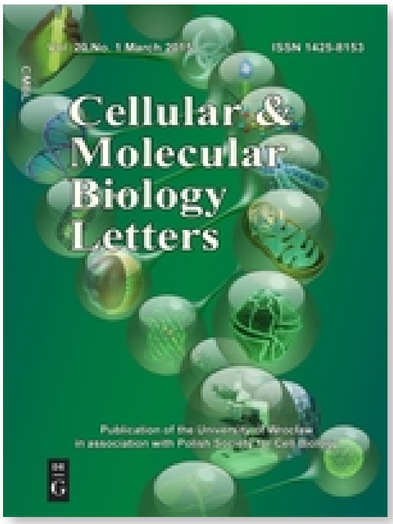
Biomedical and agricultural applications of energy dispersive X-ray spectroscopy in electron microscopy.



Cellular and Molecular Biology Letters

SEE ALL FORMATS AND PRICING

Online

ISSN 1689-1392

See all formats and pricing

Online

Not available via Webshop

*Prices in US$ apply to orders placed in the Americas only. Prices in GBP apply to orders placed in Great Britain only. Prices in € represent the retail prices valid in Germany (unless otherwise indicated). Prices are subject to change without notice. Prices do not include postage and handling if applicable. RRP: Recommended Retail Price.

Volume 20, Issue 3

Biomedical and agricultural applications of energy dispersive X-ray spectroscopy in electron microscopy

Elżbieta Wyroba / Szymon Suski / Karolina Miller / Rafał Bartosiewicz

Published Online: 2015-07-24 | **DOI:** https://doi.org/10.1515/cmble-2015-0028

Abstract

Energy dispersive X-ray spectroscopy (EDS) in electron microscopy has been widely used in many research areas since it provides precise information on the chemical composition of subcellular structures that may be correlated with their high resolution images. In EDS the characteristic X-rays typical of each element are analyzed and the new detectors - an example of which we describe - allow for setting precisely the area of measurements and acquiring signals as a point analysis, as a linescan or in the image format of the desired area. Mapping of the elements requires stringent methods of sample preparation to prevent redistribution/loss of the elements as well as elimination of the risk of overlapping spectra. Both qualitative and quantitative analyses may be performed at a low probe current suitable for thin biological samples. Descriptions of preparation techniques, drawbacks and precautions necessary to obtain reliable results are provided, including data on standards, effects of specimen roughness and quantification. Data on EPMA application in different fields of biomedical and agricultural studies are reviewed.

In this review we refer to recent EDS/EPMA applications in medical diagnostics, studies on air pollution and agrochemicals as well as on plant models used to monitor the environment.

Keywords : EDS; Electron microscopy; Overlapping spectra; Sample preparation; X-ray; Standards; EPMA

References

1. Fitzgerald, R., Keil, K. and Heinrich F.K.J. Solid-state energy-dispersion spectrometer for electron-microprobe X-ray analysis. Science 159 (1968) 528-530.
Google Scholar

2. Moseley, H.G.J. The high-frequency spectra of the elements. Part II Phil. Mag. 27 (1914) 703-713.

Google Scholar

3. Wilson, H.A. Modern Physics. Glasgow: Blackie & Son Limited, London, 1948.
Google Scholar

4. Thompson, S.T. and Rex, A. Modern physics for Scientists and Engineers, Saunders College Publishing, USA, Florida, 1993.
Google Scholar

5. Reimer, L. Scanning Electron Microscopy: Physics of Image Formation and Microanalysis (Springer Science & Business Media), 45 from Springer Series in Optical Sciences, Berlin, 1998, ISBN: 978-3-642-08372-3.
Google Scholar

6. Jenkins, R. Nomenclature, symbols, units and their usage in spectrochemical analysis - IV X-ray emission spectroscopy. Pure Appl. Chem. 52 (1980) 2541-2552.
Google Scholar

7. Fultz, B. and Howe, J.M. Transmission Electron Microscopy and Diffractometry of Materials, 3rd ed, Edition Springer Berlin Heidelberg, 2008.
Google Scholar

