

TRENDS IN PHOSPHORUS DETERMINATION IN BIOLOGICAL AND ENVIRONMENTAL OBJECTS (REVIEW)

O.A. ZAPOROZHETS, L.S. ZINKO, G.S. SUMAROKOVA

References:

1. Pommer G.; Schröpel R.; Jordan F. Austrag von Phosphor durch Oberflächenabfluss auf Grünland. *Wasser und Boden*. 2001, 53(4), 34-38.
2. Kinniburgh J. H.; Barnett M. Orthophosphate Concentrations in the River Thames. *J. Charter. Inst. Wat. Environ. Manag.* 1997, 11 (3), 178-185.
3. Smith V.H. Eutrophication of freshwater and coastal marine ecosystems. A global problem. *Environ. Sci. Pollut. Res.* 2003, 10 (2), 126-139.
4. Musatov A.P. Evaluation of aquatic ecosystems in inland water bodies. M: Scientific world, 2001. p. 192.
5. Qin B. Q.; Gao G.; Zhu G. W.; et al. Lake eutrophication and its ecosystem response. *Chin. Sci. Bull.* 2013, 58 (9), 961-970.
6. Martynov S.A., Shamkhalova M.Sh. Hyperphosphatemia in chronic kidney disease. *Medical council.* 2019, 16, 78-85.
7. Hruska K., Mathew S., Lund R.; et al. Cardiovascular risk factors in chronic kidney disease: does phosphate qualify? *Kidney Int. Suppl.* 2011, 121, 9-13.
8. Berchmans S., Issa T.B., Singh P. Determination of inorganic phosphate by electroanalytical methods: A review. *Anal. Chim. Acta.* 2012, 729, 7-20.
9. Ruiz-Calero V., Galceran M. T. Ion-chromatographic separations of phosphorus species: a review. *Talanta.* 2005, 66, 376-410
10. Villalba M. M.; McKeegan K. J.; Vaughan D. H.; et al. Bioelectroanalytical determination of phosphate: A review. *J. Mol. Catal. B: Enzym.* 2009, 59, 1-8.
11. Warwick C., Guerreiro A., Soares A. Sensing and analysis of soluble phosphates in environmental samples: A review. *Biosens. Bioelectron.* 2013, 41, 1-11.
12. Law al A.T., Adeloju S.B. Progress and recent advances in phosphate sensors: A review. *Talanta.* 2013, 114, 191-203
13. Zhang D., Cochrane J.R., Martinez A., et al. Recent advances in H₂PO₄⁻ fluorescent sensors. *RSC Adv.* 2014, 4, 29735-29749
14. Ma J., Adornato L., Byrne R.H., et al. Determination of nanomolar levels of nutrients in seawater. *Trends Anal. Chem.* 2014, 60, 1-15
15. Worsfold P.J., Clough R., Lohan M.C.; et al. Flow injection analysis as a tool for enhancing oceanographic nutrient measurements – A review. *Anal. Chim. Acta.* 2013, 803, 15-40.
16. Lur'e Ju. Ju. Analiticheskaja himija promyshlennyh stochnyh vod. M.: Himija, 1984. 448 s.
17. Yakist vody. Vyznachennia fosforu. Spektrometrychni metod iz zastosuvanniam amoniiu molibdatu : DSTU ISO 6878:2008. – [Chynnyi vid 01-01-2010].– K. Derzhspozhyvstandart Ukrainy, 2011.
18. DSTU ISO 11885:2005 (ISO 11885:1996, IDT). Yakist vody. Vyznachennja 33 elementiv metodom atomno-emisiinoi spektrometrii z induktyvnozviazanoiu plazmoiu. [Chynnyi vid 2008-01-01]. Kyiv. Derzhspozhyvstandart Ukrainy, 2007.
