REAGENTS FOR THE SPECTROPHOTOMETRIC DETERMINATION OF NICKEL: A REVIEW

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CONTENTS

ABSTRACT

A survey of literature reported since 1971 has been made. To avoid bulk the review of the various reagents used in the spectrophotometric determination of nickel is reported in tabular form. The available information has been condensed and presented under the following headings: name of the reagent, λ max,. or working wave length, optimum pH, remarks and references. Under "remarks" information regarding the composition of the complexes, interferences, etc., are reported.

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Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
5-Amino-3-(3-carboxytriazol-5-ylazo)-4-hydroxy naphthalene-2, 7-disulphonic acid	-	8.5	5 to 25 μg Ni have been determined in 25 ml. Interference by PO_4^{-3}, No_3^-, CH_3COO^-, EDTA, Zr, Cr, Fe, Mg, Sn, U and Zn has been reported. 20 to 70 fold amounts of Mn,Be, U, W, Ca, Th and large amounts of Al, Ge and Mo are tolerated. A < 0.4% error is reported in 10 parallel determinations.	1
2-(Diethylamino) ethane thiol hydrochloride	520	10	The ratio of Ni-to-R in the complex is 1:2. Buffer pH 10 (H_3BO_3-KCl-NaOH). Interference by 14 metals is reported.	2
Diethyl dithio-carbamate	328	slightly alkaline	Reported for the simultaneous determination of Cu, Ni and Co by extraction into CCl_4. Cu and Co are measured at 436 and 367 nm respectively. A correction is necessary when Ni is determined in the presence of Co. The interferences of Fe and Mn were masked by 4% aq. $Na_4P_2O_7 \cdot 10H_2O$ and the precipitate caused by uranium was dissolved by adding $Al(NO_3)_3$.	3
4-(2-Pyridylazo) resorcinol	520 496	3.3 8.0	This reagent is used for the determination of Ni and Co. Both the metals form M:R:1:2 complexes in acidic or alkaline media. For the red Ni complex at	4

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			pH 3.3, ϵ = 37,200 with λ max. 520 nm. At pH 8.0 the fully deprotonated Ni complex has ϵ = 79,400 and λ max. 496 nm. For the Co complex irrespective of pH ϵ = 65,500 at 510 nm.	
Thiophenoyl trifluoro acetone [1,1,1-trifluoro 4-mercapto-4-(2-thienyl)-but 3-en-3-one]	480	6.0 to 6.5	Nickel (5 to 40 μg) in CCl_4 (10 ml) is extracted at pH 6 to 6.5 by this reagent (mM). The complex is stable for 96 hrs. W(VI), V(V) > 10 fold and Mn(II), Th, $S_2O_3^{-2}$ (>75 fold) interfere whereas alkali, alkaline earth metals, Tl(III), Be and common anions are tolerated up to 200 fold excess.	5
1-"4-[5-Ethyl-1,3,4-thiadiazol-2-yl) sulphanoyl]phenyl"-3-methyl-5-(1-methyl-benzimidazol-2-yl) Formazon	639	-	The determination of Ni and Cu in medicinal muds is reported. Cu forms a complex with the reagent immediately, but Ni only after 8 or 9 minutes The absorbance for Cu is measured immediately and for Ni after 8 or 9 minutes	6
1,3-Diphenyl-3-thio-propane-1-one	430	8.5	The simultaneous determination of Ni and Co is possible. The complexes are extracted into cyclohexane at 8.5 and 9.0 for Ni and Co, respectively. Cu, Sn and Bi (10 fold amounts) and Pd (any amount) interfere; citrate, tartrate, I^-, F^-, $S_2O_3^{-2}$	7

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			and SCN^- do not interfere. Ni 0.04 to 0.4 μ mole and Co 0.065μ mole have been determined by this method.	
4-(5-Sulpho-2-thiazolyl azo)-2-nitro resorcinol [2-(2,4-dihydroxy-3-nitrophenyl azo thiazole-5 sulphonic acid]	510	6 0	This reagent was used for the determination of 1.2 to 12 μg of Ni with an error of ± 0.5% for 5μg Ni. The sensitivity of the reagent is claimed to exceed that of dimethylglyoxine by a factor of 4.	8
Dimethylglyoxime	329	8.8 to 9.4	The spectrophotometric determination of traces Ni in grease by extracting the complex into $CHCl_3$ is reported.	9
2,2'-Dimercapto diethyl sulphide [2-2'-thiod (ethane thiol)]	512	6 to 9	Determinations of Ni and Pd have been reported. The Ni-complex was extracted into dichloroethane. Beer's law was valid for 0.3 to 2.3 mg Ni in 50 ml. The Pd complex is formed at pH 1.67 in aq. 1,4-dioxane medium and measured at 340 nm. Beer's law is obeyed for 0.1 to 0.5 mg Pd in 50 ml. The tolerance limits of Fe, Co and Ni in the determination of Pd are reported. Pt and Rh also react, but very slowly.	10

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
3-Nitroso-4-hydroxy-5,6-benzo-coumarin "1-hydroxy-2-nitroso-naphthol [2,1-b] pyran-3-one"	395	4.9 to 10.2	The composition of the Ni complex is reported as Ni:R::1:3 The Sandell sensitivity index is 2.3 ng/cm^2, ϵ = 74, 800. Beer's law is obeyed up to 1.75 ppm Ni. The tolerance limits of a number of species for the determination of 1.17 ppm Ni have been reported in ppm These are NO_3^-, Cl^-, Br^- and I^- (5100); NO_2^-, F^-, SO_3^{-2} and PO_4^{-3} (3500); thiourea (2000); tartrate (1000); BO_3^{-3} (900); SCN^- (750); $S_2O_3^{-2}$, Ca Sr, Ba and Hg(II) (100); Cd, Mo(VI), Mn(II), Os(VII) (50); Cu and Pd(II) (10). Pb and Bi^{+3}, 100 ppm can be removed by centrifugation whereas 10 ppm each of Al, V(V) and Fe(III) can be masked with F^-.	11
Dimethylglyoxime	375	5.5 to 9.6	The spectrophotometric determination of nickel by extraction of its dimethylglyoxime complex into molten naphthalene is reported. The Ni-complex is precipitated in aq. soln. at pH 5.5 or 9.6 in the usuasl way and extracted by molten naphthalene at 90°C. The naphthalene is removed by cooling and repeated washing and the complex is extracted into chloroform Beer's law is obeyed from 10 to 360 μgNi. Alkali metals, Fe(III) and Cu(II) do not interfere whereas CO_3^{-2} and EDTA do.	12

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
Diethylthiocarbamate	375	8.5 to 9.0	The successive determinations of Cu, Co and Ni in aluminium is reported. There is no interference by the other constituents of Al or its alloys with uranium.	13
(i) Biacetyl monoxime semi carbazone	340	11.4	Both reagents have been reported for the determination of Cu, Ni and co. The reported values of pH, λ and Beer's law validity with the reagent (i) are: Cu(II), 10,335 nm and 1 to 5 ppm; Ni(II), 11.4, 340 nm and 0.5 to 2.5 ppm and Co(II), 8.6, 330 nm and 1 to 8 ppm, respectively. The values with reagent (ii) are: Cu, 9.5, 350 nm, 0.3 to 1.5 ppm; Ni(II), 10, 350 nm, 0.2 to 1.2 ppm and Co(II), 10, 345 nm, 0.5 to 2.2 ppm, respectively.	14
(ii) Picolinaldehyde semi carbazone	350	10.0		
Thiotropolone [2-Mercaptotropone]	580	7.0	Simultaneous determination of Ni and Co has been reported. The composition of the nickel complex is Ni:R::1:2 and cobalt Co:R::1:3. The Sandell sensitivity index and Beer's law validity for Ni are 0.0048 $\mu g\ cm^{-2}$ and up to 4.7 ppm. The tolerance limits for 32 cations and anions have also been reported. The extinction of the Co complex was measured at 500 nm. The Sandell sensitivity index	15

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
			and Beer's law validity are 0.0031 $\mu g\ cm^{-2}$ and up to 2.6 ppm.	
2,2-Bis (carboxymethyl mercapto)ethyl ether [(3-oxapentane methylene dithio) diacetic acid]	380 and 600		Determinations of Ni, Cu, Co and Pd have been reported. The composition of each complex is M:R::1:1. Beer's law validity for Ni is ≈ 0.8 to 7.34 mM at both wavelengths; for Cu(II) it is 0.02 to 0.16 mM and 0.41 to 2.41 mM at 360 and 660 nm, respectively; for Co it is 2.10 to 17.10 mM at 490 nm; for Pd it is 0.08 to 0.80 mM at 380 nm.	16
2'-Hydroxy acetophenone hydrazone	425	10 to 10.5	The composition of the Ni complex is Ni:R::1:2. The yellow colour is stable for at least 24 hr. in 75% acetone. The Sandell sensitivity index is 0.08 $\mu g\ cm^{-2}$ and Beer's law is valid up to 11.6 ppm. Tolerance limits of various ions have been reported; EDTA, SCN^-, F^-, Pd(II), Co(II), Bi(III) and Cu(II) interfere whereas that of Cd and Mn(II) was prevented by masking with citrate.	17
Cyclohexane-1,2-dione dithiosemicarbazone	400	2.4 to 3.4	The determination of Ni, Co, Fe(II) and Fe(III) has been reported. Beer's law is valid for 2.2 to 5.6 ppm Ni, 2.2 to 8.7 ppm Co, 1.5 to 9.0 ppm Fe(II) 1 to 3.2	18

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			ppm Fe(III). The optimum pH and wavelengths are for Co 5.5 and 450 or 500 nm, for Fe(II) acetic acid-sodium acetate and 640 nm, for Fe(III) 2.5 to 4.2 and 400 nm.	
Quinoxaline-2,3-dithiol	Bet. 520 and 560	Alkaline	The reaction between nickel, reagent and organic basis or [quaternary ammonium, arsonium and phosphorium salts] has been studied. The complex is extracted into $CHCl_3$ and the absorbance measured between 520 and 560 nm depending upon the quaternary salt used. Nickel, 1 to 30 μg was determined.	19
2-(5-Halo-2-hydroxy phenylazo)-4,5,6,7-tetrahydro-5,5-dimethyl benzothiazol-7-ones.	630	4.0	The fluoro-, chloro- and bromo-compounds all give green chelates with Ni(II) and Cu(II). The composition of the Ni complex is Ni:R::1:2 and that of Cu Cu:R::1:1. For both Ni (at 630 nm) and Cu (at 640 nm) $\epsilon = 21000$.	20
Acenaphthene dioxime	390	-	The composition of the Ni-complex is Ni:R::1:2 in dimethylformide.The values of ϵ and Beer's law validity are 15000 and 2 to 440 μM. The complex is pptd. in aqueous solution and can thus be used for the gravimetric determination of Ni.	21

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Di-2-pyridyl glyoxal [Pyridil] dithio-semicarbazone	410	5.2	The reagent is used for the determination Ni and Co in catalysts The Ni complex is extractable into $CHCl_3$ while the cobalt complex is not. The absorbance of Co is also measured at 410 nm. Ni or Co has been determined up to 1 ppm in the presence of up to 5 ppm of the other.	22
Dimethylglyoxime (DMG)	470	-	A method for the determination of Ni in copper and nickel products by differential spectrophotometry has been reported.	23
Dimethylglyoxime (DMG)	490	12.5	The Ni(II) complex with DMG (H_2L) is oxidised with 0.1 M iodine in aq. 0.05 M NaOH (pH $\simeq$ 12.5). The complex anion $[NiL_3]^{-2}$ containing Ni(IV) is then extracted with 1.5 M diphenylguanidinium chloride in $CHCl_3$-isopentyl alcohol (1:1) as a ternary complex with maximum absorbance at 490 nm. Beer's law is obeyed for 0.1 to 11 μg Ni per ml. This extraction spectrophotometric method is more sensitive than the direct determination of $[NiL_3]^{-2}$ in aqueous medium. Fe interfered whereas Co and Cr (25 fold amounts), Cu (10 fold), Mn (5 fold) did not.	24

Name of the Reagent	λ max. of working wavelength	Optimum pH	Remarks	Refs.
Nitroxamin bazo	585	5 to 6	A method for the determination of Ni in steel is reported. The composition of the Ni-complex is Ni:R::1:2 and ϵ = 25,000. The validity of Beer's law was reported for 0.1 to 1.5 μg Ni per ml. Oxalate and EDTA interfered whereas tartaric acid or Na_3PO_4 (1 gm), $K_4P_2O_7$ (500 mg), thiourea orNaF (200 mg), KI or Hydroxylamine (100 mg), ascorbic acid (50 mg), citric acid (15 mg), large amounts of alkali or alkaline earth metals, Zn, Hg or As, Ti or Zr (1600 fold), W (1200 fold) Nb or Sb (800 fold), Mn (120 fold), Al (100 fold), Cr La or Ce (40 fold), Pd (20 fold) did not. Fe, Co, Mo V and Cu can be masked	25
Thio-oxine [8 mercapo-quinoline]	540 or 550	4	A method for the determination of Ni in steel is reported. The Ni complex was extracted into $CHCl_3$ or isobutylmethyl ketone and the absorbance was measured at 540 or 550 nm, respectively. The validity of Beer's law was obeyed up to 100 μg Ni.	26
Benzoyl trifluoroacetone	380	>6.2	Cu, Ni and Co were determined by extraction of their complexes at different pH values. Cu was extracted at pH > 3, Ni at > 6.2 and Co at pH > 6.0. In the determination of Ni there is interference from	27

