METHODS OF CHEMICAL ANALYSIS

COULOMETRIC ANALYSIS. DIRECT COULOMETRY (REVIEW)

T. K. Khamrakulov and V. V. Chervyakova

UDC 543.258.062

Papers on the determination of inorganic materials by the direct coulometry (DC) method published in 1966-1974 are considered in the review.

In DC the content of material is established from the amount of electricity consumed for direct electrotransformation of the electroactive component. The determination can be carried out with a controlled potential (E = const) or controlled amount of current (i = const) as a function of conditions.

Despite the relative complexity of the experimental technique and the apparatus used DC attracts the attention of investigators because of the selectivity of the method and high accuracy and reproducibility of results of quantitative determination. A series of new variations of DC has appeared recently and the number of investigations on the theory of coulometry, equipment, coulometers, electrolyzers, and electrodes has increased. Papers are devoted mainly to the increase in precision, accuracy, and speed of analytical results (taken together or separately) with the simultaneous removal of the necessity of using complex equipment. For example, these are coulopotentiography [1], coulopotentiography with anodic solution of the precipitate [2], coulostatic method [3], chronocoulometry [4], substoichiometric coulometry [199], and variations of current integrators [5-7].

Certain aspects of theory and potentialities of DC for the determination of uranium, transuranium elements, gases, and liquids are examined in [8-10].

The analytical use of DC at E = const and i = const for analysis of inorganic materials and their compounds is illustrated by Tables 1 and 2. It is seen from data of the tables that DC is applicable to the determination in nonaqueous solutions of the following elements: s^1: H_2, Li, Na, K; s^2: Be, Mg, Sr, Ba; p^1: In, Tl; p^2: C, Sn, Pb; p^3: N_2, As, Sb, Bi; p^4: F, Cl, Br, I; d^2: Ti; d^3: V; d^4: Nb, W; d^5: Cr, Mo, Mn, Tc, Re; d^6: Fe; d^7: Co, Ru, Ir; d^8: Ni, Rh, Pt; d^9: Pt; d^{10}: Pd, Cu, Ag, Au, Zn, Cd, Hg; f^2: Ce; f^3: U; f^4: Pm; f^6: Sm; f^7: Eu, Am; f^{14}: Yb.

DC is used most widely for the determination of p- and d-elements and for uranium and plutonium of f-elements.

Fuel and inert gases [11-16], solutions of acids and bleaching vats [27-29], products of chemical reactions and chromatographic analysis [42, 43], steels, alloys [117, 118], standard solutions [120, 131], and industrial and natural objects [123-128, 137-139, 143, 144] are analytical objects. Apart from the most frequently used electrodes (Pt, Hg, Au) glassy graphite [131, 132, 156, 159], carbon pyroceramic [161], and the rotating disc electrode [134] are proposed for the working electrode.

The potentialities of DC are restricted significantly during the determination of the elements: s^1: Li, Na, K, Rb, Cs; s^2: Be, Mg, Ca, Sr; p^1: Al, Ga; d^1: Sc, Y, La, Lu, Ac; d^2: Zr, Hf; d^3: Ta, and also of certain lanthanides and actinides. These difficulties are due mainly to the electronic configuration of the indicated elements, their negative standard electrode potentials (E^0), and ability to be oxidized easily and to form stable compounds, from which they are subsequently electroreduced with difficulty. Naturally E^0 is not an absolute characteristic of the oxidation–reduction ability of systems, since the course and rate of the electrochemical process can be changed as a function of various factors, for example, nature of solvent. Therefore, it can be asserted that the use of DC for the determination of elements indicated above is a concern of the near future and success is evidently guaranteed upon using

A. Navoi Samarkand State University. Translated from Zavodskaya Laboratoriya, Vol. 41, No. 11, pp. 1297-1314, November, 1975. Original article submitted July 3, 1975.

TABLE 1. Direct Coulometry (E = const). Accepted abbreviations: W is the working electrode, A is the auxiliary electrode. I) Potential is transmitted to the working electrode from an external current source, a potentiostat; II) potential is transmitted to the working electrode from a chemical current of a galvanic element.

Determined component	Analyzed object	Determinable amounts	Potential of the working electrode, rel. s.c.e.	Experimental conditions. Interfering ions	Literature
1	2	3	4	5	6
H_2	Fuel gases	Microquantities	−0.04	W is Pt or Pd, coated with platinum black, I	11
	Helium, nitrogen, saturated hydrocarbons	10^{-4}—10^{-1}%	0.1—1.0	$H_2 \rightarrow HCl$, $H_2 \rightarrow H_2O$, 6M KOH, W is pyrographite coated with Pt black, A is metalloceramic porous Pd, II	12—16
			0.6—0.8	$H_2 \rightarrow H_2O \rightarrow O_2$, 5 M KOH, W is Ni, A is Ni, II	17
H^+	Solutions	10^{-8} mole/liter	0.2—0.4	Analyzed solution, A is Ag/AgCl, W is Pt, II	18
H_2O	Gases, organic compounds	2 mg/m^3	—	Polymeric film, adsorbing H_2O, W is Pt, A is Pt, I, II	19, 20
	Natural objects, hydrocarbons, inert gases	0—10 ppm 60	—	$H_2O \rightarrow H_3PO_4$, P_2O_5, deposited on a Pt electrode, W is Pt, A is Pt, II	15, 21—26
	Water, adsorbed on ThO_2	1—350 μg	—	P_2O_5 deposited on a Pt electrode, W is Pt, A is Pt, II	27
Acids and Bases	Solutions of acids and bases	Microquantities			28—29
H_2O_2	Solutions of bleaching vats	Microquantities	0.7—0.9	H_2O_2, O_2, 25% NaOH solution, W is porous Ag, II	30
Li (I)	Solutions	2 mg-eq	—	Acetonitrile + tetraethylammonium perchlorate, W is Hg, I	31, 32
CO	Gas mixtures	1—100 ppm	0.65—1.25	$CO \rightarrow CO_2$, W is polyfluoroethylene resin Pt gas-diffusion, I	33
	Gases, molten metal	Microquantities	0.2—0.4	Solid I_2O_5, t = 140°C, $CO \rightarrow I_2$, $CaCl_2$ + 5% CaC_2, W is Pt, A is Hg, C, II	34—35
C, CO_2	Molten metal, generator gas	Microquantities	—	$CaCl_2$ + 5% CaC_2, W is metal, A is $CO+CO_2$ mixture, II	232
CO_2	Gases, atmospheric air	Microquantities	0.2	KOH solution, W is Pt, Pd; PdH_2; A is Hg, Ag/AgCl, II	16, 36—38
$C_2O_4^{2-}$	Solutions	10^{-9}—10^{-6} N	1.6	0.5 M H_2SO_4, W is graphite filament, I. Cr(VI), Cl(IV), Fe(II), U(VI) interfere	39

NO_2^-	Gases	4 mg	0,95	1 M in CH_3CO_2H and CH_3CO_2Na, pH 4.7, I. SCN^-, Mn(II), Sb(III) interfere	40
NO, HNO_2	Chemical reaction products	10^{-6}—10^{-3}M	(—0,09)÷(—1,25)	0.5 N Na_2HPO_4, pH 5-7, 0.5 N in Na_2SO_4 and NaH_2PO_4, W is Hg, I	41
NO	N_2	10^{-7}—10^{-8}%	—0,3	$NO \rightarrow NO_2$. Quartz saturated with $FeSO_4$, t = 350°C, $KMnO_4$ in 10% H_2SO_4, 0.01 KI, W is Pt, A is Pt, I	241
NO, NO_2	Gas mixtures	Trace amounts	0,2—0,4	$NO \rightarrow NO_2$. Glass wool saturated with electrolyte solution. W is Pt, A is activated carbon, silver II. Products of acidic and basic character interfere	42
	Products of chromatographic analysis	10^{-6}—10^{-4}%	0,3	$NO \rightarrow NO_2$, 0.01 M KI, W is Pt, A is Ag, C, II	43
	Air, exhaust gases of internal combustion engines	0,02 mg/liter	0,2—0,4	$NO \rightarrow NO_2$, 1% solution in H_2SO_4 and 3% in KBr, W is Pt, A is activated carbon, Ag, II. H_2S, SO_2, SO_3, NH_3, hydrocarbons interfere	44—46
NH_3	Products of chromatographic analysis, gases	10^{-6}—10^{-4}%	0,2—0,4	$NH_3 \rightarrow NO_2$, 0.1 M KI, W is Pt, $NH_3 \rightarrow NH_4^+$, 2 M Na_2SO_4, W is Al, A is C, II	43, 47
O_2	Inert and fuel gases	Microquantities	(—0,6)—(0,8)	5 M KOH, W is Ni or Pt, coated with platinum black, A is Ni, II	48—11, 17
	Sewage	3 μg/liter	(—0,5)—(—0,6)	0.1 M HCl + 0.05 M $Na_2B_4O_7$, W is Pd, A is Ag/AgCl, II	49—52
O_2	Magnesiowüstite	Milligram quantities	0,35—0,55	1 N H_2SO_4, W is magnesiowüstite, I	53
	Aqueous solutions, SAM, organic materials	1 μg/liter	—0,6	KOH solution, 2 M $NaClO_4$ + 2 M NaI, W is Pb, Au, or Ag, A is Ag, II	54—60, 239
	Gases, steels	Microgram	—0,6	Zr_2—MgO and ThO_2—V_2O (solid electrolyte), W is metal, A is metal oxide, II	61—63
	Electrolyte solutions	Microgram quantities	(—0,5)—(—0,7)	CH_3CO_2H solution, W is Ag, Au. A is Ag, Pb, II. Diffusion barrier of polyfluoroethylene resin or polyethylene. CO, H_2S, C_2H_2, H_2, SO_2, NO interfere	64, 65
	Gases, dissolved oxygen	Microgram quantities	(—0,5)—(—0,7)	Ca and Zr salts (solid electrolyte). KOH solution, W is porous metal, Ag, A is CD, stainless steel, II	65—86
	Peroxides, hydroperoxides	Microgram quantities	(—0,6)—(—0,8)	KOH solution, W is Au, A is Pb, Zn, II	87
	Sulfuric acid solutions	Microgram quantities	(—0,5)—(—0,7)	Acetate buffer, W is Au, A is Pb, II	88

