

UNIVERSITAT DE BARCELONA

Departament de Física Aplicada i Òptica

Electron-induced x-ray emission
from solids.

Simulation and measurements

Xavier Llovet Ximenes

Barcelona, Juny de 1998

Bibliography

- E. Acosta (1997), Ph.D. Thesis.
- E. Acosta, E. Coleoni, G. Castellano, J.A. Riveros, J.M. Fernández-Varea and F. Salvat (1996), *Scanning Micros.* **10**, 625.
- R. Ambrose, D.L. Kahler, H.E. Lehtihet and C.A. Quarles (1991), *Nucl. Instr. and Meth.* **B 56/57**, 327.
- R. Ambrose, J.C. Altman and C.A. Quarles (1987), *Phys. Rev. A* **35**, 529.
- N. Ammann and P. Karduck (1990), *Microbeam Analysis* ed. by J.R. Michael and P. Ingram (San Francisco Press, San Francisco), 150.
- K. Araki, Y. Kimura and R. Shimizu (1993), *Scanning Micros. Suppl.*, **7**, 81.
- J. Armstrong (1991), *Electron Probe Quantitation* ed. by K.F.J. Heinrich and D.E. Newbury (Plenum Press, New York), 261.
- H.J. August and J. Wernisch (1991), *X-Ray Spectrom.* **20**, 131.
- L.A. Bakaleinikov and V.V. Tretyakov (1995) *Scanning* **17**, 243.
- W. Bambynek, B. Crasemann, R.W. Fink, H.U. Freund, H. Mark, C.D. Swift, R.E. Price and P.V. Rao (1972), *Rev. Mod. Phys.* **44**, 716.
- J. Baró, J. Sempau, J.M. Fernández-Varea and F. Salvat (1994), *Nucl. Instr. and Meth.*, **B84**, 465.
- J. Baró, J. Sempau, J.M. Fernández-Varea and F. Salvat (1995), *Nucl. Instr. and Meth.* **B100**, 31.
- G.F. Bastin, J.M. Dijkstra, H.J.M. Heijligers and D. Klepper (1992), *Mikrochim. Acta Suppl.* **12**, 93.
- G.F. Bastin, J.M. Dijkstra and H.J.M. Heijligers (1996), *Proc. of Microscopy and Microanalysis*, ed. by E.G.W. Bailey, J.M. Corbett, R.V.W. Dimlich, J.R. Michael and N.J. Zaluzec, (San Francisco Press, San Francisco).

- G.F. Bastin (1998), personal communication.
- M.J. Berger (1963), in *Methods in Computational Physics*, ed. by B. Alder, S. Fernbach and M. Rotenberg (Academic Press, New York), 135.
- M.J. Berger and J.H. Hubbell (1987), National Bureau of Standards, *Report NBSIR 87-3797* (Washington).
- M.J. Berger and S.M. Seltzer (1982), National Bureau of Standards, *Report NBSIR 82-2550* (Washington). Also available as ICRU Report 37 (1984).
- H.A. Bethe and W. Heitler (1934), *Proc. R. Soc. London A* **146**, 83.
- A.F. Bielajew and D.W.O Rogers (1987), *Nucl. Instr. and Meth.* **B18**, 165.
- F. Biggs, L.B. Mendelsohn and J.B. Mann (1975), *At. Data and Nucl. Data Tables* **16**, 201.
- H.E. Bishop (1965), *Proc. Phys. Soc.* **85**, 855.
- M. Born (1969), *Atomic Physics* (Blackie and Son, London).
- B.H. Bransden and C.J. Joachain (1983), *Physics of Atoms and Molecules* (Longman, London).
- D. B. Brown and J. V. Gilfrich (1975), *J. Appl. Phys.* **42** 4044.
- J.D. Brown (1966), Ph.D. Thesis.
- J.D. Brown and L. Parobek (1972), *6th Proc. ICXOM*, ed. by G. Shinoda, K. Ohra, and T. Ichinokawa (Univ. of Tokio Press, Tokio).
- J.D. Brown and L. Parobek (1976), *X-Ray Spectrom.* **5**, 36.
- D. Brusa, G. Stutz, J.A. Riveros, J.M. Fernández-Varea and F. Salvat (1996), *Nucl. Instr. and Meth. A* **379**, 167.
- J.L. Campbell, J.X. Wang (1991) *X-ray Spectrom.* **21**, 223.
- K.M. Case and P.F. Zweifel (1967), *Linear transport theory* (Addison-Wesley, Reading).
- R. Castaing (1952), *Application des sondes électroniques à une méthode d'analyse ponctuelle chimique et cristallographique*, ONERA, Publication n. 55.
- R. Castaing, J. Descamps (1955), *J. Phys. Radium* **16**, 304.
- R. Castaing, J. Hénoc (1966), *4th Proc. ICXOM*, ed. by R. Castaing, P. Deschamps and J. Philibert (Hermann, Paris).
- J. Cazaux (1992), *Mikrochim. Acta* **B9**, 107.