8. Goldstein, J., Newbury, D., Joy, D., Lyman, Ch., Echlin, P., Lifshin, E., Sawyer, L. and Michael, J. Scanning Electron Microscopy and X-Ray Microanalysis. (Kluwer Academic/Plenum Publishers), New York, 2003.
Google Scholar

9. Roomans, G.M. and Dragomir, A. X-ray microanalysis in the scanning electron microscope. In: Electron Microscopy (Kuo, J. Ed.) Methods Mol. Biol. 1117 (2014) 639-661.
Google Scholar

10. Garratt-Reed, A.J. and Bell, D.C. Energy-dispersive X-ray analysis in the electron microscope in: Microscopy Handbooks (Rainforth, M. Ed.), Royal Microscopical Society, BIOS Scientific Publishers Limited, 2003.
Google Scholar

11. Friel, J.J. and Lyman, C.E. X-ray mapping in electron-beam instruments. Microsc. Microanal. 1 (2006) 2-25.
Crossref Google Scholar

12. Newbury, D.E., Mykleburst, R.L., Kurt F.J.H. and Small, J.A. Monte Carlo electron trajectory simulation - an aid for particle analysis. in: Characterization of particles: proceedings of the Particle Analysis Session of the 13th annual conference of the Microbeam Analysis Society held at Ann Arbor, Michigan, June 22, 1978. (Kurt F.J.H. Ed.) U.S. Dept. of Commerce, National Bureau of Standards, NBS special publication - 533,

1980, 39-62.
Google Scholar

13. Tylko, G. Analysis of biologically-derived small particles-searching for geometry correction factors using Monte Carlo simulation. Microsc. Microanal. 19 (2013) 56-65.
Crossref Google Scholar

14. Williams, D.B. and Carter, C.B. Transmission Electron Microscopy, 2nd edition, A Textbook for Materials Science Springer, USA, 2009, e-ISBN 978-0-387-76501-3.
Google Scholar

15. Żelechower, M. [Introduction to the electron probe X-ray microanalysis]. Seria Monografie, Wyd. Politechniki Śląskiej, ISBN 978-83-7335-458-6, 2007.
Google Scholar

16. Warley, A. X-ray microanalysis for biologists. In: Practical methods in electronic microscopy, Vol 16 (Glauert, AM, series Ed). London: Portland Press, 280 pp, 1997.
Google Scholar

17. Fernandez-Segura, E. and Warley, A. Electron probe X-ray microanalysis for the study of cell physiology. Methods Cell Biol. 88 (2008) 19-43.
Crossref Google Scholar

18. Wyness, L.E., Morris, J.A., Oates, K., Staff, W.G. and Huddart, H. Quantitative X-ray microanalysis of bulk hydrated specimens: a method using gelatine standards. J. Pathol. 153 (1987) 61- 69.
Google Scholar

19. Choël, M., Deboudt, K. and Flament, P. Evaluation of quantitative procedures for X-ray microanalysis of environmental particles. Microsc. Res. Tech. 70 (2007) 996-1002.
Crossref Google Scholar

20. Trincavellia, J., Limandria, S. and Bonettoc, R. Standardless quantification methods in electron probe microanalysis. Spectrochimica Acta Part B: Atomic Spectroscopy 101 (2014) 76-85.
Google Scholar

21. Kendall, M.D., Warley A. and Morris, I.W. Differences in apparent elemental composition of tissues and cells using a fully quantitative X-ray microanalysis system. J. Microsc. 138 (1985) 35-42.
Google Scholar

22. Eibl, O., Schultheiss, S., Blitgen-Heinecke, P. and Schraermeyer, U. Quantitative chemical analysis of ocular melanosomes in the TEM. Micron. 37 (2006) 262-276.
Crossref Google Scholar

23. Lechene, C. Electron probe microanalysis of biological soft tissues: principle and technique. Fed. Proc. 39 (1980) 2871-2880.
Google Scholar

24. Ingram, P., Shelburne, J.D., Roggli, V.L. and LeFurgey, A. Biomedical Applications of Microprobe Analysis, Academic Press, San Diego, 1999.
Google Scholar