Table 1. (Continued)

Determined component	Analyzed object	Determinable amounts	Potential of the working electrode, rel. s.c.e.	Experimental conditions. Interfering ions	Literature
1	2	3	4	5	6
	Alcohols, SAM, gas mixtures, solutions	0,2%	−0,6	27% KOH, diffusion barrier of polyethylene, W is Ag, A is a pressed cadmium shaving or Cd, II	89—91
	Gases, electrolyte solutions	0,2 μg	(−0,6)—(−0,8)	KOH solution, W is Ag, A is Pb, foil, II	73, 90
	Steels	$3 \cdot 10^{-4}$—1%	1,0	25% KOH, W is Pt, A is Ag, II	92
	Organic materials in water, air	Microquantities	(−0,6)—(−0,8)	Oxidation of contaminating materials with CrO_3 or MnO_4. H_2O_2 solution, W is Ag, A is Zn or Cd, II	93
O_2	Air	0,05—1 μg/m³	0,2—0,5	2% NaBr + 0.1% NaH_2PO_4 + 0.01% NaI + Na_2HPO_4. W is Pt, A is carbon, II. Materials reacting with ions interfere	94, 95
O_3	Air	0,04 μg/m³	0,2—0,5	KBr or KI solution, W is Pt, A is C, Pb, or Ag	96—98
F_2	Atmosphere	Microquantities	0,5—0,7	LiCl→CdI_2 solution, W is Pt, A is Ag/AgCl, II	99, 100
Na^+	Sodium Salts	^{2}mg-eq	−2,45; −0,50	$Na^+ \rightarrow Na \rightarrow Na^+$, acetonitrile + tetraethylammonium perchlorate, W is Hg, II	31, 32
Mg (II)	Eluate				101
S	Sulfur compounds	5—20 mg	0,85; 0,50; 0,80	1 N HCl, phosphate buffer, Clark and Lubs buffer solution, W, A are Pt, I	102
$S_2O_3^{2-}$, S^{2-}, SCN^-	Aqueous solutions	Microgram		$HClO_4$ solution, Na_2SO_3, CH_3CO_2H, CH_3CO_2Na, I. W is amalgamated Ag	103—105
SO_2, H_2S, CS_2	Atmosphere	Microgram	0,2—0,5	KI solution, W is Pt, A is carbon+MnO_2, II	51, 106—108
		0,1—0,3 ppm 60	The same	Iodine solution, W is Pt, A is carbon+MnO_2, II. HCN interferes.	109, 110
Cl_2	Air	Microquantities	0,1—0,2	25% LiCl + 0.02% LiBr + 4% acetamide; 3M NaBr + $1 \cdot 10^{-3}$ M NaI, 0.1 M Na_2HPO_4 + 0.1 M NaH_2PO_4, 10% HCl, W is Ag, Pt, Au, A is porous silver, Ag/AgCl, II. SO_2, NO_2 interfere	111, 114
HCl chlorinated hydrocarbons	Air	Microquantities	0,4—0,7	HCl→Cl_2. Hydrocarbons→HCl→Cl_2. 25% LiCl + 0.02% LiBr + 4% acetamide, W is Pt, A is porous silver, II	111
ClO^-	Industrial solutions of bleaching vats	Microquantities	−0,75	$ClO^- \rightarrow O_2$, 0.25% NaOH+KIO_4, W is porous silver, I	30
K^+	Potassium salts	Microquantities	(−2,0)—(−0,5)	$K^+ \rightarrow K \rightarrow K^+$, 0.1 M KOH, W is Hg, I	32

				W is Hg, I	115
Ca (II)	Eluate, model solutions		0,05	Diethylenetriaminepentaacetic acid, pH 10, W is amalgamated Pt,	101—116
Tl (IV)	Ti-W alloys	0,1—10 mg/ml	—0,20	9 M H_2SO_4, W is Hg, I. Se(VI), As(V), Bi(III), Te(VI), Cu(II), Mo(VI) interfere	117
V (IV), V (V)	Steels	1—10 mg	1,20 or 0,50	1.5 M H_3PO_4 or 1.5 M H_3PO_4+0.05 M $Na_4P_2O_7$	118
	V(IV) salt solutions	5 mg	1,15	V(IV)→V(V), 1.5 M H_3PO_4, W is Pt	119
$Cr_2O_7^{2-}$	Standard $K_2Cr_2O_7$ solutions	$6\cdot10^{-3}$—$4\cdot10^{-2}$%	(—0,6)—(—0,8)	$K_2Cr_2O_7+H_2O_2\rightarrow O_2$, W is Au, Ag, A is Zn, Cd, II. Reducing and oxidizing agents Cl^-, Fe^{3+} interfere	120
Mn (II)	Solutions	0,5—10 mg in 25 ml	1,05—1,10	0.25 M $Na_4P_2O_7$, pH 2, W is Pt, I. Ti(I), As(V), V(III), Ce(III), Sb(III) interfere	121
MnO_4^-	Standard $KMnO_4$ solutions	0,2—1,8	(—0,6)—(—0,8)	$KMnO_4+H_2O_2\rightarrow O_2$, W is Ag, Au, A is Zn, Cd. Oxidizing and reducing agents, Cl^-, Fe^{3+} interfere	120
$Fe(CN)_6^{4-}$, $Fe(CN)_6^{3-}$	Salt solutions	10—150 mg	0,54—0,84	0.5 M KCl, W is Pt, Ag, I. I^-, SHN^- interfere	105
Fe (II), Fe (III)	Wüstite	23—24%	0,2	0.05 M H_2SO_4, W is wüstite, I	123, 124
Fe (II)	Model solutions, standard samples	0,05—112 μg	0,12—0,48	1 M HCl, I M $HClO_4$, W is Au, Pt, I	125—127
Fe	Oxide layers on iron samples	Microquantities	0,0	0.15 M in H_3BO_3 and $NaBO_3$, pH 8.4, W is Fe sample, I	128
	U-Al alloys, model solutions, nuclear fuel	1,92 mg	—0,05	W is Hg, I	129, 120
Fe (III)	Standard solutions	1 mg	0,56	1 M H_2SO_4, W is glassy graphite, I	131
Ni (II)	Eluate solution	Microquantities	—0,44	0.5 M H_2SO_4, W is glassy graphite, I	132
Cu (I)	CuBr solutions	Microquantities	—0,11	0.1 M in NaBr and $NaNO_3$, W is Cu, I	133, 31
Cu (II)	Standard Solutions	0,4 mg-eq	—0,50	0.25 M K_2SO_4, W is a rotating copper disc, I	134
		Microquantities	0,05	Diethylenetriaminepentaacetic acid, pH 5 or 10, W is amalgamated platinum, I	116
		2 mg-eq	—0,60	Cu(II)→Cu(I), acetonitrile+tetraethylammonium perchlorate, W is Hg, I	31
	Eluate	$1\cdot10^{-3}$M	0,39	0.5 M HCl, W is glassy carbon, I	132

Table 1. (Continued)