- J.N. Chapman, C.C. Gray, B.W. Roberton and W.A.P. Nicholson (1983), *X-Ray Spectrom.* **12**, 153.
- M. Cooper (1971), *Adv. Phys.* **20**, 453.
- V. Cosslett and R. Thomas (1965), *Br. J. Appl. Phys.* **16**, 779.
- H.L. Cox and R.A. Bohman (1967), *J. Chem. Phys.* **47**, 2599.
- D.E. Cullen, M.H. Chen, J.H. Hubbell, S.T. Perkins, E.F. Plechaty, J.A. Rathkopf and J.H. Scofield (1989), Lawrence Livermore National Laboratory, *Report UCRL-50400* vol. 6, rev. 4, parts A and B.
- L. Curgenven and P. Duncumb (1971), Tube Investments Research Laboratories, *Report 303*
- D.V. Davis, V.D. Mistry, C.A. Quarles (1972), *Phys. Lett.* **38A**, 169.
- J.P. Desclaux (1975), *Comput. Phys. Commun.* **9**, 31.
- Z.-J. Ding and R. Shimizu (1989), *Surf. Sci.* **222**, 313.
- Z.-J. Ding, R. Shimizu and K. Obori (1994), *J. Appl. Phys.* **76**, 7180.
- Z.-J. Ding and Z. Wu (1993), *J. Phys. D: Appl. Phys.* **26** 507.
- H. Drescher, L. Reimer and H. Seidel (1970), *Z. Angew. Phys.* **29** 331.
- U. Fano (1956), *Phys. Rev.* **103**, 1202.
- U. Fano (1963), *Annual Review of Nuclear Science* **13**, 1.
- U. Fano and J.W. Copper (1968), *Rev. Mod. Phys.* **40**, 441.
- J.M. Fernández-Varea, R. Mayol, D. Liljequist and F. Salvat (1993a), *J. Phys.: Condens. Matter* **5**, 3593.
- J.M. Fernández-Varea, R. Mayol, J. Baró and F. Salvat (1993b), *Nucl. Instr. and Meth.* **B73**, 447.
- J.M. Fernández-Varea, D. Liljequist, S. Csillag, R. Räty and F. Salvat (1996), *Nucl. Instr. and Meth.* **B108**, 35.
- J.M. Fernández-Varea (1998), *Rad. Phys. and Chem.* (in press).
- R.W. Fink and P.V. Rao (1974), in: *Handbook of Spectroscopy*, ed. by J.W. Robinson, Vol. 1 (CRC Press, Cleveland, Ohio), 219.
- C.E. Fiori and C.R. Swyt (1989), *Microbeam Analysis*, ed. by P.E. Russell (San Francisco Press, San Francisco), 236.