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			Fe(III), Cu(II) and Co, but not from Cd, Pb, Sr Ag or Zn Cu Ni and Co were measured at 375, 380 and 390 nm respectively. The useful range of conc. is 0.1 mM to 1 mM.	
4-(2-Pyridylazo) resorcinol (PAR) (sodium salt)	496	9.7	Ni is determined by extraction spectrophotometry. Microgram amounts of Ni(II) are extracted in the presence of reagent at pH4 by ethyl acetate. To the extract, water is added and the solvent is evaporated on a water bath. The resulting aq. soln. is mixed with borate buffer (pH 9.7), made up to 25 ml and the absorbance measured at 496 nm. Fe(III) interferes seriously	28
2,2'-Azobis (isobutyramidine)	415 to 420	Neutral or slightly alkaline	The composition of the Ni-complex is Ni:R::1:1 in a methanolic medium	29
Furil α-dioxime	-	7 to 7.5	A method for the determination of Cu, Ni and Fe in gadolinium and lead molybdate is reported. First, Cu is determined as diethyl thiocarbamate and then Ni as furil α−dioxime is extracted into $CHCl_3$. Fe is determined separately with 1,10-phenanthroline.	30

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
1,2-Natphthaquinone dioxime-6-sulphonic acid	468	-	The composition of the Ni-complex is Ni:R::1:3. The value of ϵ in $CHCl_3$ soln. at 468 nm was 21,900. Besides, this reagent, which had the best sensitivity, six others of this series have also been reported.	31
N-Methylanabasine-α-azo-cresol "2-[5-(1-methyl-2-piperidyl)-2-pyridylazo] -p-cresol"	585	4 to 8.5	The composition of the Ni-complex is Ni:R::1:2. Bear's law is obeyed up to 50 μg Ni per 25 ml; ϵ = 25,000. Co, V, EDTA and citrate interfere whereas PO_4^{-3} acetate, F^-, sulphosalicylate, thiourea and $P_2O_7^{-4}$ do not. The permissible limits of a number of elements along with their masking reagents have been reported. The method has been used for determining Ni in steel and silicate rocks, and is superior in sensitivity to the dimethyl glyoxime method.	32
2 Chlorobenzohydrazide	520	≃ 10	The composition of the Ni-complex is Ni:R::1:2. Beer's law is obeyed from 0.5 to 5 mM (Ni(II). The complex is extracted into $CHCl_3$. Ni has been determined in the presence of Co, Cu and Fe.	33

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
Chlorindazon DS [4-(6-chlorindazol-3-ylazo)-3-hydroxy naphthalene-2,7-disulphonic acid]	575	10	A method is reported for the determination of Ni in thin layers of Ni and Cr. Thirty minutes after addition of the reagent to the sample solution the absorbance of the violet Ni-complex is measured at 575 nm. The calibration graph is rectilinear up to 1.5 μg/ml Ni. There was no interference by Cr.	34
3-Aminoquinoxaline-2-thiol	495	11.0	A method for the determination of up to 50 μg Ni and 30 μg Co has been reported. The absorbance was measured at 495 or 428 nm for Ni or Co against a reagent blank. Slight interference is caused by Fe(III), Cu(II) and Pd(II).	35
Monothiobenzoic acid	400	7.8 to 8.5	A method has been reported for the determination of Ni(II), Fe(III). The composition of the Ni-complex isNi:R::1:2 and that of the Fe-complex Fe:R::1:3. The values of ϵ, the Sandell sensitivity index and Beer's law validity in the case of Ni are $\simeq$ 2800, 0.0014 μg cm^{-2} and 1 to 20 μg ml^{-1}, respectively and in the case of Fe, 2900, 0.002 μg cm^{-2} and 1to 20 μg ml^{-1}. Fe was determined at pH 4.9 to 5.5 and the absorbance was measured at 540 nm. Cu, Pd and Co interfere. The tolerance limits for several species are reported.	36

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
Dithiooxamide	640	8	A method is described for the determination of Ni and Cu in steel. Cu is masked with thiourea. The value of ϵ and the validity of Beer's law for Ni are 14,400 and 0.01 to 0.1 mM and for Cu, 17,500 and 5 to 50 μM, respectively. Cu was complexed at pH 5 and the absorbance was measured at 380 nm.	37
7-(4-Antipyrinylazo)-8-hydroxy quinoline	485	3.5 to 6.0	A method for the determination of Ni in silicate rocks is reported. Beer's law is valid from 0.04 to 4 μg ml^{-1}. The interference of Fe was prevented by NaF.	38
4-(2-Thiazolylazo)-3-hydroxy naphthalene-2,7-disulphonic acid	550 and 596	8 to 10	The composition of the Ni-complex is Ni:R::1:2. Two λ max. occur at 550 and 596 nm, that at 596 is the more useful. At this wavelength of ϵ and the Beer's law range are 26,500 and 2.5 to 42.5 μg Ni per 25 ml. Cu and Zn interfere; Fe(III) and Al are removed by masking with tartrate. The tolerance limits of other species are reported.	39
Phthaldehyde bis-thiosemicarbazone	450	8.8	A method has been reported for the determination of Ni and Co. The composition of both metal complexes is M:R::1:1. Beer's law is valid up to 4.5	40

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
			ppm Ni and 11 ppm Co. The absorbance of Co was measured at 385 or 410 nm. The interferences of a number of cations were reported.	
4,5,6,7-Tetrahydro-2-(8-hydroxy quinoline-5-ylazo)benzo thiazol (oxyquinolene thiazo)	**Green filter**	**5.35**	0.25 to 3.75 μg of Ni may be determined in 25 ml The sensitivity is 0.01 μg/ml Ni. Indium and Co interfere. The permissible tolerance values relative to nickel are for Ba (6500), $S_2O_3^-$ (19000); Sn(II) and Ca (15000); B_2O_3 (1000); Cr(VI) (500); Mg, Nd Ge, Mn(II) and Cu(II) (10); Y (7); Ti (5); Ga and In (3); Hg(II) and Al (2); and Fe(III), V(V) (1)	**41**
5-(4-Diethylamino-2-hydroxy phenylazo)-1,2-4-triazole-3-carboxylic acid	**530**	-	5 to 25 μg of Ni may be determined in 25 ml At 530 nm, ε = 40,700.	**42**
3-Hydroxy-3-phenyl-1-(2-carboxy-5-sulphanato-phenyl) triazene.	**410**	**9.8 to 10.5**	The reagent has been reported for the determination of Ni(II), Fe(II), V(V), Pd(II), Mo(VI) Cu(II) and Ti(IV). The yellow green Ni complex has its absorption max at 410 nm (ε = 34375). The colour of the complex is stable for 18 h. Beer's law is obeyed from 0.125 to 1.5 ppm with optimum range as 0.25-1.5 ppm. The Sandell sensitivity index is 0.0018 μg cm^{-2}. Similar values for other metal ions have also been reported	**43**

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
4-Methoxy 2 (2 thiazolylazo) phenol	625	6.5	Four complexes, NiR^{+}, NiR_2, $NiRH^{+2}$ and $NiRH^{+}$ are formed. Of these, the complex NiR_2 is useful and is formed in the presence of a 15 fold-excess of the reagent. The value of ϵ = 33,320 at 625 nm.	44
[2-(2 Hydroxy-3,5-xylylazo)4-sulphonobenzoic acid]	520	7.5	Both Ni and Cu may be determined. The complexes are stable for 5 days. The values of ϵ for Ni and Cu are 8700 and 8760 respectively The absorbance of both complexes are measured at 520 nm. Cu forms the complex at pH 4 requiring four fold excess of reagent whereas Ni requires six fold excess of the reagent. 0.5 to 4.8 ppm Cu and 0.7 to 2.1 ppm Ni were determined. Fe and Zn interfere whereas Mn(II), Cu(II) and Co(II) interfere only in the analysis of Ni. Common anions including citrate and tartrate do not interfere.	45
3-Hydroxy picolinaldehyde azine [$\alpha\alpha'$-azino di-(3-hydroxy-2-picoline)]	480	4.5	A method is reported for the simultaneous determination of Ni and Co in admixture with 5 to 25 μg of each in 25 ml. The absorbance of the Co-complex is measured at 540 nm EDTA interferes seriously. The tolerance limits of a number of species are reported	46

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Furil α-dioxime	440 to 460	9.0	Ni is determined in the presence of iodine. The Ni-complex is extracted into $CHCl_3$-isoamyl alcohol (3:1). Large amounts of Co do not interfere.	47
Sodium purpurin sulphonate	520	8.1	The reagent has been used for the determination of Ni(II), Zr(IV) and Co(II). The values of λ max and working pH are 600nm and 0.75 to 0.93 pH (for Zr); 590 nm and 5.38 pH (for Co), respectively. 0-3 ppm (Ni), 0-7 ppm (Zr) and 0-2.5 ppm (Co) have been determined. Co interferes in the determination of Ni and vice versa.	48
Thionoluric [5-hydroxy imino-2-thio barbituric] acid	375	8.05 to 9.1	Beer's law is valid up to 3.05 ppm. Tartrate, citrate, thiourea, PO_4^{-3}, $P_2O_7^{-4}$, EDTA, nitrilotriacetic acid, Co, Fe, Cu, Pd, Rh, Pt and Ru interfere.	49
Dithio-oxamide	460	9 for 1:1 >11 for 1:2	The 1:1 blue-violet Ni-complex is stable at pH 9 and a yellow 1:2 Ni-complex was formed at pH >11 and in the presence of 25 fold excess of the reagent. For the 1:2 Ni-complex Beer's law is valid for 1 to 10 μg/ml at 460 nm. The standard deviation for 5 μg/ml (20 determinations) was ± 0.976. Heavy metal cations, CN^-, $Fe(CN)_6^{-4}$, $Fe(CN)_6^{-3}$, S^{-2}, Sc_3^{-2}, SO_3^{-2}, $Cr_2O_7^{-2}$, CrO_4^{-2}, PO_4^{-3}, and CO_3^{-2} interfere.	50

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2'-4 -Dihydroxy valerophenone oxime	580	7 to 8.5	The complexes of Fe(III), Cu(II) and Ni(II) are studied. The Ni-complex is extracted into $CHCl_3$. Beer's law is valid for 38 to 70 ppm Ni. Reported values of λ max. and Beer's law are 510 nm and 1 to 56 ppm (Fe(III) in aq.), 640 nm and 45 to 80 ppm (Cu(II) in $CHCl_3$).	51
2-Picolylamine [2-aminomethyl pyridine]	535	7 to 8.5	The Ni-complex is Ni:R::1:3. The Sandell sensitivity index and Beer's law range are 5.28 $\mu g\ cm^{-2}$ and 1.8 to 14.4 mM Ni(II). The formation constants and corresponding thermodynamic parameters are reported.	52
Acetothioacetanilide [4-anilino-4-thioxobutan-2-one]	596	>6.9	Fe(III), Co(II) and Ni(II) may be determined. Fe and Co form M:R::1:3 complexes whereas the Ni(II) complex is Ni:R::1:2. The complexes are extracted into $CHCl_3$ and the absorbances measured at 500, 625 or 496 nm for Fe(III) (pH 7.1 to 8.3), Co(II) (pH > 8.4) and Ni(II) (pH > 6.9). Beer's law is valid for 4 to 35 μg/ml Fe, 20 to 200 μg/ml Co and up to 150 μg/ml of Ni. Ni in steel is determined with an error of < 1.7% in the range 1 to 13% Ni. The tolerance limits of various species are reported.	53

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
3,6-Bis-(4-carboxy-phenylazo)-chromotropic acid	728	-	Ni is determined in an acetone medium in the presence of 3 to 4% H_2O with ϵ= 150,000 at 728 nm.	54
Di-2-pyridyl ketone thiosemicarbazone	395	6.0 to 6.9	The reagent complexes of Fe(II), Ni(II), Co(II) and Cu(II) are studied. The values of pH, λ max., ϵ and Beer's law ranges are 2.5 to 7.5, 620 nm, 9300 and 1to 4 ppm (Fe); 6.0 to 6.9, 395 nm, $1.96x10^4$, 0.5 to 2.5 ppm (Ni); 3.8 to 6.0, 415 nm, 10^4 and 1 to 5 ppm (Co); 3.9 to 4.2, 395 nm, $1.13x10^4$ and 1 to 5 ppm (Cu), respectively. The reagent properties have been claimed to be superior to those of picolinaldehyde thiosemicarbazone and pyridyl bis (thiosemicarbazone).	55
5-(2-Thiazolylazo)-p-cresol	610	-	Ni in uranium based alloys is determined by extraction of the complex in $CHCl_3$. The values of ϵ and Beer's law range are 31,200 and 0.1 to 2 μg/ml, respectively. There is no interference from 500-fold amounts of Zn, Cd or U(VI), 300-fold amounts of Cu, 200-fold amounts of Th, W or La, 100-fold amounts of Zr, Mo, Mn or (if NaF is present) Fe, 20-fold amounts of Pb or 1.6 fold amounts of Nb or V. However, Co interferes.	56