Determined component	Analyzed object	Determinable amounts	Potential of the working electrode, rel. s.c.e.	Experimental conditions. Interfering ions	Literature
1	2	3	4	5	6
Zn (II)	Model solutions	Microquantities	−0,05	Diethylenetriaminepentaacetic acid, pH10, W is amalgamated platinum, I	106
Se (IV)	Model solutions	Microgram quantities	−0,45	0.2-2.0 M HCl, 0.5 M citric acid, R is Au, Hg, I	135, 136
Sr (II)	Strontium salts, eluate	10^{-4} g-eq	−1,5; −0.5	Sr(II)→Sr→Sr(II), 0.03 M $Sr(OH)_2$, W is Hg, I	32, 101, 115
Mo (VI)	Mo-Re-W alloys	0,2—10 mg/liter	−0,25	0.2 M $(NH_4)_2C_2O_4$+1.3 M H_2SO_4, pH 2.1, W is Hg, I. Fe(III), Cu(II), Bi(III), Ti(IV) (removed with preelectrolysis) interfere	137
Ru (IV)	Model solutions	0,2—2,0 mg/ml	0,5	6 M HCl, W is Pt, I. Ir(IV) interferes	138
	Ru, alloys based on Ru	100 mg	0,05	5 M HCl, W is Hg, I	139
Rh (III)	Concentrates after removal of noble metals	Milligram quantities	−0,2	0.2 M HCl, W is Hg, I	141
Ru (X)	Model solutions	0,05 mg	−0,10; 0,80	Ru(X)→Ru(III)→Ru(IV). 1 M H_2SO_4, W is Pt, I	140
Pd (II)	Palladium alloys	0.05 mg	0,55	1 M Na_2HPO_4+0.5 M H_3PO_4. W is Pt, I	142
Ag (I)	Layers of a metal deposited on a copper plate	Milligram quantities	−0,80	KCN solution, W is Hg, I	143
	Model solutions	Trace quantities	0,55	1 M $HClO_4$, W is Au, I. Au interferes	141
	Pd alloys	Microgram quantities	−0,15	0.1 M NH_4Cl+0.1 M NH_4OH, W is Pt, I	142
Ag (I)	Solutions	4 mg	−0,05; (−0,10)—(−0,15)	0.4-0.5 M $HClO_4$ or HNO_3, W is Pt, Au, I. Fe(III) interferes	246, 235
	Alloys	Milligram quantities	0,00	1 M $HClO_4$, W is Hg, I	144
Cd (II)	Standard solutions	Milligram quantities	−0,89	0.5 M ammonium tartrate + 0.35 M NH_4OH, pH 9, W is Hg, I	145, 236
	High purity Zn, solder	Trace quantities	−0,75	0.1 M KNO_3, containing ^{109}Cd, W is Hg, I	146
	Alloys	Milligram quantities	−0,63	1 M $HClO_4$, W is Hg, I	144
	Standard Samples	Milligram quantities	−0,73	0.1 M KNO_3, W is Pt, Hg, I	147, 148

	Solutions	$1 \cdot 10^{-6}$—$1 \cdot 10^{-3}$M	—1,10	0.1 M KCl, W is amalgamated Ag, I	149
		$1 \cdot 10^{-6}$M	0,9	0.1 M HCl, pH 1, W is a fine mercury film on Ag backing, I	150
In (III)	Ag—In—Cd alloys	Milligram quantities	—0,62	1 M $HClO_4$ + 1 M NaI, W is Hg, I. Ag(I), Cd(II) interfere	144
Sn (IV)	Alloys	0,1—0,4 mg	—0,29	3 M KBr + 0.2 M HBr, W is Hg, I. Cd(II), Pd(II) interfere	145
Te (IV)	Model solutions	0,02—1,0 mg	—0,6; —0,9 or —0,55	Phosphate buffer (pH 5.9), acetate buffer (pH 4.1), ammonia buffer (pH 9), W is Au or amalgamated Au, I	135
Ba (II)	Barium(II) salt solutions, eluate	0,4—1,4 mmole	—2,0	0.5 N $(C_2H_5)_4NI$, W is Hg, I	32, 115, 116, 151
Eu (III), Sm (III), Nd (III), Yb (III)	Standard solutions	1 mg-eq	—1,30; —1,70; —2,20	0.01 M tetraethylammonium perchlorate in acetonitrile, W is Hg, I	152
Eu (III)	Eu—Cd alloys	0,26—0,86 mg	—0,30	Eu(III)→Eu→Eu(III), W is Hg, I	153
Re (II), W (III)	Alloys (Re—Mo, Re—W)	0,7—80,0 mg	0,40	2 M NaOH, W is metal alloy, I	154
Ir (IV)	Model solutions	10 mg	0,32	0.2 M HCl, W is Pt, I	155
	Concentrates after removal of precious metals	Milligram quantities	0,25	0.2 M HCl, W is Pt, I	141
Pt (II)	Pd Alloys	Milligram quantities	—0,19 or 0,55	0.1 M NH_4Cl+0.1 M NH_4OH, 1 M Na_2HPO_4 + 0.5 M H_3PO_4, W is Pt, I	142
Au (III)	Pd Alloys	Milligram quantities	0,55	1 M Na_2HPO_4 + 0.5 M H_3PO_4, W is Pt, I	142
	Metal layers deposited on a copper plate	Milligram quantities	—1,0	KCN solution, W is Hg, I	143
Hg (II)	Model solutions	$4 \cdot 10^{-6}$—$4 \cdot 10^{-5}$M	0,80	0.1 M $HClO_4$, W is glassy graphite, I	156
Pb (II)	Model solutions	$1 \cdot 10^{-5}$M	0,90	0.1 M HCl, pH 1, W is a thin mercury film on Ag backing, I	150
Rb (IV)	Lead salts	Microquantities	0,4—0,6	HNO_3 solution, W is Pt, I	157
	Galenite	20 mg	0,9	Pb(II)→PbO_2→Pb(II), 1.5M HNO_3, W is Pt, i = 15 mA/cm^2, t = 20°C	242
PbO	Zn, Pb	$3 \cdot 10^{-3}$%	—1,6	3 M $HClO_4$, W is amalgamated lead, I	158

Table 1. (Continued)

Determined component	Analyzed object	Determinable amounts	Potential of the working electride, rel. s.c.e.	Experimental conditions. Interfering ions	Literature
1	2	3	4	5	6
Pb (II)	Model solutions	10^{-8}—10^{-7} mole/liter	—0,65	0.1 M $HClO_4$, W is glassy graphite, I. Cu(II) interferes	159
	Glasses, standard solutions	Milligram	—0,15	Pb(II)→Pb(Hg), 0.4 M $C_4H_4O_6$+0.30-0.70 M $HClO_4$, W is Hg, I	160
Pb (II)	Alloys, standard samples	Milligram	—0,55	3 M NaBr+0.25 M $C_4H_4O_6$, W is Hg, I	160
		$5 \cdot 10^{-8}$—$7 \cdot 10^{-7}$M	(—0,80)—(—0,0)	Pb(II)→Pb(metal), 0.1M $NaClO_4$, pH 2, W is carbon pyroceramic	161
Bi (III)	Standard solutions, glasses	Milligram quantities	0,19	Bi(III)→Bi(Hg), 0.4M $C_4H_4O_6$+0.1M $HClO_4$, W is Hg, I	160
Po (II)	Standard solutions	0,4—8,0 mg	—0,84	0.1 M $HClO_4$, W is Au, I	162
U (VI)	U—Al alloys	~24%	—0,15	U(VI)→U(IV), H_2SO_4, W is Hg, I	163
	Uranium standards	33—114 mg	—0,79	0.25 M H_2SO_4, W is Hg, I	164
	Uranium—neptunium alloys	Milligram quantities	—0,33	0.05M H_2SO_4+0.5M sulfanilic acid, W is Hg, I. Sb, Bi, Sd, Mn interfere	165
	Uranyl nitrite solutions	150—300mg	0,15—0,20	U(VI)→U(IV), 4.5M HCl+1.5M sulfanilic acid, W is Pt, I. Fe(III), Pu(IV) interfere	166
	Uranium oxides	Milligram quantities	—0,38	U(VI)→U(IV), H_3PO_4, W is Hg, I	167
	Mixture of U and Pu oxides	Milligram quantities	0,15	U(VI)→U(IV), 0.5M H_2SO_4+0.3M H_3PO_4, W is Hg, I	168
	ThO_2 and UO_2 mixture, synthetic mixtures, UO_{2+x} samples, uranium oxides, fuel for nuclear reactors	0,2—20,0 mg	(—0,24)—(—0,38)	30% H_3PO_4, 0.5M H_2SO_4+6M H_3PO_4, 6M H_3PO_4+1M $HClO_4$, 0.5-1.0M H_2SO_4, 5M H_2SO_4, W is Hg, I	169—174
	Ceramic oxides of nuclear combustible	0.2-20.0 mg	—0,35	U(IV)→U(VI), 1M H_2SO_4, W is Hg, I	175
U (IV)	Mixture of uranium and plutonium oxides	Milligram quantities	0,72	0.25M H_2SO_4+1M HNO_3, W is Au, I	176, 177

