SPECTROPHOTOMETRIC METHODS FOR THE DETERMINATION OF COBALT: A REVIEW

R. Bhatnagar, I.R. Bishnoi
and D.N. Purohit

*Department of Chemistry
M.L. Sukhadia University
Udaipur, India*

CONTENTS

	Page
REVIEW	1
REFERENCES	105

Work done on the spectrophotometric determination of cobalt since 1975 is reviewed and presented in tabular form in the following pages. The available information is presented in five columns, viz. name of the reagent, λ max or working wave-length, pH, remarks and references. Under "remarks" the procedure, composition of the complex, sensitivity, interference studies, etc., are described in a condensed form.

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Xylenol orange	580 nm	6.0	Xylenol orange is reported to be the best reagent for the determination of cobalt in pure salts and rocks at pH 6 and with a 1.5 fold excess of reagent. λ_{max} is 580 nm, $\epsilon = 30,000$ and the composition is 1:1:1. Ni , Pb , Mn(II) , Cu(II) , Mg , Ca , Al , Fe oxalate and thiocyanate interfere. Permissible amounts of other species including masking agents (relative to Co) are: F^- 340; EDTA 100; H_2O_2 190; hydroxylamine 150; ascorbic acid 100; tartaric acid 50; triethanolamine 240.	1
Sulpharsolzen 5-nitro-2,3-(p sulphophenyl-azophenyl) 1-triazene benzeneacetic acid		10.0	Difference spectrophotometric determination of cobalt at pH 10 in rocks in presence of interfering elements is reported.	2

2-Mercapto benzoic acid	570 nm	5.2-7.2	The highly stable blue-violet 1:3 complex is formed between pH 5.2-7.2 at 20°C. The presence of ascorbic acid accelerates colour development and improves the sensitivity. The analytical range is 2.9-23 µg of Co in 10 ml of final solution. Cu, Ag and Cd are masked with thiourea. B, Fe, Mn, Mo, Ni, V and W would interfere separated from Co by addition of EDTA and preferential extraction of the cobalt complex into CHCl ₃ in the presence of pyridine-aq. NH ₃ .	3
2-Thiotholuric acid	413 nm	8.8	A 1:3 cobalt complex is formed at pH > 7.5. The absorption maximum is at 413 nm and the ε values of the complex and reagent are 63,000 and 200 respectively at pH 8.8. Under identical conditions, Ni forms a 1:1 complex with ε = 7200. The interference of Ni can be prevented by adding EDTA to the solution (pH 8.8) and a large excess of the Na-salt of the reagent. Details of determining Co in the presence of up to 100 fold amounts of Ni are also reported.	4
Bis(hydroxymethyl)one of diethyl 3- 4-dioxadipate (Kethionol)	386 nm		An aqueous solution containing 0.15-1 µg Co/ml is mixed with twice its volume of a 5 mM solution of the reagent prepared in 1:1 ethanol/cyclohexanone. The absorbance is measured at 386 nm after 3 hours. The precision is ± 1.16%.	5

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
5-D methyl-amino 2-nitrophenol	456 nm		To the sample and another solution containing the same amount of sample and known added amounts of Co add 5 ml of 40% Na-citrate dihydrate solution followed by 5 ml of 0.01M reagent in 0.01M HCl. Extract with 5 ml of 1,2-dichloroethane. The absorbance of the extract is measured at 456 nm against a reagent blank. The cobalt content of several salts of Na, K and Fe were found and of HC and NH_3 solutions.	6
4-(2-Pyridylazo) resorcinol	510 nm		It is reported that cobalt forms a 1:2 complex with this reagent in slightly acid or alkaline media. The colour of the Co-complex ($\epsilon=65,000$ at $\lambda_{\text{max}}=510$ nm) does not change with increase of pH. Studies of the Ni complex are also reported. The Ni complex changes from red at pH 3.3 ($\epsilon=37,200$ at $\lambda_{\text{max}}=520$ nm) to orange at pH 8.0 ($\epsilon=79,400$ at $\lambda_{\text{max}}=496$ nm). The change in colour has been attributed to different deprotonated species of the 1:2 Ni-complex.	7

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
Nitroso-R-salt in presence of diphenyl guanidine	520 nm	7-8	An adduct of the Co-nitroso-R-salt with diphenyl guanidine can be extracted into CHCl_3 in the presence of alkali meta salts. A procedure is described for extracting the Co (0.1 ppm)-Nitroso R-salt complex at pH 7-8 into CHCl_3 containing 5% of diphenyl guanidine. The absorbance of the extract is measured at 520 nm.	8
Tetraethyl di(1-iodio-5-ylazo)acetate	620 nm	~ 5.5	A procedure for the determination of cobalt in alloys in the presence of the cerium, sub-group elements is reported. The absorbance of the Co-complex at pH ≈ 5.5 is measured at 620 nm against H_2O . In this method elements of the cerium sub-group do not interfere up to 10,000 fold excess.	9

Name of the Reagent:	λ max. or working wave-length	pH	Remarks	Refs.
2,4,6-Tri-2(2-pyridyl)-1, 3,5-triazene	485 nm	8.5	The absorbance of the 1:2 complex in aqueous ethanolic medium pH 8.5, is measured at 485 nm with a 0.01M ethanolic solution of the reagent. Full colour development takes place in 45 minutes. The calibration graphs is rectilinear over the range 4-20 ppm with a coefficient of variation of $\approx 1\%$ (2 nd determination). The Pt group and several other metals (Fe, Ni and Cu) interfere.	10
1-(2-pyridylazo) phenanthrene 2-o	570 nm	1.15-10.5	Co(II) forms a 1:2 complex with this reagent with maximum absorption at 570 nm, pH 1.15-10.5. The complex is soluble in 70% methanol and in 1,4-dioxane; methanol:H ₂ O (3:10:7) and remains stable for 20 hr. Beer's law is obeyed up to 1.61 ppm Co. The optimum concentration is 0.49-0.98 ppm. The Sandell sensitivity index is 0.002 $\mu\text{g Co}/\text{m}^2, \epsilon = 30,900$. Sn^{2+} (5 ppm) interferes at pH 1.5 and PO_4^{3-} , tartrate, F^- , Hg(II) , Ga^+ , Mo(V) , V(V) and EDTA interfere serious at all pH values.	11

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
1-(7-(quinolylazo)phenyl)thiourea (QAP)	550 nm		The absorption maximum of the 1:2 complex (reagent in 10 fold molar excess) at pH 8.0 is reported to be at 550 nm ($\epsilon=51,200$). Beer's law is valid up to 2.2 ppm of cobalt. The optimum concentration range is 0.3-1.6 ppm. The Sandell sensitivity index is $0.00112 \mu\text{g}/\text{cm}^2$. CN^- , EDTA , Pd , Rh(III) , Al , Hg and transit on metals interfere. This reagent can be used as an indicator in the direct titration of Co(II) with EDTA at $20^\circ\text{--}60^\circ\text{C}$ in the pH range 7.6-9.4.	12
1,3-Diphenyl-3-thiopropane-1-one	410 nm	9.5	Used for the simultaneous determination of Ni and Co by extraction of the complexes into cyclohexane at pH 8.5, 9.5 and 9 for Ni, Co and sum of Ni and Co, respectively. The absorbance of Co is measured at 410 nm. This method is suitable for 0.065-0.65 μM Co. Citrate, tartrate, I^- , F^- , $\text{S}_2\text{O}_3^{2-}$ and SCN^- do not interfere. If salicylaldehyde is used as a masking agent, Co can be determined in the presence of a 100 fold amount of Ni.	13

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Thiohenoyltrifluoroacetone [1,1,1-trifluoro-4-mercapto-4-(2-thienyl) but-3-ene-2-one]	490 nm		The absorbance of the red orange Co complex extracted into CCl_4 at pH 6 is measured at 490 nm. Beer's law is obeyed for 0.5-6.0 $\mu\text{g Co/ml}$. The coefficient of variation is $\pm 1.0\%$ for 20 $\mu\text{g Co}$ (10 determinations). Out of 40 ionic species, Pd^{2+} , Pb^{2+} , Au^{3+} and N^{2+} interfere seriously, but Tl^{4+} , Sb^{3+} and MoO_4^{2-} can be removed by extraction or anion exchange; and Al^{3+} , Cr^{3+} , Mn^{2+} and Zr^{4+} can be masked.	14
2-Pyridyl-2-thienyl- β -ketoxime	412 nm		3 ml of 10% ethanolic reagent are added to the neutralised test solution (74.0 $\mu\text{g Co}$) containing 40% sodium citrate solution (5 ml) and water (25 ml) followed by addition of 10 ml of 11 M HCl after 10 minutes. After a further 10 minutes, the mixture is extracted with CHCl_3 . The absorbance is measured at 412 nm ($\epsilon=2000$). Beer's law validity is from 0.15-2.7 ppm. MnO_4^- , CrO_4^{2-} , EDTA, F^- , Pd^{2+} , Pt^{2+} and Pt^{4+} interfere.	15

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
3-(5-chloro-2-pyridylazo) pyridine, 2, 6-d amine	620 nm	5	The reagent forms a deep blue water-soluble complex with Co. To a test solution ($\approx 30 \mu\text{g Co}$) add 1 ml of 0.1% ethanolic reagent. Adjust the pH to 5 with HCl and sodium acetate acetate buffer. Measure the absorbance at 620 nm. Large amounts of Cl^- or Fe(III) interfere whereas several anions including PO_4^{3-} and tartrate can be tolerated.	16
Isonitroacetanilide-3-carboxylic acid 3-(3-hydroxyiminoacetamido) benzoic acid (I) Ethyl esters of isonitroacetanilide-4-carboxylic acid [4-(3-hydroxyiminoacetamido) benzoic acid] (II) Butyl esters of isonitroacetanilide-4-carboxylic acid [4-(3-hydroxyiminoacetamido) benzoic acid] (III)			These compounds form yellow and brownish-yellow complexes with Pd(II), Co, Cu, Ni, Fe(II), Fe(III), or Mn at the appropriate pH. In a alkaline solution II and III react with Co, Cu, Ni or Fe to yield complexes that can be extracted into CHCl_3 butylamine (3:1). Beer's law is obeyed from 0.5-5 $\mu\text{g/ml}$. A solid complex of Co with (I) is also reported.	17

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
8-Hydroxy-7-nitroso-quinoline-5-sulphonic acid	525 nm	5	This reagent is reported for the determination of 9-120 μM Co in the presence of 0.5 L of the reagent in an aqueous solution at pH 5. The absorbance is measured at 525 nm. Ca, Sr, Ba, Cd, Zn, Mg, Th, U(VI), Zr and W (up to 10 fold excess) and Cl^- , acetate, SO_4^{2-} and NO_3^- (up to 0.1 M) do not interfere, but Fe, Mn and Cr^{6+} do.	20
Biacetyl monoxime; semicarbazone (I)	330 nm	8.6	Reagent (I) is reported for the determination of various metal ions including Co(II). The optimum buffer solution, pH, wave-length, range of validity of Beer's law, respectively, are for Co(II)- H_3BO_3 -NaOH, 8.6, 330 nm, 1-8 ppm for Cu(II)-aq. NH_3 - NH_4Cl , 10, 335 nm, 1-5 ppm; and for Ni(II)- H_3BO_3 -NaOH, 11.4, 340 nm, 0.5-2.5 ppm. The corresponding parameters with reagent (II) are reported for Co(II)-aq. NH_3 - NH_4Cl , 10, 345 nm, 0.5-2.2 ppm and for Cu(II)- H_3BO_3 -NaOH, 9.5, 350 nm, 0.2-1.2 ppm.	21
Picolinaldehyde-semicarbazone (II)	345 nm	10		

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Salicylaldehyde isoni-cotinoyl- hydrazine	390-400 nm		This reagent forms water-insoluble 1:1 complexes with Co(II), Mn(II), Ni, Zn and Cd. The complexes are soluble in 1:1, 1-4 dioxane water. The absorption maxima for these are in the range 390-400 nm ($\epsilon = 1,000-25,000$). Beer's law is obeyed for metal concentration between 0.5-3 ppm.	22
Phenanthroline with thiosalicylic acid	450 nm		A method is reported for Co(II), Fe(II) and Ni(II) by extracting their mixed bio-phenanthroline-thiosalicylate complexes into CHCl_3 at pH 5-6 with λ_{max} at 450 nm ($\epsilon = 18,000$), 510 nm ($\epsilon = 12,400$) and 365 nm ($\epsilon = 10,000$), respectively. A method is reported for the simultaneous determination of Co and Fe in the presence of Ni.	23

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Thiobarbitolone (2-Mercaptothiobarbitolone)	500 nm	7.0	This reagent is used for the simultaneous determination of CO(II) and Ni(II). A 0.01 M reagent solution in CHCl_3 is added to a solution containing 6.0-25.0 μg Co and 7.5-47.5 μg Ni. The absorbance of the organic layer at pH 7 is read at 500 nm and 580 nm for Co and Ni, respectively. The metal:reagent ratio, Beer's law validity range, optimum concentration range and Sandell sensitivity index are 1:3, 2.6 ppm, 0.6-2.5 ppm and 0.0031 $\mu\text{g}/\text{cm}^2$ for Co and 1:2, 4.7 ppm, 0.75-4.57 ppm and 0.0048 $\mu\text{g}/\text{cm}^2$ for Ni(II). The tolerance levels for 32 cations and anions are reported.	24
2,2'-Bis(carboxymethyl) mercaptoethylether [(3-oxapentamethylene)dithio) diacetic acid]	490 nm		This reagent forms a 1:1 complex with Co(II), Cu(II), Ni(II) and Pd(II) and is used for determination of each of these metal ions. Beer's law is obeyed from 2.10-17.10 mM at 490 nm for CO(II); 0.02-0.16 mM and 0.41; 2.41 mM at 360 and 660 nm for Cu(II); ≈ 0.82 -7.3 mM at 380 and 600 nm for Ni(II) and 0.08-0.80 mM at 380 nm for Pd(II).	25

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Di-2 pyridyl ketoxime	388 nm	8.5	This reagent is useful for determining Co in the presence of a 150 fold excess of Ni. To the test solution, containing 18-40 μg of Co, add 3 ml of 40% aq. Na citrate and 5 ml of 1% ethanoic reagent, adjust to pH 8.5, leave for 5 min., then add 3 ml 11 M HCl and dilute to 25 ml with water. Measure the absorbance at 388 nm.	26
2, 4-D methyl benzamidoxime	578 nm		The test solution containing 1.5-75 μg Co(II) is mixed with 1 ml of 0.1 M ethanoic reagent and 1 ml of 2M NaOH in 50% ethanol. The mixture is diluted to 10 ml with water. The absorbance of the blue complex is measured at 578 nm after 30 min. There is interference from Cr(III), Fe(III), Mn(II), Ni(II), Cu(II), oxidising and reducing agents.	27

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Dimedon: [5,5-dimethylcyclohexane-1,3-dione] dioxim:	400 nm	9.9.5	The Co complex is stable for 1 hour at pH 9.9.5 and the absorbance is measured at 400 nm (λ_{max}). Interference from Cu and Ni is avoided by acidification and extraction of the Co-complex into iso-butyl methyl ketone with absorbance measurements between 370-380 nm.	28
3-Hydroxypicolinaldehyde salicylaldehyde and	545 nm 570 nm		Out of these three azines, the first, i.e. 3-hydroxypicolinaldehyde azine, is picolinaldehyde azines reported to be most suitable for Co. The composition is reported as 1:3:3 Co:R. To the test solution containing 4 - 40 μg Co add 4 ml of acetate buffer solution (pH 4.5) and 5 ml of 0.02% reagent solution in DMF. Heat at 50°C for 15 minutes. Cool, dilute the solution to 25 ml with water and measure the absorbance at 545 nm ($\epsilon = 30,400$) or 570 nm ($\epsilon = 26,600$) against H_2O . The interferences of various species are reported.	29
Quinoxaline-2,3-dithiol	540 nm	Acidic	Beer's law is obeyed up to 60 μg Co and the Sandell sensitivity index is $\approx 0.0011 \mu\text{g}/\text{cm}^2$. A 150 fold amount of Ni or 15 fold amount of Cu do not interfere. A Co determination in steel is also reported.	30

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
5-(2-Pyridylazo) toluene-2,4-diamine	561 nm	2-7 M HCl	In slightly acidic, neutral or alkaline medium, cobalt reacts with this reagent to form a yellowish brown complex which can be extracted (pH 4-11) with 3 methylbutanol or butyl phosphate. The sensitivity is not very good. The yellowish brown complex becomes violet in 2-7 M HCl. Cobalt can be determined (0.001-0.4 ppm) as the violet complex at 561 nm ($\epsilon=116,000$).	31
Di-(2 pyridyl) ketone pyridyl pydra one	480 nm (λ max) 500 nm	2-11 3-8	The complex is formed at pH 2-11 (λ max, 480 nm, $\epsilon=32,000$). To the test solution containing 5-50 μ g cobalt, and aq. NH_3 (to give pH 3-8) add ethanolic reagent. Pd(II) is removed by heating, Fe(II) should be oxidised to Fe(III). The reagent concentration must be increased to avoid interference of Cu(II), Fe(III) or Ni. Absorbance measurements are made at 500 nm ($\epsilon=42,000$). Beer's law is valid up to 2 ppm cobalt. The Sandell sensitivity index is 0.0014 $\mu\text{g}/\text{cm}^2$. There is no interference from a 500 fold excess of Zn, Pb, Cd, Mn(II), Ag, Hg(II), Cr(III), Al, In, Ga, Na, K, Ca, Sr, Ba, F^- , Cl^- , Br^- , SO_4^{2-} , NO_3^- , acetate, oxalate, citrate or tartrate.	32

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
7-Amino-8-hydroxy-quinoline	490 nm	4.0	The reagent forms a 1:1 complex with cobalt at pH 4.0 with λ_{max} at 490 nm ($\epsilon = 20,000$). Beer's law is valid in the range 0.4-4.0 μg cobalt per ml. Co is determined in steel and silicate rocks.	33
5-Chloro-3-hydroxy-7-iodoquinoline	430 nm	9.1-9.3	The 1:2 complex is extractable into CHCl_3 from an aqueous medium, optimum pH 9.1-9.3 ($\text{H}_3\text{BO}_3\text{-KCl-N}_2\text{CO}_3$ buffer) with λ_{max} at 430 nm ($\epsilon = 9350$). Measurements are made against a reagent blank. Beer's law is valid up to 5 ppm.	34
4-Hydroxy-5-nitro-2,1,3-thiadiazole (I)	470 nm	6	The Co(II) complex (1:3:1M R) formed with (I) at pH 6 is extracted into CHCl_3 for measurements at ≈ 470 nm. Beer's law is obeyed for 1-100 μg Co in 10 ml. Fe and Cd interfere, but Ni, Pb, Bi, Zn, Ba and Ca do not. Fe(II) forms a 1:2 complex with II at pH 5.6. It has a broad absorption band at 570-660 nm. Reagent II is suitable for the extractive photometric determination of Co(II) in various pharmaceutical preparations at 510, 490 and 510 nm.	35
5-Hydroxy-4-nitro-2,1,3-thiadiazole (II)	410, 490 & 510 nm	6		

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
3-Aminoquinoline-2 thio derivatives	428 nm	9.6	Three quinoline derivatives were tested and 3-Aminoquinoline-2 thio is reported to be the most suitable for Ni and Co determinations. To the solution of Co (30 μg) or Ni (50 μg) are added 5 ml NH_3 , NH_4Cl buffer solution pH 11.0 for Ni, 9.60 for Co. Add water and DVF with stirring. After 10 min., reagent is added and the solution is diluted with DMF. The absorbance is measured at 495 nm or 428 nm for Ni or Co, respectively, against a blank after 5 min. Slosh: interference is caused by Fe(III), Cu(II) and Pd II).	36
2 (2-Hydroxyphenylhydrazine zone) of ethyl 2-3 dicobaltate and Rhodamine 3B	565 nm	≈ 9	Co(III) forms a negatively charged 1:2 complex with the mixed hydrate at pH 9 and this complex forms a 1:1 ion association compound with Rhodamine 3B which is extracted into benzene. It has λ_{max} at 565 nm. Beer's law is obeyed for $0.03\text{--}0.8 \mu\text{g ml}^{-1}$ Co. A 20 fold amount of Zr, Cu or Mn(II) does not interfere.	37