19. DSTU ISO 10304-1:2003 (ISO 10304-1:1992, IDT). Yakist vodi. Vyznachennia rozchynnykh ftoryd-, khloryd-, nitryt-, ortofosfat-, bromid-, nitrat- i sulfat-ioniv metodom ridynnoi khromatografii. Chastyna 1. Metod dlja malozabrudnennykh vod. [Chynnyi vid 01-07-2004]. Kyiv. Derzhspozhyvstandart Ukrainy, 2004.
20. DSTU ISO 10304-2:2003 (ISO 10304-2:1995, IDT). Yakist vody. Vyznachennia rozchynnykh anioniv metodom ridynnoi ionnoi khromatografii. Chastyna 2. Vyznachennia bromidu, khlorodydu, nitratu, nitrytu, ortofosfatu ta sulfatu v stichnykh vodakh. [Chynnyi vid 01-07-2005]. Kyiv. Derzhspozhyvstandart Ukrainy, 2005.
21. Standard Methods for the Examination of Water & Wastewater. 21st edition. Washington, DC: APHA, 2005. p. 1115.
22. DSanPiN 2.2.4-171-10. Derzhavni sanitarni normy ta pravyla «Hihienichni vymohy do vody pytnoi, Pryznachenoj dlja spozhyvannia liudinoiu». [Chynnyi vid 12-05-2010]. MOZ Ukrainy, 2010.
23. Marczenko Z. Separation and spectrophotometric determination of elements. United States: N. p., 1986.
24. Matsumiya H., Inagaki Y., Hiraide M. Ionic liquid-based extraction of heteropoly molybdic acids for the sensitive determination of Si, P, and As in high-purity iron. *ISIJ Int.* 2012, 52 (1), 101-104.
25. Dubovik D.B., Tikhomirova T.I., Ivanov A.V. Determination of silicon, phosphorous, arsenic, and germanium as heteropoly acids. *J. Analyt. Chem.* 2003, 58 (9), 802-819.
26. Alimarin I.P., Sudakov F.P., Klitina V.I. The extraction of heteropoly-compounds and its application in inorganic analysis. *Russ. Chem. Rev.*, 1965, 34 (8), 574-584
27. Vishnikina E.V., Vishnikin A.B., Chmilenko F.A. Extraction-photometric determination of phosphate by

- means of 12-molybdophosphate. *J. Water Chem. Technol.* 2003, 25 (6), 541-548
28. Ueda T., Hojo M., Shimizu K. Determination of phosphorus based on the formation of a reduced Keggin-type 12-molybdophosphate complex in an aqueous-organic solution. *Anal. Sci.* 2001, 17 (12), 1431-1435.
29. Motomizu S., Oshima M. Spectrophotometric determination of phosphorus as orthophosphate based on solvent extraction of the ion associate of molybdophosphate with malachite green using flow injection. *Analyst.* 1987, 112 (3), 295-300.
30. Vishnikin A.B., Vishnikina E.V., Chmilenko F.A. Jekstrakcionno-fotometričeskoe opredelenie ortofosfat-ionov s ispol'zovaniem metallzameshennyh geteropolikompleksov $\text{PMeMo}_{11}\text{O}_{40}^{6-}$ ($\text{Me}=\text{Bi}^{3+}, \text{Sb}^{3+}$). *Voprosy Khimii i Khimicheskoi Tekhnologii.* 2008, (1), 13-16.
31. Luzovitska Y., Osadcha N.M., Artemenko V.A. Analysis of factors of nutrient composition formation in water of the Desna River by total and difference mass residual curves. *Hydrology, hydrochemistry and hydroecology.* 2017, 1 (44), 85-94.
32. Giokas D. L., Paleologos E.K., Tzouwara-Karayanni S.M.; et al. Single-sample cloud point determination of iron, cobalt and nickel by fia-flame atomic absorption spectrometry-application to real samples and certified reference materials. *J. Anal. At. Spectrom.* 2001, (16), 521-526.