Np (IV)	U—Np mixture	Milligram quantities	1,02	0.5M H_2SO_4 containing 0.25 ml of 0.05 $Ce(SO_4)_2$ and 0.5 ml of sulfanilic acid, W is Pt, I. Au, Hg, Te, Cl^- (0.1 M) interfere	165
Np (V)	Standard solutions	Milligram quantities	—0,70	1M H_2SO_4, W is glass, I	126, 178
Pu (IV)	Pu-containing materials, solid and liquid samples	1—2 mg	0,7	Pu(IV)→Pu(III), 1-5M H_2SO_4, W is Pt, I. U(IV) interferes	172, 179
	Mixture of uranium and plutonium oxides	2,6 mg/ml	0,32	0.25M H_2SO_4 + 1M HNO_3 containing 1 ml of sulfanilic acid, W is Au, I	176
	Ceramic fuel materials	Milligram quantities	0,95	Pu(IV)→Pu(III), 1M H_2SO_4, W is Pt, I	179
	Mixture of uranium and plutonium	0,2—25 mg	0,30	0.05-0.4N H_2SO_4 + 0.03N benzophenanthrolinesulfonic acid disodium salt; 0.5M H_2SO_4 containing sulfanalic acid, W is Hg, I	180, 181
			0,70; 0,30	Pu(IV)→Pu(III), 1M H_2SO_4 1M HCl + $7 \cdot 10^{-2}$M sulfanilic acid, W is Pt, I	182
			0,93	Pu(IV)→Pu(III), 0.5M H_2SO_4 + 0.3M H_3PO_4, W is Pt, I. Nitrogen oxides, iridium, mercury interferes	126, 168 183, 184
	Uranyl nitrate solutions, reprocessing products of irradiated nuclear fuel, Pu(IV) oxides	Milligram quantities	0,55	Pu(IV)→Pu(III), 4M HCl+2M H_2SO_4, W is Pt, I	126, 130, 182, 185, 186
				Pu(IV)→Pu(III), 4M HCl + 2M H_2SO_4, W is Pt, I	
	Eluate	21—23 mg	0,74	0.5M H_2SO_4, W is glassy graphite, I	132
Pu (III), Pu (IV)	Mixtures of U and Pu oxides	Milligram quantities	0,35; 0,93	0.5M H_2SO_4 + 0.3M H_3PO_4, W is Pt, I	168
Pu (IV)	Plutonium oxides, 15% metalloceramic	1—10 mg	0,22; 0,70	Pu(IV)→Pu(III)→Pu(IV), 0.5M H_2SO_4, W is Pt, I	174, 182, 238, 243
Am (III)	Model solutions	400—1300 mg	1,05	Am(III)→Am(VI), 0.05-0.2% $AgNO_3$ + $(NH_4)_2S_2O_8$, W is Pt, I	187

TABLE 2. Direct Coulometry (i = const). Accepted abbreviations: i is the value of electrolysis current, Q_c is the content of material calculated from the amount of electricity consumed for electrosolution from the surface of the working electrode of metal ion removed preliminarily from the analyzed solution, W is the working electrode, A is the auxiliary electrode, → is transfer of the material from one phase to another.

Determined component	Analyzed object	Determinable amounts	Experimental conditions, electrolysis current	Literature
1	2	3	4	5
H_2	Steels	Microquantities	C_2H_5OH containing 50 ml of HCl and 25 ml of $C_4H_6O_6$ or CH_3OH containing 50 ml of 2M HCl and 2.5 g of citric acid, W is Pt	188
H_2, H_2O	Organic and inorganic materials	1.0—1.5 mg	15% H_3PO_4, W is Pt, A is Pt, i ≤ 36 mA	189
O_2	Copper oxide	20%	$2CuO \rightarrow 2Cu + O_2$, 1.5M NaOH, i 10 mA, W is amalgamated Pt, A is Pt	190
	Organic materials	1.0—1.5 mg	Organic material, $CO \rightarrow CO_2 \rightarrow H_2O$, i 10 mA, W is Pt, coated with P_2O_5, A is Pt	191
Ni (II)	Metals, alloys, solder based on Ag, Cu	8 μg/ml	Ni(II)→Ni→Ni(II), 0.05M H_2SO_4 + 0.05M K_2SO_4, 0.05M NH_4OH + 0.05M $(NH_4)_2SO_4$, W is C, Pt, Q_c	192, 193
Cu (II)	Brasses	0.1 mg/ml	Cu(II)→Cu→Cu(II), 0.1M H_2SO_4 + 0.1M K_2SO_4, W is Pt, C. Q_c	194
	Electrolyte solutions	Milligram quantities	Cu(II)→Cu→Cu(II), W is Pt	195
	Bronzes, Cu—Ni, Ag—Ni—Cu, Cd—Cu, Ag—Cu—Bi solders, solders based on Cu, Zn, Mg, Al, Sn, Fe	≥1 μg/ml	Cu(II)→Cu→Cu(II), 0.05M H_2SO_4+0.05M K_2SO_4, 0.05M NH_4OH+0.05M $(NH_4)_2SO_4$, W is Pt, C. Q_c.	196, —206, 234
	Semiconductor compounds, alloys based on Se, Te, Ag, Cu	≥ 1 μg/ml	Cu(II)→Cu→Cu(II), 0.05M H_2SO_4 + 0.05M K_2SO_4, ethanol, 0.1M KCl+0.1M HCl. W is Pt, C. Q_c	199—207
	Ag—Cu alloys	≥$5 \cdot 10^{-9}$ g	Cu(II)→Cu→Cu(II), 1 g of $(NH_4OH)_2SO_4$ + 1 ml of H_2SO_4 in 1 liter of H_2O, W is Pt, i 2.5-5.0 mA/cm^2	240
Zn (II)	Brasses, electrolyte solutions, galvanic vats	>8 μg/ml	Zn(II)→Zn→Zn(II), 0.05M NH_4OH+0.05M $(NH_4)_2SO_4$, 0.1M H_2SO_4+ 0.1M K_2SO_4. W is C, Pt. Q_c	194, 208 209
Se (IV)	Model solutions, alloys, semiconductor compounds, sludges, compounds on Se, Cu, Te, and Ag	> 8 μg/ml	Se(IV)→Se→Se(IV), aqueous and alcohol solutions containing 0.1 M KCl, W is copper-plated Pt, C. Q_c	210—213
Mo (VI)	Electrolyte solutions	10^{-6} mole/liter	Mo(VI)→MoO_2→Mo(VI). Citric acid solution, W is Hg	214

Ag (I)	Galvanic coatings, microresistors	Milligram quantities	0.05M H_2SO_4+0.05M K_2SO_4. W is analyzed object, $i \geq 1$ mA. HNO_3, SAM interfere	215
	Alloys, Ag–Cu, Ag–Cu–Cd, Ag–Cu–Ni, Ag–Bi, Ag–Cu–Bi, Ag–Se–Te	>8 μg/ml	Ag(I)→Ag→Ag(I), 0.05M H_2SO_4+0.05M K_2SO_4+$K_2S_2O_8$, 0.05M NH_4OH+0.05M $(NH_4)_2SO_4$+$(NH_4)_2SO_4$. W is Pt, C. Q_C	192, 193, 196–199, 216–221, 234
	Ag oxide or hydroxide, silver salts	Milligram quantities	1.3-2.0M NaOH, i 20-200 mA, W is Ni	232
	$AgNO_3$ solutions	0,2–1,2 mg	0.1 M $HClO_4$, i 2 mA, W is Pt	233
	Semiconductor compounds Ag_3SI, Ag_3SBr	>30%	i 0.05 mA. W is Ag_3SBr or Ag_3SI	234
Cd (II)	Electrolytes, alloys, solders based on Cd–Cu, Ag–Cd–Cu, Ag–Cu–Cd–Ni	>8 μg/ml	Cd(II)→Cd→Cd(II), 0.05M H_2SO_4+0.05M K_2SO_4, 0.05M NH_4OH+0.05M $(NH_4)_2SO_4$. W is Pt, C. Q_C	197
Te (IV)	Model solutions, sludges, alloys, semiconductor, compounds based on selenium, tellurium, silver, copper	> 8 μg/ml	Te(IV)→Te→Te (IV), 0.05M H_2SO_4+0.05M K_2SO_4, 0.1M HNO_3 + 0.1M KNO_3, 0.1M HCl + 0.1M KCl, ethanol containing 0.1M KCl + 0.1M HCl. W is Pt, C. Q_C	213 212
Au (III)	Electrolytes, A–S–Ag alloys	> 8 μg/ml	Au(III)→Pu→Pu(III), 0.15M KCN+0.02M K_2SO_4+0.05M K_2SO_4. W is Pt, C. Q_C	225, 226
Pb (II)	Electrolytes	Milligram quantities	Pb(II)→Pb→Pb(II), 70g/liter of NaOH, 1g/liter of NH_4OH, HCl and 20 g/liter of glycerin. W is stainless stee	227
Bi (III)	Model solutions, alloys, Ag–Bi–Cu, Ag–Bi solders, BiT_3 monocrystal	>8 μg/ml	Bi(III)→Bi→Bi(III), 0.1M HNO_3+0.1M KNO_3, W is Pt, C. Q_C	228, 229 234
U (VI)	Pure uranium, oxides	Milligram quantities	U(VI)→U(III)→U(IV)→U(VI), 1M HCl, i 10 mA. W is Pt	230
Pd (IV)	Model solutions	Milligram quantities	Pd(IV)→Pd, 10% H_2SO_4 (boil.), 10% HCl, i 3-4 mA/cm^2. W is Pt	231