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
Thiosalicydene-ethylene diamine [α' ethylenediamine di (toluene-2 thiol)]	470 nm	8.2	The colour development takes place at pH 8.2 (CH_3COONa) when a concentrated solution of the reagent is added to a Co (2.5-60 μg) solution. Water and acetone are added so that the final solution contains 75% acetone (v/v). It is left for 15 minutes and the absorbance is measured at 470 nm. Beer's law is obeyed for 2.5-60 $\mu\text{g ml}^{-1}$ Co and the Sandell sensitivity index is 0.01 $\mu\text{g cm}^{-2}$. The standard deviation was 0.022 $\mu\text{g ml}^{-1}$ ($n=10$). Halides, SO_3^{2-} , SO_4^{2-} , NO_2^- , NO_3^- , acetate, Hg, Al, and V(V) do not interfere, but CN^- , SCN^- , S^{2-} , $\text{S}_2\text{O}_3^{2-}$, EDTA, citrate, tartrate, Ni, Pd(II), Cu(II), Mg(II), Fe(II), Mo(II) and W(VI) do.	38
5-Hydroxymino barbituric acid (Violuric acid) and its derivatives	367 nm	7-10	Violuric acid and its 2-thio, 1,3 diphenyl and 1,3-diphenyl-2 thio-derivatives form 1:3 complexes with Co(III) in weakly acid or neutral media. The Co(III)-violuric acid complex at pH 7-10 has λ max at 367 nm ($\epsilon=42,000$) and Beer's law is obeyed for 2.4-30 μM Co(III). Once formed, the complex is stable even in 6M HCl. Co may be determined in the presence of a 300 fold amount of Ni because the Ni(II)-violuric acid complex is decomposed by HCl. The method has been used for determining $\approx 0.6-0.8\%$ Co in Ni.	39

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
Nitroxaminazo [4-amino-3-(2-hydroxy-5-nitro-1-sulphophenylazo)naphthalene-2,7-dicarboxylic acid]	622 nm	5.8-9.2	This reagent forms a 1:3 complex with Co(II) at pH 5.8-9.2. $\lambda_{\text{max}}=622$ nm ($\epsilon=33,200$). Beer's law is obeyed for 0.04-0.6 $\mu\text{g ml}^{-1}$ cobalt. Zn, W, Mo and 40 Mn do not interfere, but Ti, Cu, Ni and Fe do. The interfering species can be masked by $\text{P}_2\text{O}_7^{4-}$, oxalate, thiourea, NaF and tartrate. The reagent may be used for determining cobalt in steels. The coefficient of variation is <4.5% (7-11 results).	40
β -Dithionaphthol calcium[1-hydroxy-naphthalene-2-carboxithioic acid]	535 nm		The absorbance of the complex is measured at 535 nm against a reagent blank. The ϵ value is 55,000 and Beer's law is obeyed for 0.02-1.6 $\mu\text{g ml}^{-1}$ Co. Alkali metals and most common anions do not interfere, but the following do when present in the Co to metal ratio given in parentheses: Ni, Cu, Sn(II), Bi(III) (each 1:1); Pb(II), H ₂ (II), Ag, Cd, Fe(III), Al (each 1:10); Mn(II), Fe(II), Mg and Zn (each 1:100) and metals that form insoluble hydroxides (each 1:1000).	41

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
5-(8-Amino-1-hydroxy-3,6-disulpho-2-naphthyl azo)-1,2,4-triazole-3-carboxylic acid	610 nm			42
Phthalaldehyde bishiosemicarbazone	385 nm or 410	9.3	Co(II) is treated with a 0.1% solution of reagent in DMF at pH 9.3. The absorbance of the complex (1:1) is measured at 385 nm or 410 nm. Beer's law is obeyed up to 11 ppm of Co. Ni(II) is similarly determined at the same pH, but with measurement of the absorbance at 450 nm. Numerous cations interfere in both cases.	43
4-(2-Pyridyl azo) m-phenylenediamine	555 nm	1M HCl	A 1:2 complex is formed in an acidic medium and λ_{max} is at 555 nm ($\epsilon = 86,000$). Beer's law is obeyed for 0.04-1.2 $\mu\text{g ml}^{-1}$ Co. The following elements do not interfere (in the amounts w.r.t. Co shown in parenthesis): Cd or W (10,000); Mg, Al, Zn, Mo, Tl, Tl, Ga, Se, In, Ag, Sb(III), Pb, Sn(II) or Ni(1000); Mn, Ce, Se or Fe(III) (500); Cr (250); Bi or As(III) (100); Cu(50); V, Zr, Hg(II) or Be (≈ 10). The coefficient of variation is <9% (5 results).	44

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Chlorine azon DS [4-6-chlorindazol-3-ylazo-3-hydroxynaphthalene-2, 7-disulphonic acid]	512 nm	10.0	This reagent has been used for the simultaneous determination of Ni and Co in thin layers on mixture electronic components at pH 10 (ammoniacal buffer). Cobalt and nickel may also be determined when present in large quantities at 512 and 395 nm, respectively.	45
4-Ethyl-2-(2-thiazolyl azo) phenol			This reagent may be used both as a spectrophotometric reagent and metallo-chromic indicator for the determination of cobalt (II) as well as for Ca(II), Mn(II), Cu(II), Ni(II), Zn(II), Cd(II), Mg(II) and Pb(II).	46
Trois	340 nm	9.6	The absorbance of the complex is measured at 340 and pH 9.6. Beer's law is obeyed for 0.5-10 ppm Co(II). However, Ni(II), Fe(II), Fe(III), Cr(III), Cu(II) and Ti(IV) interfere. Tolerance limits (ppm) for some other species are Cd(15), Ag(10), Mn(II) (8), Pb(II) (12), Zr (12), Sr(II) (10), V(IV) (2), Zn (8), acetate (30), EDTA (40), CO_3^{2-} and oxalate (25). The optimum Co(II) range is 4-8 ppm.	47

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
3'-5'-Dichloro 2-hydroxy acetophenone oxime	400 nm or 420 nm	7.0-8.0	The complex, formed within 10 min., is extracted into CHCl_3 and the absorbance is measured at 400 or 420 nm. Beer's law is obeyed in the range 1.7-10 ppm Co(II) and the Sandell sensitivity index is $0.046 \mu\text{g cm}^{-2} \text{Co}$ at 420 nm. The tolerated amounts of foreign ions are listed.	48
Pyrazine carboxamide	380 nm	8-11	A 1:3 complex is formed at pH 8 with λ_{max} at 380 nm ($\epsilon = 0.500$). Beer's law is obeyed for 1-15 $\mu\text{g ml}^{-1} \text{Co}$. A 100 fold amount of Na, K, Ca or $\text{O}_2(\text{IV})$ and up to 100 $\mu\text{g ml}^{-1}$ of A, Zn, Sn(II) , Cr(III) , Al(III) , are tolerated, but Ag, Cu(II), Fe, Pb(II), Bi(III) and Hg(II) interfere as do large amounts of tartrate, citrate and EDTA. Standard deviations for the determination of 4, 5 and 8 $\mu\text{g m}^{-1} \text{Co}$ are 0.0835, 0.045 and 0.088 $\mu\text{g ml}^{-1}$, respectively. In ferrocobalt (1071 μg in 25 ml) and in cyanocobalamin (24.5 μg in 25 ml), the standard deviations are 2.7 and 0.5 μg , respectively.	49

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
3-Hydroxy-3 phenyl-1-(3 pyridyl) triazin	345-350 nm		Cobalt or Cu is determined in the presence of Fe. The complex is extracted into CHCl_3 and the absorbance is measured at 345-350 nm. Fe is masked with ascorbic acid in 2M NaOH in the determination of Co. The limit of detection is $0.1 \mu\text{g}$ of the cation	50
Di-2-pyridyl ketone thiosemicarbazone	415 nm	3.8-6.0	The preparation and spectra of the reagent are discussed. Besides Co(II), the reagent is also used for the spectrophotometric determination of Fe(II), Ni(II) and Cu(I). The pH range, λ_{max} (nm), ϵ values, Beer's law validity range (ppm) are respectively: Co(II)- 3.8-6.0, 415, 10,000, 1-5; Fe(II)-2.5-7.5, 620, 9300, 1-4; Ni(II)-6.0-6.9, 395, 1.96×10^4 , 0.5-2.5; Cu(I)-3.9-4.2, 395, 1.13×10^4 , 1-5.	51

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Acetothioacetophenylide [(4-amino)4-thiocobaltane-2'-on-1]	625 nm	> 8.4	In addition to Co(II), the reagent is also used for the spectrophotometric determination of Fe(III) and N (II). Cobalt (II), Fe(III) and Ni(II) form 1:3 and 1:2 complexes in eq. medium [pH > 8.4 for Co, 7.1-8.3 for Fe(III) and > 6.9 for Ni(II)] and may be extracted in CHCl_3 for spectrophotometry at 625 nm, 500 nm or 496 nm, respectively. Beer's law is obeyed for 20-200 $\mu\text{g ml}^{-1}$, 4-35 $\mu\text{g ml}^{-1}$ and up to 150 $\mu\text{g ml}^{-1}$ for Co, Fe and Ni, respectively. Mn(II) or Fe(III) may be masked for NH_4F , triethanolamine or sulphosalicylic acid.	52
6-Nitroquinoline-2,3-dithiol	530 nm	2.2	The complex is extracted with isobutyl methyl ketone and the absorbance is measured at 530 nm. The colour is stable for 30 min. Beer's law is obeyed up to 3.5 ppm Co. Serious interference arises from Ni(II), Cd, Pt(IV), Cu(II), Pd(IV) and EDTA.	53

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Bis azo derivatives of chromotropic acid	642 nm	1-2	The 3,6-bis-(3-sulphophenylazo) and 3,6-bis-(4-carboxy-phenylazo) derivatives of chromotropic acid (I & II) and 3-(2-carboxyphenylazo)-6-(4-sulphophenylazo) derivatives have been studied as spectrophotometric reagents for Co(II), Mn(II), Zn(II), Cu(II) and Ni(II). Reagent I is more sensitive for Co(II). However, the most sensitive colour reactions [reagent, medium, $\text{H}_2\text{O}(\%)$, λ_{max} (nm) and ϵ values] are for Co-I, propanol, 1-2; 42, 75,000; Mn-II, acetone, =3,720, 150,000; Zn-I, propanol, 1-2, 642, 76,000; Ni-II, acetone, 3-4, 728, 150,000.	54
Picolinylidinyde-2-pyridyl hydrazon- and eosin	547 nm	5.6	The ternary Co(II) complex is extracted into CHCl_3 -acetone. The absorbance is measured at 547 nm and Beer's law is obeyed for 0.04-0.4 ppm Co. The detection limit is 0.017 ppm. However, Cu(II), N (II), Fe(II), Pd(II) and Hg(II) interfere. Furthermore, a spectrophotometric method is also reported for Co(II) determinations.	55

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
1-Benzyl benzimidazole-2-aldoxime (I)	343 nm	9.2-12.2	A 1:2 cobalt complex is formed with I & II with λ_{max} at 343 nm ($\epsilon=23,000$) and at 325 nm ($\epsilon=17,000$), respectively. The optimum pH range for the Co-I complex is 9.2-12.2 and for Co-II 6.5-11. In addition to cobalt, a photometric determination of Cu is also reported for the 1:1 Cu-complex formed with I & II is extracted into CHCl_3 . The extract has $\lambda_{\text{max}}=337$ nm ($\epsilon=14,500$) and at 340 nm ($\epsilon=10,500$), respectively. There is no interference from alkali or alkaline earth metals.	56
Benzimidazole-2-carboxanilide oxime (II)	325 nm	6.5-11		
4-Amino-5-nitrosopyrimidine-2,6-diol	355 nm	3.7-8	Co(II) forms a yellow 1:3 complex at pH 3.7-8.0. The complex exhibits λ_{max} at 355 nm ($\epsilon=65,000$). Full colour development requires a 25 fold excess of I and heating for 10 min (pH 5.0) or 30 min. (pH <5). The standard deviation is 0.0052 ppm ($n=8$) for 0.5-1.2 ppm. Co(II), EDTA and Pd(II) interfere while Ru(III) does not (for 1 ppm Co(II)) if the reagent is added in 200 fold excess.	57

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
4-(2-Pyridylazo) resorcinol	536 nm	8	The determination of Co in enrichment products of iron ore is reported. The ore is decomposed in acid. The pH is adjusted to 8 and reagent is added followed by H_2SO_4 and H_2O . The absorbance is measured within 30 min. at 536 nm ($\epsilon = 15,400$). If the content of Fe is $> 5\%$, Fe must be added to the blank.	58
Picolinaldehyde-4-phenyl-3-thiosemicarbazone	430 nm	1	The reagent is reported for determining both cobalt and nickel. Cobalt is determined at 430 nm and pH 1, whereas Ni is determined at 390 nm and in the pH range 8-9. The determination of Ni in the presence of divalent ions is reported.	59
Salicylaldehyde hydrazine	430 nm	6.2-7.0	This reagent is used for the determination of Co and Fe. The cobalt complex is formed between pH 6-7, extracted into CCl_4 and the absorbance measured at 450 nm ($\epsilon = 4081$). The Sandell sensitivity index is 5 ng cm^{-2} , and Beer's law is obeyed for 0.58-2.32 $\mu\text{g/ml}$. The iron complex is formed between 3.5-5 with λ_{max} at 510 nm ($\epsilon = 7300$). The Sandell sensitivity index is 14 ng cm^{-2} and Beer's law is obeyed for 0.72-23.6 $\mu\text{g/ml}$.	60

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Nitron acetate	550 nm		This method is based on quantitative precipitation of a blue 2:1 complex between nitron and tetrathiocyanato cobaltate in the presence of excess SCN^- . To the sample solution containing 0.12-0.5 mg Co, are added 2 ml of 4M KSCN, 3 ml of 10% aq. Na_2SO_4 and sufficient water to make up to 50 ml. This solution is rapidly titrated with 2 mM nitron acetate. Absorbance measurements are made at 550 nm. Most heavy metal ions (MoO_4^{2-} , WO_4^{2-} , CrO_4^{2-} , Pb^{2+} , Ni^{2+} and Cd^{2+}) are tolerated, but Zn and Cu interfere, and Fe(III) must be masked by NaF. The maximum error is $\pm 1.5\%$ for 1-2 mM Co.	61
Ethylendianrinbis (acetyl acetone); [5,8-diaza-4,9-dimethyl dodeca-4,8-diene-2, 11-dione]	345 nm	10.0	The 1:1 complex exhibits λ_{max} at 345 nm ($\epsilon=3500$) at pH 10. Beer's law is obeyed for 1.2-31 $\mu\text{g ml}^{-1}$ Co. Iron (III) and Cu(II) interfere, but can be removed. Milligram amounts of making agents, anions and metal ions do not interfere. The method is used for determining 24.5% Co in an alloy containing 14.9% Ni, 47.5% Fe, 3.9% Cu, 8.2% Al and 0.8% Nb. The relative error is $< \pm 3.3\%$.	62

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
3-Hydroxy-piccolinaldehyde thiosemicarbazone	450 nm or 460 nm	7.0-9.5 or 460 nm	The synthesis and colour reactions of this reagent with Co(II), Ni(II), Cu(II), Fe(II) and Fe(III) are reported and compared with those of other reagents. It may be used for the determination of 15-175 μg Co(II) at pH 7.0-9.5 or 150-300 μg at pH 1.0-3.0. The absorbance is measured at 450 or 460 nm. Beer's law is obeyed for 0.3-3.5 ppm and 1-6 ppm, respectively. The relative error is $< \pm 0.9\%$. Interfering species were fewer at pH 1.0-3.0. No interference occurs from 100 ppm Fe(II), Zn or Cd, whereas 150 ppm Ni or Fe(III) interferes.	63
8-Hydroxyquinoline	415 nm	5-8.5	The spectrophotometric determination of Co(II), Ni(II) and Mo(IV) may be effected with this reagent (after extraction of the complexes into molten naphthalene at pH 5.0-8.5, 5.0-8.0 or 3.7-4.5, respectively. The solidified naphthalene phase is extracted with DMF and the absorbance of the solution is measured at 415, 410 or 370 nm. Beer's law is obeyed for 6-100 μg , 10-120 μg and 14-107 μg Co, Ni and Mo, respectively. The corresponding ϵ values are 8900, 7600 and 6100.	64

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
8. Hydroxy-7-nitrosoquinoline-5-sulphonic acid	520-530 nm		Add 5 ml of a saturated solution of the reagent to the test solution containing 50 μM -0.5 mM Co. Adjust the pH to 5 with a N1-acetate-acetic acid buffer. After 1 min HCl is added to give pH ≈ 0 . The absorbance is measured at 520-530 nm for Co and at 705 nm for Fe. It is reported that Cu(II), Ni(II), Zn, Mn(II), U(VI), Hg(II), As(III), Ba, Mg, Ca, Na-citrate, lactate and $\text{S}_2\text{O}_3^{2-}$ are tolerated in 100 fold excess and V(IV), Th, W and Ag in 25 fold excess.	65
2,4-Dihydroxy-3-nitro-pyridine	412 nm	3.5	The reagent is prepared by nitration of 2,4-Dihydroxypyridine. For 30-100 μg Cobalt, 5 ml of NaAc-Acetic acid buffer solution are added, and after 15 minutes the absorbance is measured at 412 nm. The reagent may also be used for the determination of 25-175 μg Fe to which 1% quinole solution has been added in addition to the reagent and buffer solution. The absorbance is measured at 655 nm.	66

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Furfural- α -methyl-oxime	405-410 nm	2.5-7	The complex of Co(III) is formed at pH 2.5-7 and is extracted into benzene; the absorbance is measured between 405-410 nm. Interference by Ni, Cu or Mn is prevented by making the aq. solution strongly acidic. Fe and Al are masked with NaF. Platinum and Pd interfere. This method may be applied to iron samples containing 0.08-0.25 % Co.	67
2,6-Dihydroxy-3-(2-thiazolylazo)benzoic acid	560 nm	6.5	Beer's law for the red complex is obeyed for 0.26-1.3 ppm Co. Many cations and some anions interfere.	68
4-Hydroxy-3-nitrobenzophthalene-1-sulphonic acid	312 or 368 nm		The cobalt complex is extracted into CHCl_3 and its absorption is measured at 213 or 368 nm. There is no interference from Ni (0.01M) or Fe(III) (0.1 mM). This method may be used to determine Co (up to 15 μM at 312 nm) in solutions of Ni-salts.	69

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
O-Nitrosophenol	420 nm	4.0	The reagent (HR) is generated in situ and forms a complex, CoR_3 , at pH 4 [Co(II) is oxidised to Co(III)]. The complex is extracted into CHCl_3 with λ_{max} at 420 nm ($\epsilon=40,000$). The method has been used to determine Co ($>0.1\%$). The reagent generated in situ may also be used for the determination of Fe(III) at 690 nm ($\epsilon=15,000$) with pH 4-8.	70
Phenylazobenzaldoxime	530 nm		After adding the reagent, the solution is diluted with ethanol. The purple-brown complex takes 30 minutes for full colour development. The absorbance is measured at 530 nm and Beer's law is obeyed with 0.6-3.5 ppm Co(II). Various foreign ions are tolerated in 20 fold excess, but Cu(II), Ni(II), Pd(II), Rh(II), Au(III) and EDIA should be absent. The analogous 4-methoxy-2- and 4-chloro and 2,3 and 4 nitrophenylazo compounds can also be used as reagents.	71

