-He$ collisions	3119
3.4.1. Excitation of H	3119
3.4.2. Excitation of He	3120
3.4.3. Comparison with data on total cross-sections for ionization	3120
3.5. Three-electron cases—excitation in He^+-He collisions	3121
3.6. Excitation in impacts involving complex systems	3121
3.6.1. Comparison with data on ionization and charge transfer	3121
3.7. Concluding remarks	3122

AUTHOR INDEX	1
--------------	---

SUBJECT INDEX	15
---------------	----