nonaqueous solvent and fusions.

The use of DC, particularly at E = const, is also promising for standardization of metal ion solutions in nonaqueous media, determination of solution products of chemical current sources, and clarification of the degree of deterioration of metallic components in petroleum products. The method gives great possibilities for establishing the stoichiometric composition of semiconductor compounds, the ionic state of an element, products of radioactive transformations, and control of content and distribution of impurities in natural objects.

The DC variant with i = const (substoichiometric coulometry) is promising for use in the determination of the thickness of a galvanic coating, composition of two-, three-, and four-component solders, analysis of stoichiometric semiconductor compounds, and the composition of galvanic vats.

LITERATURE CITED

1. H. Helbig, Chem. Techn., 19, No. 8, 496-499 (1967).
2. F. Taitiro, O. Satoshi, and Y. Takeshi, Chem. Lett., No. 10, 863-864 (1972).
3. F. Taitiro, O. Satoshi, and Y. Takeshi, Chem. Lett., No. 12, 1295-1296 (1973).
4. M. Astruc, J. Bonasze, and J. Lelen, Electronindustr., No. 9, 763-770 (1966).
5. V. I. Glinkin, E. V. Barinov, V. V. Toeier, and G. D. Voronkov, Pribory i Systemy Upravleniya, No. 3, 30-36 (1974).
6. É. V. Kazaryan, Pribory i Systemy Upravleniya, No. 3, 39-40 (1974).
7. A. P. Sharygin, É. V. Kazaryan, and N. R. Sarkisyan, Pribory i Sistemy Upravleniya, No. 3, 36-37 (1974).
8. I. G. Sentyurin and N. S. Radionova, Summary of Papers of the Scientific-Technical Conference on Analytical Methods [in Russian], November 22-24, Sverdlovsk (1972), pp. 142-143.
9. I. S. Sklyarenko, V. M. Mikhailova, and T. M. Chubukova, Zh. Anal. Khim., 27, No. 10, 1991-2003 (1972).
10. V. Z. Al'perin, D. A. Il'yasov, V. V. Nezhinskii, and V. A. Rylov, Pribory i Systemy Upravleniya, No. 7, 41-43 (1972).
11. Y. Takata and G. Muto, J. Chem. Soc. Jap. Pure Chem. Sec., 88, No. 1, 107-109 (1967).
12. S. I. Bykov, A. I. Mikhailina, and A. A. Popov, Zh. Anal. Khim., 24, No. 4, 626-628 (1969).
13. USA Patent No. 3377256.
14. P. I. Bresler, D. Kh. Kogan, M. M. Shumanovich, and N. É. Gel'man, Zavod. Lab., 37, No. 3, 278-279 (1971).
15. D. C. Walker and P. Campion, Analyst, 91, 347-351 (1966).
16. K. Teske, Mitteilungsblatt Chem. Ges., 20, No. 7, 154-156 (1973).
17. W. Bahmet and P. A. Herch, Anal. Chem., 43, No. 6, 803-805 (1971).
18. S. Araki, S. Shigetaka, and T. Hasebe, Japan Analyst, 20, No. 7, 833-840 (1971).
19. V. A. Orlov, Author's Certificate No. 319888; Otkrytiya, Izobr., Prom. Obr. i Tov. Zn., No. 33 (1971).
20. G. N. Abaev, N. M. Kotel', A. Kh. Ivanov, and V. M. Mamedova, Automation of Chemical Factories [in Russian], NIITÉKhim, Moscow (1972), No. 4, pp. 113-118.
21. S. G. Polyak, A. V. Nepryakhina, L. N. Tatarinova, et al., Zavod. Lab., 32, No. 5, 572-575 (1966).
22. English Patent No. 1151912.
23. G. F. Anisimova and V. A. Klimova, Izv. Akad. Nauk SSSR, Khimiya, 2556-2558 (1967).
24. S. Mizukamu and K. Daikatsu, Japan Analyst, 18, 394-397 (1969). Cit. in Anal. Chem., 42, No. 5, 28R(1970).
25. V. I. Murzin and N. L. Afanas'eva, Trudy Nauchno-Issledovatel'skogo i Proektnogo Instituta Azotnoi Promyshlennosti y Produktov Organicheskogo Sintexa, No. 6, 359-361 (1971).
26. V. P. Kolomiitsev, R. L. Pinkhusovich, and Yu. N. Patrushev, Author's Certificate USSR No. 360600. Cit. in RZhKhim, 7 D 40 P (1974).
27. E. A. Schalfer and J. O. Hibbits, Talanta, 15, No. 1, 129-132 (1968).
28. French Patent No. 1516308.
29. A. C. Berton, Acad. Sci. Paris. Ser. C., 266, 460-464 (1968), Cit. in Anal. Chem., 42, No. 5, 28R (1970).
30. B. Fleet and A. Y. W. Ho, Talanta, 19, No. 3, 317-327 (1972).
31. R. R. Bessette and J. W. Olver, J. Electroanalyt. Chem., 17, No. 3-4, 327-334 (1968).
32. G. Muto, K. Nozaki, and T. Mozaka, Japan Analyst, 20, 180-184 (1971).
33. H. W. Bay and K. F. Blurton, Amer. Lab., 4, No. 7, 57-58 (1972).
34. USA Patent No. 3700568.
35. English Patent No. 1000625.
36. USA Patent No. 3349011.
37. S. Waszak, Przem. Chem., 52, No. 3, 221-222 (1973).
38. USA Patent No. 3709812.