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
1,10-Phenanthroline-'pheoxine'	570 nm	5-9	The ternary complex $[\text{Me}^-(\text{phen})_2]^{2+} [\text{phiox}]^{2-}$ where Me^+ is Co, Ni or Zn, phen is 1,10-phenanthroline and phiox is 'ph oxine' (tetrabromochlorofluorescein, Na salt) in aqueous solution at pH 5-9, has an absorption maximum at 570 nm and can be used for the determination of these metals. Beer's law is obeyed for 2.94-35.34 $\mu\text{g Co}$, 3.27-40 $\mu\text{g Zn}$ or 2.93-35.22 $\mu\text{g Ni}$ in 25 ml of solution.	72
1-(2-Quinolylazo)-2-acenaphthylidene	550 nm		Try the sample solution containing 2-9 $\mu\text{g Co}$ add an excess of a 2 mM solution of the reagent in methanol and 2-4 ml 2M- Na-acetate. The final solution (10 ml) should be 50% v v methanol. The Co- complex is extracted into 10 ml of CCl_4 from the solution and its absorbance is measured at 550 nm. The reagent may also be used in the spectrophotometric determination of Ni and Cu under similar conditions with the absorbance measured at 560 nm and 545 nm, respectively. Cyanide, PO_4^{3-} , citrate, EDTA, Fe(II), Zn and several other species interfere.	73

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
1-(5-Mercapto-1,3,4-thiadiazol-2-ylazo)-2-naphthol (I)	680 nm	9.2	Both these reagents form complexes with Co(II) at pH 9.2. Beer's law is obeyed for 0.06-1.65 $\mu\text{g ml}^{-1}$ Co at 680 nm for I and for 0.06-1.47 $\mu\text{g ml}^{-1}$ Co at 560 nm for II. Co(II) may be determined in several pharmaceuticals with either reagent.	74
4-(1,3,4-Thiadiazol-2-ylazo)resorcinol (II)	560 nm	9.2		
Rubeanic acid (dithio-oxamide) and piperidine	440 nm	11.4	An aliquot of test solution (containing up to 0.1 m of Co) is treated with 1 ml of 0.1% ethanolic rubeanic acid and 4 ml of aq. 10% piperidine. The solution is diluted to 20 ml with 90% ethanol, and the pH adjusted to 11.4 before diluting to 25 ml with H_2O . The absorbance is measured at 440 nm. Beer's law is obeyed for 0.5-5 ppm Co and the Sandell sensitivity index is 4.8 mg/cm^2 . Phosphate, EDTA, B., Zn, Cd, Hg(I), Hg(II), Pd and Cr interfere even at low concentration, the tolerance levels for other cations and anions are reported.	75

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Zincon	665 nm	7.5	A violet 1:1 complex turning green is formed with Co(II) at pH 7.5 (imidazole-HClO ₄ buffer solution). The green complex shows λ_{max} at 665 nm ($\epsilon = 1.7 \times 10^4$). Beer's law is obeyed over the range 0.3-8 ppm Co; the Sandell sensitivity index is 3.5 ng/cm ² .	76
Nitritotriacetic acid	510 nm		The Co(II) solution (0.025-0.4 mM) is placed in a 10 ml flask. Then 12% NTA solution in aq. 14.4% Na acetate (1 ml) is added and the solution is diluted to 10 ml. The absorbance is measured at 510 nm after 30 minutes. Mn(II), Fe(II) does not interfere. The interference of Fe(III) may be overcome by prior reduction. The reagent also forms complexes with Ni and Cu having maximum absorbance at 392 and 850 nm, respectively. Binary mixtures containing Co and Ni and also Co and Cu may be analysed. Co can be determined in the presence of 1.75 times excesses of Ni or Cu.	77

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Di-2 pyridyl ketoneazine	435 nm	Ammoniacal niacal buffer	This reagent reacts with Co(II) to form a 2:3 complex in an ammoniacal buffer solution; the absorbance is measured at 435 nm. Beer's law is valid for 2-14 ppm cobalt. With Ni(II), it forms a 1:1 complex at pH 4.5, which can be determined at 360 nm or, after extraction into CHCl_3 , at 370 nm.	78
2,4,6 Triamino-5-micro pyrimidine	380 nm	4.6-6.5	This reagent is used to determine 0.6-2 ppm Co(II) or Fe(II); 1-4 ppm Ru(III) or 5-30 ppm Ir(III) in the respective pH ranges 4.6-6.5; 6.6-8.0; 1.1-3.5 or 4.5-7.0. The corresponding absorption maxima of the complex species are 380, 640, 510 and 375 nm.	79

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
2-Mercaptobenzo- γ -thiopyrone [2-mercapto-4-thiochrome]	350 nm	6.5-9.8	The reagent (as a 1% aq. solution) reacts with μg amounts of Co(II) at pH 6.5-9.5 and of Ni(II) at pH 5-10 to form coloured complexes. The complex is extracted into ethyl acetate (for Co) or CHCl_3 (for Ni). The absorbance of the cobalt complex is measured at 350 nm while that of the Ni-complex is measured at 415 nm. The sensitivity for both is $\approx 3 \text{ ng/cm}^2$. Many common ions are tolerated, but V(VI) , U(VI) , Re(V) , Se(IV) , Fe(III) , Cu(II) and Ag interfere seriously. The mean error is $\approx 1.6\%$ for Co (0.6-5.5 ppm).	80
2-Carboxyl-2'-hydroxyl-3', 5'-dimethylazobenzene-4-sulphonic [2-(2-hydroxy-3,5-xylyazo)-5-sulpho benzoic] acid	630 nm	7.5	In the presence of a six fold excess of the reagent, a 1:2 cobalt complex is formed at pH 7.5 with maximum absorbance at 630 nm ($\epsilon=4100$). The Sandell sensitivity index is $0.053 \mu\text{g/cm}^2$ and Beer's law is obeyed for 0.58-2.35 ppm cobalt. Mn(II) , Zn , oxalate, tartrate, citrate and EDTA interfere.	81

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
5-Chlorothiophen-2-ylidenehydrazine	423 nm	7.2-9.1	To the test solution are added 1 ml of M-Na tartrate, 1 ml of 0.082% ethanolic reagent solution, 2 ml of aq. borate buffer, pH 8 and 1 ml of M-KNO ₃ and the solution is extracted with 10 ml of benzene for 10 min. The absorbance of the extract is measured against a reagent blank. The absorption max. is at 425 nm ($\epsilon = 74,000$). Beer's law is obeyed for up to 8 μ g Co. Of 15 species studies Ag, Al, Cr(III), Cu(II), Fe(III), Hg(II), Ni(II), V(IV) and Zn seriously interfere, but Al and Fe(III) may be masked by sodium tartrate. Ag, Cu(II), Hg(II), Ni, V and Zn were removed by washing the extract with H ₂ SO ₄ .	82
2-Methyl-(4-nitroso) resorcinol	400 nm	4.6	Co(III) forms a 1:3 complex with maximum absorbance at 400 nm ($\epsilon = 37,500$) and 292 nm. 0.1-2.1 ppm Co can be determined at pH 4.6 (acetate buffer). The effects of 29 foreign species are listed: V(IV), V(V), Cr(III), Ni(II), EDTA and 1,2-diaminocyclohexanetetra acetate cause serious interference.	83

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2-Salicylindeneamino benzene-thio	450 nm	6.3-7.0	An extractive photometric determination of cobalt is reported. To the sample solution (10-30 ml) containing 65 μg of Co are added 1 ml of M-acetic acid and 1M Na-acetate buffer to adjust the pH to 6.5. Then 1 ml of ethanolic 0.1% reagent is added and solution is diluted to ≈ 50 ml with H_2O . The cobalt chelate is extracted with 10 ml of CHCl_3 . The absorbance of the extract is measured at 450 nm ($\epsilon=9400$). Beer's law is obeyed for up to 6.5 $\mu\text{g ml}^{-1}$ Co in CHCl_3 . The determination of Co in high speed steel is also reported.	84
6-Nitroquinoxaline-2,3-d thio	530 nm	2.1	The simultaneous determination of Co(II) and Ni(II) with this reagent is reported. To the solution (3-15 μg Co and 4-27 μg of Ni) add 5 ml of 0.5% reagent solution in concentrated NH_3 . Add conc. NH_3 to make it strongly alkaline. Adjust the solution to pH 2.1, extract with isobutyl methyl ketone (2×4 ml), dry the extract with Na_2SO_4 , dilute to 10 ml and measure the absorbance at 530 and 710 nm against reagent blanks. Rare-earth metals, Mg, Ti, Tl, In, Ga, Te, Ag, Au, Al, As and common ions do not interfere, but Cu(II), Pd, Pt and Os (VIII) must be removed.	85

Name of the Reagent	$\lambda_{\text{max.}}$ working wave-length	pH	Remarks	Refs.
Nicro-R-salt	Green filter	≈ 6	Traces of Co in agrochemical samples have been determined. Samples are digested with HCl and $\text{HN}(\text{O}_3)_2$, buffered with N-acetate to pH ≈ 6 , and reagent is added. The color develops on boiling. The absorption is measured (green filter) and Co is determined with the help of a calibration curve prepared from a standard Co solution.	86
Quinolyazo-E [8-Hydroxy-7(8-quinolyazo)-naphthalene-1,6-disulphonic acid	582 nm	4.8	To 5 ml portion of a solution containing 42 mg Fe, 5 mg Mn and 1 mg each of Ni and Al, 0.5 mg each of Cr and V and 0.125 mg of Ti were added different amounts (2.5-25 mg) of Co. Each mixture was treated with 1 ml of 10% K-oxalate, 7.5 ml of 15% $\text{Ni}_2\text{P}_4\text{O}_7$ solution and, after 10 minutes, 1 ml each of 50% sodium tartrate and 2% NaF and 0.5 ml of 5M-HCl. After 30 minutes 0.1% reagent and 4 ml of H_2SO_4 (1:1) are added and the absorbance is measured at 582 nm.	87

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
4-(2-Pyridylazo) resorcinol	560 nm	5.0	A method is reported for the extractive photometric determination of Co, Fe, Zr and Nb when present together. To determine Co the initial sample solution is treated with 20 ml of 0.1% of the reagent, 10 ml of acetate buffer solution (pH 5) and sufficient 1M-NaOH to give a pH of 5. After colour formation, 12 ml of H_2SO_4 (1:5) are added and the volume is made up to 100 with water. The absorbance is measured at 560 nm. Procedures for the determination of Fe, Zr and Nb are also described.	88
Thiochrome in the presence of Triton-X-100	628 nm	4.7	Co(II) is determined by its reaction with SCN^- in the presence of Tri on X-100 at 628 nm ($\epsilon=1770$) and pH 4.7. Best results are obtained at a SCN^- conc. of 1.25M and a Triton-X-100 conc. of 2.5%. Beer's law is obeyed for 10 μM of Co. Cadmium may be masked by further addition of Tri on X-100, $\text{F}_2(\text{III})$ by addition of F^- and Cu(II) by addition of hydroxylammonium chloride.	89

Name of the Reagen.	λ_{max} or working wave-length	pH	Remarks	R:fs.
3-Hydroxy-1-phenyl-3-pyrazol-5-yl triazene	410 nm	8-10	This reagent is reported for the separation and determination of Ni, Co and Cu. The metals may be determined sequentially by extraction of Cu at Ph 4.6 and measurement at 400 nm ($\epsilon = 19,300$) and extraction of Ni at ph 8.6 in the presence of NH_3 at 420 nm ($\epsilon = 11,500$). After H_2O_2 exudation of Co(II) to Co(III) and elimination of NH_3 at pH 8-10, Co is extracted and measured at 410 nm ($\epsilon = 27,400$).	90
Sodium DCTA (diamino-cyclohexanetetra acetate)	540 nm	4	The method is based on catalytic oxidation of Co(II) to Co(III) by a 2-3 fold excess of Hg(II) in the presence of excess of Na_2DCTA . The pH is adjusted to 4 with acetate buffer, 2 ml of mercury (II) is added and the mixture is shaken for 5 minutes; Hg is filtered off. The filtrate is diluted to 50 or 100 ml and the absorbance is measured at 540 nm. Beer's law is obeyed for up to 155 ppm of Co(III). Cations that form a coloured complex with DCTA interfere.	91

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
5-Isoxypropyl-4-(2-pyridylazo)-o-cresol	630 nm	6-9	This reagent forms an insoluble complex with Co^{2+} in aq. medium, pH 6-9. It is extracted by CHCl_3 after making the aq. phase 3M in H_2SO_4 . It exhibits max. absorption at 630 nm ($\epsilon=9600$). Beer's law is obeyed for 0.5-10 $\mu\text{g Co}$. Fe(III) and Ni do not interfere. The method may be used to determine 5-10% of Co in steel. Other analogues have been reported for the determination of Ni(II) .	92
Uranyl diacetic acid	266 nm	3.6-6.1	The composition of the Co complex is reported as 1:1 with an absorption max. at 266 nm ($\epsilon=6400$). Beer's law is obeyed for 0.24-9.80 $\mu\text{g Co}$. The Sandell sensitivity index is 9 ng cm^{-2} . The complex is stable for 2 days and is unaffected by heating to 100°C .	93

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
[2-Amino-7-(2-aminophenyl)-5-naphthalene-1,6-disulphonic acid]	580-582 nm	5.6-7.4	The 1:1 Co-complex formed at pH 5.6-7.4 exhibits max. absorbance at 580-582 nm ($\epsilon = 18,600$). To determine the complex the solution is treated with dil. H_2SO_4 , 20 minutes after mixing the reagents. The sensitivity of the method is $0.36 \mu\text{g Co}$. The method may be used to determine Co in steel or aluminosilicate rocks.	94
2,4-Dihydroxydithiobenzoic acid			The reagent can exist in three anionic forms according to the pH value. It forms 1:2 complexes with Co(II) and Ni(II) and a 1:3 complex with Fe(III) . Beer's law is obeyed for 2, 6 and $8 \mu\text{g ml}^{-1}$ of these metals. The i.r., U.V.-visible spectra of the reagent and complexes are presented. Ag, Pb(II), Hg(I), Hg(II), Cd, Cu, Bi(II), Sb(III), Zn, La, Al, Fe(CN)_6^{4-} tartrate and oxalate interfere when present in equimolar quantities.	95

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
Ammonium thiocyanate and crown ethers	623 nm	1-7	A procedure for the determination of Co is reported. A solution of Co ($2 \mu\text{M}$) is mixed with 20 mM of NH_4SCN and 0.5 mM of 18-crown-6 in a total volume of 25 ml. The pH is adjusted to 1-7 and the mixture is shaken for 10 minutes with 10 ml of 1,2 dichloroethane. The absorbance of the organic layer is measured at 623 nm. The calibration graph is rectilinear for 0.1 mM Co. Extraction is adversely affected by Fe when more than one third of the concentration of the Co is present	96
Mercurion [4-(5-hydroxy-3,4-bis(hydroxymethyl)-4-methyl-2-pyridyl azo)benzene sulphonamide]	510-520 nm	6.9-8.3	A pink-violet cobalt complex in acetone- H_2O (2:1) is formed at pH 6.9-8.3 with λ_{max} at 510-520 nm. The limit of determination is $0.04-0.1 \mu\text{g ml}^{-1}$ Co.	97

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2-Pyridyl 2-thienyl- β -ketoxime	412 nm	9.0	Co in lake or river water is concentrated by extraction (as its complex with 2-nitroso-1-naphthol) into CHCl_3 . The extract is digested with H_2SO_4 , HNO_3 and HClO_4 , evaporated to dryness and the residue is dissolved in 0.1M HCl. The complex formed by buffering at pH 9.0 in the presence of citrate is extracted by CHCl_3 and its absorbance is measured at 412 nm. Beer's law is obeyed for 0.05-0.6 ppm Co in the final extract. The range of method is 0.15-14 ppb in the sample. The effect of various metals, anions and humic acids is discussed.	98
2',4'-Dihydroxyvalerophenone oxime	400 nm	7.0-9.5	This reagent forms a 1:2 complex with Co(II) in a medium containing 25% ethanol at pH 7.0-9.5. The complex is extracted into CHCl_3 and has λ_{max} at 400 nm. Beer's law is obeyed for 2-160 ppm Co. The Sandell sensitivity index is 20 ng/cm^2 . In determining 30 ppm Co there is no interference from 2000 ppm of Cl^- , SO_4^{2-} or acetate; 1000 ppm of NH_4^+ , K, NO_3^- , Cl^- , Br^- or I^- ; 750 ppm of SO_3 ; 500 ppm of citrate, tartrate, Ba, Sr or Ca or 200 ppm of An, Cd or Be. However, Cu(II), Pd(II), Fe(III), U(VI), Mn(II) and Ni interfere seriously.	99

Name of the Reagent	λ max or working wave-length	pH	Remarks	Refs.
2-Pyridyl-2-thienyl- β -ketoxime	412 nm	8.6	A method is described for Co in refined iron and A.R. grade iron salts. After dissolution of the sample in acid, Co forms a complex with the reagent at pH 8.6 (aq. NaOH) with citrate. The mixture is then made $\approx$ in HCl. The complex is extracted by CHCl_3 and the absorbance is measured at 412 nm in a 4 cm cell. Beer's law is obeyed for 0.05-0.6 ppm. Amounts of Mn(II), Cu(II) and Ni up to 9, 30 and 50 times that of cobalt do not interfere.	100
Furoin thiosemicarbazone	365 nm	7.5	At pH 7.4 a Co complex is formed with excess of reagent {0.25% solution in $\text{H}_2\text{O}-\text{CH}_3\text{OH}$ (1:1)}. The absorbance is measured at 365 nm ($\epsilon = 8095$). Beer's law is obeyed for up to 10 ppm Co. Ni (which must be absent), Mn(II) and Fe(III) interfere; however, Mn and Fe, up to 30 μm each, can be masked with F^- .	101

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
N-Methyl aminothioformyl-N'-Phenyl-hydroxylamine [N-hydroxy-N'-methyl-N phenylthiourea]	470 nm	8	Cobalt forms a 1:2 complex at pH $\approx$ 8 and the absorbance (in 40% ethanol) is measured at 470 nm ($\epsilon = 16,500$). Beer's law is obeyed for 6-60 μ M Co. It is reported that 500 ppm of Zn, Cd, Pb or Mn(II). 0.4 mg of MoO_4^{2-} , 0.25 mg of VO_4^{2-} or 1.5 mg of U do not interfere.	102
Violic acid and Zephiramine	372 nm	7.5-8.5	The test solution is treated with 4 mM violic acid, the pH adjusted to 7.5-8.5 with H_3BO_3 . $\text{KCl-Na}_2\text{B}_4\text{O}_7$ and water added. After 30 min. Zephiramine is added and the complex is extracted into 10 ml CHCl_3 . The organic phase is dried over Na_2SO_4 and the absorbance is measured at 372 nm ($\epsilon = 210,000$). Beer's law is obeyed for up to 12 μ g Co in the extract. The molar ratio of Co to violic acid is 1:3.	103

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
Meraptoquinoline (I) with 1,10 Phenanthroline (II)	465 nm	4-10	Add 5 ml of ascorbic acid and 1 ml of 0.2% (I) solution to a sample solution containing $\leq 50 \mu\text{g Co}$. The pH is adjusted to 5 and the solution is diluted to 30 ml with H_2O . Then 5 ml of 0.1% (II) solution are added and the ternary complex is extracted into 10 ml CHCl_3 . The CHCl_3 phase is washed with 20 ml of 2M HCl and the absorbance is measured at 465 nm ($\epsilon = 11,500$) at pH 4-10. A method is also reported for the determination of Co in high speed steel.	104
6-Amino-2-benzylthio-5-nitro-3,4-dihydro pyrimidin-4-one	410 nm	2-6	The sample solution containing 1-9 $\mu\text{g of Co}$ is treated with 3 ml of 0.01M ethanolic reagent solution, the pH adjusted to 3 (1 ml acetate buffer) and the mixture diluted to 10 ml and extracted with 10 ml of CHCl_3 . The extract is washed with 10 ml of 3M HCl and 10 ml H_2O . The absorbance is measured at 410 nm ($\epsilon = 61,200$) at pH 2-6 against a reagent blank. Beer's law is obeyed for 1-9 $\mu\text{g Co}$ in 10 ml. Up to 25 μg each of Cr(III) , Fe(II) and Mn(II) and up to 50 μg of Ni(II) and Mg(II) do not interfere.	105