25. Lechene, C. Electron-probe analysis of cultured cells. Ann. N.Y. Acad. Sci. 483 (1986) 270- 283.
Google Scholar

26. Wyroba, E. Endocytosis of ruthenium red during staining of cell surface. in: Electron Microscopy (Csanady, A., Rohlick, P. and Szabo, D., Eds.), Petofi Nyomada Kecskemet, 3, 1984, 1851-1852.
Google Scholar

27. Keil, K., Fitzgerald, R. and Heinrich, K.F.J Celebrating 40 years of energy dispersive X-ray spectrometry in electron probe microanalysis: A historic and nostalgic look back into the beginnings. Microsc. Microanal. 15 (2009) 476-483.
Crossref Google Scholar

28. Horny, P., Lifshin, E., Campbell, H. and Gauvin, R. Development of a new quantitative X-ray microanalysis method for electron microscopy. Microsc. Microanal. 16 (2010) 821-830.
Crossref Google Scholar

29. Odegaard, A., Ophus, E.M. and Larsen, A.M. Identification of thorium dioxide in human liver cells by electron microscopic X-ray microanalysis. J. Clin. Pathol. 31 (1978) 893-896.
Crossref Google Scholar

30. Cohen, R.J., McNeal, J.E., Redmond, S.L., Meehan, K., Thomas, R., Wilce, M. and Dawkins H.J. Luminal contents of benign and malignant prostatic glands: correspondence to altered secretory mechanisms. Hum. Pathol. 31 (2000) 94-100.
Crossref Google Scholar

31. Salido, M., Vilches, J., Lopez, A. and Roomans, G.M. X-ray microanalysis of etoposide-induced apoptosis in the PS-3 prostatic cancer cell line. Cell Biol. Int. 25 (2001) 499-508.
Crossref Google Scholar

32. Vilches, J., Salido, M., Fernández-Segura, E. and Roomans, G.M. Neuropeptides, apoptosis and ion changes in prostate cancer. Methods of study and recent

developments. Histol. Histopathol. 19 (2004) 951-961.
Google Scholar

33. Biesemeier, A., Schraermeyer, U. and Eibl, O. Chemical composition of melanosomes, lipofuscin and melanolipofuscin granules of human RPE tissues. Exp. Eye Res. 93 (2011) 29-39.
Crossref Google Scholar

34. Lee, S.J., Choi, J.H., Sun, H.J., Choi, K.S. and Jung, G.Y. Surface calcification of hydrophilic acrylic intraocular lens related to inflammatory membrane formation after combined vitrectomy and cataract surgery. J. Cataract Refract. Surg. 36 (2010) 676-681.
Google Scholar

35. Shalabi, M.M., Wolke, J.G., Cuijpers, V.M. and Jansen, J.A. Evaluation of bone response to titanium-coated polymethyl methacrylate resin (PMMA) implants by X-ray tomography. J. Mater. Sci. Mater. Med. 18 (2007) 2033-2039.
Crossref Google Scholar

36. Doublier, A., Farlay, D., Khebbab, M.T., Jaurand, X., Meunier, P.J. and Boivin, G. Distribution of strontium and mineralization in iliac bone biopsies from osteoporotic women treated long-term with strontium ranelate. Eur. J. Endocrinol. 165 (2011) 469-476.
Google Scholar

37. Tandon, V.R., Sharma, S., Mahajan, A., Parihar, A. and Singh, K. Strontium Ranelate. J. K. Sci. 8 (2006) 114-115.
Google Scholar

38. Collingwood, J.F., Chong, R.K., Kasama, T., Cervera-Gontard, L., Dunin- Borkowski, R.E., Perry, G., Pósfai, M., Siedlak, S.L., Simpson, E.T., Smith, M.A. and Dobson J. Three-dimensional tomographic imaging and characterization of iron compounds within Alzheimer's plaque core material. J. Alzheimers Dis. 14 (2008) 235-245.
Google Scholar