- J.B. Furness and I.E. McCarthy (1973), *J. Phys. B: At. Molec. Phys.* **20**, 2280.
- R. Gauvin, G. L'Espérance and S. St-Laurent (1992), *Scanning* **14**, 37.
- S.K. Goel and R. Shanker (1996), *Phys. Rev.* **54**, 2056.
- M. Gryzinski (1965), *Phys. Rev.* **138**, 336.
- M. Green (1963), *Proc. Phys. Soc.* **82**, 204.
- F.Q. He, X.F. Peng, X.G. Long, Z.M. Luo, Z. An (1997), *Nucl. Instr. and Meth. B* **129**, 445.
- J. Heckel and P. Jugel (1983), *Exp. Tech. Phys.* **31**, 493.
- E. Heikinheimo and H. Jalkanen (1998), *Proc. 3rd EMAS Regional Workshop*, ed. by X. Llovet, C. Merlet and F. Salvat, (Univ. of Barcelona, Barcelona), 345.
- W. Heitler (1954), *The Quantum Theory of Radiation* (Oxford Univ. Press, London).
- B.L. Henke, E.M. Gullikson and J.C. Davis (1993) *At. Data and Nucl. Data Tables* **54**, 2, 181.
- J. Hénoc and F. Maurice (1991), in *Electron Probe Quantitation* ed. by K.F.J. Heinrich and D.E. Newbury (Plenum Press, New York), 105.
- W. Hink and H. Paschke (1971), *Phys. Rev. A* **4**, 507.
- J.H. Hubbell, W.J. Veigle, E.A. Briggs, R.T. Brown, D.T. Cromer and R.J. Howerton (1975), *J. Phys. Chem. Ref. Data* **4**, 471. Erratum: *ibid.* **6** (1977) 615.
- J.H. Hubbell, H.A. Gimm and I. Overbo (1980), *J. Phys. Chem. Ref. Data* **9**, 1023.
- J.H. Hubbell, P.N. Trehan, N. Singh, B. Chand, D. Mehta, M.L. Garg, R.R. Garg, S. Singh, S. Puri (1994), *J. Phys. Chem. Ref. Data* **23**, 339.
- H.J. Hunger (1979), *Phys. Status Sol. A* **56**, K45.
- H.J. Hunger (1988), *Scanning* **10**, 65.
- H.J. Hunger, S. Rogaschewski (1986), *Scanning* **8**, 257.
- S. Ichimura and R. Shimizu (1981), *Surf. Sci.* **112** 385.
- International Commision on Radiation Units and Measurement (1984), ICRU Report 37 (ICRU, Bethesda, MD).
- M. Inokuti (1971), *Rev. Mod. Phys.* **43**, 297.
- M. Inokuti and D.Y. Smith (1982), *Phys. Rev. B* **25**, 61.

- J.D. Jackson (1975), *Classical Electrodynamics* (John Wiley and Sons Inc., New York).
- F. James (1980), *Rep. Prog. Phys.* **43**, 1145.
- K.O. Jensen and A.B. Walker (1993), *Surf. Sci.* **292**, 83.
- J. Jessenberg and W. Hink (1975), *Z. Phys.* **A275**, 331.
- D.C. Joy and S. Luo (1989), *Scanning* **11**, 176.
- P. Karduck and W. Rehbach (1988), *Microbeam Analysis* ed. by D.E. Newbury (San Francisco Press, San Francisco), 277.
- P. Karduck and W. Rehbach (1991), in *Electron Probe Quantitation* ed. by K.F.J. Heinrich and D.E. Newbury (Plenum Press, New York), 191.
- Md.R. Khan and M. Karimi (1980), *X-Ray Spectrom.* **9** (1980) 32.
- P. Kirkpatrick and L. Wiedmann (1945), *Phys. Rev.* **67**, 321.
- L. Kissel, C.A. Quarles, R.H. Pratt (1983), *At. Data Nucl. Data Tables* **28**, 381.
- C. Kittel (1976), *Introduction to Solid State Physics* (John Wiley and Sons Inc., New York)
- M. Kotera, K. Yamamoto and H. Suga (1992), *Proc. 50th Annual Meeting of the Electron Microscopy Society of America* ed. by G.W. Bailey, J. Bentley and J. Small (San Francisco Press, San Francisco), 1670.
- H. Kolbenstvedt (1976), *J. Appl. Phys.* **18** 4785.
- H.A. Kramers (1923), *Philos. Mag.* **46** 836 .
- M. Krumrey, E. Tegeler and G. Ulm (1989), *Rev. Sci. Instrum.* **60**, 2287.
- D.F. Kyser and K. Murata (1974) *IBM J. Res. Dev.* **18**, 352.
- M.C. Lépy, J. Plagnard, P. Stemmler, G. Ban, L. Beck and P. Dhez (1997), *X-ray Spectrom.* **26**, 195.
- C.L. Lee, K.Y. Kong, H. Gong and C.K. Ong (1996), *Surf. Interface Anal.* **24**, 15.
- D. Liljequist (1978), *J. Phys. D: Appl. Phys.* **11**, 839.
- D. Liljequist (1983), *J. Phys. D: Appl. Phys.* **16**, 1567.
- J. Lindhard (1954), *Danske Mat. Fus. Meddr.* **28**, n. 8, 1.
- X. Long, M. Lu, F. Ho and X. Peng (1990), *At. Data Nucl. Data Tables* **45**, 353.