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
Ammonium thiocyanate	600 nm		A Co(II) SCN ⁻ complex is formed in Aq. 50 % acetone containing 5 % of NH ₄ SCN. The absorbance of the complex is measured at ≈ 600 nm against a reference solution containing 5-7 $\mu\text{g ml}^{-1}$ of Co and this reagent. Beer's law is obeyed for 1-10 $\mu\text{g ml}^{-1}$ Co. The method is used for determining $\approx 18-32\%$ of Co-Te semiconductor, the coefficient of variation is $< 0.4\%$ ($n=5$). Up to a 100 fold amount of Te (relative to Co) does not interfere.	106
1,2-Diaminoanthraquinone	690 nm		The absorbance of the 1:3 Co-ligand complex is measured at 690 nm. For 1-2.5 ppm Co the error ranges from 0.40 to 1%.	107
Di-2-pyridyl (ketone) pyrimidin-2-yl-hydrazone	460 nm 440 nm	2.5-11.5 2.5 - 6.5M HClO ₄	Co forms a 1:2 complex at pH 2.5-11.5 with a 3 fold molar excess of reagent (in 95 % ethanol). It has $\lambda_{\text{max}} = 440$ nm ($\epsilon = 29,500$) and Beer's law is obeyed for up to 2.1 ppm Co. The optimum analytical range is 0.47-1.99 ppm. The wave-length of max absorption shifts to 440 nm ($\epsilon = 31,500$) when HClO ₄ is added. The sensitivity of the method is greatly enhanced in a more acid medium.	108

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
Chlorindazon DS [4-(6-chlorindazol-3-ylazo)-3-hydroxy naphthalene-2, 7-disulphonic acid]	638 nm	6.5	A procedure is reported for the accurate determination of Co in steel. To the sample solution (containing <140 $\mu\text{g Co}$) are added 0.1% reagent in dil. aq. NH_3 (6.3 ml) and KH_2PO_4 -NaOH (pH 6.5) buffer. The mixture is heated at 60°C for 20 min (or 100°C for 5 min.) and the volume of the cool solution is made up to 100 ml. The absorbance of the 1:3 cobalt complex is measured at 638 nm. The analytical range is 0.4-1.4 ppm and the Sandell sensitivity index is $\approx 2 \text{ } \mu\text{g cm}^{-2}$. The coefficient of variation is 0.5% ($n=10$) for 1 ppm.	109
2-Ethyl hexyl mercapto acetate	494 nm	7.6-9	A 1:2 complex is formed at pH 7.5-9 (ammoniacal acetate) and is extracted into CHCl_3 with λ_{max} at 494 nm ($\epsilon = 16,700$). Beer's law is obeyed for 0.5-5 $\mu\text{g ml}^{-1}$. Cr(II) (a 500 fold molar excess of reagent is needed), Mo, W(VI), V(V), Cr(III), Cd and $\text{S}_2\text{O}_3^{2-}$ do not interfere. Amounts of diverse ions relative to Co which can be tolerated are Th (100), Ga (120), Al, Pb or Lanthanoids (50), Bi (40), Ti(IV) (10), EDTA (2), Cu(II) (10).	110

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
4-(2-Thiazolylazo) resorcinol and Zephiranine:	550 nm	8	The anionic Co(II)-4-(2-thiazolylazo)resorcinol complex is extracted at pH 8 with CHCl_3 as the ion pair with Zephiranine. The absorbance is measured at 550 nm. Beer's law is obeyed for up to 2 mg/lit. of Co. The use of citrate, thiourea and acetate as masking agent prevents interference from various metals. Washing the extract with EDTA is also effective.	111
EDTA & DIPA amides	525 nm 530 nm	10.5-12	The synthesis of the EDTA and DTPA amides is described. The Co(III) complexes are studied in aqueous solution at pH 10.5-12.0. Absorption maxima are at 525 nm (EDTA) and 530 nm (DTPA) with ϵ values of 216 and 226, respectively. Beer's law is obeyed in the range 15-220 $\mu\text{g ml}^{-1}$ Co(III). The stoichiometry of both complexes is 1:1.	112
2,2'-Pyridyl bis-(2-quinolhydrazine)	530 nm 510 nm	3N- HClO_4 3.0	Using this reagent Co (2-20 μg) may be determined in highly acidic medium (2M HClO_4) at 530 nm and also in moderately acidic (pH 3) and 50% alcoholic medium at 510 nm. Serious interference is reported from EDTA, $\text{S}_2\text{O}_8^{2-}$ and CN^- .	113

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
KOOB s-[α -(3-methyl 5-oxo-1-phenyl-2-pyridin-4-ylidene)-p-tolyl] phosphonate	417 nm	10M HCl to pH 2	The yellow Co(II) complex formed (in <30 fold molar excess of the reagent) is extracted from 8M HCl into CHCl_3 . The absorbance is measured at 417 nm ($\epsilon=15,400$) and Beer's law is obeyed over the range 10-60 μM . The extraction is quantitative over the range 10M HCl to pH 2. Comparable quantities of Fe, Cu, Ni, Cr, Mo, Bi, Pb, Zn and Cd do not interfere.	114
EDIA	535 nm	4-6	The spectrophotometric determination of Co(II) in alloys is reported. Co(II) is oxidised to Co(III) by Mn(III) pyrophosphate at pH 4-6 in the presence of EDTA to give a violet Co(II)-EDTA complex. The absorbance is measured at 535 nm. Co(III) should be absent as it also forms a violet complex with EDTA. However, if present it may be removed by precipitation of FeCl_3 . The calibration graph is rectilinear for 1-10 mg of Co. For alloys containing 8-47% of Co, the accuracy is reported to be ± 0.1 - $\pm 0.25\%$.	115

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Eriochrome black-T	580 nm		The ion association complex of the Co-Eriochrome Black T species with Tetraphenylarsonium is extracted into CHCl_3 and its absorbance is measured at 580 nm ($\epsilon=50,000$). The Sandell sensitivity index is 1.18 ng cm^{-2} and Beer's law is obeyed for $0.03\text{--}0.9 \text{ } \mu\text{g ml}^{-1}$ Co with a relative error of 2.81% for 1% photometric error. Cl^- , SO_4^{2-} , F^- and acetate do not interfere, but ClO_4^- , NO_3^- , EDTA and diethyldithiocarbamate do.	116
Eriochrome black-T	587 nm	7-8	Co is extracted as methyltriocryla ammonium tetra thiocyanato cobaltate (II) (in benzene) at pH 8 (Tris- H_2SO_4 buffer). The organic phase is washed with 5 ml of a solution which is 0.5M in KSCN, 0.7M in Na-citrate, 0.9M in $\text{Na}_2\text{S}_2\text{O}_3$ and after addition of 52.6 μM Eriochrome Black T and 10 ml of saturated $\text{Na}_2\text{B}_4\text{O}_7$ at pH 7, the two phases are shaken together for 5 min. The separated organic phase is washed with H_2O and then shaken for 50 min. with 15 ml of 5% H_2O_2 - 10 μM -Mn(II) solution (pH 8.0) and finally dried over Na_2SO_4 and the absorbance measured at 587 nm ($\epsilon=66,200$) against a reagent blank. Beer's law is obeyed for $0.51\text{--}4.0 \text{ } \mu\text{g Co}$.	117

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2-[Di-(2 pyridyl) methylidene-hydrazino]-quinoline [Di-2 pyridyl] ketone-2 quinoxalinezone]	510 nm 530 nm	2-12 0.1-5M HClO_4	Cobalt is determined with this reagent in two different pH ranges: (i) in orange yellow water soluble complex at pH 2-12 has λ_{max} at 510 nm ($\epsilon=36,500$). The optimum analytical range is 0.2-1.73 ppm Cu(II), Mn(II), Fe(II), Cd and Hg(II) interfere, but can be tolerated up to at least 20 ppm by using masking agents. Cyanide, EDTA , $\text{S}_2\text{O}_8^{2-}$ and V(V) also interfere. (ii) A pink complex formed in 0.1-6.0M HClO_4 has λ_{max} at 530 nm ($\epsilon=41,000$). The range of the method is 0.22-1.85 ppm Cobalt, EDTA , Cu^{2+} and $\text{S}_2\text{O}_8^{2-}$ interfere, but Cu (80 ppm) and V(V) (20 ppm) can be tolerated if the HClO_4 concentration is 5M.	118
6-Amino-2'-d-methyl amino-4-hydroxy-5-nitrosopyrimidine	395 nm	5.5-6.8	Co(III) forms a yellow complex exhibiting max. absorbance: (pH range 5.5-6.8) at 395 nm ($\epsilon=63,000$). The Sandell sensitivity index is 0.944 ng cm^{-2} . Beer's law is obeyed for up to 1.4 $\mu\text{g ml}^{-1}$ Co. Ni and Cu(II) interfere, but can be masked by KCN. The reagent also forms a blue complex with Fe(II) at pH 5.6-10.5 with $\lambda_{\text{max}}=660$ nm ($\epsilon=30,500$). The Sandell sensitivity index is 1.8 ng cm^{-2} and Beer's law is obeyed to 2 $\mu\text{g ml}^{-1}$ Fe.	119

2-(4-Methyl-2-quinoylazo)-1-naphthol	550 nm	7-9	This reagent forms a complex with cobalt in the pH range 7-9. The complex is extracted by CCl_4 and the absorbance is measured at 550 nm. Beer's law is obeyed at the ppm level. The reagent has also been used to determine Zn (540 nm), Cd (540 nm), Cu (545 nm), Hg (535 nm) and Ni (550 nm). The pH range for Zn, Cd or Cu is 7-10, for Hg 10-11 and for Ni 7-8. EDTA, PO_4^{3-} , CN^- , citrate and Fe(III) are reported to interfere, but Cl^- , Br^- , NO_3^- , SO_4^{2-} , Ba, Sr, Bi, UO_2^{2+} and La do not.	120
2,3,5-Triphenyltetrazolium chloride and NaOCN	631 nm	5-8	The blue ternary complex formed at pH 5.8 is extracted into 4-methyl-1,3-dioxolan-2-one and the absorbance of the dilute extract containing 0.25-20 ppm Co is measured at 631 nm ($\epsilon=1080$) vs. a reagent blank. Many ionic species do not interfere, but CN^- and EDTA do so seriously.	121
Nitroso-R salt	415 nm	Na A:	A method for determining cobalt in pyrites and cinders is reported. The sample is dissolved in aqua regia, filtered, evaporated to dryness and to it are added 5 ml of 40% Na-acetate solution and 5 ml of 0.4% nitroso-R salt solution, and after boiling for 1 min. and then cooling the absorbance is measured at 415 nm. The relative error is <6% for 5-10 μg Co.	122

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Benzimidazoly-azo-derivatives I & II	420 nm 440 nm	6 7	These two dyes (I & II) have been prepared by diazotising 5-amino-benzimidazole and coupling this product with 3-hydroxy-naphthalene-2,7-disulphonic acid (R acid) or with 8-hydroxy quinoline (in the 4 or 5 position, respectively) in NaOH medium. The optimum pH values, λ_{max} and rectilinear ranges of calibration (ppm) are with I: Co-6, 420, 0.6-3.5; Ni-3, 480, 0.7-3.5; Cu-7, 490, 0.6-5.7; with II: Co-7, 440, 0.4-2.4; Ni-8, 440, 0.1-0.47; Cu-5, 430, 0.4-2.5. The coefficient of variation for amounts of $\approx 30 \mu\text{g}$ is $\approx 0.03\%$.	123
2'-Hydroxy-3',5'-dimethyl acetophenone oxime	440 nm	7.5-10.0	This oxime reacts with Co(II), Mn(II) and UO_2^{2+} to give 1:2 complexes in the pH ranges 7.5-10.0, 9.0-10.0 and 4.45-4.65, respectively. The absorption maxima (nm) (and ϵ values) of the complexes are 400 (1250), 405 (1300) and 410 (750), respectively. The Co(II) complex is extractable into CHCl_3 . Beer's law is obeyed for 1-13 ppm for Co; 1-12 ppm Mn(II) and 20-200 ppm UO_2^{2+} .	124

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Biacetyl mono-(2-pyridyl) hydrazone;	505 nm	4.5	A spectrophotometric study of Cu(II), Ni, Co and Fe(II) with the reagent (BPH) is reported. The sample of Co at pH 4.5 is mixed with ethanolic 0.25% BPH. After 10 minutes HClO_4 , H_2O and ethanol are added and the absorbance is measured at 505 nm. Zn, Cd, Hg, Pb, U(VI) or Fe(III) do not interfere.	125
2-Pyridyl carboxylic (picolinic) acid hydrazides	350 nm		The absorbance of the Co complex is measured at 350 nm. Beer's law is obeyed for 2-6.5 ppm cobalt and the error ranged between 0.8-0.6%. Colour reactions between the reagent and Ag, Hg(II), Cu(II), Fe(II), Pd(II), Pt(II), Au(III), Se(IV), V(V), Ce(IV) and Os(VII) have already been reported.	126

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
3-(2-Acetylphenyl)-1-methyl-4-triazan-N-oxide	460 nm	6.8-10.0	To 2 ml of Co(II) soln. (25 $\mu\text{g ml}^{-1}$) are added 1 ml 0.05% ethanolic reagent and 10 ml H_2O_2 . The pH is adjusted to 6.8-10.0. The solution is then made up to 25 ml with ethanol to give a 50% ethanolic solution and absorbance is measured at 460 nm. Beer's law is obeyed for 0.25-4.5 ppm Co. The optimum analytical range is 0.56-2.0 ppm. There is interference from Cr(III), VO(II), $\text{UO}_2(\text{II})$, Ce(IV), Mo(VI), Cr(II), Al and EDTA. These ions Fe(II), Pb(II) may be masked with NH_4F -HF and ammonium-acetate, respectively.	127
1,10-Phenanthroline, Eosine BNX [4',5'-dibromo-2',7'-dimethylfluorescein (disodium salt)]	560 nm	4.6	The spectrophotometric determination of Co(II), Ni(II) and Cu(II) in the ternary system M^{2+} -1,10-phenanthroline-Eosine BNX at pH 4.6 (acetate buffer) are reported. The ϵ values at 560 nm are 20 000, 25 000 and 52 000 for Co, Cu and Ni, respectively. The molar ratio is 1:2:1 in each instance. Beer's law is obeyed for 0.06-1.68, 0.1-0.7 and 0.12-1.40 $\mu\text{g ml}^{-1}$ of Co, Cu and Ni, respectively.	128

Name of the Reagent	λ_{max} or wavelength	pH	Remarks	Refs.
KSCN and pro yptylinium cation	(i) 342 nm (ii) 622 nm	1-7 1-7	Cobalt (up to 200 μg) can be extracted from aq. solution (pH 1-7) containing an excess of KSCN into CHCl_3 -acetone as an ion pair with the pro yptylinium cation. The spectrophotometric determination can be made at either 342 nm ($\epsilon=52,000$) or at 622 nm ($\epsilon=25,000$) against a reagent blank. The spectrophotometric determination is made at 362 nm. The method is applicable to the direct analysis of steel after addition of NH_4F to mask Fe(III) and $\text{Ni}_2\text{S}_2\text{O}_3$ (to mask Cu). A short review on ion pair extraction is included.	129
Heterocyclic azo dye 4-(5-chloro-2,3-dihydroxy-4-pyridylazo) benzoic acid	550 nm	9.0-10.3	The pH of the Cu(II) , Ni(II) or Cu(II) solution is adjusted to the appropriate range 9.0-10.3, 8.9-10.2 or 8.6-11.0, respectively and the absorbance is measured at 550, 510 or 560 nm, respectively. For Fe(II) the pH is adjusted to 5.2-5.5 and the absorbance is measured at 580 nm.	130

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Solochrom Red B (C.I. Mordant Red 9)	495 nm	10-11	The absorbance of the complex is measured at pH 10-11 at 495 nm ($\epsilon = 1.68 \times 10^6$). The sensitivity is 0.07 ppb. For 0.354 ppm and 2 ppb Co the coefficients of variation are 0.84% and 3.85%, respectively, and the corresponding errors are 1.17 and 4.88%. Al, As(III), Be, Ca, Cd, Fe(III), Ga, Hg(II), K, La, Li, Na, Sr, Zn and Zr do not interfere.	131
Ethyl thioxanthate	390 nm	5-9.5	The Co ethyl thioxanthate complex is extracted by molten naphthalene and dissolved in CHCl_3 . The absorbance is measured at 390 nm. Many cations and anions do not interfere, but oxalate, citrate, tartrate, Fe(III), Ni and Cu(II) are tolerated only in small amounts. This method has been applied to alloys but is not applicable in the presence of EDTA.	132

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
1,2-Diamino anthra quinone-3-sulphonic acid	580 nm		The determination of cobalt (0.9-38 ppm) is reported with an average error of 0.38%.	133
5-(4-Diethylamino-2-hydroxy-phenylazo)-1,2,4-triazole-3-carboxylic acid	525-540 nm		This reagent may be used to determine Co in geological materials. The finely ground sample is heated with HCl and NH_4F . The mixture is heated to fumes with conc. HNO_3 and H_2SO_4 (1:1) and then with 10 ml H_2O . The solution is diluted to 100 ml with water and filtered. A portion of the filtrate from the solution is mixed with 40% Na-citrate solution and reagent solution, then 10 ml HCl and 25 ml H_2O are added. The absorbance is measured at 525-540 nm against a reagent blank. This method is applicable to samples containing 20 ppm-1.6% Co.	134

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
S substituted 6-amino-5-nitroso- 2-thio uracils	400 nm		Thirteen pyrimidine derivatives are reported as analytical reagents for Co and Ni. The pH of a solution containing 10 μg of Co is adjusted with ammonium acetate-acetic acid buffer and 1.5 ml of reagent solution and 10 μg Fe(II) is mixed with 1 ml of 1% hydroxy ammonium chloride. The solution is extracted by CHCl_3 . The absorbance of the Co(II) complex is measured at 400 nm ($\epsilon = 10^4$ - 10^5) and that of the Fe complex at 370 or 650 nm against a reagent blank.	135
Ammonium pyrrolidine-1-carbo- dithioate (ADPC)	370 nm	4-5	Cobalt is extracted with molten micro-crystalline naphthalene at pH 4.5 as its complex with ADPC. The absorbance of the DMF solution of the extract is measured at 370 nm. Beer's law is valid for 4-48 μg Co in 10 ml DMF. A (20 mg), Zn (400 μg), Pb (II) (400 μg), Fe (4 μg) and Ni (4 μg) interfere.	136

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2,6-Diamino-2-(2-thiazolylazo) toluene	590 nm		Two methods are reported. In the first a solution containing 2.5-17.5 μg Co is mixed with 2 ml of reagent, 5 ml aq. 1M NH_3 and 70% HClO_4 and 25 ml water and the absorbance is measured at 590 nm. Beer's law is obeyed for 0.1-0.7 ppm Co. In the second method the solution containing 25-50 μg Co is mixed with 2 ml of reagent in HClO_4 , 2 ml of sodium acetate and 25 ml H_2O and the absorbance is measured at 590 nm. Beer's law is valid from 0.05-0.6 ppm Co. The second method is more sensitive. Cobalt is determined in low alloy steels, catalysts and Ni-salts and the results obtained are in good agreement with those obtained by AAs.	137
Thiocyanate and promethazine	622 nm		The extractive spectrophotometric determination of cobalt as a mixed-thio cyanate-promethazine is reported. The absorbance of the blue extract in CHCl_3 is measured at 622 nm. Beer's law is obeyed for 0.5-45 ppm and the limit of detection is 42 ng. The tolerance limits are tabulated for 45 ions.	138

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
1,10-Phenanthroline and hydroxy xarthen dyes	545 nm	7-8	Divalent cobalt forms a Co(II)-1,10-phenanthroline complex (1:3:1) in aq. medium at pH 7-8. The complex is extracted into CHCl_3 and the absorbance is measured at λ max, i.e., at 545 nm ($\epsilon=91,000$). Beer's law is valid for $\approx 0.01-1.7 \mu\text{g ml}^{-1}$ Co(II). The coefficient of variation is $<5\%$ (10 results).	139
Quinalizarin-hydroxygen peroxide	565 nm	12.0	A study of a catalytic reaction for the determination of cobalt in concentrations down to 0.5 ng ml^{-1} is reported. The optimum conditions are pH 12.0, a molar ratio of H_2O_2 to quinalizarin of 200, temperature 25°C and concentration range 10-200 nM cobalt. The absorbance is measured at 565 nm. A mucicavear catalytic reaction is exhibited by the ions N(II) , Fe(II) , Fe(III) , MnO_4^{2-} and Cu(I) . The ions CN^- , EDTA , tartrate, citrate and oxalate inhibit catalysis.	140

