RECENT DEVELOPMENTS IN ELECTROPLATING, 1960-1964

PART II—ALLOYS

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INTRODUCTION

In a previous communication[1] the recent developments in the electroplating of metals have been reviewed for the period 1960-1964. This paper covers a similar review on binary alloys. Ternary alloy deposition has already been reported in detail[2].

ALLOYS OF TIN

Tin-Nickel : Alloys of tin with nickel have been deposited from chloride[3, 4], chloride-fluoride [5-7], stannate-cyanide [6, 8] and pyrophosphate[9] baths. Chloride solutions gave adherent, bright and tarnish resistant plates, with 25-34 per cent nickel, suitable for use on steel or copper and as a base for chromium plating[4]. Alloys containing 35 per cent had a thickness of 15-25 μ. Deposits from the chloride-fluoride bath with a thickness of 15 μ gave maximum protection to polished steel with a copper underlayer[5]. The addition of para-phenolsulphonic acid was helpful in obtaining non-brittle plates even with a high concentration of ammonium chloride in the solution[6]. The pyrophosphate bath gives deposits over a wider range of composition, whereas the chloride-fluoride, bath has a higher cathode efficiency.

Tin-Copper: The stannate-cyanide bath with a high throwing power has been used for the production of white bronze containing 70-74 per cent copper[10]. Additions of rochelle salt and triethanolamine have been mentioned[11] for plating up to a current density of 7 amp/dm^2. Several workers have studied the pyrophosphate bath prepared from the metal chlorides and pyrophosphate[12], as well as from the metal pyrophosphates [13, 14]. The advantages of the pyrophosphate bath over stannate-cyanide are reported to be: higher permissible cathode current density up to 10 amp/dm^2, higher cathode efficiency, lower bath voltage, and easier control and maintenance[14]. Amongst acid baths work has been carried out with the sulphate bath containing thiourea[15], and the fluoborate bath with additions of gelatin and beta-naphthol-sulphonic acid [16, 17]. Paths containing copper thiocyanate and stannous chloride have been reported to give satisfactory plates with a silver white colour and more corrosion resistant than nickel plates of the same thickness[18].

Tin-Lead and Tin-Zinc: Fluoborate and phenolsulphonic acid[19] baths have been mentioned for the plating of tin-lead alloys. High lead alloys containing 80-90 per cent have been obtained from fluosilicate solutions containing glue[20], and amido-sulphonic acid solutions with pyrocatechol and gelatin[21]. Detailed studies have shown that the pyrophosphate bath[22] is suitable for the deposition of alloys containing up to 90 per cent tin, the bath comparing very well in performance with the fluoborate bath.

Tin-zinc alloy plates containing 20 per cent zinc have been found to be superior to tin or zinc coatings for decorative purposes as well as protection against atmospheric corrosion[23]. Work done in this laboratory[24] has shown that this bath has many favourable points compared with the stannate-cyanide bath: composition range up to 81 per cent zinc, cathode current density up to 8 amp/dm^2 as compared with 2 amp/dm^2 reported by others[25], bath voltage, control and maintenance. Solutions containing sodium hydroxide and additions like gelatin and bakelite have produced electroplates comparable in quality to those obtained from stannate cyanide solutions[25].

Other Alloys : Several other tin alloys have been electrodeposited, the alloying metal and the bath being: (*a*) antimony-sulphate with glue and phenol [26, 27], and fluoride with gelatin and phenol[28], the latter being suitable for hardness and decorative properties; (*b*) bismuth-sulphate[27], and stannous sulphate and bismuth nitrate with glue and phenol[29]; (*c*) cadmium-fluoborate with glue[30]; (*d*) germanium-sulphide with high throwing power and giving corrosion

resistant plates[31]; (*e*) manganese-chloride with gelatin giving alloys containing 40 per cent manganese[32]. Alloys of tin with aluminium, indium and lead have been electrodeposited from molten systems and reported to be useful as solders or in fabrication of electronic devices such as transistors[33]. The role of alloys of tin and other metals in metal finishing has been reviewed[34].

ALLOYS OF NICKEL

Nickel-Cobalt: The codeposition of nickel with cobalt has been studied with sulphate and chloride solutions containing sodium hypophosphite chiefly for magnetic properties[35]. The baths gave alloy deposits having 200-300 and 600-800 oersteds coercive force and residual induction of 5000 and 500 gauss respectively. The sulphate bath has been mentioned for plating on titanium and its alloys[36]. The pyrophosphate[37] and sulphamate[38] baths have been studied in detail in this laboratory and their performance compared with the sulphate-chloride baths. The former solution has some favourable points, namely, speed of plating and throwing power, and the latter hasthe same plating characteristics as the sulphate-chloride type. In both cases the deposit composition was not much affected by changes in current density.