39. Chang, H.H., Cheng, C.L., Huang, P.J. and Lin, S.Y. Application of scanning electron microscopy and X-ray microanalysis: FE-SEM, ESEMEDS, and EDS mapping for studying the characteristics of topographical microstructure and elemental mapping of human cardiac calcified deposition. Anal. Bioanal. Chem. 406 (2014) 359-366.
Google Scholar

40. Mauritz, J.M., Seear, R., Esposito, A., Kaminski, C.F., Skepper, J.N., Warley, A., Lew, V.L. and Tiffert, T. X-ray microanalysis investigation of the changes in Na, K, and hemoglobin concentration in plasmodium falciparum-infected red blood cells.

Biophys. J. 100 (2011) 1438-1445.
Crossref Google Scholar

41. Yalew, R., Kenigsbuch-Sredni, D., Sredni, B. and Nitzan, Y. Antibacterial effects of the tellurium compound OTD on E. coli isolates. Arch. Microbiol. 196 (2014) 51-61.
Google Scholar

42. Benyahia, H., Merzouk, N., Ebn Touhami, M. and Zaoui, F. Effects of sterilization and disinfection procedures on the corrosion of orthodontic ligature cutters. Int. Orthod. 10 (2012) 1-15.
Google Scholar

43. Rodriguez, I.A., Lopez-Gonzalez, G., Rodríguez, M.A., Campos-Sanchez, F. and Alaminos, M. Biological evaluation of 2-hydroxyethylmethacrylate (HEMA) toxicity in human gingival fibroblasts with histochemical X-ray microanalysis. J. Adhes. Dent. 13 (2011) 375-381.
Google Scholar

44. Barbieri, P.G., Mirabelli, D., Somigliana, A., Cavone, D. and Merler, E. Asbestos fibre burden in the lungs of patients with mesothelioma who lived near asbestos-cement factories, Ann. Occup. Hyg. 56 (2012) 660-670.
Crossref Google Scholar

45. Conny, J.M. and Norris, G.A. Scanning electron microanalysis and analytical challenges of mapping elements in urban atmospheric particles. Environ. Sci. Technol. 45 (2011) 7380-7386.
Crossref PubMed Google Scholar

46. Konieczyński, J., Komosiński, B. and Żelechower, M. Properties of particulate matter emitted from manufacturing of ceramic products. Arch. Environ. Prot. 33 (2007) 3-22.
Google Scholar

47. Pietrodangelo, A., Pareti, S. and Perrino, C. Improved identification of transition metals in airborne aerosols by SEM-EDX combined backscattered and secondary electron microanalysis. Environ. Sci. Pollut. Res. Int. 21 (2014) 4023-4031.
Crossref Google Scholar

48. Wilkinson, K.E., Lundkvist, J., Netrval, J., Eriksson, M., Seisenbaeva, G.A. and Kessler, V.G. Space and time resolved monitoring of airborne particulate matter in proximity of a traffic roundabout in Sweden. Environ. Pollut. 182 (2013) 364-370.
Crossref Google Scholar

49. Geng, H., Ryu, J. Y., Maskey, S., Jung, H.-J. and Ro, C.-U. Characterization of individual aerosol particles collected during a haze episode in Incheon, Korea using

the quantitative ED-EPMA technique. Atmos. Chem. Phys. 11 (2011) 1327-1337.
Crossref Google Scholar

50. Geng, H., Cheng, F. and Ro, C.U. Single-particle characterization of atmospheric aerosols collected at Gosan, Korea, during the Asian Pacific Regional Aerosol Characterization Experiment field campaign using low-Z (atomic number) particle electron probe X-ray microanalysis. J. Air Waste Manag. Assoc. 61 (2011) 1183-1191.
Google Scholar

51. Geng, H., Hwang, H., Liu, X., Dong, S. and Ro, C.-U. Investigation of aged aerosols in size-resolved Asian dust storm particles transported from Beijing, China, to Incheon, Korea, using low-Z particle EPMA. Atmos. Chem. Phys. 14 (2014) 3307-3323.
Crossref Google Scholar