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Muslic acid	360 nm	10	The complex (1:1) is formed at 40°-45°C at pH 10 (H_2BO_3^- buffer) and its absorbance is measured at 360 nm. The optimum range is 9.5-25 $\mu\text{g/ml}$ Co and the Sandell sensitivity index is 0.024 $\mu\text{g cm}^{-2}$. The method is applied to samples of cyanocobalamin after pretreatment with concentrated HNO_3 and HClO_4 . The relative error is 0.5% for 87 ppm Co and 2% for 44 ppm.	141
Salicylaldehyde thio semicarbazone	400 nm	5	The spectrophotometric determination of Co(II) in the presence of large amounts of iron is discussed. At pH 5 the absorbance is measured at 400 nm ($\epsilon=11,000$). Beer's law is valid for 0.2-6 ppm Co. Interference from Fe, Cu and Ni is prevented by precipitation with Na_2HPO_4 and by masking with $\text{Na}_2\text{S}_2\text{O}_3$ and citrate, respectively.	142

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
4-(5-Bromo-2-pyridyl(2))-m-phenylenediamine and Anthranilnon-2-sulphonic acid	573 nm	5	To an acidic solution containing 1.5-10 μg Co are added 1 ml of 0.2 M acetate buffer (pH 5), 2 ml of ethanolic reagent, 2 ml of 0.01M-anthraquinone-2-sulphonic acid and 10 ml of CHCl_3 . To a 2-3 ml portion of this CHCl_3 extract, 10 ml of 2.4M-HCl are added and the absorbance of the aq. phase is measured at 573 nm. 3 ppb Co can be determined.	143
1,2-Diamino propane- N,N',N''-tri-acetamide	535 nm	≈ 11	The preparation of this reagent is described. To the test solution add 1 ml of 0.5% reagent and a drop of 30% H_2O_2 solution. Adjust the pH to 11 and after 2 hrs measure the absorbance at 535 nm. Beer's law is obeyed for 73-251 μg ml. 10 fold amounts of Ni or Fe(III); 7 fold amounts of Cr and equal amounts of Pb(II), Mn(II), Zn, Cd or Cu(II) may be tolerated.	144

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Potassium malonate	615 nm	Acetic acid-ammonium acetate buffer	To the neutral solution containing 1-20 mg Co are added 2 ml of undiluted acetic acid, 5 ml of 20% $\text{CH}_3\text{COONH}_4$, 20 ml of 0.5M K-Malonnate and 1 g of PbO_2 . It is filtered after 10-20 min. with intermittent shaking. The absorbance of the filtrate is measured at 615 nm. There is slight interference from Fe, Ni and Cr; Cu and Mn must be removed before oxidation of Co. The colour is due to formation of the tris-(malonato)-cobaltate(III) complex.	145
4-Methylhydrobenzofurano-[6,7-b] coumarin {4-methyl-6,7,8,9-tetrahydro benzo furo(3,2-g)-1-benzopyran-2-one}	380 nm	10	To the test solution are added 10 ml of pH 10 buffer solution and 7 ml of 0.1% reagent solution. This mixture is diluted to 25 ml and the absorbance measured at 380 nm ($\epsilon = 19,100$). Beer's law is obeyed for 2.0-7.5 ppm cobalt.	146

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
3-(4-Sulphophenylazo) propionic acid (SPADNS)	580 nm	5.5-6.0	In addition to cobalt this reagent has also been used for determination of Fe and Ni. The optimum pH values, working wavelength, molar and Sandell sensitivities are 5.5-6.0, 2.5-3.0 or 6.0, 580 nm, 580 nm, 575 n.n., 14,000, 4800, 7000; 0.06, 0.08 and 0.05 $\mu\text{g cm}^{-2}$ for Co, Fe and Ni, respectively. The respective complexes are stable for 24, 6 and 4 hours. The 3 metals may be determined in the presence of each other by use of suitable masking agents. There is interference from citrate, tartrate, AsO_4^{3-} , PO_4^{3-} , F^- , Be , Zn , Cd , Al , Zr and Th .	147
Ethylenediamine- $\text{N,N}'$ -dipropionic acid	550 nm	7.5-9	The 1:1 complex formed by Co with the reagent in the presence of H_2O_2 shows maximum absorbance at 550 nm at pH 7.5-9. The Beer's law validity range is 35-195 $\mu\text{g ml}^{-1}$ Co, Cr(VI), Mo(VI), Mn(II), Cu(II), Fe(II), A, NO_3^- and tartrate interfere.	148

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Morpholine-4-carbo dithioate	360 nm		An aqueous solution of the potassium salt of the reagent is added to Co^{++} and the complex is extracted into 100 ml of methylal and then CHCl_3 . Beer's law is obeyed for Co (360 nm), Cu (440 nm), Ni (390 nm) and Fe (415 nm) in the ranges 0.5-8.1, 0.5-7.0, 0.6-9.0 and 0.57-12.5 $\mu\text{g ml}^{-1}$, respectively.	149
2,6-Diamino-3-(4-methyl-2-thiazolylazo) pyridine	610 nm	HClO_4	This reagent (R) forms CoR_2^{2+} and CoHR_2^{3+} and complexes with cobalt. The absorbance of the later complex (formed in HClO_4) is measured at 610 nm. The range of the method is 0.2-1.5 ppm.	150
10-(benzothiazol-2-ylazo) phenanthren-9-ol	560 nm	6-7	The test solution (10 $\mu\text{g Co}$) is mixed with 1 ml of Triton-X-100 and 0.8 ml of 1 mM reagent solution in dioxan and is heated and cooled. The absorbance is measured at 560 nm at pH 6-7. Bivalent Ni, Cu (II), Zn, Pd(II) or Cd interfere positively and species that are precipitated at pH 6.7 interfere negatively.	151

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
N,N-dimethyl-4-(2-pyridylazo)-m-phenylene diamine	603 nm	2.4M-HCl	The Co(II) complex is stable and has a deep blue purple colour in 2.4 M HCl. The ϵ value at 603 nm is 1.14×10^5 and Beer's law is obeyed for 0.01-0.5 ppm Co. Pd(II) interferes and Cu(II) can be masked with $\text{Na}_2\text{S}_2\text{O}_3$. This method is used to determine traces of Co in high purity beryllium. Other derivatives have also been synthesized and examined.	152
Benzyl-2-pyridyl ketone-2-pyridylhydrazine	480 nm	4.0	The determination of cobalt paint samples is reported. The test solution (containing 6.27-75 μg Co) is treated with 2 ml of masking solution, 5 ml of ethanolic reagent, 4 ml of acetate buffer, 10 ml of ethanol and 25 ml of H_2O . The absorbance is measured at 480 nm.	153
Acenaphthenequinone monosemicarbazone	410 nm	8.4-9.8	The complexes of Co, Ni or Cu show max. absorbance at 410, 420 or 430 nm, in the pH range 8.4-9.8, 6.3-8.4 and 5.4-8.0, respectively. Beer's law is obeyed for ≤ 10.57 ppm Co, ≤ 14.7 ppm Ni or ≤ 7.95 ppm Cu. The corresponding Sandell sensitivity indices are 12, 20 and 10 ng cm^{-2} . ϵ values are 4800, 2850 and 5800, respectively.	154

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Biacetyl monoxime-2-pyridyl-hydrazone	430 nm	HCO_3	A yellow coloured complex is formed in HCO_3 medium (0.05M) containing 20% DMF. The absorbance is measured at 430 nm ($\epsilon=3100$). Beer's law is obeyed for 0.8-15 ppm.	155
2-(2-Thiazolylazo)-4-methyl-5-(sulphomethyl amino)-benzoic acid 5-(2-thiazolylazo)-p-toluic acid	655 nm	5	To the sample solution are added 2-9 ml of 5 mM reagent, plus 2 ml of 0.4% KIO_4 and the pH is adjusted to 5 with acetate buffer. After 10 min. the volume is made up and the absorbance is measured at 655 nm. Beer's law is obeyed for up to 520 $\mu\text{g/lit}$ of Co and the Sandell sensitivity index is 0.52 ng/cm^2 . The method is used in the determination of Co in glass (0.001-0.01% Co) and in Ni salts (0.003-0.12% Co). Acetate, chloride, sulphate, nitrate and perchlorate do not interfere.	156

Name of the Reagent	λ_{max} of working wave-length	pH	Remarks	Refs.
Sodium alizarin sulphate	600 nm	7.0 ± 0.1	A 1:1 violet complex with Co(II) formed at pH 7.0 ± 0.1 has $\epsilon = 6000$ at 600 nm. The 1:1 orange N (II) complex is formed at pH 7.0 ± 0.1 and has $\epsilon = 5500$ at 520 nm. Beer's law is obeyed for 0-10.6 ppm Co(II) and for 0-9.8 ppm N (II). The Sance'll sensitivity indices are 0.009 and $0.010 \mu\text{g cm}^{-2}$, respectively.	157
5-(4-Diethyl amino-2-hydroxy-phenylazo)-1,2,4-triazole-3-carboxylic acid	510 nm	2.4M HCl	This reagent is highly selective and sensitive for the determination of Co. The absorbance is measured at 510 nm in 2.4M HCl medium. Beer's law is obeyed for 0.04-0.4 $\mu\text{g m}^{-1}$ Co and the limit of detection is 0.8 ng/ml. Large amounts of Fe^{3+} (III), Ni(II), Cu, Al, Cr(III), Mn(II), V(V) or Zn do not interfere. This reagent can also be used for the determination of Ni. The absorbance of the N (II) complex is measured at 540 nm at pH 7.4. Beer's law is obeyed for 0.1-1 $\mu\text{g ml}^{-1}$ Ni. The reagent can be applied to minerals and geological samples.	158

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Ethyl trithiocarbonate	390 nm	5.75	The metal (Co, Ni or Pd-20 μg -ethyl trithiocarbonate complex (2 ml of 0.1% solution) formed at pH 5.75 is extracted into 2 g molten naphthalene at 85-90°C. After cooling and filtration, the naphthalene layer is dissolved in CHCl_3 (10 ml) and dried with Na_2SO_4 . The absorbance is measured for Co at 390 nm ($\epsilon=6190$); for Ni at 500 nm ($\epsilon=8800$); for Pd(II) at 345 nm ($\epsilon=11,600$). This method may be used in the analysis of alloys.	159
1-(1,2,4-Triazol-3-ylazo)-2-naphthol	565 nm	6.0	An ethanolic solution of the reagent is added to an aqueous ethanolic solution of the metal. The absorbance of the Co(II) complex, formed at pH 6, is measured at 565 nm after 20 min. Beer's law is valid in the range 0-3 ppm. The reagent has also been used for the determination of Fe(III)-pH 5 at 540 nm and for Mn(II)-pH 8 at 515 nm. The absorbance of the Fe-complex is measured immediately after adding the reagent. Beer's law is valid from 0-1 ppm whereas in the case of Mn(II) the absorbance is measured after 105 min. Beer's law is valid for 0-2.5 ppm.	160

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2,4-Dichlorobenzyltriphenyl chloride and potassium phosphonium thiocyanate	625 nm	1-8	The ternary Co complex, 2,4-dichlorobenzyltriphenyl phosphonium tetra thiocyanate cobaltate (II), is extracted from aq. solution, pH 1-8, into a.e.one-1, 2-dichloroethane (1:9). The absorbance is measured at 625 nm ($\epsilon=1800$) or alternatively at 328 nm ($\epsilon=11,000$) if a reagent blank is used. Beer's law is valid up to 100 μg Co in 25 ml of extract. At 50 μg the coefficient of variation values are 0.73 and 0.77% for wavelengths 328 nm and 625 nm, respectively. The method may be used to determine Co (up to 100 μg) in steels. Fe(III) interferes and is masked by the addition of 10 ml of aq. 40% NH_4F .	161
10-(Benzothiazol-2-ylazo)phenanthren 9-ol	560 nm	6.7	To the test solution (10 μg Co), add 1 ml of triton X-100 solution (0.2 g/ml) and 9.8 ml of the reagent is dioxan (1 mM) at pH 6.7. Heat on a water bath, cool and dilute to 25 ml with water and measure the absorbance at 560 nm. The ions $\text{Ni}(\text{II})$, $\text{Cr}(\text{II})$, Zn , $\text{Pb}(\text{II})$ or Cd interfere positively; species that are precipitated at pH 6.7 interfere negatively.	162

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Acenaphthenequinone monosemicarbazone (AQSC)	410 nm	8.4-9.8	Apart from Co(II) this reagent is also used for Ni(II) and Cu. The complexes of Co(II), Ni(II) and Cu(II) exhibit λ_{max} at 410, 420 and 430 nm in the pH range, 8.4-9.8, 6.3-8.4, 5.4-8.0. Beer's law is valid for ≤ 1057 ppm Co; ≤ 14.7 ppm Ni or ≤ 7.95 ppm Cu. The Sandell sensitivities are 1%, 20 and 10 ng cm ⁻² and the ϵ values 4800, 2850 and 5800, respectively.	163
2-(2-Mercaptoacetamido)benzenesulphonate	510 nm	5.5	The absorbance of the complex is measured at 510 nm ($\epsilon \approx 21,700$). Beer's law is valid for 4.5-45 μ M Co. There is no serious interference from common anions, alkali or alkaline earth metals: Pb(II), Mn(II), Cd or Zn. However, the tolerance limits for some other ions are ≤ 0.3 mg Mo, 0.15 mg V or 0.95 mg U.	164
K-Morpholine-4-carbodiimide	365 nm	5.16	The cobalt complex with K-Morpholine-4-carbodiimide is extracted by molten naphthalene and filtered. The naphthalene layer is dissolved in CHCl ₃ , dried and its absorbance is measured at 365 nm. Beer's law is obeyed for 6-10 μ g Co.	165

Name of the Reagent	λ_{max} or working wave length	pH	Remarks	Refs.
Hexaethylpyridinium chlorides (I) and phenylflorone (II)	620 nm		The formation of a highly stable ternary complex with a molar composition I:Co:II::2:4 is reported. The absorbance is measured at 620 nm. Beer's law is obeyed in the range 8-600 $\mu\text{g l}^{-1}$ Co.	166
5'-Chloro-2',4'-dihydroxy-propiophenone oxime	410 nm	7.5-8.5	The reagent is used for the determination of Co(II) and Mn(II) at pH 7.5-8.5 and 8.7-10.0, respectively. The 1:2 complexes have λ_{max} at 410 and 405 nm for Co and Mn, respectively. Beer's law is obeyed in the range 2-10 ppm Co and 1-6 ppm of Mn. The Sandell sensitivity indices are 12 ng cm^{-2} for Co(II) and 8.8 ng cm^{-2} for Mn(II). The ions Ca(II), Pd(II), Ni(II), Fe(III), UO_2^{2+} interfere. Tolerable concentrations of Cl^- , SO_4^{2-} , acetate, NO_3^- , B^- , C^- , I^- citrate, tartrate, alkaline earth metals, alkali metals, Bi, Zn and Cd range from 40-700 fold relative to Co or Mn.	167
3-(1,2,4-Triazol-3-ylazoxy)oxo-ene-2,6-dianiline	490 nm	5-6	After adding the reagent to the test solution the pH is adjusted to 5.6 and sodium vanadate is added, and after 1 hr, H^+ICl_4 and the solution is made up with water. The absorbance is measured at 490 nm. The method is applicable to alloys and steels.	168

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
2-(4-Nitrobenzoyl) acetanilide and sulphocyanide (thiocyanate)	625 nm	2.0	The mixed complex of cobalt formed with NH_4SCN and the reagent at pH 2 is extracted with isobutyl methyl ketone and the absorption of the dried extract is measured at 625 nm. The optimum range of the method is 6.18 ppm. The coefficient of variation is 0.92% (n+10). The method may be used to determine Co in monel metal and Ni-ore without interference from the associated metals.	169
1,3-Bis-(2-pyridyl) methyleneamino) thiourea (I) 1,3-Bis-(2-pyridyl) methyleneamino) guanidine (II)	420 nm 460 nm 450 nm	Acid medium 2.45	With I, Co(II) forms a stable yellow complex in acid medium whose absorbance is measured at 420 nm ($\epsilon=22,000$) or at 460 nm ($\epsilon=11,500$). Beer's law is obeyed for 0.2-1.4 $\mu\text{g ml}^{-1}$ and 0.2-2.0 $\mu\text{g/ml}$, respectively. With II, a complex is formed at pH 2.45 and its absorbance is measured at 450 nm ($\epsilon=311,000$). Beer's law is obeyed for 0.25-2.20 $\mu\text{g/ml}$. Co Reagent I is more selective, whereas II is more sensitive.	170

Name of the Reagent	λ_{max} working wave-length	pH	Remarks	Refs.
2-[(<i>o</i> -Hydroxy-3-methoxyphenyl) methyl]ene], [1-hydroxy-3- methoxybenzaldehyde thiosemi- carbazone]	404 nm	3 ml NaOH	A complex is formed in the presence of NaOH and its absorbance is measured at 404 nm. Beer's law is obeyed for 0.04-2 ppm Co and the Sandell sensitivity index is $3 \mu\text{g cm}^{-2}$. In the determination of 1 ppm Co, 1, 2, 3, 4 or 5 ppm Os(VI), Pd(II), Ru(III), Ba(II) and Rh(III), respectively, can be tolerated.	171
Rubeanic acid (dithioamide) in presence of quinoline, 2-picoline and collidine	390 nm	7-8.1	A yellow Co complex is formed with Rubeanic acid and one of these heterocyclic bases. The absorbance is measured at 390 nm for complexes of quinoline (I) or collidine (II) and 410 nm for complexes for 2-picoline (III) in aq. ethanol. Beer's law is obeyed for 0.58-3.5 ppm with (i) and for 0.5-4 ppm Co with (II) and (III). The optimum pH range is 7-8.1. The sensitivities are 4.2, 4.1 and 3.4 ng cm^{-2} for (I), (II) and (III), respectively. In the determination of 2-3 ppm Co, 50 ppm of acetate, 100 ppm of oxalate, 300 ppm of tartrate or citrate and 400 ppm of Mo, W and V may be tolerated.	172

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Di-2-pyridyl-ketone pyrimidin-2-ylhydrazone	460 nm	9.0	This reagent forms a complex with Co(II), Fe(II) and Ni(II) at pH 9.0 with λ_{max} at 460, 580 and 430 nm. Sets of linear equations are derived to determine simultaneously the concentration of each element in mixtures of Co with Fe or Ni with Fe. The method is applicable in the ranges $[\mu\text{g ml}^{-1}]$ 0.1-2 for Co, 0.4-4 for Fe and 0.1-1 for Ni. In the Fe-Co system Mn, Zn, Hg, Ag and V may be tolerated at low ppm, but Cd, Cu and Ni interfere seriously.	173
3-Hydroxy-3-methyl-1,4-naphthoquinone monoxime	430 nm	5.0-7.5	For the determination of Co(II) (3.5-41.5 μg) in solution at pH 5.0-7.5, 0.5 ml of reagent is added and the absorbance is measured at 430 nm ($\epsilon=32,400$).	174
2,2'-Dipyridyl-2-benzo thiazolyl-hydrazone [di-(2-pyridyl) ketone benzo thiazol-2-ylhydrazone]	540 nm	2.0-9.3	A stable 1:3 complex is formed, pH 2-9.3 with λ_{max} at 530 nm and a working wave-length of 540 nm. The complex is extracted into CHCl_3 and its absorbance is measured at 540 nm.	175