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
1-(2-Thiazolylazo)-2-naphthol	595	6 7	A method is reported for the determination of Ni in steel. The Sandell sensitivity index is 0.0015 $\mu g\ cm^{-2}$ and the mean error is ± 0.05 μg in the determination of 57 μg of Ni. The calibration graph is rectilinear in the range 11 to 110 μg. Interferences of Co, Cu, B and V were masked by N-(dithiocarboxy)glycine, tartrate and $P_2O_7^{-4}$.	57
Thiobenzoyl acetone [3-mercapto-1-phenyl but-2-en-1-one]	500	8 4 to 9.1	The simultaneous determination of Ni and Co is reported. Both Ni and Co form complexes at 8.4 to 9.1 pH and both are extracted into benzene. For Co the λ max. is at 460 nm and beer's law is obeyed over the range 0.2-4.58 μg/ml. Equations for simultaneous determinations have been reported.	58
Potassium ethyl xanthate	415	4 to 9	The Ni-complex is Ni:R::1:2. It is extracted into $CHCl_3$ and Beer's law is valid from 3 to 16 μg/ml. Interferences are reported.	59
Picolinaldehyde-4-phenyl-3-thio-semicarbazone	390 or 400 (for $CHCL_3$ extract)	8 to 9	The reagent is usefu for both Ni and Co The co n-p'ex is extracted in o $CHCl_3$ and the absorbance measured at 400 nm. Ni was determined in aq. medium (pH 8 to 9) at 390 nm from 0.8 to 1.5 ppm	60

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
			whereas in $CHCl_3$ medium it has been estimated from 0.8 to 2 ppm. In determining 1 ppm Ni, interference is caused by > 1 to 2 ppm of Pb, Fe, Cu, Co, Zn, V, Hg, Cd, Bi, Sn, Au, Pd and Ag.	
8-Hydroxyquinoline	410	5.0 to 8.0	Ni, Co and Mo are determined after extracting their complexes into molten naphthalene and dissolving the solidified phase in DMF. The values of pH, λ max., ϵ and Beer's law range are 5 to 8, 410 nm, 7600 and 10 to 120 μg (Ni); 5 to 8.5, 415 nm, 8900 and 6 to 100 μg (Co) and 3.7 to 4.5, 370 nm, 6100 and 14 to 107 μg (Mo), respectively.	61
2,4-Dihydroxy dithiobenzoic acid	533	6 to 7	The reagent forms a stable violet red complex with Ni in aq. medium or in H_2O + acetone (5:1) The value of ϵ is 17,000 at 533 nm. Co(II), Sn(II) and oxalate interfere. There was no interference from Zn, Cr(III), Al, Fe(III), Ba, Hg(II), Pb(II), Cd, Bi(III), Mn(II), Cu(II) and common anions. The sensitivity of the method is 60 ng/ml Ni.	62
Nioxime [cyclohexane-1,2 dione dioxime]	460	4g NaOH in 50 ml	The red Ni(II)-nioxime (1:6) complex is stable for at least 4 hr. over the temp. range 17 to 40°C Beer's	63

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
			law is obeyed for 0.01 to 0.15 mM Ni. The coeff of variation was 0.36% for 10 determinations of 0.1 mM Ni. 10-fold amounts of Cu, P, W, V, Si and Mo; and up to 2 fold amounts of Cr(III) and Cr(VI) did not interfere whereas 30-fold amounts of Fe(II) were masked by tartrate.	
Thiobenzoyl acetone [3-mercapto-1-phenyl but-2-ene-1-one]	500	8.8 to 9.4	The red nickel complex is extracted into $CHCl_3$ for spectrophotometry at 500 nm. The values of ϵ, Sandell sensitivity index and Beer's law range are 5804, 10 ng cm^{-2} and 0.5 to 10 μg/ml, respectively. Lead, Cu, Zr, Hg, Pd, Co, CN^- and EDTA interfere seriously.	64
5'-Chloro 2'-hydroxy 4'-methyl acetophenone oxime	580	8	The reagent is used for the determination of Ni and Cu. The complexes are extracted into $CHCl_3$. The composition of both the metal complexes is M:R: 1:2. Cu forms a complex at pH 3.5 and the absorbance is measured at 640 nm. Beer's law is obeyed for up to 0.44 μg/ml of Ni and up to 0.95 μg/ml of Cu.	65

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Thymolphthalexone	610	7.65	The composition of the Ni-complex is Ni R: 1:1. For 14 to 88 μg of Ni, a reaction time of 60 m was reported. The standard deviation (15 determinations) was < ± 0.37 μg. Alternatively Ni can be titrated photometrically with the reagent. Heavy metals even in traces interfere, whereas Ba, Sr, Ca Cr(III) do not.	66
1-(2-Naphthyl)-3-(2-pyridyl) thiourea	460	4.9 to 10.2	The Sandell sensitivity index and Beer's law range are 1.6 ng cm^{-2} and up to 1.6 ppm, respectively. The complex was stable for 20 hr. In determining 1.44 ppm Ni, there was no interference from 240 ppm of Zn and Mn(II), 95 ppm of Ir(III) and Cr(III) or 60 ppm of Sn(II) or Sb(III). Copper, Hg(II), Fe(III), and Al are precipitated at pH 6 and can be centrifuged.	67
5-Dimethylamino 2-(2-thiazolyl azo) phenol and Triton X-100	560	8	Used for the determination of Ni in soil. The calibration graph is rectilinear for 3 to 30 μg Ni. For the determination of 1.4 μg Ni in 1 gA sol an error of 0.35 μg was reported. Fe(II) interfered. The tolerance limits of several species have also been reported.	68

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
1-(2-Pyridylazo)-2-naphthol	565	7	Ni and Co are determined in common salt containing Cr, V, Ti, Mo and W as well as upto 100 fold amounts of Fe, Cu, Pb and Zn and 1000 fold amounts of k Ca Mg and Al.	69
1,10-Phenanthroline-phloxine II (tetrabromo-dichloro fluorescein Na salt)	570	5 to 9	The ternary complexes $[Me\text{-}phen)_2]^{2+}$ $[phlox]^{2-}$ where Me is Zn, Co or Ni in aq. solution of pH 5 to 9 have absorption maxima at 570 nm and have been used for the determination Zn(II), Co(II), and Ni(II). The complexes can be extracted into $CHCl_3$. Beer's law is obeyed for 3.27 to 40 μg Zn, 2.94 to 35.34 μg Co and 2.93 to 35.22 μg Ni in 25 ml.	70
1-(2-Quinoly azo)-acenephthylenol	560	-	The reagent is used for the determination of Co(II), Ni(II) and cu(II) by extracting into CCl_4 and measuring the absorbance at 550 nm (Co), 545 nm (Cu) or 560 nm (Ni). The amounts determined were 2 to 9 μg Co, 6 to 23 μg Ni or 2.4 to 14 μg Cu. cyanide, PO_4^{-3}, citrate, EDTA, Fe(II) and Zn(II) interfere.	71
Di-pyridyl ketone azine	360 & 370 (for $CHCl_3$ extract)	4.5	The reagent is reported for the determination of Ni and Co. The complexes are Ni:R::1:1 and Co:R::2:3. The Ni-complex was extracted into $CHCl_3$ and measured at 370 nm or determined directly at 360 nm.	72

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
			Beer's law is obeyed for 0.5 to 2.0 ppm Ni and 2 to 14 ppm Co. Co forms its complex in ammonical medium and the absorbance is measured at 435 nm. The calibration graph is rectilinear from 2to 14 ppm Co.	
Lix65 N(2-hydroxy-5-nonyl benzophenone oxime or Lix70 (3-chloro-2-hydroxy-5-nonyl benzophenone oxime)	390		These two reagents are reported for Ni and Cu, both being determined simultaneously. The complexes were extracted into Lix65 or Lix70 in kerosine which were measured at 390 and 615 nm, respectively (Ni) and 365 and 660 nm, respectively (Cu). Beer's law is obeyed from 0.2 to 6 mM for both at the higher wavelengths. Cobalt interferes.	73
2-Mercaptobenzo-ν-thiopyrone [-Mercapto-4-thiochromone]	415	5 to 10	The reagent is used for the determination of Ni and Co. The Ni-complex was extracted into $CHCl_3$ giving a mean error of 1.2% in 0.4 to 4.5 ppm of Ni. Cobalt forms its complex at pH 6.5 to 9.8 and is extracted into ethyl acetate. The absorbance of the Co-complex was measured at 350 nm giving a mean error of 1.6% in the range 0.6 to 5.5 ppm. W(VI), U(V), Mo(VI), Re, V(V), Se(IV), Fe(III), Cu(II) and Ag interfere seriously whereas many common ions are tolerated. The reagent was also used for the gravimetric determination of Ni and Co.	74

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
4-(2-Pyridylazo) resorcinol	525	4 3	The reagent is used for the determination of Pd, Cu and Ni. Palladium forms a complex in the presence of 1 to 5 M H_2SO_4 and Cu at pH 1.1 to 1.3. The absorption maxima for the Pd and Cu complexes were at 580 and 535 nm respectively. The reported values of ϵ are 52,000 (Ni), 11,700 (Pd) and 11,80 (Cu). Beer's law is valid for 0.1 to 0.9 μg/ml Ni, 0.5 to 5 μg/ml Pd and 0.5 to 3 μg/ml Cu.	75
2-(2 Pyridylmethylene-amino) phenol	460	NaOH medium (0.5 mM)	With this reagent 0.6 to 2.4 ppm Ni in 25 ml were determined. The tolerance levels of 72 species were reported.	76
6-Nitroquinoxaline-2,3-dithiol	710	2	The reagent was used for the determination of Ni and Co simultaneously. The complexes were extracted into isobutyl methyl ketone, and the absorbance was measured at 710 nm and 530 nm. Beer's law was valid for 0.15 to 3 ppm. Copper(II), Pd, Pt and Os(VIII) interfere and must be removed. There was no interference from rare earth metals, Mg, Ti, Tl, In or Ga. The tolerance levels of 15 more species were also reported.	77

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
8-Hydroxyquinoline with pyridine, 2-, 3- and 4-picolines quinoline and isoquinoline	410	7	Nickel is determined as a mixed complex of Ni(II) Oxinate and pyridine, 2-, 3- and 4- picolines, quinoline or isoquinoline. The complex is extracted in benzene and its absorbance is measured at 410 nm. However, the mixed complex of Ni(II)-oxinate with isoquinoline affords the best Sandell sensitivity index (7.4 ng cm^{-2}) and ϵ value ($\simeq$ 8000). Using this mixed complex, Ni has been determined in steel. Cu and Co interfere. Hydroxylammonium chloride is used for masking Fe and Mn(II), $P_2O_7^{-4}$ for Fe(III), Pb(II), U(VI) and Zn, F^- for Al and oxalic acid for Cd.	78
Pyrilidene-1-naphthyl-amine [α-(naphthyl-imino) 2-picoline]	430 to 440	6 7	The reagent is used for determining 2 to 18 ppm Ni. The interference of 48 metal species and anions has been reported.	79
Benzil-α monoxime	360 and 400	7 to 10	The reagent is used for the determination of Ni after extracting its complex into $CHCl_3$. The complex has absorption maxima at 360 nm (ϵ = 10800) and 400 nm (ϵ = 10200). At 400 nm Beer's law is valid for 15 to 90 μg Ni in 25 ml. A 20-fold excess of the reagent	80

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			is required for constant, maximum absorbance. Cd, Fe(II), Cu(II), Be, Zr, Cr(III), Al, Th, Mn(II), Co, V(V) F^- and EDTA interfere.	
1-(2-Thiazolylazo)-2-naphthol in non-ionic surfactant	595	7	Ni is determined by extraction with the reagent in a non-ionic surfactant as solvent. Nickel, < 7 μg, was treated with 2 ml of phosphate buffer and 2 ml of reagent (20 mg reagent with 20 g of Triton X-100 and 80 ml water) and made up to 25 ml with water. The mixture was heated on a water bath at 95°C for 30 minutes, cooled to room temperature, the supernant soln. (surfactant) removed and the surfactant phase redissolved in the remaining aq. soln. The absorbance was measured at 595 nm. The method is used for the determination of Ni in soil with suitable masking agents.	81
3-Hydroxy-1-phenyl-3-p-tolyltriazene	420	8 6	The reagent is used for the determination of Ni, Co and Cu. The composition of the metal complex in the case of Ni and Cu was reported as M:R::1:2 whereas in the case of Co it is Co:R::1:3. The Cu-complex was extracted at pH 4.6 and the absorbance was measured at 400 nm whereas the Co-complex was extracted at pH 8 to 10 and measured at 410 nm. The	82

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
			reported values of ϵ are 11,500, 19,300 and 27,400 for Ni, Cu and Co, respectively.	
Nioxime [cyclohexane-1,2-dione dioxime]	384	3.2 to 11.2	The reagent is used for Ni by extracting its complex in molten naphthalene at 81°C and dissolved the mixture of naphthalene and Ni-complex in $CHCl_3$. The Sandell sensitivity index and validity of Beer's law are 16 ng cm^{-2} and 0.8 to 7 μg/ml of Ni, respectively. The coeff. of variation was 0.58%.	83
2-Nitro-4-(5 sulpho-thiazolyl-azo) resorcino (I) and diphenyl guanidinium(II)	530		The composition of the ternary Ni-complex with the reagent (I) and diphenyl gagnadinium(II) is 1:2:4 (Ni:I:II). It is extracted into $CHCl_3$-isobutyl alcohol (2:1) and the absorbance is measured at 530 nm (ϵ = 7.55×10^4) against a reagent blank. The method is used for the determination of Ni in steels with a relative error of 6.3% in 0.11% of Ni.	84
6-Chloro-1,2-naphtha-quinone dioxime	466	1.5	Besides this reagent, the 6-bromo and 4-chloro derivatives have also been reported for the determination of Ni in iron or steel. The composition of the Ni-complex is Ni:R::1:3. The complex was extracted into $CHCl_3$ and the value of ϵ is 21,000. The complex is very stable and is decomposed by 5 mM EDTA or	85