33. Sreenivasarao K.; Doyle F. Solubility constants of salts of selected metal ions and anionic C12 surfactants. *Sep. Purif. Technol.* 1997, (12), 157-164.
34. Katsaounos C.Z., Giokas D.L., Vlessidis A.G., et al. The use of surfactant-based separation techniques for monitoring of orthophosphate in natural waters and wastewater. *Sci. Total Environ.* 2003, (305), 157-167.
35. Afkhami A.; Norooz-Asl R. Cloud point extraction for the spectrophotometric determination of phosphorus(V) in water samples. *J. Hazard. Mater.* 2009, (167), 752-755.
36. Tihomirova T.I., Kuznecov M.V., Dubovik D.B., et al. Preconcentration of arsenic(V) as molybdoarsenic heteropoly acid by dynamic sorption. *J. Anal. Chem.* 2000, 55 (9), 846-850.
37. Medveckij A.V., Tihomirova T.I., Cizin G.I., et al. Sorption-spectroscopic determination of phosphates in waters as molybdenum heteropoly acids. *J. Anal. Chem.* 2003, 58 (9), 841-844.
38. Starova T.V., Vishnikin A.B., Tsiganok L.P. Sorption-spectrophotometric and visual test determination of phosphates as an ion associate of 11-molybdobismuthophosphate with Crystal Violet. *Method and Object Chemical Analysis.* 2007, 2 (2), 162-168.
39. Suhan V., Trohimenko O., Klokoza Z. Quantitative measurements in sorption-spectroscopic analyse with application of polyurethane foams and. Taras Shevchenko National Univ. Chim. Bull. 2006, (43), 16-18.
40. Zui O.V., Takahashi H., Hori T., et al. Luminol chemiluminescence under interaction with heteropoly acids. *Talanta.* 2009, 78 (3), 1185-1189.
41. Trokhimenko O.M., Sotnik T.V., Nabivanets B.I. Spectrophotometric determination of phosphorus (V) as ionic associate of molybdophosphate with brilliant green. *Ukr. Chem. J.* 2002, 68 (6), 87-90.
42. Heckmann H-J. Highly sensitive flow analysis determination of orthophosphate using solid phase enrichment of phosphor-molybdenum blue without need for organic solvents in elution. *Anal. Chim. Acta.* 2000, 410 (1-2), 177-184.
43. Zaporozhec O.A., Zin'ko L.S., Kachan I.A. Solid-phase-spectrophotometric and test determination of simultaneously present phosphorus forms (phosphorus speciation) in water. *J. Anal. Chem.* 2007, 62 (12), 1146-1150.
44. Zaporozhets O.A. Kachan I.A., Zinko L.S. The solid-phase reagents on the base of heteropolyacids and their ion associates immobilized onto silica. *Kharkov Univ. Bull. Chem. Series.* 2007, 770, 15 (38), 155-162.
45. Kachan I.A., Zaporozhec O.A., Zin'ko L.S., et al. Tverdogazno-spektrofotometričeskoe opredelenie vosstanovitelej v rastvore po reakcii obrazovanija «sinej» geteropolikisloty. *Method and Object Chemical Analysis.* 2006, 1 (2), 127-131.
46. Kubota T., Yamaguchi T., Okutani T. Determination of arsenic content in natural water by graphite furnace atomic absorption spectrometry after collection as molybdoarsenate on activated carbon. *Talanta.* 1998, 46 (6), 1311-1319.
47. Yuchi A., Ogiso A.; Muranaka S. Preconcentration of phosphate and arsenate at sub-ng ml⁻¹ level with chelating polymer-gel loaded with zirconium (IV). *Anal. Chim. Acta.* 2003, 494, (1-2), 81-96.
48. Karapetjan Z.A. Ionnye asociaty molibdenovyh geteropolikisloty fosfora, mysh'jaka i kremnija s trifinilmetanovymi osnovnimi krasiteljami i ih ispol'zovanie v fotometričeskom analize : diss. kand. him. nauk : 02.00.02 / In-t obshhej i neorganicheskoi himii Akad. Nauk Armjanskoi SSR. Erevan, 1984. 187 l.