Name of the Reagent	$\lambda_{\text{max.}}$ working wave-length	pH	Remarks	Refs.
Hydrazine carbothioamide-2-(2-furanyl methylene); (2-furaldehyde thiosemicarbazone)	388 nm	1M NaOH	To the sample solution (1.25-62.5 $\mu\text{g Co}$) 5 ml of ethanol, 4 ml of 0.3% reagent solution and 5 ml of 1M NaOH are added, and the mixture is diluted to 25 ml with water. The absorbance is measured at 388 nm ($\epsilon=11,000$). Beer's law is obeyed for 0.05-2.5 $\mu\text{M Co}$ and the Sandell sensitivity index is 5 ng cm^{-2} .	176
1,10-Phenanthroline	346 nm		Cobalt forms a 1:3 complex with this reagent. The absorbance is measured at 346 nm. Beer's law is obeyed up to 50 μM and the limit of detection is 1 $\mu\text{M Co(I)}$.	177
Ammonium thiocyanate	320 nm 625 nm	5 5	Cobalt is extracted at pH 5 (citrate-phosphate buffer) as tetrathiocyanato-cobaltate(II) with propylene carbonate (4-oxoethyl-1,3-dioxolan-2-one). The absorbance is measured either at 320 nm ($\epsilon=11,500$) or at 625 nm ($\epsilon=1800$). Beer's law is obeyed for $\leq 50 \mu\text{g Co}$ at 320 nm and $\leq 300 \mu\text{g Co}$ at 625 nm with coefficients of variations of 1.06 and 0.64%, respectively.	178

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
4-(5-chloro-2-pyridylazo)-m-phenylenediamine	570 nm	5	Cobalt forms a stable red complex with the reagent at pH 5 (phosphate buffer) containing hydroxylamine. The absorbance is measured at 570 nm and Beer's law is obeyed in the range 0.8-80 $\mu\text{g ml}^{-1}$ Co.	179
2-Hydroxy-1-naphthaldoxime	387 nm	8.8	To the solution containing up to 50 μg of Co(II), 10 ml of aq. borate buffer (pH 8.8) are added and solution is diluted to 30 ml with H_2O . This solution is extracted with 10 ml of 0.01M 2-hydroxy-1-naphthaldoxime. The absorbance of the extract is measured at 387 nm ($\epsilon = 117,000$). Beer's law is obeyed for up to 5 $\mu\text{g/ml}$ of Co. The Sandell sensitivity index is 5.1 ng cm^{-2} . The coefficient of variation is 0.93% ($n=6$). Cu(II), Ni(II) and Fe(III) interfere seriously.	180
α -Methyl-2,4-dihydroxybenzylidene-2-aminoaniline [4-(1-(2-aminophenylimino) ethyl)resorcinol]	400 nm	8-11	The brown 1:1 Co-complex has $\lambda_{\text{max}} = 400 \text{ nm}$ ($\epsilon = 2000$) at pH 8-11. Beer's law is obeyed for 0.6-17.7 $\mu\text{g Co}$. The Sandell sensitivity index is 29 ng cm^{-2} . Cu(II), Mn(II), Zn, V(V) and Cr(VI) interfere, but Mo(VI), Cl, V(IV), Ti(IV) and Fe(III) are tolerated in amounts 2-8 times that of Co without excess. Ba and Zn are tolerated in ≤ 300 fold excess.	181

Name of the Reagent	λ_{max} or wavelength	pH	Remarks	Refs.
Maleonitri le dithio ate (disodium salt)	410 nm	0.5M HCl	The sample solution containing 100 μg Co is made 0.5M in HCl and 5 ml of 0.1% reagent are added. The complex is extracted in <i>o</i> -isobutyl methyl ketone. The extract is diluted and its absorbance is measured at 460 nm ($\epsilon=5010$). Beer's law is obeyed for 1-8 ppm Co. The Sandell sensitivity index is 1.0 mg cm^{-2} . The effects of foreign ions and their removal are discussed.	182
2-45-Bromo-2-pyridylazo)-5-diethyl-amir ophe nol	580 nm	dil. H_2SO_4 medium	The test solution is mixed with 1 ml of 10% NH_4F and 2 ml of 0.5 mM reagent solution. After 5-10 min. 1:2 H_2SO_4 is added with 25 ml water. The absorbance is measured at 580 nm.	183

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Thiocyanate and Brilliant green	660 nm	2	The ternary Co(II) complex in aq. solution at pH 2 in the presence of gum acacia is reported to have a composition 1:4:2 with SCN^- and Brilliant green. The absorbance is measured at 660 nm ($\epsilon=17,700$). Beer's law is obeyed up to 15 μg Co in 25 ml.	184
10-(2-Pyridylazo) phenanthrene-9-ol	605 nm	4.5	A method for determination of Co in steel is reported. To the test solution of the steel in mineral acids add NaF to mask Fe, adjust the pH to 4.5 and add ethanolic reagent. After 10-15 min., 4.75 ml ethanol and 2 ml 11M HCl are added. The absorbance of the solution is measured at 605 nm ($\epsilon=30,900$). The Sandell sensitivity index is 1.9 ng cm^{-2} .	185
Tetrabutylammonium tetra-thiocyanate	620 nm 320 nm		The test solution is treated with 3 ml 0.1M NH_4SCN plus 1 ml 0.05M reagent and diluted to 15 ml with water. The complex is extracted into CHCl_3 . The absorbance is measured either at 620 nm ($\epsilon=16,900$) or at 320 nm ($\epsilon=10,900$). Beer's law is obeyed for 0.08-1.2 mM Co at 620 nm and 0.01-0.1 mM Co at 320 nm.	186

Name of the Reagent	$\lambda_{\text{max.}}$ working wave-length	pH	Remarks	Refs.
5,6-Diphenyl-3-(4-phenyl-2-pyridyl)-1,2,4-triazine with tetraphenyl borate	500 nm	2.5-8.3	A 0.08% ethanolic solution of the reagent (1.8-5 ml), 3 ml of buffer solution (pH 2.5-8.3) and 0.5-4 ml of aq. 1% tetraphenyl borate are added to the test solution. After 15 min. 2 ml of 20% naphthalene solution in acetone are also added. The separated solid phase is filtered, washed with water, dried at 50-60°C and dissolved in acetonitrile (10 ml). The absorbance is measured at 500 nm. Beer's law is obeyed for 8-140 μg Co.	187
Triphenylsulphonium chloride with thiocyanate	625 nm	7	The sample solution is mixed with 3 ml of 5M NH_4SCN , 4 ml of phosphate aq. buffer (pH 7), 2 ml of 3 mM triphenyl sulphonium chloride, diluted to 15 ml with water and then 2 ml of acetone are added. The triphenyl sulphonium tetrathiocyanato cobaltate(II) complex is extracted into 1,2-dichloroethane. The absorbance is measured at 625 nm. Beer's law is obeyed for 0-100 μg Co. There is some interference from Cr(III) , U(IV) , Hg(II) , Zn , Bi and Fe(II) , but CN^- and EDTA interfere seriously.	188

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
5,7-Dichloro-2-methyl-quinoxaline-8-ol	390 nm	7-8	This reagent is used for determination of both Co and Ni separately. The Co or Ni complex is extracted at pH 7-8 with CHCl_3 and its absorbance is measured at 390 or 388 nm, respectively. Beer's law is obeyed for 0.8-24 $\mu\text{g ml}^{-1}$ Co and 1.3-18.2 $\mu\text{g ml}^{-1}$ Ni.	189
5-Methylsalicylaldehyde	380 nm	7.3-8.3	The 1:2 Co complex of this reagent is extracted into CHCl_3 between pH 7.3-8.3. The complex has maximum absorbance at 380 nm. Beer's law is obeyed over the range 10-60 μM .	190
1'-Hydroxy-2'-acetonaphthone oxime	380 nm	8.6	This reagent is used in the determination of Co, Ni and Pd. The complexes formed are extracted into CHCl_3 from solution at pH 8.6 for Co, 9.0 for Ni and 5.6 for Pd. The complexes exhibit λ_{max} at 380 nm ($\epsilon=5600$), 396 nm ($\epsilon=5750$) and 378 to 380 nm ($\epsilon=9300$), respectively. Beer's law is obeyed for 2.0-7.0 $\mu\text{g ml}^{-1}$ Co, 1.0-6.5 $\mu\text{g ml}^{-1}$ Ni and 1.0-5.5 $\mu\text{g ml}^{-1}$ Pd. In binary mixture, Pd is extracted first at pH 5 and then the pH is raised for extraction of the second metal.	191

Name of the Reagent	λ_{max} , or working wave-length	pH	Remarks	Refs.
Ethyl thioxanthate (ethyl tri thiocarbonate)	389 nm	4-11	The reagent is used in the determination of both Co and Ni separately. The complex extracted by CCl_4 quantitatively at pH 4-11 for Co and 4-6.7 for Ni. The absorbance is measured at 389 nm for Co and 495 nm for Ni. Beer's law is obeyed for $\leq 3.5 \mu\text{g ml}^{-1}$ for Co and $\leq 7 \mu\text{g ml}^{-1}$ for Ni. Cu(II), Bi(III) and Fe(III) interfere. However, Fe(III) may be masked by F^- . Tartrate, thiocyanate, EDTA and citrate interfere with Ni and the last two with Co.	192
5,6-Diphenyl-3-(4-phenyl-2- pyridyl)-1,2,4-triazine and tetraphenylborate	510 nm	3.6-7.4	To the sample solution containing 1-14 $\mu\text{g Co}$ add 3 ml of 0.08% ethanolic reagent solution, 2.5 ml of 1% aqueous ceric borate. Adjust the pH between 3.6-7.4 and add 1.2 g of naphthalene. The mixture is heated till the naphthalene melts and is shaken vigorously, cooled and filtered. The ternary complex is dissolved in acetonitrile (10 ml) and the absorbance is measured at 510 nm. Beer's law is obeyed for 8-140 $\mu\text{g Co}$ in 10 ml. The coefficient of variation ($n=10$) is 1.1%.	193

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
1-(5-Bromo-2-pyridylazo)naphthalene-2,7-diol	555 nm	4.2-6.4	The red violet complex formed at pH 4.2-6.4 has λ_{max} 555 nm ($\epsilon=35,000$). Beer's law is obeyed for 0-25 μg of Co(II). The reagent may be used in the determination of Co(II) in iron and cast iron.	194
NH_4SCN with 2,3,4-Picoline or 2,4,6-Collidine	620 nm	dil HCl	To the sample solution containing 100-800 μg Co add 5 ml of water, 1 ml of 30% NH_4SCN , 2 ml of 2M HCl and 1 ml of either of the reagents. The ternary complex is extracted into ethyl acetate and the absorbance is measured at 620 nm. Beer's law is obeyed for $\approx 4-40 \mu\text{g ml}^{-1}$ Co. The Sandell sensitivity index is $\approx 40 \text{ ng cm}^{-2}$.	195
2-Nitroso-5-(N-propyl-N-sulphopropylamino)phenol [3-(3-hydroxy-4-nitroso-N-propylamino)propanesulphonic acid]	490 nm	4-8	The determination of traces of Co in Ni salts is reported. The sample solution is treated with 5 ml of 10 mM hexadecylpyridinium bromide and 5 ml of reagent. The pH is adjusted to 4-8 and 5 ml of 0.2 M iminodiacetic acid are followed by 5 ml of 6M HCl. The absorbance of the solution is measured at 490 nm ($\epsilon=5300$). The coefficient of variation is 1.2% ($n=8$).	196

Name of the Reagent	λ_{max} or working wave length	pH	Remarks	Refs.
5-Methoxy-2-nitrosophenol	450 nm	1 ml of 2M acetic acid	The 1:2 complex is dissolved in acetic acid and the absorbance is measured at 450 nm ($\epsilon=550,000$). The Sandell sensitivity index is 10.7 ng cm^{-2} . Beer's law is obeyed up to 8.1 ppm Co.	197
2,2'-Dipyridyl ketone-2-picolinine; [N-(di-2-pyridyl methyl)ene]-N-(2-pyridyl methyl amine)]	580 nm	8.5-11.1	To the sample solution add 1 ml of 10% Na-L-ascorbate and 5 ml of 10 mM reagent solution. Add NH_3 buffer to adjust to pH 8.5-11.1. Boil, cool and dilute to 50 ml. The absorbance is measured at 580 nm.	198
Thioglycolic acid anilide [2-mercaptoacetanilide]	485 nm	6.2	The sample solution (11-90 $\mu\text{g Co}$) is treated with 5 ml of 10% ethanolic reagent (0.01M), 2 ml of ethanolic 4-picoline and 2 ml of aq. 2% MgCl_2 . Extract with CHCl_3 at pH 6.2. The absorbance of the dried (Na_2SO_4) extract is measured at 485 nm ($\epsilon=11,287$). The optimum range for determination is 1.1-6.5 ppm in the final solution.	199

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
EDTA and t-butyl hydroperoxide	580 nm	11.6	A ternary complex, $\text{Co(III)-EDTA-t-butyl hydroperoxide}$ (1:1:1) is formed at pH 11.6 (phosphate buffer) with λ_{max} 580 nm ($\epsilon=249$). Beer's law is obeyed for 20-160 $\mu\text{g m}^{-1}$ Co and the Sandell sensitivity index is 0.237 $\mu\text{g cm}^{-2}$ in the determination of 31.5-147.2 $\mu\text{g ml}^{-1}$ Co. The standard deviation range is 2.0-4.1 ng m^{-1} . NH_4^+ , $\text{C}(\text{II})$, A , Mn(II) and CH^- interfere seriously.	200
3',5'-Dichloro 2'-hydroxy acetophenone oxime	400 nm	7.5	The sample solution is heated with 1% ethanolic reagent at pH 7.5 (1M $\text{CH}_3\text{COONH}_4$ aq. NH_3 buffer) and at 40-50°C for 20 min. Add a 2% naphthalene solution in acetone to the mixture. The pp. is filtered, washed, dried and dissolved in DMF and its absorbance is measured at 400 nm ($\epsilon=3560$). The Beer's law validity is for 0.17-1.02 $\mu\text{g ml}^{-1}$ Co.	201

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
2-(2-Hydroxy-3,6-disulpho-1-naphthylazo) benzoic acid	410 nm	7.6	The pK_a values of the carboxy- and hydroxy- groups of this reagent are reported. Its Co-complex absorbs at 410 nm and the Ni-complex has λ max at 490 nm. The stability constant and I.R. spectra of the reagent and its Co-complex are given. Co is determined spectrophotometrically at pH 7 and 410 nm. The sensitivity is $0.2 \mu\text{g m}^{-1}$. Cr(III), Fe(III), Ni, Cu(II) and Zn interfere.	202
2,4-Dibromo-5-(5-chloro-2-pyridylazo) toluene	570 nm	6	Cobalt forms a 1:2 complex with this reagent in an acetate buffer medium (pH 6) which shows λ max = 570 nm ($\epsilon = 120,000$). Beer's law is obeyed up to $10 \mu\text{g Co}$. The method may be used to determine Co in ores, steels and cyanocobalamin.	203

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
Trifluoroethylxanthate	350-355 nm	6	This reagent is used for the determination of both Co and Cu. To the test solution are added 0.2% tetrafluoroethylxanthate solution, acetic acid-Na-acetate buffer, pH 6, and sufficient 1M KNO_3 to give an overall concentration of $>0.1\text{M}$. The complexes formed at pH 6 are dissolved in acetone. The absorbance is measured at 350-355 nm and 425-435 nm for Co and Cu, respectively. Beer's law is obeyed in the range 0.4-2.6 $\mu\text{g ml}^{-1}$ and 0-1.7 $\mu\text{g ml}^{-1}$ for Co and Cu.	204
3'-Bromo-2'-hydroxy-5'-methyl acetophenone oxime	400 nm	7.0-8.5	The oximate complex of Co and Cu are formed at pH 7.0-8.5 and 4.0-8.5, respectively, and are adsorbed in methylnaphthalene. The adsorbed complex is dissolved in DMF. $\lambda_{\text{max}} = 400 \text{ nm}$ ($\epsilon = 1190$). Beer's law is valid for 2.31 ppm Co and 4.8-35 ppm Cu. The analytical sensitivities in lices are 0.049 $\mu\text{g cm}^{-2}$ for Co and 0.095 $\mu\text{g cm}^{-2}$ for Cu.	205

Name of the Reagen.	λ_{max} or working wavelength	pH	Remarks	Refs.
Neotetrazolium chloride [3,3'-(4,4'-Biphenylene) bis-(2,5-diphenyl-2-H tetrazolium chloride)]	620 nm	4.5	To this test solution (20-70 μg Co) at pH 4.5 are added 4 ml of aq. 10% NH_4SCN , 4 ml of a 0.4% solution of the reagent in aq. 50% ethanol and 2 ml of H_2O . The ternary complex is dissolved in 5 ml of DMF and then extracted with 7 ml of isobutyl methyl ketone. The absorbance is measured at 620 nm ($\epsilon=3,000$) and Beer's law is obeyed for up to 13 μg m^{-1} cobalt. For 6.5 μg m^{-1} cobalt the coefficient of variation is 17%; the colour is stable for 2 $\frac{1}{2}$ hrs.	206
N Butylxanthate	355 nm	4.3-8.1	This reagent is used for the determination of Cobalt Ni at pH 4.3-8.1 and 4.1-6.8, respectively. The complex formed is taken into methylene naphthalene. The naphthalene layer is dissolved in CHCl_3 and the absorbance of this solution is measured at 355 nm for Co or 418 nm for Ni. Beer's law is obeyed for 0.5-5.5 $\mu\text{g}/\text{ml}$ Co or 0.8-8 $\mu\text{g}/\text{ml}$ Ni.	207

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Isosonitrosothiocamptothioxanthine	350 nm	1M HCl	The complex is extracted with CHCl_3 and then washed with 0.5 M NaOH and the absorbance is measured at 350 nm ($\epsilon = 17,000$). Beer's law is obeyed for 0.2-1.5 ppm Co. The Sandell sensitivity index is 2.5 ng cm^{-2} . Cu(II) and Pd(II) interfere, but can be masked with tartrate and $\text{S}_2\text{O}_3^{2-}$, respectively.	208
Isophthalodihydroxamic acid (K salt)	330 nm	Alkaline medium	Cobalt forms a 1:1 complex with λ_{max} at 330 nm ($\epsilon = 13,000$). To the test solution (1-3 ppm Co) are added 8 ml of 5.4 mM K-Iso-phthalohydroxamate and 4 ml of 2M NaOH. The mixture is diluted to 25 ml with H_2O . The absorbance is measured after 30 min. The relative error is $\pm 3\%$. Equal amounts of Fe, Cu, Mn, Mg, Be and EDTA interfere, but tartrate and F^- are tolerated in >50 fold amounts and Al may be masked by F^- .	209

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
D-2-pyridyl (keton-)-4-amino-5-mercaptop-1,2,4-triazol-3yl hydrazon:	520 nm	8.2	The complex is formed at pH 8.2 (borate buffer) and its absorbance is measured at 520 nm. If Cu(I), Zn, Cd or Mg is present, 3 ml of 0.1M EDTA are added after the buffer solution, and if Ni(II), Cd or Pb is present 5 ml of 70% HClO_4 are added. The absorbance is measured at 500 nm.	210
4-(2-Pyridylazo) resorcinol		9.0	This reagent is used for simultaneous determination of cobalt and nickel using dual wave-length spectrophotometry. The complexes are formed in a citric buffer solution (pH 9). Cobalt and Ni are determined by measuring the difference in absorption at 480 and 550 nm at 531 and 498 nm. The ϵ values for Co and Ni are 23,500 and 13,700 respectively. The calibration graph is rectilinear for $\leq 60 \mu\text{g Co or Ni in 50 ml}$.	211
Sodium dodecyl xanthate	345 nm	7.0	This reagent is used for the determination of Co and Ni at pH 7. Cobalt is determined at 354 nm ($\epsilon = 14,800$) and Beer's law is obeyed for 2.5-10 μM cobalt. Nickel is determined at 509 nm ($\epsilon = 4,390$) and Beer's law is obeyed for 2.3-97 μM Ni.	212