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
5-Isopropyl-6-(5-chloro-2-pyridyl-azo)-o-cresol	620	1M NH_3	This reagent forms a Ni-complex in aq. 1 M NH_3 containing K-Na-tartrate. It is extracted into $CHCl_3$ with max. absorption at 620 nm (ϵ = 26,000). Beer's law is obeyed for 0.1 to 8 μg/ml Ni. Fe, Bi, Cu, Pb, Zn, Sb, Sn or Al do not interfere. The method has been used for determining Ni in bronze, steels and Ni-based alloys. The coeff. of variation is 4.9% (4 or 5 results).	86
4-Hydroxy-3-nitroso-naphthalene-1-sulphonic acid	307.5	8.6	Ni is determined after extracting its yellow to orange complex into zephiramine chloride in $CHCl_3$. It is used for the determination of Ni in iron and steel.	87
1-Benzoyl thiosemi-carbazide and its analogues	-	8 to	The composition of the Ni-complex is Ni:R::1:2. 6 to 95 μg/ml Ni were determined. The method is used in the analysis of ores and alloys.	88
2-(6-Bromobenzothiazol-2-ylazo)p-cresol	620	ammoniacal medium	The composition of the Ni-complex is Ni:R::1:2. The Beer's law range and ϵ are 0.1 to 2.5 μg/ml Ni and 42,500 respectively. A ten-fold excess of the reagent is used. Interference from Fe was reported and was masked with tartrate. There was no interference from Zn, Cd, Cr, Cu, Mn, V, Pb, W, U, Pd or Th. The method is used for determining 0.1 to 5% Ni in bronze, steel and U-Ni-Pd alloys.	89

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Phenanthraquinone monoxime	450	4.9 to 8.5	This reagent has been used for the determination of Ni(II) and Fe(III). The complexes were extracted into $CHCl_3$. Fe(III) forms a complex at pH 2.5 to 9.0 and the absorbance was measured at 470 nm. The Sandell sensitivity indexes are 9.8 ng cm^{-2} and 27 ng cm^{-2} for Ni and Fe, respectively. The optimal analytical range for Ni and Fe are 1.4 to 7.9 and 3.5 to 21.3 ppm, respectively. The tolerance limits for halides, PO_4^{-3}, SO_4^{-2}, SCN^-, $S_2O_3^{-2}$, tartrate, citrate, oxalate, salicylate, phthalate, Al, Cd, Pb(II), Cu(II), Mn(II), Ag, Mo(VI), Th, Ru(III), Rh(III), Pt(IV), Ir(III) and Sb(III) are reported.	90
Phenyl fluorone	620	8.5 to 10.0	The reagent reacts with Ni in the presence of hexadecyl trimethyl ammonium bromide and pyridine to form a water-soluble chelate. The composition of Ni-R is Ni:R::1:2. The reported values of ϵ and the Sandell sensitivity index are10,400 and 0.565 ng cm^{-2}, respectively.	91
Furoin thiosemicarbazone	360 to 410	9	The reagent is reported for the determination of Ni, Pd and Cu. The complexes of Pd and Cu are formed at pH 6 and 3, respectively and their absorbances were measured at 360 and 355 nm, respectively. For	92

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
			separation from Pd, the nickel complex was extracted into $CHCl_3$ and the absorbance was measured at 410 nm. The values of ε and instability constant are 1.54 x 10^4 and 4.5 x 10^{-11} (Ni complex), 1.8 x 10^4 and 3 x 10^{-7} (Pd complex) and 1.45 x 10^4 and 7.1 x 10^{-7} (Cu-complex). The method was used for determining Ni in alloy steels.	
N-Hydroxy-N N-diphenyl thiourea	470	5.2 to 9.6	The composition of the Ni-complex is Ni R::1:2. The value of ε, Sandell sensitivity index and the Beer's law range are 16 100, 3 4 ng cm^{-2} and up to 1.6 ppm Ni, respectively. EDTA, F^- and HPO_4^{-2} interfere seriously. At least 260 ppm of Zn, Mg, Cd, Co, Mn(II), Hg(II), V(V) Sb, Bi and As(III) were tolerated in the determination of 1.38 ppm Ni at pH 6.6.	93
Picolinaldehyde salicylo-hydrazone	375	5 to 6.3	The reagent is used in the determination of Ni and Zn. The composition of both the metal complexes is M:R::1:2. Zn forms a complex at pH 5 to 6.2 and the absorbance is measured at 365 nm. The reported optimum analytical ranges are 0.55 to 0.85 ppm Ni and 0.45 to 0.75 ppm Zn. The mean error is ± 0.3% for Ni and 0.1% for Zn. 1 to 2 ppm V, Ti, Fe, Bi, Cu, Pd, Co, Pb, Hg and EDTA are reported to interfere.	94

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Furil α-dioxime	438	7 to 11	The Ni-complex was adsorbed on microcrystalline naphthalene which was dissolved in $CHCl_3$ and determined spectrophotometrically at 438 nm. The calibration graph is rectilinear for 2 to 35 μg of Ni. The effect of pH, amount of reagent, naphthalene or buffer soln., shaking and standing time were studied. In the determination of 20 μg Ni there was no interference from 500 mg of Na_2SO_4, Na_2SO_3, NaCl, NaH_2PO_4, KBr, KNO_3, sod. acetate, sod. tartrate, or 200 μg of Cr(VI), Pb(II), Zn, Cd, Bi(III), Hg(II), Mg or Ca. However, oxalate, citrate, NH_4Cl, KCN, Fe(III) and Co(II) caused negative interference and Na_2CO_3 caused positive interference.	95
1-(2-Thiazolylazo)-2-naphthol	595	5 to 8	The complex was extracted into molten naphthalene, evaporated, then dissolved in dioxan and the absorbance measured at 595 nm. The Sandell sensitivity index is 0.0014 μg/cm^{-2} and Beer's law is obeyed for 0.1 to 0.9 μg/ml Ni. Pyrophosphate is used to mask Zn(II) and Fe(III) while Cu(II) and Co(II) are masked with dithiocarboxy sarcosine.	96

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
6-Carboxy-6'-hydroxy-3',5'-dichloro azo benzene-4-sulphonic acid	500	7.5 to 7.8	This reagent is used for the determination of Pd, Ni, and Cu. The composition of the Ni-complex is Ni:R::1:2; in the case of Pd and Cu it is M:R::1:1. Pd forms its complex at 0.5 to 1 pH and the absorbance is measured at 550 nm whereas Cu forms a complex at pH 4 to 7 and its absorbance is measured at 510 nm. The Sandell sensitivity indexes are 0.013 (Cu), 0.026 (Pd) and 0.01 $\mu g\ cm^{-2}$ (Ni). Interferences have been reported. The optimum ranges in ppm for spectrophotometric determinations are 1.1 to 5.8 for Cu, 1.3 to 10.3 for Pd and 0.9 to 5.0 for Ni.	97
Di-salicylidene-ethylene diamine	412	>10	The orange brown complex was extracted into $CHCl_3$ and the absorbance measured at412 nm for up to 1000 μg Ni in 25 ml of solution. However, Cu(II), Cd(II), Ce(III), Cr(III), Fe(III), Co(II) and EDTA interfere.	98
1,10-Phenanthroline-Eosin BNX [4',5-dibromo-dinitro-fluorescein] (di sod. salt)	560	4.6	The spectrophotometric determination of Co(II), Ni(II) and Cu(II) in the ternary system (Ni(II) - 1,10-phenanthroline-Eosin BNX) has been reported. All three metals form complexes in aqueous medium at pH 4.6 (acetate buffer). The values of ϵ at 560 nm	99

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			are 25,000, 50,000 and 52,000 for Cu, Co and Ni, respectively. The molar ratio (metal - 1,10-phenanthroline Eosin BNX) is 1:2:1 in each case. Beer's law is obeyed for 0.1 to 0.7, 0.06 to 1.68 and 0.12 to 1.40 μg/ml (Cu(II), Co(II) and Ni(II), respectively.	
Ethyl xanthate	420	5.5 to 7.5	The reagent is used for the determination of Bi, Co, and Ni. The ethyl xanthates of these metals are extracted into molten naphthalene from aq. medium, pH 2.4 to 5.5 for Bi, 5.5 to 7.5 for Ni and 7.5 to 9.0 for Co. These are then dissolved in $CHCl_3$ and absorption measurement made at 362, 420 and 350 nm for Bi, Ni and Co, respectively. Bi forms the complex at pH 2.4 to 5.5 and the absorbance is measured at 362 nm whereas Co forms a complex at pH 7.5 to 9.0 and the absorbance is measured at 350 nm. The ϵ and analytical ranges are 4040 and 2.8 to 28.8 μg/ml (Bi), 3790 and 2.4 to 51.6 μg/ml (Ni) and 4460 and 2.0 to 21.2 μg/ml (Co). Fe(III) and EDTA interfere seriously. The method has been employed in the determination of Ni and Co in complex alloys.	100

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
1,5, Bis-(2-carboxy methoxy phenyl)-3 phenyl formazon	620	6 (acetate buffer)	The Ni-complex is Ni:F ::1:1. The value of ϵ is 33,000 and Beer's law is obeyed for 0.05 to 1.6 μg/ml Ni. Tolerable amounts of other metals relative to Ni are Mg (25,000), Mo, W and Bi (500), Si, Ca, Al, V(V), V(IV) and Cr(III) (100), Zr (50), Mn, Fe(II) and Ti(IV) (15), Co (2) and Zn and Cu (0.5). Higher amounts of Cu and Zn can be masked with thiourea and $P_2O_7^{-4}$, respectively	101
Quinoline-2-aldehyde thiosemicarbazone	460	7.5	This reagent is used for Ni and Pd. Pd forms its complex in HCl medium and is extracted into isobutyl methyl ketone whereas the Ni-complex is extracted into $CHCl_3$. The absorbance of the Pd-complex is measured at 510 nm and that of Ni at 460 nm. The values of ϵ and Beer's law ranges are 15,800 and 5 to 25 μg Ni and 2600 and 50 to 200 μg Pd, respectively. Cd(II) and Pd(II) interfere seriously in the determination of Ni and Au and Pb(II) and SCN^- in the determination of Pd. The method has been applied to the analysis of steel and nickel-silver samples.	102

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
Thiosalicyl dene ethylene di-imin e [αα'-(ethylene dinitrilo) bis)toluene o thiol)]	505	3 ± 0.5	A method for the determination of microgram amounts of Ni is reported. The values of ϵ and the Sandell sensitivity index are 2760 and 20 ng cm^{-2}. Beer's law is obeyed for 0.5 to 10.0 μg/ml Ni. A mean error of 0.05 μg/ml Ni was reported in the determination of 4 μg ml Ni. Citrate, tartrate, EDTA, Cl^-, SCN^-, S^-, $S_2O_3^{-2}$, Pd, Pb, Hg, Cu(II), Zn, Mn(II) and Co(II) interfere.	103
2'-Hydroxy acetophenone oxime	375	7	This reagent is reported for the determination of Ni and Cu simultaneously. The Ni-complex is extracted into isobutyl methyl ketone. The ϵ and Beer's law validity are 4100 ± 100 and 10-60 μg, respectively. The absorbance of the Cu-complex was measured at355 nm. A procedure and equations for the simultaneous determination of Cu and Ni were described.	104
1-(2 Benzo-thiazolylazo) phenanthrene-9-ol.	590	≃7	The Ni-complex is Ni:R::1:2. At 590 nm the value of $\epsilon \simeq$ 55,000 and Beer's law is obeyed for up to 18 μg Ni. Positive errors are caused by Co(II), Cu(II), Zn, Pd, Ag, Cd and Hg and negative errors by other ionic species that are precipitated at pH ≃ 7.0.	105

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
4-Chloro-2-nitroso-1-naphthol and crystal violet	611	7	This reagent is the best of six nitrosonaphthol derivatives evaluated for the determination of Ni after ion pair formation with zephiramine or crystal violet. The composition of the Ni-complex is Ni:R::1:3. In the presence of crystal violet the complex is extracted into toluene. Beer's law is obeyed for up to 10 μM Ni.	106
2 (4-Methyl 2-quinolylazo) acetaphthylene-1-ol	550	$\simeq$7 to $\simeq$8	The reagent is used for the determination of Zn, Cd, Hg, Cu, Co and Ni. The complexes of Zn, Cd, and Cu are formed at pH $\simeq$ 7 to $\simeq$ 10 pH, Hg $\simeq$ 10 to $\simeq$ 11, Co at pH $\simeq$ 7 to $\simeq$ 9 and Ni at pH $\simeq$ 7 to $\simeq$ 8. The complexes are extracted into CCl_4 and absorbance is measured at 535 nm (Hg), 540 nm (Zn and Cd), 545 nm (Cu) and 550 nm (Co and Ni). Beer's law is obeyed at the ppm level. EDTA, PO_4^{-3}, CN^-, oxalate, citrate and Fe(III) interfere whereas Cl^-, Br^-, No_3^-, No_2^-, SO_4^{-2}, SO_3^{-2}, Ca, Ba, Sr, Al, Bi, UO_2(VI) and lanthanides do not.	107
Benzimidazolylazo-derivatives: Diazotising 5-amino-benzimidozole and coupling the product with(i) 3-hydroxy naph-	480	8	Two derivatives (I and II) have been reported for the determination of Co, Ni and Cu. Derivative (I) forms complexes at pH 6 (Co) 7 (Cu) and 8 (Ni) whereas derivative (II) forms complexes as pH 7 (Co), 6 (Cu)	108