- G. Love, M.G. Cox and V.D. Scott (1977), *J. Phys. D.: Appl. Phys.* **10**, 7.
- Z.M. Luo, Z. An, F. He, X. Long, X. Peng (1996) *J. Phys. B: At. Mol. Opt. Phys.* 4001.
- S.T. Manson (1972) *Phys. Rev. A* **6**, 1013.
- J.D. Martínez, R. Mayol and F. Salvat (1990), *J. Appl. Phys.* **67** 2955.
- G. Massoumi, N. Hozhabri, W. Lennard and J. Schultz (1991), *Phys. Rev. B* **44**, 341.
- R. Mayol and F. Salvat (1990), *J. Phys. B: At. Mol. Opt. Phys.* **23**, 2117.
- R. Mayol and F. Salvat (1997), *At. Data and Nucl. Data Tables* **65**, 55.
- E.J. McGuire (1971), *Phys. Rev. A* **3** 267.
- C. Merlet (1992), *X-Ray Spectrom.* **21**, 229.
- C. Merlet (1992), *Mikrochim. Acta Suppl.* **12**, 107.
- C. Merlet (1995), *Proc. Microbeam Analysis*, ed. by E. S. Etz, (VCH Publishers).
- C. Merlet (1998a), *Proc. 3rd EMAS Regional Workshop*, ed. by X. Llovet, C. Merlet and F. Salvat (Univ. Barcelona, Barcelona), 176.
- C. Merlet (1998b), personal communication.
- C. Møller (1932), *Ann. Physik* **14**, 531.
- N.F. Mott and Q.S.W. Massey (1965), *The Theory of Atomic Collisions* (Oxford University Press, London).
- K. Murata, T. Matsukawa and R. Shimizu (1971), *J. Appl. Phys.* **10**, 679.
- K. Murata, M. Kotera and K. Nagami (1983), *J. Appl. Phys.* **54** 1110.
- K. Murata and K. Sugiyama (1989), *J. Appl. Phys.* **66**, 4456.
- K. Murata, M. Yasuda and H. Kawata (1995) *Scanning* **17**, 228.
- G. Neubert and S. Rogaschewski (1984), *J. Phys. D: Appl. Phys.* **17** 2439.
- W.A.P. Nicholson and M. McKenzie (1998), *Proc. 3rd EMAAS Regional Workshop*, ed. by X. Llovet, C. Merlet and F. Salvat, (Univ. of Barcelona, Barcelona), 192.
- V.I. Ockur (1965), *Soviet. Phys., JETP*, **20**, 1175.
- M. Ohring (1990), *The materials science of thin films*, (Academic Press, New York).

- R.H. Packwood (1986) *Microbeam Analysis* ed. by A.D. Romig and W.F. Chmabers, (San Francisco, San Francisco Press), 268.
- R.H. Packwood, V. Moore and S. Thomas (1989), *Microbeam Analysis* (San Francisco Press, San Francisco), 211.
- E.D. Palik (1985), *Handbook of Optical Constants of Solids*, (Academic Press, New York).
- J.H. Paterson, J.N. Chapman, W.A.P. Nicholson and J.M. Titchmarsh, (1989) *J. Microsc.* **154**, 1.
- P.A. Pella, L. Feng and J.A. Small (1985), *X-ray Spectrom.* **14**, 3.
- S.T. Perkins, D.E. Cullen, M.H. Chen, J.H. Hubbell, J. Rathkopf and J. Scofield (1991), Lawrence Livermore National Laboratory, *Report UCRL-50400*, vol. **30**
- L.T. Pockman, D.L. Webster, P. Kirkpatrick and K. Harworth (1947), *Phys. Rev* **71**, 330.
- J.L. Pouchou and F.M. Pichoir (1984), *Rech. Aerosp.* **5**, 349.
- J.L. Pouchou (1996), *Mikrochim. Acta Suppl.* **13**, 39.
- C.J. Powell (1976), *Rev. Mod. Phys.* **48**, 33.
- C.J. Powell (1985), *Electron Impact Ionization* ed. by T.D. Märk and G.H. Dunn (Springer, Wien).
- S.J.B. Reed (1993), *Electron Microprobe Analysis* (Cambridge University Press, Cambridge).
- W. Rehbach (1988), Doctoral Thesis.
- L. Reimer and E.R. Krefting (1976) in *Use of Monte Carlo Calculations in Electron Probe Microanalysis and Scanning Electron Microscopy*, ed. by K.F.J. Heinrich, D.E. Newbury and H. Yakowitz, NBS Special Publications 460, Washington, pp. 46.
- L. Reimer (1968), *Optik* **27**, 86.
- L. Reimer (1985), *Scanning Electron Microscopy* (Springer-Verlag, Berlin).
- L. Reimer and D. Stelter (1986), *Scanning* **8** 265.
- W. Reuter, J.D. Kuptsis, A. Lurio and D.F. Kyser (1978) *J. Phys. D* **11**, 2633.
- R. Ribberfors and K.-F. Berggren (1982), *Phys. Rev. A* **26**, 3325.