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
3-Ethyl-5-hydroxy-5-D arabinotetrahydroxy butyl thiazolidine-2-thione (I)	362 nm	9.0	Co(II) forms a complex with I having λ_{max} at 362 nm ($\epsilon = 120,000$) and pH 7.5. The complex formed with II has λ_{max} at 320-322 nm ($\epsilon = 126,000$) and pH 9.0. Interfering ions include Fe(III), Cu(II), Ni(II) and Cr(III).	213
3-Bur, 1-5-hydroxy-5-D arabinotetrahydroxy butyl thiazolidine-2-thione (II)	320 nm 362 nm			
Potassium propylxanthate	480 nm 620 nm	3.5-6	The Co(II) complex can be extracted (pH 3.5-6) into CHCl_3 . The extract has λ_{max} at 480 and 620 nm. Beer's law is obeyed for 10-100 ppm at either wavelength. The ϵ values and the Sandell sensitivity index are 63 and 420 and 0.09 and 0.14 $\mu\text{g cm}^{-2}$. The coefficient of variation is 0.48%. Oxalate and EDTA interfere seriously.	214
[5-D(ethylamino)-2-(4,5-dimethyl-2-thiazolylazo)phenol] (DTMAE) and sodium codacylsulphate	592 nm 614 nm	3.4-8.6 (0.1M HCl)	Cobalt is determined with this reagent in the presence of sodium dodecyl sulphate at pH 8.4-8.6. The absorbance is measured at 592 nm ($\epsilon = 61,400$). Cobalt is determined in an acidic medium (3M HCl) at 614 nm ($\epsilon = 45,200$). Other metal complexes are decomposed in the acidic medium.	215

Name of the Reagent	λ max. or working wave-length	pH	Remarks	Refs.
β -Mercaptopyruvic acid anilide [3-mercaptopyruvic acid anilide]	480 nm	6.2	The reagent and picoline are added to the sample solution containing 11-68 μ g Co and the pH is adjusted to 6.2. The red (1:5) cobalt complex is extracted into CHCl_3 . λ max is at 480 nm ($\epsilon = 13,380$) and the Sandell sensitivity index is 4.4 ng cm^{-2} . The coefficient of variation is 1.6% ($n=10$). Beer's law is obeyed from 1.1-6.8 ppm. Fluoride is used to mask Be, F-(II) and A; Mg-EDTA is used for As(III), Sb(III), Bi(III), Th IV, Pb II and Cd. The method may be used to determine Co in ore (limonite), alloys and vitamin pharmaceuticals.	216
Biacetyl monoxime-2-pyridylhydrazine	480 nm	8-12	The absorbance of the orange complex formed in aqueous DMF in the pH range 8-12 is measured at 480 nm. Beer's law is obeyed in the range 0.2-7 ppm.	217

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2-(3,5-Dibromo-2-pyridylazo)-5-dimethyl amino aniline	570 nm	6	The red purple Co complex formed with this reagent at pH 6 has an absorption maximum at 570 nm ($\epsilon = 79,500$). The Sandell sensitivity index is 0.74 ng/cm ² . Beer's law is obeyed for $\leq 0.48 \mu\text{g ml}^{-1}$ Co. This method may be used to determine traces of cobalt in wheat, cyanocobalamin and steel.	218
5-(5-Chloro-2-pyridylazo) toluene-2,4-diamine (5-C-PADAT)	585 nm	5	The 1:2 complex exhibits λ_{max} at 585 nm ($\epsilon = 112,000$) at pH 5. Beer's law is obeyed for $0.5 \mu\text{g/ml}$ Co. In the determination of $10 \mu\text{g Co}$, $< 2 \mu\text{g Pd(II)}$, $< 5 \mu\text{g Cu(II)}$, Sn(II) , Cd , La , V(IV) , Cr(VI) or W(VI) and $> 10 \mu\text{g Ni}$ interfere. Up to 5 mg Fe(III) are tolerated. The method may be used to determine Co in steel and Ni.	219
Cyclohexan-1,3-dione bis thiosemicarbazone monohydrochloride	580 nm	6.0-3.5	The absorbance of the 1:3 complex is measured at pH 6.0-8.5 at 580 nm. Beer's law is obeyed for $0.35-4.4 \mu\text{g ml}^{-1} \text{Co}$. EDTA interferes seriously, but Fe(II) , Ni and Cu(II) in 100 fold, 20 fold and 2 fold excess, respectively, are tolerated if masked with NaF (F^-), citrate (Ni) and citrate (Cu).	220

Name of the Reagent	λ_{max} or working wavelength	pH	Remarks	Refs.
Cyclohexylthioglycolate (2-cyclohexylthioacetate)	500 nm	8.5-10.5	4 ml of 0.1% ethanolic reagent are mixed with 0.2-2 ml of 0.1 mM CoCl_2 and the pH is adjusted to 8.5-10.5. The complex is extracted into CHCl_3 and the absorbance is measured at 500 nm ($\epsilon=20,030$). Beer's law is obeyed from 0.116-1.16 $\mu\text{g ml}^{-1}$. The Sandell sensitivity index is 2.9 ng/cm^2 .	221
3,4-Dihydroxybenzaldehyde guanyldrazone [amidino- hydrazone] (3,4 DBGH)	355 nm	20% HClO_4	The Co(II) complex is formed in 20% HClO_4 medium and the ϵ value is 2880 at 355 nm. Beer's law is obeyed in the range 0.5-16 ppm Co(II) . The method is used to determine Co in artificial water samples.	222
3-(2'-Thiazolyl)-2,6-diaminobenzene [4-(2-thiazolyl)-2,6-diaminophenylendiamine] (I)	580 nm		Conditions for the determination of cobalt with these two reagents (conditions for the second reagent in parentheses) are as follows. To the sample solution containing 0.6-11.8 μg (3.0-59 μg) Co are added 4 ml of 0.1M-NaOH (5 ml of $\text{NH}_3\text{NH}_4\text{ClO}_4$ buffer of pH 9.4) and 2 ml of a 1 mM solution of the reagent. The mixture is set aside for 1 hr. Then 10.8 ml (6 ml) of 60% HClO_4 are added, the mixture is diluted to 25 ml with H_2O , and the absorbance is measured at 580 nm (595 nm) vs a reagent blank; $\epsilon=95,000$ (11,600). The second reagent may be used to determine Co in low-alloy steel and hydrofining catalysts.	223
3-(2'-Thiazolyl)-2,6-diaminopyridine [3-(2-thiazolyl)pyridine-2,6-diamine] (II)	595 nm			

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2-Pyridyl-3'-sulphophenyl methanone 2-(5-nitro) pyridyl hydrazone (PSNPH) (I)	496 nm	2-6	The pK_2 values of these reagents have been determined spectrophotometrically. The values obey Hammett's law. Out of the three, PSNPH is reported to be the most sensitive for Co(II) determination. It reacts with Co(II) to form a 1:2 (M:R) complex. This complex is rapidly oxidised at about pH 2 to give a stable Co(III) complex with λ max at 496 nm (pH 2-6). Beer's law is obeyed over the range 0.05-1.0 $\mu\text{g/ml}$ Co and the apparent molar absorptivity of the complex is $5.69 \times 10^4 \text{ l mol}^{-1} \text{ cm}^{-1}$ at 496 nm. No anions interfere except EDTA. Cu(II), Pd(II), Fe(II) and Ni(II) interfere when no masking agent is present. The method may be applied to the determination of Co in steels.	224
2-Pyridyl-3'-sulphophenyl methanone 2-(3-methyl) pyridyl hydrazone (PSMFH) (II)	488 nm	4		
2-Pyridyl-3'-sulphophenyl methanone 2-(5-chloro) pyridyl hydrazone (PSCPFH) (III)	490 nm	4		
3-Hydroxy-4-(2-pyridylazo) naphthalene-1-sulphonic acid	566 nm		A sensitive and selective method for the determination of cobalt as its complex with 3-hydroxy-4-(2-pyridylazo) naphthalene-1-sulphonic acid is proposed. The maximum absorbance of the 1:2 complex is at 566 nm ($\epsilon = 23,000$).	225

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
Dipicolylmethylhydroxamic [pyridine-2,6-diethylhydroxamic] acid	357 nm	5 ml 1M NaOH	To the test solution (1-4 ppm of Co) are added 10 ml of 1 mM reagent and 5 ml of 1M NaOH and the solution is made up to 25 ml with H_2O . The absorbance of the complex is measured at 357 nm. Tolerance levels are ≤ 10 ppm for Pd(II), Fe(III), Ce(III), Ru(IV), Ca, Cr(III), U(VI), EDTA, CN^- , Cu(II), Cd, Ni and Mn(II).	226
EDTA	535 nm	5	A spectrophotometric method is reported for determination of milligram levels of cobalt, based on oxidation of the Co(II)-EDTA complex with Au(III) chloride at pH 4.0-6.5 and 100°C. The sample solution (4-8 mg Co in H_2O - HNO_3 -HCl) is boiled with 3 ml of 0.25M-EDTA, 10 ml of 0.1M Na acetate-acetic acid buffer (pH 5) and 6 ml of 0.01M AuCl_3 for 15 min. The solution is diluted to 50 ml with H_2O . The absorbance of the violet Co(III)-EDTA complex is measured at 535 nm. The precision is not affected by the presence of several metal ions including coloured ones such as Cu(II).	227

Name of the Reagent	λ_{max} or working wave-length	pH	Remarks	Refs.
2-(3-5-Dichloro-2-pyridyl azo)-5-dimethylamino phenol (3,5-di Cl-DMAPA)	590 nm	4.0	<p>N (II) and Fe(II). Chromium (III) interferes since it also forms a violet complex with EDTA, but can be removed by separation with pyridine. The calibration graph is rectilinear to 1.0-8.0 mg Co(III). The method is used in the determination of cobalt in alloys based on iron-cobalt analysis.</p> <p>This reagent reacts with cobalt in aqueous solution at pH 2.2-6.0 and room temperature to form a water-soluble ML_2 complex. To this sample solution (containing $< 1.3 \mu\text{g Co}$) and 1 ml of 0.1M acetate buffer (pH 4.0) are added 0.5 ml of 0.1 ml/l reagent solution and 3 ml of H_2O. After 60 min. the Co(II) complex is extracted with benzene and the absorbance of the extract is measured at 590 nm ($\epsilon = 84,000$). Beer's law is obeyed up to $7.5 \mu\text{M-Co(II)}$. The method has been applied to the determination of Co in carbon steels. The interference of other transition metals can be eliminated by solvent extraction with 8-hydroxyquinoline. The coefficient of variation is 1.3% ($n=8$) for the determination of $5.0 \times 10^{-6}\text{M cobalt}$.</p>	228

This survey of the literature reveals that a large number of reagent and methods have been reported for the spectrophotometric determination of cobalt. However, only a few hydroxytriazenes have been reported so far in this connection. In particular, the reagents of this series are gaining importance because of their ease of preparation and low cost of production and also because of their superiority in the determination of various metal ions.

REFERENCES

1. E.A. Bashirov and A.M. Ayubova, *Uchen. Zap. azerb. gos. Univ., Ser. Khim. Nauk*, **3**, 24 (1971); Referat. Zh. Khim., 19GD, **10** (1972), Abstr. No. 10G86.
2. E.A. Bashirov and A.M. Ayubova, *Uchen. Zap. azerb. gos. Univ., Ser. Khim. Nauk*, **4**, 28 (1971); Referat. Zh. Khim., 19GD, **11** (1972), Abstr. No. 11G134.
3. M.M.L. Khosla and S.P. Rao, *Microchem. J.*, **17**, 338 (1972).
4. L.V. Evshova, *Zav. Lab.*, **38**, 905 (1972).
5. W. Gorski and S. Podlasin-Paradowska, *Acta Pol. Pharm.*, **29**, 31 (1972).
6. S. Motomizu, *Analyst (London)*, **97**, 986 (1972).
7. D. Nanova and B. Evtimova, *Analyt. Chim. Acta*, **62**, 456 (1972).
8. M.B. Shustova and V.A. Nazarenko, *Zav. Lab.*, **39**, 18 (1973).
9. N.A. Batasheva, O.V. Sivonava and N.N. Gritsienko, *Zav. Lab.*, **39**, 17 (1973).
10. J. Mohamed, J. Mirjehan and H. Gilbert Ayres, *Analyt. Chem.*, **44**, 2263 (1972).
11. A.K. Rishi, B.S. Garg and R.P. Singh, *Indian J. Chem.*, **10**, 1037 (1972).
12. R.N. Virmani, B.S. Garg and R.P. Singh, *J. Prakt. Chem.*, **314**, 965 (1972).
13. E. Uhlemann and B. Schuknecht, *Analyt. Chim. Acta*, **63**, 236 (1973).
14. R.R. Mulye and S.M. Khopkar, *Mikrochim. Acta*, **1973** (I), 55.
15. H.R. Notenboom, W.J. Holland and R.G. Billinghamurst, *Mikrochim. Acta*, **1973** (III), 467.
16. S. Shibate, M. Furukawa and K. Gots, *Talanta*, **20**, 426 (1973).
17. J. Dunach and F. Buscarons, *Analisis*, **2**, 510 (1973).
18. T. Kuroha, *Japan Analyst.*, **20**, 1565 (1973).
19. E.L. Krukovaskya, S.T. Talipov, L.M. Zhabitskaya and J. Lobanova, *Zh. Analit. Khim.*, **27**, 2427 (1972).
20. I.M. Issa and M.M. Aly, *Z. analyt. Chem.*, **266**, 127 (1973).
21. M.P. Martinez Martinez, D. Perez Bendito and F. Pino Perez, *Ann. Quim.*, **69**, 747 (1973).
22. G.S. Vasilikiotis and T.A. Kouimtzis, *Microchem. J.*, **18**, 85 (1973).
23. I.V. Pyatnitskii and G.N. Trochinskaya, *Zh. Analit. Khim.*, **28**, 704 (1973).
24. J.N. Srivastava and R.P. Singh, *Talanta*, **20**, 1210 (1973).
25. E. Casassas, J.J. Arias and A. Mederos, *Ann. Quim.*, **69**, 1121 (1973).

26. W.J. Holland, M. Depooter and J. Bozic, *Mikrochim. Acta*, **1974** (I), 99.
27. K. Manolov and N. Motekov, *Mikrochim. Acta*, **1972** (II), 231.
28. R. Belcher, S.A. Ghonaim and A. Townshend, *Talanta*, **21**, 191 (1974).
29. A. Garciae Torres, M. Valcarcel and F. Pino Perez, *Analyt. Chim. Acta*, **68**, 466 (1974).
30. L.I. Chernomorchenko, T.V. Chuiko and A.G. Akhmetshin, *Zh. analit. Khim.*, **27**, 2262 (1972).
31. S. Shibata and M. Furukawa, *Japan Analyst*, **22**, 1077 (1973).
32. G.S. Vasilikiotis, T. Kouimtzis, C. Apostolopoulou and A. Voulgaropoulos, *Analyt. Chim. Acta*, **70**, 319 (1974).
33. S.T. Talipov, N.G. Smaglyuk and A. Khodzhev, Referat. *Zh. Khim.*, **19GD**, 1973(20), Abstr. No. 20G69; *Anal. Abstr.*, **28**, B-170 (1975).
34. N. Ohta, S. Tama, H. Nunokawa and H. Terai, *Japan Analyst*, **23**, 931 (1974).
35. S.A. Dyachenko, S.O. Gerasimova, I.A. Belen'kaya and V.G. Pesen, *Zh. analit. Khim.*, **29**, 877 (1974).
36. K. Ohira, Y. Kidani and H. Koike, *Japan Analyst*, **23**, 658 (1974).
37. Yu. A. Mittsel and A.V. Vasilev, *Zh. analit. Khim.*, **29**, 596 (1974).
38. A.R. Saple and D.N. Patkar, *J. Indian Chem. Soc.*, **51**, 738 (1974).
39. L.V. Ershova, V.H. Ivanov and A.I. Busev, *Zh. analit. Khim.*, **29**, 1367 (1974).
40. Yu. M. Dedkov, T. Ya. Kalenchenko, A.S. Grzhegorzhevskii, *Zh. analit. Khim.*, **29**, 1374 (1974).
41. H. Gorniak and B. Jamk, *Z. analyt. Chem.*, **273**, 127 (1975).
42. M. Israilov, Yu. M. Yusupov, D.N. Pachadzhinov and Kh. Dadzhinov, Manuscript No. 1360-74 at INTI, Moscow, 1974, 10 pp; *Anal. Abstr.*, **29**, 4B211(313) (1975).
43. M. Rueda Rueda and J.A. Munozhieva, *Quim. analyt.*, **29**, 122 (1975).
44. N. Kh. Makusdov, Z.B. Nasyrova and S.N. Khosolapova, *Zh. analit. Khim.*, **29**, 2063 (1974).
45. D. Molch, H. Koening and E. Than, *Z. Chemie. Lpz*, **15**, 410 (1975).
46. F. Kai and H. Egoshi, *Analyt. Lett.*, **8**, 575 (1975).
47. C.K. Bhaskare and S.K. Deshmukh, *Z. analyt. Chem.*, **271**, 127 (1975).
48. K. Lal and S.P. Gupta, *Indian J. Chem.*, **13**, 973 (1975).
49. H. Tomica-Sikorska, *Chem. Analit.*, **20**, 1025 (1975).
50. E.D. Korotkaya, A. Kh. Kilbus, V.E. Pochinok and T.S. Shulgach, *Izv. Vyssh. Ucheb. Zaved. Khim. Khim. Tekhnol*, **18**, 1695 (1975).

51. M.P. Martinez, M. Valcarcel and F. Pino Perez, *Analyt. Chim. Acta*, **81**, 157 (1976).
52. K. De and J. Das, *J. Indian Chem. Soc.*, **52**, 1026 (1975).
53. C.K. Bhaskare and V.D. Jagdale, *Z. analyt. Chem.*, **278**, 127 (1976).
54. S.B. Savvin, T.V. Tetova and T.G. Dzherayan, *Zh. analit. Khim.*, **30**, 2092 (1975).
55. P.R. Haddad, P.W. Alexander and L.E. Smythe, *Talanta*, **23**, 275 (1976).
56. K.N. Bagdasarov, M.S. Chernov'yants, T.M. Chernovanova and E.G. Tsupak, *Zav. Lab.*, **42**, 143 (1976).
57. A.K. Singh, M. Katyal and R. P. Singh, *Ann. Chim.*, **65**, 109 (1975).
58. T.L. Radovskaya, *Zav. Lab.*, **42**, 398 (1976).
59. J.L. Gomez Ariza and J.M. Cano Pavon, *Analyt. Lett.*, **9**, 677 (1976).
60. H.L. Ray, B.S. Garg and R.P. Singh, *J. Chin. Chem. Soc. (Taipei)*, **23**, 47 (1976).
61. S. Shahine, M. Fathy Elshahat and S. Khamis, *Microchem. J.*, **21**, 279 (1976).
62. D.G. Gambarov, S.B. Bilalov and A.K. Babaev, *Zh. analit. Khim.*, **31**, 1731 (1976).
63. J.M. Cano Pavon, A. Lavado and F. Pino Perez, *Mikrochim. Acta*, **1976 (II)**, 233.
64. M. Satake, M. Shimizu and Y. Nagaosa, *Fukui Daigaku Kogakubu Kenkyu Hokoku*, **24**, 53 (1976).
65. S. A. Abbasi, B.G. Ghat and R.S. Singh, *Z. analyt. Chem.*, **282**, 222 (1976).
66. S. Musumeci, E. Rizzarelli, I. Fragala, S. Samaritano and R.P. Bonomo, *Z. analyt. Chem.*, **282**, 221 (1976).
67. F. Vlacil and A. Jehlickova, *Coll. Czech. Chem. Comm.*, **41**, 3749 (1976).
68. F. Garcia Montelogo and J.A. Lopez Cancio, *Ann. Quim.*, **73**, 248 (1977).
69. S. Motomizu and K. Toei, *Analyt. Chim. Acta*, **89**, 167 (1977).
70. V.M. Peshkova, T.V. Polenova and Yu. A. Barabalat, *Zh. analit. Khim.*, **32**, 471 (1977).
71. A.E. Mahgoub, A.S. Shawali and M.M. Shoukry, *Z. analyt. Chem.*, **284**, 205 (1977).
72. G. Popa and N. Dumitrescu, *Rev. Chim. (Bucharest)*, **28**, 486 (1977).
73. Ishwar Singh, B.S. Garg and R.P. Singh, *Z. analyt. Chem.*, **284**, 42 (1977).
74. E. Domaglina and S. Zareba, *Farm. Pol.*, **33**, 207 (1977).