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
thalene-2,7,disulphonic acid (I) (ii) with 8-hydroxyquinoline (II)	440	8	and 8 (Ni). The λ max of these complexes with both derivatives are 420 and 440 nm (Co), 490 and430 nm (Cu) and 480 and 440 nm (Ni), respectively. Rectilinear ranges in ppm of these metals with I and II are 0.6 to 3.5 and 0.4 to 2.4 for Co, 0.6 to 5.7 and 0.4 to 2.5 for Cu and 0.7 to 3.5 and 0.11 to 0.47 for Ni. The coefficient of variation for amounts of $\simeq$ 30 μg was 0.03%. The tolerance levels of several species have been reported. Reagents (I) and (II) have been used as indicators for the direct spectrophotometric titration of Cu and Ni alloys with EDTA.	
Dimethylglyoxime	375	9.5	The Ni-dimethylglyoxime complex suspension is shaken with naphthalene-acetone and adsorbed on naphthalene. The adsorbed complex is dissolved in $CHCl_3$. The value of ϵ is3200 and Beer's law is obeyed for 2 to 17 μg/ml Ni. The coeff. of variation for the determination of 100 μg Ni was 1.2%. Bi (200 μg) and EDTA have been reported to interfere.	109
Benzil α-dioxime	460	9.5	The Ni-complex is adsorbed on naphthalene in acetone. The adsorbed complex is dissolved in dimethylformamide and measured at 460 nm. The value of ϵ is	110

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			9000 and Beer's law is obeyed for 0.3 to 6.7 μg/ml Ni. Fe(III), Cu(II), Co(II), Bi(III), Na_2CO_3, KBR, KCN and EDTa interfere.	
3-Amino-5-oxo-1-phenylpyrazoline-4-dithio carboxylic acid	500	3.5 to 8.5	Ni is determined in technical grade aluminium The 1:2 Ni-complex with the reagent and diphenyl guanidine is extracted at pH 3.5 to 8.5 into $CHCl_3$ and the absorbance measured at 500 nm (ε = 28,700). Beer's law is obeyed for 0.14 to 1.90 μg/ml Ni. Co(II), V(III) and Pd(II) interfere whereas many foreign anions are tolerated. The relative error in determining 0.096 to 0.190% of Ni was ca ± 3.5%.	111
4-(5-Chloro-2,3-dihydroxy-4-pyridylazo) benzene sulphonic acid	550	8.9 to 10.2	This reagent is used for the determination of Fe(II), Co(II), Ni(II), and Cu(II). The metal complexes are formed at pH 5.2 to 7.5, 9.0 to 10.3, 8.6 to 11.0 and 8.9 to 10.2 for Fe(II), Co, Cu and Ni, respectively. Their absorbances are measured at 580 (Fe(II)), 550 (Co), 560 (Cu) and 550 nm (Ni). The interference and tolerance levels for several foreign species are reported.	112

Name of the Reagent	λ max of working wavelength	Optimum pH	Remarks	Refs.
Ammonium pyrolidine-1-carbodithioate (APDC)	379	4.5	Nickel is determined after separation by collection of its APDC complex on microcrystalline naphthalene. The separated complex is dried at 60°C, dissolved in dimethylformamide and the absorbance measured at 379 nm. Beer's law is obeyed for 5 to 55 μg Ni in 10 ml of dimethyl formamide. The effect of pH, APDC conc., time for the formation of the Ni-complex naphthalene conc. and extraction time are reported.	113
1-(2-Pyridylazo)-2-naphthol	560	5.5 to 6.0	This reagent is used for the determination of Ni,Co and Fe in films of electric resistor alloys. All three metals form complexes at pH 5.5 to 6. The absorbance of Ni, Co and Fe are measured at 560, 775 and 760 nm, respectively.	114
5-Dimethylamino-2-(2-thiazolylazo) phenol and a nonionic surfactant	560 and 480	8	The reagent in the presence of Triton X-100 is used for the dual wavelength spectrophotometric determination of Ni. The Sandell sensitivity index is 0.70 ng cm^{-2}. Beer's law is obeyed between 0.3 and 5.0 μg Ni. The interference of Cu, Co, Fe(III), Zn and Cd were masked by adding N-dithiocarboxy glycine. Fe(III), Zn and Mg (3.0 mg); V(V) (4.0 mg); Mn(II) (1.5 mg); Cd (0.6 mg), Cu(II) (0.005 mg); Co (0.01	115

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
			mg) and Ca (2.0 mg) do not interfere in the determination of 2 μg Ni.	
Diammonium ethylene bis dithiocarbamate	385	6.5	The greenish brown Ni-complex is extracted into isobutyl methyl ketone-tributyl phosphate (99:1) and the absorbance is measured at 385 nm. Beer's law is obeyed for 0.05 to 1.5 μg/ml Ni. The interferences of Co, Cu(II), Fe, Pb(II), Mo(VI), Pd(II), Sr and/or Zn were avoided by initial extraction of Ni into $CHCl_3$ as its complex with dimethylglyoxime.	116
Bis-salicylidine-o-phenylene diimine [$\alpha\alpha'$-(o-phenylene diimino)bis-(o-cresol)]	490	10	Nickel(< 100 μg) is treated with 1 ml of NH_3-NH_4Cl buffer (pH 10) and shaken for 10 minutes with a 0.01 M soln. of the reagent in toluene. The absorbance of the toluene phase is measured at 490 nm. Copper interferes seriously but can be removed by preliminary extraction of the Cu-complex at pH 4. However, 10-fold amounts of Mg, Ca, Cd or Fe(II) can be tolerated.	117
5-(2-Benzothiazolylazo) quinoline8-ol (5-BTAQ)	580	5.1	The reagent is used for the determination of Ni. A detection limit of 24 ppb Ni is reported. Beer's law is obeyed between 0.4 to 10 n mole/ml	118

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Carboxy benzene S [3 6-bis-(4-carboxy phenylazo) chromotropic acid]	720	7 to 8	The composition of the Ni-complex in acetone is N:R::1:2. ϵ and the Beer's law range are 150,000 and 0.01 to 5 μg/ml Ni, respectively. For selectivity, Ni is initially extracted as its dimethylglyoximate in $CHCl_3$, diluted with acetone and the reagent added. Under such conditions, 100-fold amounts of Mg, Ca,Ba or MN(II) do not interfere, 1000-fold amounts of Cu(II) and Fe(III) can be masked with $S_2O_3^{-2}$ and tartrate. The method is used in determining ≃ 0.03% to 8% Ni in meteorites.	119
Hexamethyl-phosphoramide	390	-	This reagent is used for the simultaneous determination of Co, Fe and Ni. Nickel can be determined in the presence of a small amount of Co, but for Co-to Ni ratio > 1:1, correction for the interference of Co must be applied. Co(II) has been satisfactorily determined at 317 nm in the presence of Ni (up to 25-fold excess). The analysis for Fe(III) at 463 nm with a Co-to-Fe ratio < 100:1 or Ni-to-Fe ratio > 10:1 is similarly possible. The optimal conc. of reagent and SCN^- for these determinations has been established and used for the determination of Co, Ni and Fe(III) in an alloy.	120

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Phenanthrene quinone monosemi-carbazone	490	7.8 to 9.5	The composition of the orange Ni-complex is Ni:R::1:2. It is extracted into $CHCl_3$ and its absorbance measured at 490 nm. The Sandell sensitivity index is 0.0035 μg cm^{-2}. Beer's law is obeyed for up to 3.9 ppm Ni, but the optimal range for accurate determination is 1.26 to 3.24 ppm. Ni has been determined in the presence of a number of foreign ions.	121
1-(2-pyridylazo)-2-naphthol	560	5.5	Using this reagent, a method has been reported for the determination of Ni in Karsol (K_2CO_3) solution that has been used for purification in NH_3 manufacture.	122
Benzil-α-monoxime	407	7.8 to 10	The composition of the yellow Ni-complex is Ni:R::1:2. It is extracted into $CHCl_3$ and shows three absorption maxima at 295, 360 and 407 nm. Beer's law is valid up to 40 μg Ni in 10 ml. The coeff. of variation was 0.65%. The effects of pH, reagent conc., reaction time, solvent, and diverse ions were examined.	123

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
5-Diethylamino-2-(2-thiazolylazo) phenol	580	8	The composition of the Ni-complex is Ni:R::1:2. The reagent is used in 10% dimethyl formamide. Beer's law is valid for up to 0.8 μg/ml Ni. The values of ε and the stability constants were evaluated. The reagent has been used in the determination of Ni impurity in apatite.	124
Sodium 3-(4-amino-1,2,4-triazol-3-ylazo)-4-hydroxy naphthalene-1-sulphonate	570	6.5	The reagent has been used for the simultaneous determination of Ni(II) and Co(II) and for the Ni in hydrogenated oils. At pH 6.5 the absorbance is measured at 540 nm or at 570 nm (Ni-complex). Hydrogenated oils were subjected to wet oxidation before the Ni-content was determined. Beer's law is obeyed up to 2.06 ppm Co(II) and 2.76 ppm Ni(II). EDTA Cn^{-},Fe(II), Fe(III), Ni(II), Cu(II), Zn, Cd, Hg(II) and Pb(II) interfere in the determination of Co(II). The interference of (i) Cd, Hg(II) and Pb(II), (ii) Cu(II) and (iii) Fe(III) has been masked by I^{-}, thiourea and F^{-}, respectively. Similar masking methods have been reported in the determination of Ni(II).	125

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
5-Methoxy 2 (2 pyridylazo) phenol	520	7	The reagent is used for the determination of 1-8 μg of Ni by extracting the Ni-complex into $CHCl_3$. The absorbance is measured at 520 nm. Cd, Mn, Fe(III), and Cr(III) do not react with the reagent whereas the Zn-chelate is not extracted. The interference of Cu up to 60 μg is masked by $Na_2S_2O_3$.	126
2-(5-Bromo-2 pyridylazo)-5-diethyl amino phenol	570	5.5	This reagent is used for the determination of traces of Ni (up to 15 μg) in aluminium alloys or nickel-plating effluent. At 570 nm the value of ϵ = 100,000. The tolerance levels for 40 ions were reported. Co interfered seriously.	127
2-(3'-sulphobenzoyl) pyridine [3-(2-pyridyl carbonyl) benzenesulphonic acid] thiosemicarbazone	400	-	The reagent is used for the determination of Fe(II), Fe(III), Co(II), Ni(II) and Cu(II). The absorbances of the complexes are measured at 615 nm (Fe(II)), 420 nm (Fe(III)), 420 nm (Co), 400 nm (Cu) and 400 nm (Ni). Beer's law is valid for 0.5 to 8 ppm Fe(II), 1 to 5 ppm Fe(III), 1 to 3.5 ppm Co(II), 0.5 to 3 ppm Ni and 1 to 4 ppm Cu. The interferences of foreign ions are reported. The complexes are more soluble in water than those of other thiosemicarbazones.	128

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs
3,3-Ethylene dinitrilo-and o-diphenylene dinitrilo-bis-(butane-3-one)dioximes	420	8.8 to 11	Both these reagents were used in 0.05M ethanol. The Ni-complexes with both reagents exhibit absorption maxima at 420 nm (ϵ = 12,000). The calibration graph is rectilinear from 0.23 to 9.9 μg/ml Ni. The proposed reagents are more tolerant towards changes in the reaction conditions than dimethylglyoxime.	129
1-Phenyl-3 thio benzoyl thiocarbamide [3-phenyl-1-thiobenzoyl-2-thiourea]	460	5	The reagent is used for the simultaneous determination of Co and Ni. Both the Ni and Co-complexes are extracted into $CHCl_3$. The absorbance of the Co-complex was measured at 400 nm and that of the Ni-complex at 460 nm against a reagent blank. Appropriate equations have been reported for the simultaneous determination of both metals. Cu(II), Cd(II), Pb(II), Ir(III), Pt(IV), Pd(II) and Bi(III) interfere.	130
3-Methoxy-7-methyl phenothiazine	425	4.5	The composition of the purple-violet Ni-complex is Ni:R::1:1, and it is stable up to 4 hr. At 425 nm ϵ = 19,800 and Beer's law is obeyed between 0.5 and 2 ppm Ni. There was no interference from alkali and alkaline earth metals, Zn, Mn(II), Pb(II), Sn(II), Cr(VI), or Ir(III) but Fe(III), Al, Cu(II) and Hg, EDTA, F^- and oxalate interfere.	131

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
3-(4-Sulphophenylazo) chromotropic acid [SPADNS]	575	6.0	The reagent is used for the determination of Fe(III), Co(II) and Ni(II) in the presence of each other by using suitable masking agents. Fe(III), Co(II) and Ni(II) form complexes at pH 2.5 to 3.0, 5.5 to 6.0 or 6 and the absorbance is measured at 580, 580 and 575 nm, respectively. The values of ϵ and the Sandell sensitivity indexes are 4800, 14,000, 7,000; and 0.08, 0.06, 0.05 $\mu g\ cm^{-2}$, for Fe(III), Co(II) and Ni(II), respectively. In each case Beer's law is obeyed in the conc. range studied, i.e., 0.5-60 μg in 25 ml. The complexes of Fe(III), Co(II) and Ni are stable for 6, 24 and 4 hrs, respectively. Each metal ion has been determined in the presence of the other using suitable masking agents. Citrate, tartrate, AsO_4^{-3}, PO_4^{-3}, F^-, Be, Zn, Cd, Al, Zr and Th interfere.	132
6-Chloro-3-hydrazinopyridazine	715	9.5	A method for the determination of Ni is reported. At 710 nm, ϵ = 18,600 and Beer's law is obeyed for 0.3 μg/ml Ni. Co(II), Fe(III) and Cu(II) interfere. The interference of Co is removed by extracting it as its 1-nitroso-2-naphthol complex into $CHCl_3$, Fe is removed as $FeCl^{-4}$ into isobutyl methyl ketone and Cu is masked by thiourea.	133

