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1. W. Kossel und C. Gerthsen, <i>Prüfung von D-Leuchten, das von einem nahezu parallelen Elektronenbündel angeregt ist, auf Polarisation</i> , Ann. Phys. (Leipzig) 77 (1925); 273–277, 286	345
2. H.W.B. Skinner, <i>On the Excitation of Polarised Light by Electron Impact</i> , Proc. Roy. Soc. A 112 (1926); 642, 651–660 ...	351
3. H.W.B. Skinner and E.T.S. Appleyard, <i>On the Excitation of Polarised Light by Electron Impact. II.—Mercury</i> , Proc. Roy. Soc. A 117 (1927); 224–225, 237–244	363
4. J.R. Oppenheimer, <i>Zur Quantenmechanik der Richtungsentartung</i> , Z. Phys. 43 (1927) 27–46	373
5. J.R. Oppenheimer, <i>On the Quantum Theory of the Polarization of Impact Radiation</i> , Proc. Nat. Acad. Sci. 13 (1927) 800–805	393
6. J.R. Oppenheimer, <i>On the Quantum Theory of Electronic Impacts</i> , Phys. Rev. 32 (1928) 361–376	CD
7. K. Steiner, <i>Die Polarisation des Stoßleuchtens bei Edelgasen</i> , Z. Phys. 52 (1928) 516–530	CD
8. W.G. Penney, <i>Effect of Nuclear Spin on the Radiation Excited by Electron Impact</i> , Proc. Nat. Acad. Sci. 18 (1932) 231–237	399
9. H. Bethe, <i>Polarisation des Stoßleuchtens</i> , Handbuch der Physik 24 (1933) 508–515	CD
10. N.F. Ramsey, <i>Collision Alignment of Molecules, Atoms, and Nuclei</i> , Phys. Rev. 98 (1955) 1853	407
11. I.C. Percival and M.J. Seaton, <i>The Polarization of Atomic Line Radiation Excited by Electron Impact</i> , Phil. Trans. Roy. Soc. A 251 (1958) 113–124, 129–138	409

12. K. Jost and J. Kessler, <i>Production of Highly Polarized Electron Beams by Low-Energy Scattering</i>, Phys. Rev. Lett. 15 (1965) 575–577	431
13. K. Jost and J. Kessler, <i>Zur Polarisation langsamer Elektronen durch Streuung an Quecksilber zwischen 180 und 1700 eV</i>, Z. Phys. 195 (1966) 1–12	CD
14. B. Bederson, <i>The Perfect Scattering Experiment. I</i>, Comm. At. Mol. Phys. 1 (1969) 41–44	435
15. B. Bederson, <i>The Perfect Scattering Experiment. II</i>, Comm. At. Mol. Phys. 1 (1969) 65–69	439
16. B. Bederson, <i>Electron-Atom Excitation with Spin Analysis</i>, Comm. At. Mol. Phys. 2 (1970) 160–164	CD
17. J. Kessler and J. Lorenz, <i>Experimental Verification of the Fano Effect</i>, Phys. Rev. Lett. 24 (1969) 87–88	445
18. U. Heinzmann, J. Kessler, and J. Lorenz, <i>Elektronen-Spinpolarisation bei der Photoionisation unpolarisierter Cäsiumatome mit zirkularpolarisiertem Licht. Untersuchung des Fano-Effekts am Cäsium</i>, Z. Phys. 240 (1970) 42–61	CD
19. D.H. Jaecks, D.H. Crandall, and R.H. McKnight, <i>Measurement of Differential Charge-Transfer Cross Sections and Probabilities by Photon-Particle Coincidence Technique</i>, Phys. Rev. Lett. 25 (1970) 491–494	447
20. J.H. Macek and D.H. Jaecks, <i>Theory of Atomic Photon-Particle Coincidence Measurements</i>, Phys. Rev. A 4 (1971) 2288–2300	451
21. G. Rhamat, G. Vassilev, J. Baudon, and M. Barat, <i>Differential Measurement of the $\text{He } 3^3P$ Excitation, in $\text{He}^+ - \text{He}$ Collisions, by Using an Ion-Photon Coincidence Method</i>, Phys. Rev. Lett. 26 (1971) 1411–1413	465
22. J. Wykes, <i>The Variation with Electron Scattering Angle of the Polarisation of Atomic Line Radiation Excited by Electron Impact</i>, J. Phys. B 5 (1972) 1126, 1135	469
23. M. Eminyan, K.B. MacAdam, J. Slevin, and H. Kleinpoppen, <i>Measurements of Complex Excitation Amplitudes in Electron-Helium Collisions by Angular Correlations Using a Coincidence Method</i>, Phys. Rev. Lett. 31 (1973) 576–579	471

24. M. Emelian, K.B. MacAdam, J. Slevin, and H. Kleinpoppen, <i>Electron-Photon Angular Correlations in Electron-Helium Collisions: Measurements of Complex Excitation Amplitudes, Atomic Orientation and Alignment</i>, J. Phys. B	7	(1974) 1519–1542	CD
25. U. Fano and J.H. Macek, <i>Impact Excitation and Polarization of the Emitted Light</i>, Rev. Mod. Phys.	45	(1973) 553–565, 572–573	475
26. G.F. Hanne and J. Kessler, <i>Direct Observation of Exchange Scattering by Spin Flip of Polarized Electrons in Excitation of Mercury</i>, Phys. Rev. Lett.	33	(1974) 341–343	491
27. G.F. Hanne and J. Kessler, <i>Study of Exchange Collisions in Mercury by Means of Polarized Electrons I. Experiment</i>, J. Phys. B	9	(1976) 791–804	CD
28. J.H. Macek and I.V. Hertel, <i>Theory of Electron Scattering from Laser Excited Atoms</i>, J. Phys. B	7	(1974) 2173–2188	495
29. G. Vassilev, G. Rhamat, J. Slevin, and J. Baudon, <i>Measurements of Photon Polarization and Angular Correlation for $\text{He}^+ - \text{He}$ Collisions Using an Ion-Photon Coincidence Technique</i>, Phys. Rev. Lett.	34	(1975) 444–447	511
30. D.H. Jaecks, F.J. Eriksen, W. de Rijk, and J. Macek, <i>Polarized-Photon, Scattered-Atom Coincidence Measurements in $\text{He}^+ - \text{He}$ Collisions</i>, Phys. Rev. Lett.	35	(1975) 723–725	515
31. M.C. Standage and H. Kleinpoppen, <i>Photon Vector Polarization and Coherence Parameters in an Electron-Photon Coincidence Experiment on Helium</i>, Phys. Rev. Lett.	36	(1976) 577–580	519
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