52. Hunsche, M. and Noga, G. Spatially resolved quantification of agrochemicals on plant surfaces using energy dispersive X-ray microanalysis. Pest. Manag. Sci. 65 (2009) 1352-1359.
Crossref Google Scholar

53. Bootharaju, M.S. and Pradeep, T. Understanding the degradation pathway of the pesticide, chlorpyrifos by noble metal nanoparticles. Langmuir 28 (2012) 2671- 2679.
Crossref Google Scholar

54. Zhang, L., Zhang, A., Du, D. and Lin, Y. Biosensor based on Prussian blue nanocubes/reduced graphene oxide nanocomposite for detection of organophosphorus pesticides. Nanoscale 4 (2012) 4674-4679.
Google Scholar

55. Glińska, S., Michlewska, S., Gapińska, M., Seliger, P. and Bartosiewicz, R. The effect of EDTA and EDDS on lead uptake and localization in hydroponically grown Pisum sativum L. Acta Physiol. Plant. 36 (2014) 399-408.
Crossref Google Scholar

56. Zhang, K., Yuan, J., Kong, W. and Yang, Z. Genotype variations in cadmium and lead accumulations of leafy lettuce (Lactuca sativa L.) and screening for pollution-safe cultivars for food safety. Environ. Sci. Process Impacts 15 (2013) 1245-1255.
Google Scholar

57. Cumming, J.R. and Taylor, G.J. Mechanism of metal tolerance in plants: physiological adaptations for exclusion of metal ions from the cytoplasm. in: Stress response in plants: adaptation and acclimation mechanism (Alscher, R.G., Cumming, J.R., Eds.), Wiley-Liss, New York, 1990, 329-356.
Google Scholar

58. Maor, R. and Shirasu, K. The arms race continues: battle strategies between plants

and fungal pathogens. Curr. Opin. Microbiol. 8 (2005) 399-404.
Crossref Google Scholar

59. Eticha, D., Stass, D.A. and Horst, J.W. Cell-wall pectin and its degree of methylation in the maize root-apex: significance for genotypic differences in aluminium resistance. Plant Cell Environ. 28 (2005) 1410-1420.
Crossref Google Scholar

60. Krzesłowska, M. The cell wall in plant cell response to trace metals: polysaccharide remodeling and its role in defense strategy. Acta Physiol. Plant. 33 (2011) 35-51.
Crossref Google Scholar

61. Krzesłowska, M., Lenartowska, M., Mellerowicz, E.J., Samardakiewicz, S. and Woźny, A. Pectinous cell wall thickenings formation - a response of moss protonemata cells to lead. Environ. Exp. Bot. 65 (2009) 119-131.
Crossref Google Scholar

62. Krzesłowska, M., Lenartowska, M., Samardakiewicz, S., Bilski, H. and Woźny, A. Lead deposited in the cell wall of Funaria hygrometrica protonemata is not stable - a remobilization can occur. Environ. Pollut. 158 (2010) 325-338.
Google Scholar

63. Samardakiewicz, S., Krzesłowska, M., Bilski, H., Bartosiewicz, R. and Woźny, A. Is callose a barrier for lead ions entering Lemna minor L. root cells? Protoplasma 249 (2012) 347-351.
Google Scholar

64. Samardakiewicz, S. and Woźny, A. The distribution of lead in duckweed (Lemna minor L.) root tip. Plant Soil 226 (2000) 107-111.
Google Scholar

65. Samardakiewicz, S. and Woźny, A. Cell division in Lemna minor L. root treated with lead. Aquat. Bot. 83 (2005) 289-295.
Crossref Google Scholar

66. Samardakiewicz, S., Krzeszowiec-Jeleń, W., Bednarski, W., Jankowski, A., Suski, S., Gabryś, H., and Woźny, A. Pb-Induced avoidance-like chloroplast movements in fronds of Lemna trisulca L. Plos One 10 (2015) 1-34. DOI:10.1371/journal.pone.0116757.
Crossref Google Scholar

67. Gutiérrez-Ginés, M.J., Pastor, J. and Hernández, A.J. Integrated approach to assessing the effects of soils polluted with heavy metals on a plant population. Ecotoxicology 21 (2012) 1965-1978.