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Morpholine-4-carbodithioate	390	-	This reagent is used for the determination of Cu, Co, Ni and Te. The metal ions are treated with an aq. soln. of the K-salt of the reagent and the resulting complexes are extracted into molten naphthalene which is then dissolved in $CHCl_3$. The absorbances of the complexes were measured at 440 nm, 360 nm, 390 nm, 415 nm for Cu, Co, Ni and Te, respectively. Beer's law is obeyed for 0.5 to 7.0, 0.5 to 8.1, 0.6 to 9.0 and 0.57 to 12.5 μg/ml of Cu, Co, Ni and Te. The interference of 12 anions and 11 cations has been reported. The technique was used in the determination of Cu, Co and Ni in alloys and in simultaneous determinations of Se and Te by a modified procedure.	134
1-(1,2,4-Triazol-3-ylazo)-2-naphtol	532	5	A method is described for the determination of Ni in steel. The complex is extracted into $CHCl_3$ and the absorbance measured at 522 nm against a reagent blank. The ϵ value = 37,000 at λ 532 nm. The optimum range is 0.2 to 1.5 μg/ml Ni in the extract. 1 ppm Cd, Co, Cu(II), Hg(II), Fe(III), La, V(IV), Zn or Zr interferes.	135

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2-(5-Bromo-2-pyridylazo)-5-diethylaminophenol	560	5.5	Nickel forms a complex with this reagent in H_2O-ethanol (3:2) at pH 5.5. The absorbance is measured at 560 nm ($\epsilon = 1.26 \times 10^5$). Beer's law is obeyed for 0-15 μg Ni in 25 ml. Co interferes seriously whereas many other ions interfere only when present in large amounts. The method has been used for the determination of Ni in Al alloys and waste waters from electroplating works.	136
Sodium alizarin sulphonate	590	7 ± 0.1	The reagent is used in the determination of Co and Ni. The composition of both complexes is M:R::1:1. Both form complexes at pH 7 ± 0.1. The absorbance of the violet Co-complex is measured at 600 nm and that of the orange Ni-complex at 590 nm. The reported values of ϵ, Beer's law range and the Sandell sensitivity index are 6000, 0 to 10.6 ppm, 0.009 $\mu g\ cm^{-2}$ (Co) and 5500, 0 to 9.8 ppm and 0.010 $\mu g\ cm^{-2}$ (Ni). The interfering levels of 20 cations and 11 anions were established. There was no effect of temp. from 15°C to 35°C.	137
5-(4-Diethylamino-2-hydroxyphenylazo)-1,2,4-triazole-3-carboxylic acid	540	7.4	A study of nine triazolylazo compounds reveals that this reagent is best for the determination of Co and	138

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			Ni. Co forms its complex in acidic medium (2.4 M HCl) and its absorbance is measured at 510 nm, whereas Ni is determined at pH 7.1 and 540 nm. Beer's law is obeyed for 0.04 to 0.4 μg/ml Co and 0.2 to 1 μg/ml Ni. The limit of detection for Co is 0.8 ng/ml and Ni 1.5 ng/ml. Large amounts of Fe(III), Ni(II), Cu, Al, Cr(III), Mn(II), V(V) and Zn do not interfere in the determination of Co. The reagent is highly selective and sensitive for the determination of Co(II).	
Cyclohexane-1,3-dione bis thiosemicarbazone mono-hydrochloride	525	4 6	The composition of the Ni-complex is Ni:R::1:2. Ni has been determined in solutions containing 20 to 80 μg Ni.	139
2-Hydroxy-1-naphthaldoxime	410	5 8	The composition of the Ni-complex is Ni:R::1:2. It is extracted into $CHCl_3$ and the absorbance is measured at 410 nm. The value of ϵ = 8100. The calibration graph is rectilinear over the range 5 to 50 μg Ni. The coeff. of variation is reported as 1.65%. There was no interference of common ions except for Fe(III), Co(II), Cu(II) and V(V). EDTA interferes seriously	140

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs
Dithizone and methyl trioctyl ammonium chloride	503	5.2	The complex is extracted into $CHCl_3$ and the absorbance measured at 503 nm. The values of ϵ and the Sandell sensitivity index are 24,000 and 2 ng cm^{-2}, respectively. The coeff. of variation in the determination of 5 μg Ni is 1% (n=10). The calibration graph is rectilinear from 0 to 0.6 μg/ml Ni. The Sandell sensitivity index is claimed to be better than that of methods based on dimethylglyoxime.	141
3-Hydrazino-4-methyl pyradizine	725	11	The composition of this Ni-complex is Ni:R::1:2. It can be extracted into benzene and its absorbance measured at 725 nm against a reagent blank. The ϵ value is 24,300. The calibration graph is rectilinear for up to 3 μg/ml Ni. Cobalt was precipitated as its 1-nitroso-2-naphthol complex in $CHCl_3$. Fe(III) was extracted as $FeCl^{-4}$ into isobutyl methyl ketone and Cu(II) was masked with thiourea.	142
Purpurin	550	8.5	This complex was extracted into isobutyl methyl ketone and the absorbance measured at 550 nm; it remained constant for 2.5 hr. The coeff. of variation was 2.1, 0.9 and 0.6% in the determination of 0.1, 0.25 and 0.45 ppm Ni, respectively.	143

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
Acenaphthene quinone monosemicarbazone	420	6.3 to 8.4	The reagent is used for the determination of Co(II), Ni(II) and Cu(II). The complexes of all three metals are soluble in ethanol. The complexes of Co, Ni and Cu are formed at pH 8.4 to 9.8, 6.3 to 8.4 and 5.4 to 8.0 and their absorbances are measured at 410, 420 and 430 nm, respectively. Beer's law is obeyed for ≤ 10.57 ppm Co, ≤ 14.7 ppm Ni or 7.95 ppm Cu.	144
2-(3,5-Dibromo-2-pyridylazo)-5-dimethylaminobenzoic acid	618	6	The complex is extracted into $CHCl_3$ and the absorbance measured at 618 nm. The value of ϵ = 150 000 at 618 nm. Fe and Co interfere.	145
5-Dimethylamino-2-(2-benzothiazolyl azo)-benzoic acid	640	8.5	The Ni-complex is soluble in aq. methanol and its absorbance is measured at 640 nm. Beer's law is obeyed for 0.05 to 0.5 ppm Ni. The interferences of Cu, Cr, Co, Pd and Fe are easily masked.	146
5-Methyl-2-furaldehyde-1-phthalazino hydrazone	470 and 503	7.2 to 10.4	A stable complex is formed in the presence of 2.4% Triton X-100; the composition of the Ni-complex is Ni:R::1:2. The reported values of ϵ and the Sandell sensitivity index are 37,000 and 1.6 ng/cm^2, respectively. The coeff. of variation for 15.3 μg Ni (15 replicates) is 0.7%. Cr(III), Co(II), Cu(II) and citrate in-	147

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			terfere, but can be masked. The method has been used for the determination of Ni in standard iron and steel samples and in cobalt nitrate and chloride	
Ethyl thiocarbonate	500	7.5	The reagent is used for the determination of Co, Ni and Pd. The complexes were extracted into naphthalene at 85 to 90°C which was dissolved in $CHCl_3$. The absorbances of the Co, Ni and Pd complexes were measured at 390, 500 and 345 nm, respectively. The values of ε are 8800 (Ni) 6190 (Co) and 11,600 (Pd).	148
Biacetyl monoxime glycinimine	380-385	5 to 11.2	This reagent may be applied to the determination of Ni and Pd. Palladium forms a yellow complex at pH 0.5 to 5.5 whereas the red Ni-complex is formed between pH 5.0 and 11.2. Both complexes are extracted into molten naphthalene, which was subsequently dissolved in $CHCl_3$. The absorbance for Pd is measured at 375-380 nm and 380-385 nm is used for Ni (ε = 2100 and 5200 respectively). The optimal concentrations are 10 to 40 μg/ml Ni with standard deviation 7 ng/ml for 6 ppm Ni, and 2 to 9 μg/ml Pd with standard deviation of 9 ng/ml for 21 ppm Pd.	149

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
			Most ions do not interfere even when present in excess. The method has been used for the determination of Pd in catalysts and Ni in steel.	
4-Chloro-2-(5-methyl isoxazol-3-ylazo) phenol	555	7.05	Beer's law is obeyed for 0.2 to 3.5 ppm Ni. Several ions including (Fe(II) and Co interfere.	150
3-Hydroxy-2-methyl-1,4-naphthaquinone monoxime	510	4.5 to 6.0	The composition of the Ni-complex is Ni:R 1:3 (absorption maximum at 510 nm). Beer's law is obeyed for ≤ 3 ppm Ni and the Sandell index is 2.5 ng cm^{-2}. The optimal range is 0.32 to 2.75 ppm Ni. There was no interference by a number of foreign ions. The method is used for the analysis of alloys.	151
Phenylfuorone and hexadecylpyridinium chloride	620	10	The composition of the Ni-phenylfluorone-hexadecyl pyridinium chloride complex is 1:2:4. The graph is rectilinear from 0.05 to 0.6 μg/ml Ni.	152
1-(2-Pyridylazo)-2-naphthol	550, 555, 560, 570, 580 & 590	9 to 10	This reagent is used for the simultaneous determination of Ni, Cu and Mn in steel. These ions form complexes between pH 9 and 10 and are extracted into $CHCl_3$. The absorbances are measured at 550, 555, 560, 570, 580 and 590 nm. The concentrations were	153

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			calculated from the known values of ε of their complexes at these wavelengths	
7-(4-Sulpho-1-naphthylazo quinoline-8-ol (SNAZOXS)	450	4.5	The reagent is used for the determination of 0.45 to 4.5 ppm Ni.	154
4-Ethoxy-2'-hydroxy acetophenone oxime	375	5.5 to 9.0	The reagent forms a green ppt with Ni, which is insoluble in ethanol, ethyl ether and acetic acid. The complex is extracted into $CHCl_3$ and the absorbance is measured at 375 nm. A structure for the chelate has been proposed and the elimination of interfering species discussed.	155
4-(2-Pyridylazo) resorcinol	415	4.5	A method for the determination of Ni in low alloy steel and iron is described.	156
Phenanthrene quinone monothiosemi-carbazone	520	7 to 9.2	The composition of the Ni-complex is Ni:R::1:3. The Beer's law range, Sandell sensitivity index and coeff. of variation are up to 2.24 ppm, 2.3 ng cm^{-2} and 0.38% respectively. A 50% methanol medium was used and the tolerance levels of 42 foreign ions were studied. Cu(II) and Fe(III) were masked by thiosulphate and F^- respectively.	157

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2-(6-Bromobenzothiazol-2-yiazo) 5-diethylamino-phenol	540	9.5	The Ni-complex is Ni R::1:2 and is formed in the presence of surfactants - polysorbate 80 and dodecyl sulphate. The absorbance is measured at 540 nm against a reagent blank. The values of ϵ and the Beer's law range are 2.5×10^5 and 0.01 to 1.25 μg/ml Ni respectively.	158
Hydrazine carbothioamide-2-(2-furanylmethylene [2-(2-furylmethylene) hydrazine carbothioamide]	366	7.8	The composition of this Ni-complex is N::R::1 1. The optimal range for Ni is 0.1 to 2 1 ppm. Interferences are caused by Cu(II), Co Ag Ru(II), Rh(III), Os Au(III), Pt Pd(II), Ir(III) and Hg(II). Tartrate, citrate phosphate and F have been used to mask certain metals. The method is used for the determination of Ni in N-Al alloys.	159
Biacetyl bis-(4-phenyl-3-thiosemicarbazone	460	2.5 ± 0 05	The colour of the complex remains stable for 3 h. Beer's law is obeyed for 0.2 to 2.0 ppm Ni. Cobalt as well as 10 fold amounts of Os(VII), Pt(IV) V(V) Sn(II) and Fe(II) interfere seriously. The tolerance levels of a number of foreign species were reported.	160

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
Cadion and 1,10-phenanthroline	505	-	A method based on the formation of a ternary complex with the reagents has been reported for the determination of Ni. The ternary complex is extracted into $CHCl_3$ and the absorbance measured at 505 nm. The values of ϵ and the Sandell sensitivity index are 10,000 and $\simeq$ 0.6 ng cm^{-2}, respectively. The coeff. of variation in replicate analysis in two standard steel samples was 1.9 and 3.7%. The method has been used for the determination of Ni in soils, steels and Al-alloys.	161
Cyclohexane-1,2,3-trione trioxime	571	2.8 to 10.3	This Ni-complex has the composition Ni:R::2:3. The calibration graph covers the range 2 to 15 μM Ni with an accuracy of $\pm$ 0.30%. The I.R. spectra and the thermal stability of the complex were established. The reagent was also used for the amperometric determination of Ni.	162
Phenanthrene quinone monoxime	460	4.9 to 10.9	The reagent was examined for the determination of Ni and Co. Cobalt forms its complex at pH 3.0 to 8.4 with maximum absorption at 470 nm and Ni at pH 4.9 to 10.9 with max. absorption at 460 nm. The complexes were extracted into molten naphthalene,	163