49. Mytsuk O.A., Midiani S.V., Mytsuk R.D. Sorbtsiino-fotometričnye vyznachennia fosforu v pryrodnykh vodakh. Naukovyi visnyk LNUVMBT imeni S.Z. Hzytskoho. 2010, 12, 3 (45) 4, 233-236.
50. Kostenko E.E., Butenko E.N., Maksimenko E.V. The interface spectrophotometric determination of phosphorus in the manner of ion association molybdophosphoric heteropolyacid with base blue K-Ky-2×8. *Method and Object Chemical Analysis.* 2015, 10 (3), 135-142.
51. Medvetsky A.V., Tihomirova T.I., Sorokina N.M., et al. Preconcentration of phosphate and silicate ions on cellulose filters as hydrophobic ion associates of heteropoly acids with tri-n-octylamine. *Vestn. Mosk. Un-ta. Himija.* 2004, ser. 2., 45 (4), 250-254.
52. Zui O.V., Birks J.W. Trace analysis of phosphorus in water by sorption preconcentration and luminol chemiluminescence. *Anal. Chem.* 2000, 72 (7), 1699-1703.
53. Zhao B., Liu T., Fang Y., et al. A new selective chemosensor based on phenanthro[9,10-d]imidaz-

- ole-coumarin with sequential "on-off-on" fluorescence response to Fe^{3+} and phosphate anions and its application in live cell. *Sensors and Actuators B*. 2017, 246, 370–379.
54. Kahveci Z., Martínez-Tomé M.J.; Mallavia R., et al. Fluorescent biosensor for phosphate determination based on immobilized polyfluorene-liposomal nanoparticles coupled with alkaline phosphatase. *Appl. Mater. Interfaces*. 2016, 9 (1), 136–144.
55. Borse V., Jain P.; Sadawana M., et al. 'Turn-on' fluorescence assay for inorganic phosphate sensing. *Sensors and Actuators B: Chemical*. 2016, 225, 340-347.
56. Cong D.; Yang C.-X.; Yan X.-P. Ratiometric fluorescent detection of phosphate in aqueous solution based on near infrared fluorescent silver nanoclusters/metal-organic shell composite. *Anal. Chem*. 2015, 87 (22), 11455–11459.
57. Jońca J., Fernández V.L., Thouron D., et al. Phosphate determination in seawater: Toward an autonomous electrochemical method. *Talanta*. 2011, 87, 161-167.
58. Berchmans S., Karthikeyana R., Gupta S., et al. Glassy carbon electrode modified with hybrid films containing inorganic molybdate anions trapped in organic matrices of chitosan and ionic liquid for the amperometric sensing of phosphate at neutral pH. *Sensors and Actuators B*. 2011, 160, 1224–1231.
59. Xue Y., Zheng X., Li G., et al. Determination of phosphate in water by means of a new electrochemiluminescence technique based on the combination of liquid-liquid extraction with benzene-modified carbon paste electrode. *Talanta*. 2007, 72 (2), 450–456.
60. Panasjuk N.V., Tkachuk A.O., Tkach V.I., et al. 12-molibdofosforna kislota yak analitychnyi reagent na orhanichniy kation vitaminu. *Visnyk Dnipropetrovskoho universytetu. Seriya «Khimii»*. 2011, 17, 168-172.
61. Kim H.-Jin.; Hummel J.W.; Birrell S.J.; Sudduth K.A. Evaluation of Phosphate Ion-Selective Membranes for Real-time Soil Nutrient Sensing. ASAE Annual International Meeting : agricultural and biosystems engineering conference proceedings and presentations, 17-20 July, 2005. Tampa: Florida. Iowa State University Digital Repository, 2005. p. 1-12.