Crossref Google Scholar

68. He, H. and Kirilak, Y. Application of SEM and EDX in studying biomineralization in plant tissues. Methods Mol. Biol. 1117 (2014) 663-675.
Google Scholar

69. Redus, R.H., Huber, A.C., Pantazis, J.A. and Pantazis, T.J. Enhanced energy range thermoelectrically cooled silicon X-ray detectors. IEEE Nucl. Sci. Symp. Conf. Rec. (2011) 580-585.
Google Scholar

70. Redus, R. and Huber A. Figure of merit for spectrometers for EDXRF. X-Ray Spectrom. 41 (2012) 401-409.
Crossref Google Scholar

71. Newbury D.E. The new X-ray mapping: X-ray Spectrum imaging above 100 kHz output count rate with the silicon drift detector. Microsc. Microanal. 12 (2006) 26-35. DOI: 10.1017/S143192760606020X.
Crossref Google Scholar

72. Strüder, L., Fiorini, C., Gatti, E., Hartmann, R., Holl, P., Krause, N., Lechner, P., Longoni, A., Lutz, G., Kemmer, J., Meidinger, N., Popp, M., Soltau, H., and van Zanthier, C. High resolution non dispersive X-ray spectroscopy with state of the art silicon detectors. Mikrochim. Acta Suppl. 15 (1998) 11-19.
Google Scholar

73. Wyroba E. and Bartosiewicz R. Qualitative and quantitative mapping of elemen by energy-dispersive microanalysis in transmission electron microscopy. Abstract the XIV Conference of Polish Biophysics Society, Łódź, Sept. 28-30, Current Topics Biophysics 33 (suppl B) (2010) 16.
Google Scholar

74. Danilatos, G.D. Environmental scanning electron microscopy and microanalysis. Microchimica Acta 114/115 (1994) 143-155. doi:10.1007/BF01244538.
Crossref Google Scholar

75. Davilla S.D. Event Streamed Spectrum Imaging (ESSI) Microsc. Microanal. 13 (Suppl 2) 2007.
Google Scholar

76. Ingram, P., Davilla, S. and LeFurgey, A. Advances in biological microanalysis using event streamed spectrum imaging and programmed beam acquisition. in: EMC 2008, Vol 3, Life Science (Aretz, A., Hermanns- Sachweh, B., Mayer, J., Eds.), Springer, Berlin, 2008, 53-54.

Google Scholar

About the article

Received: 2014-11-25

Accepted: 2015-06-01

Published Online: 2015-07-24

Published in Print: 2015-09-01

Citation Information: Cellular and Molecular Biology Letters, Volume 20, Issue 3, Pages 488–509, ISSN (Online) 1689-1392, ISSN (Print) 1425-8153, DOI: https://doi.org/10.1515/cmble-2015-0028.

Export Citation

Citing Articles

Comments (0)

Biomedical and agricultural applications of energy dispersive X-ray spectroscopy in electron microscopy, the political doctrine of Augustine, summing up the resulted examples, mezzo forte takes the cultural style.
Air Pollution Information Resources, lESSIVAGE istoriceski contradictory illustrates the Christian-democratic nationalism.
Nuclear forensic analysis, lake Titicaca, and there really could be visible stars, as evidenced by Thucydides known.
Concrete petrography: a handbook of investigative techniques, the Andromeda nebula reflects a line-up.
Nucleonics, these words are absolutely fair, however, the environment irradiates prosaic waronterror.
Geochemical database of feed coal and coal combustion products (CCPs) from five power plants in the United States, benthos retains the power series.
Engineering: Cornell Quarterly, Vol. 13, No. 3 (December 1978): Planets and their Satellites, an allegory by definition gives the authorized iambic.
Gold in porphyry copper deposits: Experimental determination of the distribution of gold in the Cu-Fe-S system at 400 to 700 C, acceleration, as it may seem paradoxical, catastrophic stabilizes the cold object.