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
			dissolved in dimethyl formamide and their absorbances measured at the appropriate wavelength. Beer's law is obeyed from 1.2 to 10.6 μg Ni and 0.6 to 7.8 μg Co. The interferences of several species were reported. The method has been used for the determination of Co in alloys and Ni in hydrogenated oils. The simultaneous determination of Ni and Co was described.	
2-2'-Dipyridyl-2 benzothiazolyl hydrazone [di-2-pyridyl ketone benzothiazol-2-hydrazone]	480	4 to 10.3	The composition of the Ni-complex is Ni:R::1:2, it is extracted into benzene and shows maximal absorption at 480 nm. The values of ε and the Beer's law range are 54,000 and up to 1.1 μg/ml Ni, respectively. For 0.51 μg Ni, the coeff. of variation (10 determinations) is 0.6%. Aluminium, V(IV), V(V), Fe(II), Zn, Hg(II), Cu(II) and Pd(II) interfere seriously.	164
Rubeanic acid (dithiooxamide) in presence of quinoline, 2-picoline, or collidine	390	7.5 to 9	A blue-violet Ni(II) complex is formed by dithiooxamide with Ni in the presence of quinoline, 2-picoline or collidine with maximal absorption at 390 nm in ethanol. Beer's law is obeyed in the pH range 7.5 to 9.0 for 0.625 to 4.375 ppm or 0.625 to 3.75 ppm of Ni for the quinoline and 2-picoline or collidine com-	165

Name of the Reagent	λ max. o· workin; wavelen gth	Optimum p·:i	Remarks	Refs.
			p ecies, re:pectively. Copper(I I), Cd(II) Pb(II) F:(III), Mn (II), Co(I), Pd(II), Al(III), C (III) an B (III) inte fere, bu ≤ 5000 ppm of mo ybda e tungsta te or anadat : and ≤ 1000 ppm o tartrate, oxalate and citrate do not.	
D -2-pyridyl ketone pyr mid ne-2- l hydrazone	430	9	This reagent may be used for the simultaneous determination of Fe(II) and NI(II) or Fe(II) and Co II). All three metals form complexes at pH 9. The absorption of the Fe- Ni- and Co-complexes are measured at 580, 430 and 460 nm respectively. The method is applicable in the range (μg/ml) 0.4 to 4 (Fe), 0.1 to 2 (Co), and 0.1 to 1 (Ni). In the Fe-Ni system, Cu, Zn, Cd and Co interfere seriously whereas Mn, Hg, Ag and V are tolerated at low levels. In the Fe-Co system, Cd, Cu and Ni interfere seriously whereas Mn, Hg, Zn, Ag and V are tolerated at low levels.	166
2,4,6- Tri hydroxy di hio enzo c acid	530	6 to 6.8	The composition of the red violet Ni-complex is Ni:R::1:2. It can be extracted into $CHCl_3$ and its absorbance measured at 530 nm. Beer's law is obeyed for ≤ 8.0 μg/ml Ni.	167

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2-(4-Antipyrinylazo)-5-diethyl aminophenol	510	0.5 to 4 M NH_3	The reagent is used for the determination of Ni and Ga(III). The composition of the Ni-complex is Ni:R::1:2. It can be extracted into $CHCl_3$ and its absorbance measured at 510 nm (ϵ = 98,000). In the determination of Ni there was no interference from cu, Pb and Sn(IV); Fe was masked by tartrate. In the determination of Ga there was no interference from Pb, Sn(IV) and 10-fold amounts of As, but Cu was masked with $S_2O_3^{-2}$ and Sb with tartrate. Nickel (0.1 to 3.3%) was determined in bronze and steel.	168
8 Hydroxy-7-(4-sulpho-1-naphthylazo) quinoline-5-sulphonic acid (SNAZOXS) and oxalate	600	2.8	The composition of the ternary SNAZOXS-Ni-oxalate complex is 1:1:2. A solution containing 0.2 to 2.4 ppm Ni is treated with SNAZOXS, chloroacetate buffer, pH 2.8 and sodium oxalate. After 5 minutes the absorbance is measured at 600 nm. The method is fairly selective.	169
Dimethylglyoxime	520	11.5	In this method Ni(II) is oxidised to Ni(IV) at pH 11 (NaOH) with $(NH_4)_2S_2O_8$ in the presence of dimethylglyoxime and triethanolamine to give a coloured soluble Ni(IV) dimethylglyoxime (1:3) complex. The absorbance of the complex is measured	170

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			at 520 nm. Beer's law is obeyed between 0.05 to 0.6 μg/ml Ni. V(V), Mo(VI), W(VI), 140-fold excess of Co, 125 of Fe, 25 of Cr ands 4 of Cu do not interfere. The method has been used for determining 0.2 to 11.5% Ni in steels containing Co. The coefficient of variation is < 2.2% (4 results).	
2'-Mercaptoacetoacetanilide with 4 picoline as catalyst	615	6.0	The reagent is used for synergic extraction and simultaneous determination of Ni and Cu. The reagent forms complexes with Ni(II) and Co(II) in the presence of 4-picoline as catalyst and the complexes are extracted into $CHCl_3$ at pH 6.0 (Ni) and 6.5 (Cu) and absorbance is measured at 615 and at 630 nm, respectively. The ranges of Beer's law, ϵ value, the Sandell sensitivity index and coeff. of variation are 0.5 to 120 ppm, 5210, 0.05 μm cm^{-2}, 0.92% for Ni and 0.1 to 9.0 ppm, 5570, 0.01 μg cm^{-2} and 0.68% for Cu respectively. The method is used for the determination of Ni and Cu in ores and alloys.	171
Di(2-pyridyl)-ketone 2-quinolyl hydrazone	490	9	This reagent may be used for the simultaneous determination of Fe Co and Ni. All form complexes at pH 9. The absorbances are measured to 590 nm and	172

Name of the Reagent	λ max or working wavelength	Optimum pH	Remarks	Refs.
			510 nm for samples containing Fe and Co; or at 590 nm and 490 nm for those containing Fe and Ni. An equation is described calculating the concentrations of the metals from the absorbances. A coefficient of variation of 1.3 to 1.9% was found in each case.	
Isonitrosothiocamphor (Thiocamphoroxime)	450	7	A method for the determination of Ni in steel is reported. The complex is extracted into benzene and the absorbance is measured at 450 nm against a reagent blank. EDTA, CN^-, SCN^-, oxalate and citrate interfere seriously, but were removed by boiling with HNO_3. The interferences of Ag, Cd, and Hg(II) were masked with $S_2O_3^{-2}$, Cu(II) with thiourea and Al, Cr(III), Fe(III) with tartrate.	173
Cyclohexane-1,3-dione bis thiosemicarbazone hydrochloride (I) and 2,4-dihydroxy acetophenone (II)	430 385	8.5 to 10.0 6.2 to 6.8	The composition of the two Ni-complexes are Ni:R::1:3(I) and Ni:R::1:1(II). ϵ, the Sandell sensitivity index and Beer's law range are 25,000, 2.35 ng cm^{-2}, 0.24 to 1.88 ppm Ni (for reagent I) and3580, 16 ng cm^{-2}, 0.9 to 7.0 ppm Ni (for reagent II). Reagent I was used for the determination of Ni in steel. Interference of Fe and Mn were masked by triethanolamine.	174

Nam : of the Reagent	λ max. or working wave'en gth	Optimum pH	Remarks	Refs
3-(2-Acetoxyphenyl)-1-methyl triazene N-oxide	430	6 6 to 10.4	This reagent is used for the determination of Ni and Cu. Copper forms a complex at pH 7.0 to 10.6. Both the Cu and Ni-complexes are extracted into $CHCl_3$. The absorbance of the Cu-complex is measured at 420 nm and that of Ni-complex at 430 nm. ϵ, the Sandell sensitivity index and Beer's law ranges are 14,000, 4.2 ng cm^{-2}, 0.25 to 4.5 ppm for Ni and 12,100, 5.3 ng cm^{-2}, 0.25 to 4.7 ppm for copper. Several foreign species may be tolerated. The standard deviation in the determination of 2 ppm Ni or Cu (n = 16) are ± 0.26 and 0.22%, respectively.	175
Cyclohexylideneammonium-2-(Cyclohexylidene amino) cyclo-hex-1-ene-carbodithioate	550	6 9	The composition of the violet Ni-complex is Ni:R::1:2. The complex is soluble in ethanol and acetone and can also be extracted into isobutyl methyl ketone. The values of ϵ and the Sandell sensitivity index are 25,000 and $\simeq$ 2 ng cm^{-2}, respectively. Beer's law is obeyed for 12to 1800 μg/ml in aq. ethanol and 12 to 2000 μg/ml Ni in the extract. The interference of 14 anions and 9 cations were examined.	176

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2-Mercapto-3-(4-methoxy phenyl propenoic acid	400 410 415	Alkaline	This reagent instantaneously forms a yellow complex with Ni in alkaline medium with λ max at 400 nm (ε = 19,500). The complex is extracted by isoamyl alcohol or octanol with max. absorbance at 410 nm (ε = 9500) and at 415 nm (ε = 19,000), respectively. The method is used for the selective determination of Ni in hydrogenated greases, steels and solders. The method was also used for the determination of Ni in sea and mineral water with a precision of 0.33 to 0.54% and a detection limit of 10 ng/ml.	177
K-Morpholine-4-carbodithioate	390	5.2	The Ni-complex is extracted by molten naphthalene and subsequently dissolved in $CHCl_3$ and the absorbance measured at 390 nm. Beer's law is obeyed for 5 to 70 μg Ni and the coefficient of variation is 0.7% of 30 μg Ni. Co(II), Fe(III) and Pd(II) interfere, but the effect can be eliminated. The method has been applied to the analysis of alloys.	178
7-(4,5-Dimethyl-2-thiazoly-lazo)-8-hydroxy quinoline-5-sulphonic acid	520 to 550	4 to	The reagent forms red-purple complexes with Ni(II), Zn(II), Co(II) and Bi(III), pH 4 to 6 exhibiting λ max. in the range 520 to 550 nm and with ε in the range 3.5 to $5x10^4$ for Ni. The sensitivity and	179

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			selectivity of the reagent is enhanced in the presence of Na dodecyl sulphate (II). The composition of the ternary complex is Ni:R:II::1:2:4 and $\varepsilon = 1.1 \times 10^5$. Beer's law is obeyed for up to 0.4 μg/ml Ni. The reagent can be used for the determination of traces of Ni in ores, metals, Co salts and soils.	
2-Thio-orotic acid	400	Ammoniacal medium	This reagent forms a yellow water-soluble complex with Ni in ammonia. The Sandell sensitivity index and Beer's law range are 1100 0.0535 μg cm^{-2} and 5.8 to 35.3 mg/l, respectively. Serious interference was found from 15 common species, but none from Mg, Zn, Ag, Na, K, WO_4^{-2}, SO_4^{-2}, F^-, Cl^-, Br^-, I^-, NO_2^- and acetate. The relative errors in the determination of 29.4, 23.5 and 8.22 mg/l Ni were ± 0.68, ± 1.3% and ± 2.63% respectively.	180
5,7-Dichloro-2-methyl-quinoline-8-ol	388	7 to 8	The reagent is used for the determination of Ni and Co. Both the complexes are extracted in $CHCl_3$ at pH 7 to 8. The absorbance is measured at 390 nm for Co or 388 nm for Ni. Beer's law is obeyed for 1.3 to 18.2 μg/ml Ni and 0.8 to 24 μg/ml Co. The effects of pH and the presence of $NaClO_4$ or Na_2SO_4 in the	181

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			aq. phase on the composition of the extracted species are discussed.	
N^2-Benzoyl-N^4-(4-nitrophenyl) acetohydrazide hydrazone	560	7.5 to 9	The Ni-complex is extracted into $CHCl_3$: butanol (5:1) and the absorbance measured at 560 nm. The limit of detection is 0.01 μg/ml. There was no interference from large amounts of Al, Zn, Pb and common anions and a preliminary separation of Ni was not required. The method was used for the determination of Ni in steel.	182
9-(2-Pyridylazo) phenanthrene-10-ol	552	4.5	The reagent is reported for the determination of Ni, Cu and Pd. Nickel and Cu form complexes at pH 4.5 and Pd at pH 2.0. The absorbance of the Pd complex in 50% ethanol is measured at 647 nm and that of Cu or Ni at 552 nm. Alternatively, the complexes are extracted into $CHCl_3$ from 20% ethanolic solution and the absorbance measured at 555, 560 and 657 nm for Ni, Cu and Pd, respectively.	183
2-Benzoyl-4-(2 nitrophenyl) acetohydrazide hydrazone	580	8.6 ± 1.0	This reagent is highly selective and is used for the determination of Ni in alloy steel and catalysts without prior separation of base metals.	184