39. S. Kihara and T. Yamamoto, Japan Analyst, 21, No. 4, 496-502 (1972).
40. J. E. Harrar, Anal. Chem., 43, No. 1, 143-145 (1971).
41. D. L. Ehman and D. T. Sawyer, J. Electroanalyt. Chem., 16, No. 4, 541-549 (1968).
42. USA Patent No. 3314863.
43. S. I. Krichmar, V. E. Stepanenko, and T. M. Galan, Zh. Anal. Khim., 36, No. 7, 1340-1343 (1971).
44. V. Z. Al'perin, T. K. Khamrakulov, D. A. Il'yasov, et al., Zavod. Lab., 38, No. 6, 643-644 (1972).
45. T. K. Khamrakulov, D. A. Il'yasov, and D. M. Ivnitskii, in: Physical-Chemical Methods of Analysis and Control of Production. Electrochemical Methods [in Russian], Makhachkala (1972), pp. 108-112.
46. T. K. Khamrakulov, D. A. Il'yasov, P. K. Agasyan, and D. M. Ivnitskii, Zavod. Lab., 38, No. 12, 1447-1448 (1972).
47. C. J. Sambucetti, Anal. Chem., 38, No. 1, 105-108 (1966).
48. USA Patent No. 3607701.
49. M. Honda, Y. Tekemori, and S. Ishizaka, Rev. Polarogr., 15, No. 3, 76-81 (1969).
50. B. I. Flis and G. I. Foif, Zh. Anal. Khim., 27, No. 4, 736-739 (1972).
51. Ya. M. Chernin, V. Z. Al'perin, M. G. Rol'bina, and V. V. Nezhinskii, in: Automation of Chemical Factories [in Russian], NIITÉKhim, No. 4, (1973), pp. 16-19.
52. A. A. Kuz'min, É. I. Konnik, and D. N. Smirnov, Author's Certificate No. 292465. Otkrytiya, Izobr., Prom. Obr. i. Tov. Zn., No. 34 (1972).
53. O. M. Baeva and G. G. Mikhailov, Zh. Anal. Khim., 29, No. 2, 391-393 (1974).
54. G. W. Hung and R. H. Dinius, Microchem. J., 17, No. 4, 410-430 (1972).
55. K. I. Karrman and K. Ronald, Talanta, 19, No. 1, 67-71 (1972).
56. A. A. Kuz'min and A. I. Kulikov, Zavod. Lab., 39, No. 4, 413-414 (1973).
57. R. Marvet, Uchebnye Zapisi Tartusskovo Un-ta, No. 289, 80-83 (1971).
58. A. A. Kuz'min in: Transport and Storage of Petroleum Products and Hydrocarbon Raw Material [in Russian], No. 12, (1971), pp. 16-19.
59. N. N. Ushev, N. T. Shevyakina, and A. I. Orlov, Trudy Irkutskogo Politekhnicheskogo In-ta, No. 46, 179-184 (1969).
60. USA Patent No. 3316166.
61. G. R. Fitterer, J. Metals, 19, 92-95 (1967).
62. D. Naumann, W. Durk, and H. Ullmann, Anal. Chem., 42, No. 5, 88R (1970).
63. R. L. Pinkhusovich and Yu. N. Patrushev, Automation of Chemical Factories [in Russian], NIITÉKhim, No. 1, 36-43 (1973).
64. USA Patent No. 3301775.
65. A. Takakhasi, Sange Kogai, 8, No. 2, 89-93 (1972). Cit. in RZhKhim, 18G174 (1972).
66. USA Patent No. 3334039.
67. USA Patent No. 3305458.
68. USA Patent No. 3328277.
69. K. H. Maney, Am. Chem. Soc. Div. Water Waste Chem. Preprints, 7, 51-54 (1967). Cit. in Anal. Chem., 40, 70R (1968).
70. USA Patent No. 3322662.
71. S. A. Stenbergh, and W. M. Hilkam, NASA Accession No. 66-33456, Rept. NO NASA-CR-534 (1966), pp. 50-54. Cit. in Anal. Chem., 40, 70R (1968).
72. M. Kolodney and B. Minushkin, Electrochem. Technol., 3, 244-248 (1966).
73. USA Patent No. 3260656.
74. Dutch Patent No. 6602746. Cit. in Anal. Chem., 40, 70R (1968).
75. USA Patent No. 3269924.
76. GDR Patent No. 42587.
77. R. Kober and D. Hankel, Chem. Tech., 18, 631-635 (1966).
78. USA Patent No. 3528415.
79. USA Patent No. 3291705.
80. USA Patent No. 3235477.
81. USA Patent No. 331166.
82. W. G. James and A. H. Fisher, Chem. Ind., 272-275 (1967).
83. FRG Patent No. 53900. Cit. in Anal. Chem., 40, 70R (1968).
84. USA Patent No. 3334623.
85. USA Patent No. 3239444.
86. G. E. Hillman and J. Rightwood, Anal. Chem., 38, 1430-1434 (1966).

87. FRG Patent No. 53354.
88. E. K. Kalinin, V. V. Poddubnyi, and M. M. Kulakov, Prom. i San. Ochistka Gazov, No. 2, 13-15 (1971).
89. T. K. Khamrakulov, V. V. Nezhinskii, and V. V. Abramova, Summary of II All-Union Symposium on Methods of Determining Microelements in Natural Objects [in Russian], November 24-27, Samarkand (1973), p. 93.
90. R. Marvet, I. Ya. Raudeyan, and T. T. Tenno, Author's Certificate No. 296022. Otkrytiya, Izobr., Prom. Obr. i Tov. Zn., No. 8 (1971).
91. English Patent No. 1057753.
92. L. T. S. Harrison and S. A. Marshall, Steel Times, 198, No. 9, 629-630 (1970). Cit. in RZhKhim., 3D74 (1971).
93. B. Feet, A. Y. W. Ho, and L. Tenygl, Analyst, 97, No. 1154, 321-333 (1972).
94. T. M. Dmitriev and V. Z. Al'perin, Gig. Sanit., No. 2, 54-58 (1971).
95. V. Z. Al'perin, Automation of Chemical Factories [in Russian], NIITÉKhim, No. 5, 96-98 (1968).
96. USA Patent No. 3314864.
97. USA Patent No. 3234117.
98. USA Patent No. 3681228.
99. S. Kaye and M. Griggs, Anal. Chem., 40, 2217-2221 (1969).
100. N. Sh. Vol'berg, T. N. Grazhdanova, and I. I. Pochina, Summary of Papers of the II All-Union Symposium on Methods of Determining Microelements in Natural Objects [in Russian], Samarkand (1973), pp. 80-81.
101. Y. Takata and Y. Arikawa, Japan Analyst, 22, No. 3, 312-318 (1973).
102. K. S. V. Santhaman and V. K. Z. Krishman, Z. Anal. Chem., 234, No. 4, 256-260 (1968).
103. E. Jakobsen and D. T. Sawyer, J. Electroanalyt. Chem., 15, No. 2-3, 181-192 (1967).
104. Y. Takata and H. Miyashite, Japan Analyst, 15, 573-578 (1966).
105. Y. Takata and G. Muto, Japan Analyst, 15, 269-271 (1966).
106. V. Z. Al'perin and Ya. M. Chernin, Automation of Chemical Factories [in Russian], NIITÉKhim, No. 1, 76-80 (1968).
107. N. Sh. Vol'berg, Trudy Glavnoi Geofizicheskoi Observatorii, No. 238, 107-114 (1969).
108. USA Patent No. 3650696.
109. I. V. Nobak, Coll. Czech. Chem. Comm., 30, No. 8, 2703-2716 (1965).
110. H. Koyoshi, Japan Analyst, 22, No. 7, 866-872 (1973).
111. N. Sh. Vol'berg, Trudy Glavnoi Geofizicheskoi Observatorii, No. 254, 162-171 (1971).
112. Z. Ersepke and J. Baranek, Chem. Prümysl., 16, No. 8, 496-497 (1966).
113. W. H. Parth, ISA Trans., 12, No. 2, 142-146 (1973). Cit. in RZhKhim., 2D64 (1974).
114. J. Waclawik and S. Waszak, Chem. Anal., 12, 877-881 (1967). Cit. in Anal. Chem., 42, No. 5, 28R (1970).
115. R. R. Shvedov and V. B. Solovev, Proc. Conf. Appl. Phys.-Chem. Methods Chem. Anal., Budapest, 1, 279-281 (1966). Cit. in Anal. Chem., 42, No. 5, 23R (1970).
116. T. Kawaguchi and G. Muto, Japan Analyst, 17, No. 1, 38-42 (1968).
117. L. P. Rigdon and J. E. Harrar, Anal. Chem., 43, No. 6, 747-751 (1971).
118. L. P. Rigdon and J. E. Harrar, Anal. Chem., 41, No. 12, 1673-1675 (1969).
119. F. B. Stephens, F. Jakob, L. P. Rigdon, and J. E. Harrar, Anal. Chem., 42, No. 7, 764-774 (1970).
120. B. Fleet, A. Y. W. Ho, and J. Tenygl, Anal. Chem., 44, No. 13, 2156-2161 (1972).
121. J. E. Harrar and L. P. Rigdon, Anal. Chem., 41, No. 6, 758-765 (1969).
122. G. Sivaramaiah and V. R. Krishnan, Z. Anal. Chem., 231, No. 3, 192-194 (1967).
123. G. G. Mikhailov, V. A. Kozheurov, Yu. Ya. Ageev, et al., Zh. Anal. Khim., 23, No. 9, 1498-1501 (1968).
124. E. I. Pil'ko and V. A. Kozheurov, Sbornik Nauchnykh Trudov Chelyabinskogo Politekhnicheskogo Un-ta, No. 66, 72-75 (1970).
125. I. S. Sklyarenko, I. G. Sentyurin, and T. M. Chubukova, Zh. Anal. Khim., 26, No. 3, 467-474 (1971).
126. I. S. Sklyarenko, T. M. Chubukova, and I. G. Sentyurin, Scientific-Technical Conference on Methods of Analysis (Summary of Papers) [in Russian], September 22-24, Sverdlovsk (1972), pp. 143-144.
127. V. M. Mikhailov and B. F. Myasoedov, Zh. Anal. Khim., 29, No. 3, 493-496 (1974).
128. S. Norio and N. Takemori, Electrochem. Soc., 114, No. 6, 585-586 (1967).
129. D. R. Bohl and D. E. Sellers, U. S. At. Energy Comm., MLM-1543, pp. 8-11 (1968), Cit. in Anal. Chem., 42, No. 5, 24R (1970).
130. B. Eicher, J. Hüller, and W. Brandt, Zentralinst. Kernforsch. Rossendorf b. Dresden, Dtsch. Akad. Wiss. Berlin, 355, No. 193, 1-4 (1969), Cit. in RZhKhim, 2 G 116 K (1971).
131. C. E. Plock and J. Vasquer, Talanta, 16, No. 11, 1490-1492 (1969).
132. T. Fujinaga, Pure Appl. Chem., 25, No. 4, 709-726 (1971).
133. D. G. Peters and R. Z. Caldwell, Inorg. Chem., 6, No. 8, 1478-1483 (1967).
134. V. J. Puglisi and A. J. Bard, Anal. Lett., 3, No. 8, 443-448 (1970).