62. Abbas M.N.; Radwan A.L.A., Nooredeen N.M.; et al. Selective phosphate sensing using copper mono-amino-phthalocyanine functionalized acrylate polymer-based solid-state electrode for FIA of environmental waters. *J. Solid State Electrochem*. 2016, 20 (6), 1599-1612.
63. Udnan Y., McKelvie I.D., Grace M.R., et al. Evaluation of on-line preconcentration and flow-injection amperometry for phosphate determination in fresh and marine waters. *Talanta*. 2005, 66 (2), 461–466.
64. Talarico D., Cinti S., Arduini F., et al. Phosphate detection through a cost-effective carbon black nanoparticle-modified screen-printed electrode embedded in a continuous flow system. *Environ. Sci. Technol*. 2015, 49 (13), 7934–7939.
65. Huang Y., Ye Y., Zhao G., et al. An all-solid-state phosphate electrode with H_3PO_4 doped polyaniline as the sensitive layer. *Int. J. Electrochem. Sci*. 2017, 12, 4677-4691.
66. Mizutani F., Yabuki S., Sato Y., et al. Amperometric determination of pyruvate, phosphate and urea using enzyme electrodes based on pyruvate oxidase-containing poly(vinyl alcohol)/polyion complex-bilayer membrane. *Electrochim Acta*. 2000, 45 (18), 2945–2952.
67. Rahman Md. A.; Park D.-S.; Chang S.-C.; et al. The biosensor based on the pyruvate oxidase modified conducting polymer for phosphate ions determinations. *Biosens. Bioelectron*. 2006, 21(7), 1116-1124.
68. Cinti S. Talarico D., Palleschi G., et al. Novel reagentless paper-based screen-printed electrochemical sensor to detect phosphate. *Anal. Chim. Acta*. 2016, 919, 78-84.
69. Mozzhukhin A.V.; Moskvina A. L.; Moskvina L. N. Stepwise injection analysis as a new method of flow analysis. *J. Anal. Chem*. 2007, 62 (5), 475-478.
70. Morais I. P.A.; Miró M.; Manera M.; et al. Flow-through solid-phase based optical sensor for the multi-syringe flow injection trace determination of orthophosphate in waters with chemiluminescence detection. *Anal. Chim. Acta*. 2004, 506 (1), 17–24.
71. Liang Y.; Yuan D.; Li Q.; et al. Flow injection analysis of ultratrace orthophosphate in seawater with solid-phase enrichment and luminol chemiluminescence detection. *Anal. Chim. Acta*. 2006, 571 (2), 184–190.
72. Liang Y.; Yuan D.; Li Q.; et al. Flow injection analysis of nanomolar level orthophosphate in seawater with solid phase enrichment and colorimetric detection. *Mar. Chem*. 2007, 103 (1-2), 122–130.
73. Colorimetric determination of phosphate (VISOCOLOR® alpha Phosphate). Macherey-Nagel : website. URL: <http://www.mn-net.com/tabid/5038/default.aspx> (date of application: 11.06.2019).
74. Kiso Y., Kuzawa K.; Saito Y.; et al. A spot test for aqueous phosphate by color band formation. *Anal. Bioanal. Chem*. 2002, 374 (7-8), 1212–1217.
75. Jayawardane B.M., McKelvie I.D., Kolev S.D. A paper-based device for measurement of reactive phosphate in water. *Talanta*. 2012, 100, 454–460.
76. Knyazev D.A., Zhevnerov A.V., Ivanov V.M.; et al. Blister-colorimetric determination of phosphate ions in water, agricultural samples, and biological samples. *J. Anal. Chem*. 2007, 62 (1), 37-41.
77. Zaporozhets O.A., Kachan I.A., Zinko L.S. Interaction of molybdo-phosphoric and molybdo-antimono-phosphoric heteropoly acids with silica gels modified with aliphatic and heterocyclic quaternary ammonium salts. *Ads. Sci. Technol*. 2011, 29 (3), 319-330.