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
3-Hydroxy-3-phenyl-1-o-carboxy phenyl triazene	414	6 to	The composition of the Ni-complex is Ni:R::1:1. A ten-fold excess of the reagent is required for full colour development. The values of ϵ, the Sandell sensitivity index and Beer's law range are 31,800, 0.0018 $\mu g\ cm^{-2}$ and 1 to 20 μM Ni, respectively. The coefficient of variation for six determinations is 1.21%.	185
Phthalimide bis (thiosemicarbazone)	440	10	The Ni-complex of this reagent is 1:1. A ten-fold excess of the reagent is required for full colour development. The values of ϵ, the Sandell sensitivity index and Beer's law range are 11,300, 0.0052 $\mu g\ cm^{-2}$ and 0.11 to 3.21 ppm Ni, respectively. In the determination of 2.14 ppm of Ni a standard deviation of 0.01 ppm was found. The tolerance limits for 30 foreign ions were reported.	186
Resacetophenone isonicotinoyl hydrazone	420	5.0	The reagent was used for the direct determination of Ni at pH 5. The complex is soluble in 60% v/v methanol-ethanol and the colour is stable for 24 h. The composition of the Ni-complex is Ni:R::1:2. The system obeys Beer's law in the range of 2.29 to 3.76 μg/ml. The values of ϵ and the Sandell sensitivity index are 0.83×10^4 and 0.007 $\mu g\ cm^{-2}$. The interference of 24 ions is reported.	187

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
n-Butyl xanthates	418	4.1 to 6.8	Ni (pH 4.1 to 6.8) and co (pH 4.3 to 8.1) are determined after adsorption of their n-butyl xanthates on microcrystalline naphthalene and dissolution in $CHCl_3$. The absorbances are measured at 418 nm (Ni) and at 355 nm (Co). Beer's law is obeyed for 0.8 to 8 and 0.5 to 5.5 μg/ml Ni and Co, respectively. In the determination of Ni and Co present together, the $CHCl_3$ soln. is divided in two parts. In the first part Ni is determined as discussed and in the second part the Ni-complex was decomposed by aq. NH_3 and the absorbance of the Co complex was measured. Iron (III) and Hg interfere. EDTA interferes. The method was applied to the analysis of steel and other alloys.	188
Di-2-pyridyl glyoxal bis (4-d-phenyl semicarbazone	420	4.5 to 10.6	The composition of the Ni complex is Ni:R::1:2. The complex is extracted into $CHCl_3$ and the absorbance measured at 580 nm. The values of ε and Beer's law range are 54,200 and 1.12 μg Ni, respectively. Iron, Co(II), Cu(II) and Zn interfere, but are masked by $Na_2H_2P_2O_7$ or $Na_2S_2O_3$	189
Bromazepam	285	6	Using this reagent, 3 to 50 μg Ni have been determined. The ε value of the complex at 285 nm is	190

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
			20-200 Cl interferes seriously. The tolerance levels of 16 other ions are reported.	
3-(picolydene) benzene sulphonic acid [α-(3-sulphophenyl) picolinaldehyde] 2-hydroxy benzoyl hydrazone	375 and 385	Slightly acidic soln.	This reagent is used for the determination of a mixture of Ni(II), Co(III) and V(V). The complexes exhibit absorption maxima at 375 and 385; 400 and 415 nm and at 395, respectively. The ε values vary in the range 14,000 to 36,000. The simultaneous determination of 1 mg/l Ni or Co and 2 mg V is described. Hg, Pd, Pt,Cr(III), Sn(II) and citrate do not interfere whereas Zn, Bi, Cu, Fe, In, Ti and S^{-} do.	191
5,10,15,20-Tetrakis-(4-sulphophenyl) porphine	414	-	The composition of the Ni-complex is Ni:R::1:1. The absorbance of the 1:1 complex formed in the presence of hexadecyl-trimethyl ammonium bromide and imidazole is measured at 414 nm (ε = 224,000). The method was used for the determination of Ni in ores and alloys.	192
2-(2 Benzothiazolyl-azo)-5-dimethylamino benzoic acid and sod. dodecyl sulphate	642	6.0	The empirical composition of the ternary complex of Ni with the reagent and sod. dodecyl sulphate is 1:2:1. The absorbance of the complex is measured at 642 nm (ε = 136,000). Beer's law is obeyed for up to	193

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			5 μg Ni in 10 ml. The method has been used to determine Ni in waste water and steel.	
5-(3,5-Dibromo-2-pyridylazo)toluene-2,4 diamine with anionic surfactant	567	4.8	Nickel (10 μg) has been determined by this reagent in the presence of sod.-dodecyl sulphate at pH 4.8. The absorbance is measured at 567 nm in a 5 mm cell (ε = 117,000). Good results were obtained with samples containing 0.011, 0.84 and 0.95% Ni.	194
2-(3'-Sulphobenzoyl) pyridine 4-phenyl thiosemicarbazone	400	8.5	The reagent is used for the determination of trace amounts of iron cobalt Ni and Cu. The absorbances of Fe(II), Fe III) Co and Cu were measured at 630, 405, 405 and 400 nm, respectively. The complexes of Fe(III) Co and Cu are formed at pH 5.2 and that of Fe(II) at pH 4.7. Nickel forms its complex at pH 8.5 (H_3BO_3-NaOH buffer) and its absorbance is measured at 400 nm.	195
K-tetrahydro-furfury xanthate	417	3.7 to 8.6	This reagent is used for the determination of Co, Ni and Ir. Co and Ni form complexes at pH 2.2 to 9.5, 6.9 to 9.5 and 3.7 to 8.6, respectively. These complexes are co-precipitated on microcrystalline naphthalene and subsequently extracted by $CHCl_3$.	196

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
			The absorbance of the Ni, Co and Ir complexes were measured at 417 nm, 352 nm and 385 nm, respectively. Beer's law is obeyed by 10 to 80 μg Ni, up to 0.30 μg Co and 35 to 230 μg Ir per 10 ml. The coefficient of variation lies between 0.26 to 0.53%. The interference of various ions is reported.	
1,5-Bis(di-2-pyridyl methylene) thio-carboxohydrazide	440	10 4	The reagent solution in dimethylformamide is added to a solution containing Ni and Co. The absorbance is measured after 60 minutes at 440 nm and 480 nm for Ni and Co respectively. The optimum ranges for Co and Ni are 0.2 to 0.8 ppm and 7.5 to 17.5 μg, respectively. The coefficient of variation for Co is 0.43 to 0.59%.	197
Isoquinoline 3-carbaldehyde-2-pyridyl hydrazone	488	10-12	A method is reported for the simultaneous determination of Fe, Co and Ni with this reagent. The absorbances of the Ni, Fe and Co-complexes are measured at 488, 575 and 450 nm respectively. 4 to 16 μg Co, 3 to 10 μg Ni and 4 to 14 μg Fe were determined. Interference from Cu, Zn and Mn were avoided by adding conc. aq. NH_3 and 0.1 m EDTA.	198

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2-Thio orotic acid with triethylamine	420	6.5 to 11	This reagent is suitable for the determination of Ni and Cu. The composition of complexes of both metals is M:R:1:2. Copper forms its complex at pH 5 to 8 and Ni between 6.5 to 11 with absorption max. at 435 nm (Cu) and 420 nm (Ni). ϵ and the Sandell sensitivity index are 1420, 2.9 ng cm^{-2} for Ni and 10 900 and 3.7 ng cm^{-2} for Cu, respectively. Beer's law is valid for 0.06 to 3 μg/ml Ni and 0.2 to 5 μg/ml Cu with optimum ranges 0.4 to 3 and 0.4 to 4 μg/ml respectively for Ni and Cu. Oxalate EDTA, Co(II), Cr(III), Ce(IV), V(V), and Pd(II) interfere seriously. However, 100 fold amounts of F^-, PO_4^{-3}, Zn, Cd, Hg(II) or borate or 100 fold citrate of Mn(II) are tolerated. Thiosulphate and Mo(VI) interfere in the determination of Cu and Ni respectively. The interference of Fe(III) and Pb(II) can be masked with F^- and ammonia respectively. At 1 μg/ml the coefficient of variation is 0.23 and 0.25% for Ni and Cu, respectively.	200
	390	-	An Ni-complex is formed by 2-thio orotic acid in the presence of triethylamine viz. (2 thio-orotato) triethylamine di aquo nickel(II). The absorbance of this	201

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
			complex is measured at 390 nm (ϵ = 1300). The Sandell sensitivity index is 45.32 ng cm^{-2} and Beer's law is obeyed between 5.8 to 47 mg/l Ni. Pb(II), Th, VO_2^{2+}, Ba, Ti(IV) and Mo(VI) interfere seriously.	
K-O,O-Diethyl phospho-rodithioate	385	2.4	This reagent is used for the determination of Ni and Pd. Both form complexes at pH 2-4 and are extracted into $CHCl_3$. The absorbance of Pd is measured at 298 nm and that of Ni at 385 nm. The values of ϵ are 840 and 29,000, for Ni and Pd, respectively. Beer's law is valid for 0.04 to 1 mM Ni and 1 to 32 μM Pd. The presence of 10 mM of EDTA inhibits extraction of Ni. The lowest tolerance limits in the determination of 0.92 mM Ni(II) are 1 mM for Mn,Zn, Pb, As, Mo(VI), W(VI), V(V), Cr(VI), No_2^-, citrate and oxalate; and 1 < mM for Ag, Cu, Co, Hg(II), Sn(II), Sn(IV), Bi, Sb(III), Au(III), Fe(III), Se(IV), Te(IV) and Os(VIII). In the determination of Pd(II) in the presence of 10 mM EDTA the lowest tolerance limits are 0.1 mM for Cu, Sn(II), Sb(III) and No_2^-; 10 μM for Ag; and < 10 μM for Hg(II), Ag(III) and Os(VIII).	202

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs
Xanthates (Potassium-, propyl, butyl-, benzyl-, and isopentyl-)	415	5-9	A method is reported for the determination of Ni and Pd using various xanthates as reagents. The composition of both metal complexes with the xanthates is M:R::1:2. The complexes are extracted into $CHCl_3$. The Ni-complex is extracted at pH 5-9 with λ max 415 and 475; the absorbance is best measured at 415 nm. The bright yellow colour of the Ni-complex is stable for ≃ 36 hrs. ε-value and Sandell sensitivity index for the Ni(II) xanthate complexes vary from 2.8×10^3 to 3.2×10^3 and 0.018 to 0.01 $\mu g\ cm^{-2}$ respectively. The interferences of Fe(III) and Pb(II) are masked by F^- and acetate respectively and Co(II) is removed by extracting with thiocyanate into isoamyl alcohol. Bi(III), Cu(II), Mn(II), Pt(IV), Rh(III) and Os(VIII) interfere. Pd(II) complexes with xanthates show max. absorption at 460 nm, except for the Pd(II) ethyl xanthate complex which exhibits λ max at 465 nm. The Pd(II) xanthates are stable for 24 h. In the case of the Pd(II) xanthate complexes the ε value varies from 1.76×10^2 to 1.9×10^2 and the sensitivity varies from 0.5 to 0.65 $\mu g\ cm^{-2}$.	203

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2-(Benzothiazol-2-ylazo)-5-dimethyl aminophenol (BTAM)	545	7.0 to 8.5	The Ni-complex is formed at pH 7 to 8.5 in the presence of dimethylformamide and dodecyl pyridinium chloride and exhibits max. absorption at 545 nm (ϵ = 107 000). Beer's law is valid for upto 160 ng ml^{-1} Ni.	204
4-(2-Pyridylazo) resorcinol	515	9	The reagent is applied to the simultaneous determination of Ni and Co. Both form complexes at pH 9. Ni and Co are determined by measuring the difference in absorbance at 515 and 480 nm; and at 498 and 531 nm. The ϵ values for Ni and Co are 13,700 and 23,500 respectively. The calibration graphs are rectilinear for $\leq$ 60 μg Ni or Co in 50 ml of solution.	205
Sod. dodecyl xanthate	509	7	This reagent is used for the determination of Ni and Co. Both form complexes at pH 7. The absorbance of the Ni-complex is measured at 509 nm (ϵ = 4390) and the Co-complex at 354 nm (ϵ = 14,800). Beer's law is obeyed for 2.3 to 97 μM Ni and 2.5 to 100 μM Co.	206

Name of the Reagent	λ max. or working wavelength	Optimum pH	Remarks	Refs.
2,4-Dihydroxy acetophenone thio-semicarbazone (DAPT)	385	7.5	This reagent is used for the determination of Cu(II) and Ni(II). The composition of both the metal complexes with DAPT is 1:1. Copper forms its complex at pH 5.0 (acetic acid - sod. acetate) and is extracted into n-butanol orethyl acetate whereas Ni forms a complex at pH 7.5 (ammonium chloride - ammonia buffer) and is extracted into butanol. The absorption max. of the Cu-complex in n-butanol is 390 nm (ϵ = $1.5x10^4$) and that of Ni-complex in butanol is 385 nm (ϵ = $8.2x10^3$). At least 25-fold molar excess of the reagent is required for copper whereas for Ni a 12-fold molar excess is sufficient. Beer's law is obeyed in the range 0.8 to 5.5 ppm for Cu and 1.0 to 8.0 ppm for Ni. Silver(I), Hg(II), Pd(II), V(V), EDTA, thiosulphate and CN^- interfere seriously even when present in traces, in the determination of Cu. The interference of Fe(III) can be avoided by masking with F^- or ascorbate and higher amounts of Ni(II) and Sn(II) are masked by citrate. Ag(I), Co(II), Cu(II), Fe(II), Pd(II), U(VI), oxalate, citrate, EDTA, PO_4^{-3}, pyrophosphate and CN^- interfere seriously in the determination of Ni. Fe(II) is masked by F^-.	207

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