135. L. B. Agasyan, A. G. Yurchenko, and P. K. Agasyan, Zh. Anal. Khim., 22, No. 2, 229-233 (1967).
136. T. S. Tso and H. M. Yang, Hsuch T'ung Pao, 17, 75-79 (1966).
137. L. P. Rigdon and J. E. Harrar, Anal. Chem., 40, 1641-1644 (1968).
138. N. I. Stenina, Yu. A. Krylov, and P. K. Agasyan, Zh. Anal. Khim., 21, No. 11, 1319-1323 (1966).
139. G. Weldrick, G. Phillips, and G. W. C. Milner, Analyst. 94, No. 1123, 840-843 (1969).
140. D. K. Avdeev, V. V. Prelovskii, and E. N. Tekster, Zh. Anal. Khim., 24, No. 8, 1188-1190 (1969).
141. G. W. VanLoon and J. A. Page, Anal. Chem., 43, No. 4, 602-603 (1971).
142. Y. Takata and G. Muto, Japan Analyst, 15, No. 8, 862-864 (1966).
143. G. Muto, Y. Takata, and A. Tachiki, Japan Analyst, 16, 206-209 (1967).
144. A. Borello and G. R. Guidotti, Anal. Chem., 43, No. 4, 607-608 (1971).
145. W. M. Wise and D. E. Campbell, Anal. Chem., 38, No. 8, 1079-1080 (1966).
146. A. P. Landgrebe, L. T. McLendon, J. R. Devoe, et al., Anal. Chim. Acta, 39, No. 2, 151-159 (1967).
147. P. A. Pella, A. P. Landgrebe, and J. R. Devoe, Anal. Chem., 39, No. 14, 1781-1785 (1967).
148. P. Lanza, Atti Accad. Naz. Lincei, Rend. Cl. Sci. Fis., Mat. E. Natur., 47, No. 6, 542-548, 1969 (1970).
149. L. B. Eliseeva and O. L. Kabanova, Zh. Anal. Khim., 28, No. 9, 1710-1716 (1973).
150. L. B. Eliseeva and O. L. Kabanova, Zh. Anal. Khim., 29, No. 10, 1971-1975 (1974).
151. J. J. Lingane, J. Electroanal. Chem., 15, No. 2-3, 211-220 (1967).
152. E. J. Cokal and E. N. Wise, J. Electroanal. Chem., 12, No. 2, 136-147 (1966).
153. T. G. Timofeeva and M. G. Savin, Izv. Akad. Nauk KazSSR, Khimiya, 17, 80-96 (1967).
154. S. Tribalat, C. Piolet, and D. Mofidi, Bull. Soc. Chem. France, No. 2, 844-848 (1968).
155. J. E. Harrar and I. Shain, Anal. Chem., 38, No. 9, 1148-1158 (1966).
156. O. L. Kabanova and E. A. Zalogina, Zh. Anal. Khim., 26, No. 4, 826-827 (1971).
157. G. Facsko and F. Columbioschi, Proc. Conf. Appl. Phys.-Chem. Methods, Chem. Anal., Budapest, 1, 346-349 (1966), Cit. in Anal. Chem., 42, No. 5, 23R (1970).
158. A. Salata and L. Zanardi, Metallurgia ital., 60, No. 6, 486-490 (1968).
159. O. L. Kabanova and S. M. Veniaminova, Zh. Anal. Khim., 26, No. 1, 111-116 (1971).
160. Y. Su and D. E. Campbell, Anal. Chim. Acta, 47, No. 2, 261-266 (1969).
161. O. L. Kabanova and Yu. A. Goncharov, Zh. Anal. Khim., 28, No. 9, 1665-1668 (1973).
162. R. C. Propst, Anal. Chem., 40, No. 1, 244-246 (1968).
163. Y. L. Duigon and K. F. Lauer, Communante Eur. Energy At.-EURATOM, EUR-3601f, 26-30 (1967), Cit. in Anal. Chem., 42, No. 5, 24R (1970).
164. G. C. Goode and J. Herrington, Anal. Chim. Acta, 38, No. 3, 369-379 (1967).
165. C. E. Plock, Talanta, 14, No. 11, 1356-1359 (1967).
166. W. Davies, W. Gray, and K. C. McLeod, Talanta, 17, No. 10, 937-944 (1970).
167. J. C. Viguie and J. P. Chabert, Anal. Chim. Acta, 48, No. 2, 367-380 (1969).
168. N. E.Barring and G. Jonsson, Anal. Chim. Acta, 50, 229-234 (1970).
169. K. H. Neeb and H. Neidl, Z. Anal. Chem., 253, No. 1, 29-31 (1971).
170. M. M. Privalova and S. A. Kremenetskaya, Zh. Anal. Khim., 27, No. 10, 1986-1990 (1972).
171. Y. L. Duigon and K. F. Lauer, Z. Anal. Chem., 261, No. 4-5, 393-399 (1972).
172. G. R. Waterbury and C. F. Metz, Anal. Chem. Nucl. Fuels. Proc. Panel. Vienna, Vienna (1972), pp. 71-80. Cit. in RZhKhim, 11 G 97 (1973).
173. G. G. Koshcheev, V. V. Rachev, et al., Vestnik MGU. Khimiya, 21, 54-56 (1966).
174. G. W. C. Milner, A. J. Wood, G. Phillips, and G. J. Weldrick. Z. Anal. Chem., 224, No. 1, 346-356 (1967).
175. L. Lorenzini, Anal. Chem. Nucl. Fuels Proc. Punel Vienna, Vienna (1972), pp. 91-96. Cit. in RZhKhim, 11G158 (1973).
176. J. B. Fardon and I. R. McGowan, Talanta, 19, No. 11, 1321-1334 (1972).
177. C. F. Metz and G. R. Waterbury, Anal. Chem. Nucl. Fuels Proc. Panel. Vienna, Vienna (1972), pp. 85-90. Cit. in RZhKhim, 11G191 (1973).
178. R. C. Propst, Anal. Chem., 43, No. 8, 994-999 (1971).
179. G. W. Milner, A. J. Wood, G. J. Weldrick, and G. Phillips, Analyst, 92, No. 1093, 239-246 (1967).
180. J. R. Stokely, Jr. and W. D. Shults, Anal. Chem., 43, No. 4, 603-605 (1971).
181. L. M. Angelit, W. I. Bartschev, and M. I. Maurise, Z. Anal. Chem., 297, 8246-8249 (1969).
182. G. W. C. Milner and D. Grossley, Analyst, 93, 429-431 (1968).
183. E. Schmid, Österr. Chem. Ztg., 67, 8-12 (1966).
184. I. S. Sklyarenko, I. G. Sentyurin, and T. M. Chubukova, Zh. Anal. Khim., 28, No. 7, 1318-1322 (1973).
185. G. Bataller and C. Sapy, Commis. Energ. At. (Fr.), Rapp., CEA-R-3430, 26-28 (1968). Cit. in Anal. Chem., 42, No. 5, 23 (1970).