75. M.B. Saha and A.K. Chakraborty, *J. Indian Chem. Soc.*, **53**, 1137 (1976).
76. M.A. Dosal Gomez and J.A. Perez-Bustamante, *Ann. Quim.*, **73**, 968 (1977).
77. N. Ahmad and C. Munir, *Microchem. J.*, **22**, 381 (1977).
78. M. Valcarcel, M.P. Martinez and F. Pino Perez, *Quim. analit.*, **31**, 75 (1977).
79. A.K. Singh, M. Katyal and R.P. Singh, *J. Indian Chem. Soc.*, **53**, 691 (1976).
80. C.P. Savariar and T.R. Hariharan, *J. Indian Chem. Soc.*, **54**, 274 (1977).
81. S.B. Ghosle, A.S. Ghormade and R.B. Kharat, *J. Indian Chem. Soc.*, **53**, 728 (1976).
82. T. Odashima and H. Ishii, *Bunseki Kagaku*, **26**, 678 (1977).
83. V. Gonzalez Diaz, J.J. Arias and F. Garcia Montelongo, *Ann. Quim.*, **73**, 1300 (1977).
84. K. Watanabe, A. Fujiwara, M. Sakai and K. Kawagaki, *Bunseki Kagaku*, **26**, 844 (1977).
85. C. K. Bhaskare and U.S. Jagadal, *Analyt. Chim. Acta*, **93**, 335 (1977).
86. M.L. Tsap, Z.V. Proskura, N.S. Gedz and S.P. Sheredeko, *Agrokimiya*, 120 (1977).
87. Yu.M. Dedkov, T.Ya. Kalenchenko and Yu.I. Usalinko, *Izv. Vyssh. Uchebn. Zaved, Khim. Khim. Tekhnol.*, **21**, 357 (1978).
88. N.P. Mukhovikova, M.I. Bulatov and V.F. Vushukova, *Izv. Vyssh. Uchebn. Zaved, Khim. Khim. Tekhnol.*, **21**, 510 (1978).
89. K. Kayashi, Y. Sasaki, S. Tagashira, K. Itoh and M. Sujuki, *Bunseki Kagaku*, **27**, 204 (1978).
90. C. Marone and R. Olsina, *Cron. Chim.*, **49**, 10 (1977).
91. F. Jimenez Sierra and M. Cordoba Hernandez, *Ann. Quim.*, **74**, 261 (1978).
92. S.I. Gusev, V. Yu. Gusev, I.N. Glushkova, L.G. Zazhina, M.V. Zhuvakina, L.A. Ketova and I.A. Kozhevnikova, *Zh. analit. Khim.*, **33**, 734 (1978).
93. M.J. Presas Barrosa, F. Bermezo Martinez and J.A. Rodriguez Vazquez, *Bol. Soc. Quim. (Peru)*, **43**, 26 (1977).
94. T. Ya. Kalenchenko, G.A. Butenko and Yu. M. Dedkov, *Vopr. Khim. Khim. Tekhnol.*, **46**, 78 (1977).
95. E. Wajda and B. Janik, *Chem. Analit. (Warsaw)*, **23**, 295 (1978).
96. M. Yoshio, M. Yugamura, H. Noguchi and M. Nagamastu, *Analyt. Lett.*, **11**, 281 (1978).

97. A.O. Onov, *Khim. Geol. Nauk.*, **4**, 110 (1977).
98. P.W. Beaupre and W.J. Holland, *Mikrochim. Acta*, **1978** (II), 95.
99. J. Singh and S.P. Gupta, *Acta Ciencia Indica*, **3**, 112 (1977).
100. P.W. Beaupre and W.J. Holland, *Mikrochim. Acta*, **1978** (II), 239.
101. C.K. Bhaskare, S.V. Kulkarni, K.N. Ganage and S. Devi. *J. Indian Chem. Soc.*, **55**, 199 (1978).
102. S.P. Mathur, R.S. Thakur, C.S. Bhandari and N.C. Sogani, *Talanta*, **25**, 592 (1978).
103. K. Matsusaki, *Yamaguchi Daigaku Kogakubu Kenkyu Hokobu*, **28**, 249 (1978).
104. K. Watanabe and K. Kowagaki, *Bunseki Kagaku*, **27**, 467 (1978).
105. K. Nakashima, H. Hirahara and S. Akiyama, *Bunseki Kagaku*, **27**, 529 (1978).
106. L.V. Evmakova and V.A. Petrova, *Zh. analit. Khim.*, **34**, 168 (1979).
107. F. Capitan Garcia, M. Roman Ceba and F. Garcia Sanchez, *Rev. Univ. Ind. Santander. Invest.*, **8**, 43 (1978).
108. R.B. Singh, P. Jain, B.S. Garg and R.P. Singh, *Analyt. Chim. Acta*, **104**, 191 (1979).
109. S.f. Cham and O.W. Lau, *Mikrochim. Acta*, **1979** (I), 241.
110. D.G. Gombarov, *Zh. analit. Khim.*, **39**, 738 (1979).
111. K. Ueda, *Bull. Chem. Soc. Japan*, **52**, 1215 (1979).
112. J.M. Grana Molares, C. Baluja Santos, A. Alvarez Devesa and F. Bermezo Martinez, *Analisis*, **7**, 249 (1979).
113. H. Kulshreshtra, R.B. Singh and R.P. Singh, *Analyst (London)*, **104**, 572 (1979).
114. A.K. Panova, D.I. Bakurdzhieva and G.V. Angelova Dokl, *Bolg. Akad. Nauk*, **32**, 461 (1979).
115. B.V. Rao, D. Venkteswara Rao and K.C. Sarojam, *Indian J. Tech.*, **16**, 336 (1978).
116. G. Bianchi, C. Bianchi and E. Gerlo, *Afinidad*, **35**, 30 (1978).
117. Y. Rokugalva, M. Sugawara and T. Kambara, *Bull. Chem. Soc. (Japan)*, **52**, 2303 (1979).
118. R.B. Singh, H.L. Ray, B.S. Garg and R.P. Singh, *Talanta*, **26**, 898 (1979).
119. M. Tsuchiya, *Nippon Kagaku Kaishi*, **5**, 597 (1979).
120. I. Singh, J.L. Sharma, B.S. Garg and R.P. Singh, *J. Chin. Chem. Soc. (Taipei)*, **26**, 121 (1979).
121. M.C. Mehra and D. Leblani, *Microchem. J.*, **24**, 435 (1979).
122. N.V. Popandopulo, V.K. Zlobin and T.N. Vladimirskaia, *Metody Anal. Kontrolya Kach. Prod. Khim. Prom-sti.*, **6**, 23 (1978).

123. M.M. Khater, Y.M. Issa, A.F. Shouksy and F.A.A. El-Seify, *Mikrochim. Acta*, **1979** (II), 501.
124. U.K. Jetley, J. Singh and S.N. Rastogi, *Acta Ciencia India*, **5**, 169 (1979).
125. A.G. Asuero and M.M. Rodriguez, *Analyst (London)*, **105**, 203 (1980).
126. J. Gimenner Plaza and J.D. Jimenez Gallardo, *Afinidad*, **36**, 237 (1979).
127. N.R. Biswas, B.C. Ray and S. Lahiri, *Indian J. Chem. Sec. A.*, **19**, 58 (1980).
128. G. Popa and N. Dumitrescu, *Ser. Chim. Metal*, **40**, 17 (1978).
129. D. Thorburn Burns and P. Hanprasopnattana, *Analyt. Chim. Acta*, **115**, 389 (1980).
130. O.S. Chauhan, I. Singh, B.S. Garg and R.P. Singh, *Ann. Chim. (Rome)*, **69**, 363 (1979).
131. A.A. Elsirafy, *Z. analyt. Chem.*, **301**, 26 (1980).
132. B.K. Puri and M. Gautam, *J. Chem. Tech. Biotechn.*, **30**, 244 (1980).
133. F. Garcia Sanchez, F. Bosch Reig and J.M. Estela, *Ann. Quim. Ser. B.*, **76**, 273 (1980).
134. M.Yu. Yusupor, M.A. Israilov, D.N. Pachadzhanov and E.V. Panova, *Zav. Lab.*, **46**, 390 (1980).
135. K. Nakashima and S. Akiyama, *Yakugaku Zasshi*, **100**, 515 (1980).
136. M. Satake and N. Yoshida, *Fukui Daigaku, Kagakubu Kenkyu Hokoku*, **27**, 261 (1970).
137. F. Montelongo Garcia, C.R. Tallo Gonzalez and V. Gonzalez, *Analyst (London)*, **105**, 762 (1980).
138. P.G. Ramappa, H. Sanke Gowda and S. Manjappa, *J. Indian Chem. Soc.*, **57**, 304 (1980).
139. M.A. Matveets, S.D. Akhmetova and P.S. Shcherbov, *Zh. analit. Khim.*, **35**, 1640 (1980).
140. G. Ionescu, A. Duca and F. Matei, *Mikrochim. Acta*, **1980** (I), 329.
141. A. Gonzalez Portel, L. Pias Garcia, F. Bermezo Martinez and C. Baluja-Santos, *Microchem. J.*, **25**, 353 (1980).
142. N. Subba Rami Reddy and D. Venkata Reddy, *Analyt. Chim. Acta*, **120**, 395 (1980).
143. O. Baudino and B. Carlos Marone, *Analyt. Chim. Acta*, **119**, 393 (1980).
144. J.M. Fernandez Soles, A. Alvarez Devera, F. Bermezo Martinez and G. Manuela Gonzalez, *Acta Quim. Compostelana*, **3**, 19 (1979).
145. M.S. Al-Obadie, *J. Indian Chem. Soc.*, **57**, 1059 (1980).

146. A. Tyagi, R.P. Tyagi and B.C. Joshi, *Afinidad*, **37**, 333 (1980).
147. A.K. Bhattacharjee and M.K. Mahanti, *Indian J. Chem. Sec. A.*, **20**, 427 (1981).
148. C. Laino, M. Carmen, L. Ferreira, R. Antonia and B. Martinez, *Acta Quim. Compostelana*, **3**, 134 (1979).
149. M. Gautam, R.K. Bansal and B.K. Puri, *Bull. Chem. Soc. Japan*, **54**, 3178 (1981).
150. J.J. Arias, M.L. Perez-Pont and F. Garcia Montelongo, *Ann. Quim. Ser. B*, **77**, 353 (1981).
151. S. Okawa, B. Kominami and A. Kawase, *Bunseki Kagaku*, **31**, 373 (1982).
152. M. Furukawa, R. Nakashima, E. Kamta and Shozoshibata, *Nagoya Kogyo Gijutsu Shikensho Hokoku*, **30**, 287 (1981).
153. F. Garcia Sanchez, A. Navas, J.J. Laserna and A. Arbaizar, *Analyst (London)*, **107**, 35 (1982).
154. S.K. Singh, M. Kamini and S.K. Sindhvani, *J. Chin. Chem. Soc. (Taipei)*, **29**, 131 (1982).
155. G. Asuero Agustin, D. Rosales and M.M. Rodriguez, *Analyst (London)*, **107**, 1065 (1982).
156. H. Wada, T. Ishizuki, G. Nakagawa, *Analyt. Chim. Acta*, **135**, 333 (1982).
157. P.K. Govil and S.K. Benerji, *Bull. Inst. Chem., Acad. Sin.*, **28**, 93 (1981).
158. M.A. Israilov, M. Yu. Pachadzanov and D.N. Pachadzanov, *Izv. Akad. Nauk Tadzh. SSR, Otd. Fiz-Mat, Geol-Khim. Nauk*, **1**, 45 (1981).
159. B.K. Puri, C.L. Sethi and A. Kumar, *J. Chin. Chem. Soc. (Taipei)*, **29**, 173 (1982).
160. P. J. Cacho and C. Nerin de la Puerta, *Afinidad*, **39**, 44 (1982).
161. D. Thorburn Burns, P. Hanprasapwatlana and B.P. Murphy, *Analyt. Chim. Acta*, **134**, 397 (1982).
162. S. Okawa, B. Kominami and A. Kawase, *Bunseki Kagaku*, **31**, 373 (1982).
163. M. Satake, B.K. Puri, J. C. Yuh and L.F. Chang, *Fukui Daigaku Kogakubu Kenkyu Hokoku*, **30**, 63 (1982).
164. S.P. Mathur, V.P. Mehta and M. Hasan, *Chem. Analit. (Warsaw)*, **26**, 1081 (1981).
165. C.L. Sethi, A. Kumar, B.K. Puri and M. Satake, *Analyst (London)*, **108**, 528 (1983).
166. M.M. Tananaiko and G.A. Todradze, *Ukr. Khim. Zh. (Russ. Ed.)*, **49**, 391 (1983).

167. J. Singh, K.N. Sharma, U.K. Jetly, S.K. Rastogi and G.S. Bhuee, *Chem. Era*, **18**, 218 (1982).
168. J.J. Arias, F. Jimenez, A.I. Jimenez and F. Garcia Montelongo, *Ann. Quim. Ser. B.*, **79**, 248 (1983).
169. G. K. Mukherjee and J. Das, *J. Indian Chem. Soc.*, **60**, 70 (1983).
170. F.J. Barragan de la Rosa, J.L. Gomez Ariza and F. Pino Perez, *Mikrochim. Acta*, **1983** (II), 455.
171. H.S. Gowda, K.N. Thimmaiah and S.M. Ahmed, *Current Sci.*, **52**, 636 (1983).
172. M.B. Saha and A.K. Chakraborty, *J. Indian Chem. Soc.*, **60**, 176 (1983).
173. B.K. Deshmukh, *Chem. Analit. (Warsaw)*, **28**, 297 (1983).
174. M. Kamini, F. Kamil and S.K. Sindhwani, *J. Indian Chem. Soc.*, **60**, 388 (1983).
175. R.B. Singh, T. Odashima and H. Ishii, *Analyst (London)*, **109**, 43 (1984).
176. H.S. Gowda, K.N. Thimmaiah and S.M. Ahmed, *Indian J. Chem. Sect. A.*, **22**, 551 (1983).
177. C.H. Evans, *Anal. Biochem.*, **135**, 335 (1983).
178. D.T. Burns and S. Kheawpintong, *Analyt. Chim. Acta*, **156**, 329 (1984).
179. X. Chen, R. Zhou, D. Wu and L. Dong, *Nanjing Daxue Xuebao, Ziran Kexue*, **1**, 84 (1983).
180. S. Yamaguchi and K. Uesugi, *Bunseki Kagaku*, **33**, 112 (1984).
181. S. Srinivasan and V. Seshagiri, *Acta Ciencia Indica*, **9**, 97 (1983).
182. S.P. Bag and B. Bhattacharya, *J. Indian Chem. Soc.*, **60**, 596 (1983).
183. K. Huo, *Fenxi Huaxue*, **12**, 558 (1984).
184. Y. He and D. Huang, *Fenxi Huaxue*, **12**, 389 (1984).
185. M. Milla Gonzalez, M.P. Martinez Martinez and J.A. Perez-Bustamante, *Ann. Quim. Ser. B.*, **80**, 351 (1984).
186. J. Hernandez-Mendez, A. Alonso-Mateos and E.J. Martin Mateos, *Microchem. J.*, **30**, 12 (1984).
187. J.L. Lin, L.-F. Chang, M. Katyal and M. Satake, *Z. analyt. Chem.*, **319**, 308 (1984).
188. D.T. Burns and S. Kheawpintong, *Analyt. Chim. Acta*, **162**, 437 (1984).
189. A. Izquierdo, R. Compano and E. Bars, *Mikrochim. Acta*, **1984** (II), 345.
190. D. Ivanovic, R. Milosevic and D. Radulovic, *Acta Pharm. Jugosl.*, **34**, 163 (1984).

191. K.V. Reddy and A. Paul, *Indian J. Chem. Sect. A.*, **23**, 790 (1984).
192. A.L.J. Rao and J. Shekhar, **30**, 283 (1984).
193. J.L. Lin, *J. Chin. Chem. Soc. (Taipei)*, **31**, 395 (1984).
194. G. Yang, Y. Liu, Q. Wu and Z. Wei, *Huaxue Shiji*, **6**, 347 (1984).
195. P. Chattopadhyay and S.K. Majumdar, *J. Indian Chem. Soc.*, **61**, 621 (1984).
196. I. Yoshida and K. Veno, *Bunseki Kagaku*, **34**, 77 (1985).
197. N.F. Mody, *J. Inst. Chem.*, **57**, 6 (1985).
198. T. Kato and K. Kano, *Bunseki Kagaku*, **34**, 36 (1985).
199. C. Ray and J. Das, *Indian J. Chem. Sec. A.*, **24**, 40 (1985).
200. P. Bermezo Barrera, J.F. Vazquez Gonzalez and F. Bermazo Martinez, *Analyst (London)*, **110**, 811 (1985).
201. M. Satake, S.R. Malhotra and K. Lal, *Acta Ciencia Indica*, **10**, 242 (1984).
202. E. Stefancu and D. Stefancu, *Rev. Chim. (Bukharest)*, **36**, 863 (1985).
203. G. Zhang, Y. Wu, C. Li, Y. Jin and B. Liu, *Fenxi Huaxue*, **13**, 618 (1985).
204. M.F. Hussain, B.K. Puri, R.K. Bansal and M. Satake, *Mikrochim. Acta*, **1985** (I), 227.
205. S. Malhotra and K. Lal, *Oriental J. Chem.*, **1**, 107 (1985).
206. A.K. Singh, D. Kumar and M. Katyal, *Analyt. Chim. Acta*, **172**, 303 (1985).
207. B.K. Puri, A.K. Gupta, A.L.J. Rao and M. Satake, *Chim. Acta Turc.*, **12**, 245 (1984).
208. P.K. Paria and S.K. Majumdar, *Indian J. Chem. Sect. A.*, **24**, 989 (1985).
209. F. Salinas, M. Jimenez-Arrabal and I. Duran, *Microchem. J.*, **33**, 194 (1986).
210. C. Samara and T.A. Koumitzis, *Microchem. J.*, **33**, 255 (1986).
211. S. Lus and Z. Yang, *Fenxi Huaxue*, **14**, 47 (1986).
212. K. Hayashi, Y. Sasaki, S. Tagashira and N. Mito, *Bunseki Kagaku*, **35**, 413 (1986).
213. J.R. Castillo, A. Lopez, J.M. Mir, O. Valiente and A. Alvarez, *Quim. analit. (Barcelona)*, **4**, 360 (1985).
214. P.K. Paria and S.K. Majumdar, *Indian J. Chem. Sec. A.*, **25**, 103 (1986).
215. Y. Zheng and Y. Lui, *Fenxi Shiyanshi*, **5**, 7 (1986).
216. C. Ray and J. Das, *J. Indian Chem. Soc.*, **63**, 236 (1986).
217. M.J. Navas, A.G. Asuero and D. Rosales, *Microchem. J.*, **33**, 331 (1986).

218. G. Zhang, C. Li, Y. Hu, M. An and Y. Fan, *Fenxi Shiyanshi*, **5**, 13 (1986).
219. X. Qui, Y. Zhu and L. Zhang, *Rev. Chim. (Bukharest)*, **37**, 586 (1986).
220. K.H. Reddy and D.V. Reddy, *Chim. Acta Turc.*, **13**, 77 (1985).
221. A.L.J. Rao, U. Gupta and J.S. Sandhu, *J. Inst. Chem. (India)*, **58**, 171 (1986).
222. E. Kavlentis, *Mikrochim. Acta*, **1**, 27 (1986).
223. V. Gonzalez, M.J. Sanchez and F. Garcia Montelongo, *Quim. analit. (Barcelona)*, **5**, 335 (1986).
224. T. Odashima, T. Kikuchi, W. Ohtani and H. Ishii, *Analyst (London)*, **111**, 1383 (1986).
225. Z. Zhou, Z. Liang and B. Hu, *Fenxi Shiyanshi*, **5**, 31 (1986).
226. F. Salinas, R. Forteza and J.M. Esteda, *Ann. Quim. Ser. B*, **83**, 109 (1987).
227. B.V. Rao, V.G.R. Menon and K.C. Sarojam, *Talanta*, **34**, 367 (1987).
228. M. Nakamura, Y. Sakanshi, H. Chikushi, F. Kai, S. Sato, T. Sato and S. Uchikawa, *Talanta*, **34**, 369 (1987).