- R. Ribberfors (1983), *Phys. Rev. A* **27**, 3061.
- R.Y. Rubinstein (1981), *Simulation and the Monte Carlo method* (Wiley, New York).
- E.B. Saloman, J.H. Hubbell and J.H. Scofield (1988), *At. Data and Nucl. Data Tabl* **38**, 1.
- F. Salvat and J. Parellada (1984), *J. Phys. D* **17**, 185.
- F. Salvat, J.D. Martínez, R. Mayol and J. Parellada (1987), *Phys. Rev. A* **36**, 467.
- F. Salvat and J.M. Fernández-Varea (1992), *Nucl. Instr. and Meth.* **B63**, 255.
- F. Salvat and R. Mayol (1993), *Comput. Phys. Commun.* **74**, 358.
- F. Salvat, J.M. Fernández-Varea, J. Baró and J. Sempau (1996), Informes Técnic Ciemat n. 799 (CIEMAT, Madrid).
- F. Salvat, J. Sempau and W. Williamson (1998), to be published.
- M. Seltzer and M.J. Berger (1985), *Nucl. Instrum. Meth. B* **12**, 95.
- J. Sempau (1995), Ph. D. Thesis.
- J. Sempau, E. Acosta, J. Baró, J.M. Fernández-Varea and F. Salvat (1997), *Nu Instrum. Meth. B* **132**, 377.
- K.D. Sevier (1972), *Low energy electron spectrometry* (John Wiley and Sons, New Yor
- D.A. Sewell, G. Love and V.D. Scott (1985), *J. Phys. D: Appl. Phys.* **18**, 1233.
- D. Schalkoord, P. Karduck and W.P. Rehbach (1990), *Scanning*, **12**, 185.
- K. Shima (1979), *Nucl. Instrum. and Meth.* **165**, 21.
- K. Shima (1980), *Phys. Lett.* **77A**, 237.
- K. Shima, T. Nakagawa, K. Umetani, T. Mikumo (1981), *Phys. Rev. A* **24**, 72.
- R. Shimizu, K. Murata, G. Shinoda (1966), in *4th Cong. X-ray Optics and Microan* ysis, ed. by R. Castaing, P. Descamps and G. Shinoda (Hermann, Paris), 127.
- R. Shimizu, Y. Kataoka and T. Matsukawa (1976), *J. Phys. D.: Appl. Phys.* **8**, 820.
- J.A. Small, S.D. Leigh, D.E. Newbury and R.L. Myklebust (1987), *J. Appl. Phys.* **6** 459.
- D.G.W. Smith and S.J.B. Reed (1981), *X-ray Spectrom.* **10**, 198.
- A. Sommerfeld (1931), *Ann. der Physik* **11**, 257.

- P.J. Statham (1976), *X-Ray Spectrom.* **5**, 154 (1976).
- P.J. Statham (1981), *J. Microsc.* **123**, 1.
- M.R. Sogard (1980), *J. Appl. Phys.* **51**, 4412.
- P.J. Statham (1981), *J. Microsc.* **123**, 1.
- E. Storm (1972), *Phys. Rev. A* **5**, 2328.
- J. Trincavelli, G. Castellano and J. Riveros (1998), *X-Ray Spectrom.* **127**, 81.
- A. Vignes and G. Dez (1968) *Brit. J. Appl. Phys. (J. Phys. D)*, **1** 1309.
- D.W. Walker (1971), *Adv. Phys.* **40**, 590.
- D.L. Weathers, J.L. Duggan, M.R. McNeir, Y.C. Yu, F.D. McDaniel, C.A. Quarles, H. Lehtihet and D. Kahler (1991) *Nucl. Instrum. and Meth. B* **56/57**, 964.
- U. Werner, F. Koch and G. Oelgart (1988), *J. Phys. D: Appl. Phys.* **21** 116.
- J. Wernisch (1985), *X-ray Spectrom.* **14** 109.
- C.R. Worthington and S.G. Tomlin (1965), *Proc. Phys. Soc. (London) A* **69**, 401.