186. G. S. Barney, U. S. At. Energy Comm., ARH-SA-55, 13-17 (1970).
187. J. R. Stokely, Jr. and W. D. Shults, Anal. Chim. Acta, 45, No. 3, 417-424 (1969).
188. Yu. A. Klyachko, V. G. Starchak, A. I. Grusinova, and L. G. Barg in: Methods of Determining Gases in Nonmetal and Alloys [inRussian], Moscow (1971), pp. 113-114.
189. M. N. Chumachenko and N.B. Levina, Izv. Akad. Nauk SSSR, Khimiya, No. 11, 2438-2442 (1970).
190. R. Vijayavalli, P. V. Vasudeva Rao, and H. V. K. Udupa, J. Electroanalyt. Chem., 24, No. 1, 201-206 (1970).
191. K. Nakamura, M. Nishumura, and T. Mitsui, Microchem. J., 15, No. 3, 461-469 (1970).
192. P. K. Agasyan and T. K. Khamrakulov, Summary of Papers of the VIII Conference of Plant and Industrial Laboratories of Kazakhstan and Central Asia [in Russian], Alma-Ata (1968), pp. 143-144.
193. P. K. Agasyan and T. K. Khamrakulov, Technical and Economical Information. Methods of Analysis and Control of Manufacture [in Russian], NIITÉKhim, No. 11, 111-116 (1969).
194. P. K. Agasyan and L. N. Smyshlyaeva, Zavod. Lab., 38, No. 11, 1326-1327 (1972).
195. G. S. Barney, U. S. At. Energy. Comm. ARH-SA-55, 13-17 (1970).
196. T. K. Khamrakulov, P. K. Agasyan, And É. L. Lutfullaev, Zh. Anal. Khim., 28, 1285-1287 (1973).
197. P. K. Agasyan and T. K. Khamrakulov, Zavod. Lab., 35, 644-648 (1969).
198. P. K. Agasyan and T. K. Khamrakulov, Zavod. Lab., 38, 24-26 (1972).
199. P. K. Agasyan and T. K. Khamrakulov, Zh. Anal. Khim., 23, No. 1, 19-25 (1968).
200. P. K. Agasyan and T. K. Khamrakulov, Vestnik MGU. Khimiya, No. 4, 106-110 (1968).
201. P. K. Agasyan and T. K. Khamrakulov, Vestnik MGU. Khimiya, 11, No. 6, 705-708 (1970).
202. P. K. Agasyan and T. K. Khamrakulov, Summary of XXI International Congress on Pure and Applied Chemistry [in Russian], Prague (1967), A-93.
203. P. K. Agasyan and T. K. Khamrakulov in: Experience of Operation of Test Analytical Laboratories [in Russian], Tsvetmetinformatsiya, Moscow (1969), pp. 43-46.
204. P. K. Agasyan, T. K. Khamrakulov, and A. I. Kordumov, Zavod. Lab., 34, No. 7, 778-781 (1968).
205. P. K. Agasyan and T. K. Khamrakulov, Summary of Papers of the III Polish Analytical Conference [in Russian], (1968), pp. 103-105.
206. W. Helbig, Z. Chem., 6, No. 7, 273-278 (1966).
207. T. K. Khamrakulov, P. K. Agasyan, and T. I. Petaeva, Zh. Anal. Khim., 28, No. 9, 1759-1762 (1973).
208. P. K. Agasyan, L. N. Smyshlyaeva, and T. K. Khamrakulov, Zh. Anal. Khim., 27, 257-260 (1972).
209. T. K. Khamrakulov and N. V. Mishchenkova, Trudy Samarkandskogo Universiteta, No. 180, 79-82 (1970).
210. T. K. Khamrakulov and D. A. Il'yasov, Trudy Samarkandskogo Universiteta, No. 180, 83-87 (1970).
211. T. K.Khamrakulov, P. K. Agasyan, and D. A. Il'yasov, Zh. Anal. Khim., 27, 399-402 (1972).
212. T. K. Khamrakulov, P. K. Agasyan, and T. I. Petaeva, Summary of Papers of the II All-Union Symposium on Methods of Determining Microelements in Natural Objects [in Russian], November 24-27, Samarkand (1972), pp. 103-104.
213. T. K. Khamrakulov, T. I. Petaeva, and D. A. Il'yasov, Summary of Papers of the III All-Union Conference on Analytical Chemistry of Nonaqueous Solutions and Their Physicochemical Properties [in Russian], Gor'ki (October 1971), pp. 63-64.
214. A. M. Gary, G. Goldstein, P. Jost, Ph. Lagrange, E. Pilmont, and J. Schwing, Bull. Soc. Chim. France, No. 7, 2989-2993 (1972).
215. P. K. Agasyan and T. K. Khamrakulov, Summary of Papers of the Rumanian National Conference on Analytical Chemistry [in Russian] (1969), p. 47.
216. P. K. Agasyan, T. K. Khamrakulov, and V. V. Chervyakova, Zh. Anal. Khim., 27, No. 3, 492-496 (1972).
217. P. K. Agasyan, T. K. Khamrakulov, and É. L. Lutfullaev, Summary of Papers of the II All-Union Symposium on Methods of Determining Microclements in Natural Objects [in Russian], Samarkand, April 24-27 (1973), pp. 102-103.
218. T. K. Khamrakulov, V. I. Kruglov, É. L. Lutfullaev, and V. N. Boikova, Summary of Papers of the II All-Union Symposium on Methods of Determining Microelements in Natural Objects [in Russian], Samarkand, April 24-27 (1973), p.88.
219. P. K. Agasyan and T. K. Khamrakulov, Summary of Papers of the Conference of Young Scientists of MSU [in Russian], Izd-vo MGU, Moscow (1968), p. 35.
220. T. K. Khamrakulov and É. L. Lutfullaev, Trudy Samarkandskogo Universiteta, No. 206, 299-303 (1972).
221. P. K. Agasyan and T. K. Khamrakulov, Summary of Papers of Young Scientists of MSU [in Russian], izd. MGU, Moscow (1967), p. 35.
222. R. Vijayavally, P. V. Vasudeva Rao, and H. V. K. Udupa, Bull. Acad. polon. sci. Ser. Chim., 17, No. 6, 359-364 (1969).

223. E. Bishop and M. Riley, Analyst, 98, No. 1167, 416-425 (1973).
224. N. Valverde, Z. Phys. Chem., 75, No. 1-2, 1-6 (1971).
225. L. N. Smyshlyaeva and P. K. Agasyan, Zh. Anal. Khim., 28, No. 11, 2152-2156 (1973).
226. L. N. Smyshlyaeva and P. K. Agasyan, Summary of Papers of the II All-Union Symposium on Methods of Determining Microelements in Natural Objects [in Russian], Samarkand, April 24-27 (1973), p. 61.
227. I. S. Zykova and M. S. Kashtan, Zh. Anal. Khim., 27, No. 4, 793-794 (1972).
228. T. K. Khamrakulov, P. K. Agasyan, and É. L. Lutfullaev, Trudy Samarkandskogo Universiteta, No. 206, 290-294 (1972).
229. T. K. Khamrakulov and V. V. Chervyakova, Trudy Samarkandskogo Universiteta, No. 180, 70-75 (1970).
230. J. Malinowski, Talanta, 14, No. 2, 263-265 (1967).
231. G. P. Chernova, L. S. Kupriyanova, G. V. Chukapovskaya, and N. D. Tomashev, Zh. Prikl. Khim., 44, No. 11, 2424-2429 (1971).
232. USA Patent No. 3650696.
233. USA Patent No. 3718567.
234. T. K. Khamrakulov and É. L. Lutfullaev, Summary of Papers of the XXIV International Congress on Pure and Applied Chemistry [in Russian], Hamburg, September (1973), p. 89.
235. K. A. Van Lente, J. Chem. Educ. 43, 306-309 (1966).
236. D. F. A. Koch and D. E. Scaife, J. Electrochem. Soc., 113, 302-305 (1966).
237. R. C. Propst, J. Electroanalyt. Chem., 16, No. 3, 319-326 (1968).
238. G. W. Wilner and D. Grossley, Analyst, 98, 429-432 (1973).
239. D. R. Kendall, Anal. Chem., 43, No. 7, 944-947 (1971).
240. W. Helbig, Z. Anal. Chem., 246, No. 6, 353-357 (1969).
241. S. I. Krichmar and T. M. Galan, Zavod. Lab., 38, No. 10, 1193-1194 (1972).
242. O. A. Songina, I. F. Mazalov, et al., Zh. Anal. Khim., 29, No. 10, 1971-1975 (1974).
243. A. N. Mogilevskii, I. G. Sentyurin, I. S. Sklyarenko, et al. in: Summaries of Papers. IV Polish Conf. on Anal. Chem., Warsaw. August 26-31 (1974), p. 77.
244. T. M. Chubukova and I. S. Sklyarenko. in: Summaries of Papers. IV Polish Conf. on Anal. Chem., Warsaw, August 26-31 (1974), p. 78.
245. I. G. Sentyurin, A.N. Mogilevskii, et al., Zh. Anal. Khim., No. 1, 53-58 (1975).
246. A. Sobkowska, Chem. Anal. (PRL), 15, No. 5, 959-964 (1970).