Nickel—Zinc: The cyanide bath has been used for the deposition of nickel-zinc alloys[7, 39]. Coatings containing 82-90 per cent zinc have very good corrosion resistance as compared with zinc coatings. The alloys are of the solid solution type with different phase structures depending on the current density used[7]. High-zinc alloys from chloride solutions have also been reported to have high resistance to corrosion[39, 40]. Periodic reverse current plating has been employed for the deposition of these alloys[41, 42]. During deposition from sulphate-ammonia solutions[43, 44] the current density showed no effect on plate composition[43]. The deposits were bright and corrosion resistant, and the hardness increased from 60 kg/cm^2 for pure zinc to 520 kg/cm^2 for a 50 per cent alloy. Reverse current plating has been reported to be beneficial. It has been found difficult to obtain high-nickel alloys from sulphamate solutions[45]. The constancy of composition with current density has also been observed during deposition from the pyrophosphate bath[46]. The current density was as high as 15 amp/dm^2 and there were sudden changes in plate composition and cathode potential at low current densities due to the deposition of alloys of different phases as shown by x-ray studies.

Nickel-Iron and Nickel-Copper: Chloride solutions[47] gave nickel-iron alloys having a hardness of 340-530 kg/mm^2 and adhesive strength of 1900kg/cm^2. Sulphate - chloride solutions[48] have also been studied and the iron content of the deposit found to decrease with an increase in thickness approaching a value of 20 per cent above 3000A. The pyrophosphate[49] and sulphamate[50] baths have been found to be suitable for nickel-iron deposition. The limiting current densities were 4 for pyrophosphate and 10 amp/dm^2 for sulphamate, there being a tendency for constancy of composition in the higher current density range. The composition did not vary with time during plating from sulphamate solutions.

Nickel-copper alloys have been deposited from the pyrophosphate bath in the current density range 0.25-8.0 amp / dm^2. X-ray studies indicate that the plates have the same f.c.c. structure as nickel or copper deposited from this bath[51]. Polarization measurements have also been reported[51-53]. Alloys with copper in the form of foil have been deposited[54] on polished stainless steel from an electrolyte containing sulphate and $Na_3C_6O_7$.

Other Alloys: Nickel has been codeposited with other metals, the alloying metal and the bath being: (*a*) rhenium: sulphate-perrhenate[55]; (*b*) titanium-sulphate[56]; (*c*) antimony: nickel chloride-antimony fluoride[57].

ALLOYS OF TUNGSTEN AND MOLYBDENUM

Alloys of tungsten with nickel have been deposited from the sulphate[58] and pyrophosphate[59] baths. In the former case an alloy containing 19 per cent tungsten has been obtained with a current efficiency of 88 per cent. The pyrophosphate bath can be operated up to 30 amp/dm^2 giving plates containing 6-53 per cent tungsten at a cathode efficiency of 5-74 per cent. Codeposition with cobalt has been studied from sulphate - ammonia[60, 61], citrate[62] and pyrophosphate solutions[63]. From sulphate-ammonia solutions, it was possible to obtain alloys containing up to 57 per cent tungsten at 21-73 per cent efficiency and 1-40 amp/dm^2. The addition of citric acid increased the brightness of plates[61]. The deposits from the citrate bath have been stated to be suitable for plating gun barrels, tools and other components. The high cost of material, the need for high bath temperature and pH are disadvantages which deny the

use of these plating baths for industrial scale applications. Pyrophosphate solutions could be operated up to 20 amp/dm² to obtain alloys containing 11-49 per cent tungsten at an efficiency of 13-59 per cent. They have also been shown to be satisfactory for the plating of iron-tungsten[64] alloys containing 17-56 per cent tungsten with 9-65 per cent efficiency and 0.5-12.0 amp/dm².

The performance of the pyrophosphate bath for the codeposition of tungsten with nickel, cobalt and iron, is similar to that of the citrate type. In all cases, there is a tendency for constancy of composition at higher current densities, as also noted during deposition from other solutions. Wheel axles have been coated with cadmium-tungsten alloys containing 1 per cent tungsten from cyanide-citrate solutions[65]. The electrodeposition of alloys of cobalt with tungsten, molybdenum and other metals has been recently reviewed[66].

Alloys of molybdenum with nickel have been obtained from citrate[67, 68], pyrophosphate[69] and sulphate[70, 71] solutions. The molybdenum content was 30-50 per cent with the citrate, but quite low with the other baths. Citrate[72] and pyrophosphate[73, 74] baths have also been used for the depostion of cobalt-molybdenum alloys with a molybdenum content ranging from 10 to 56 per cent. Although both these alloys have been reported to be adherent and bright, there were inclusions of non-metallic matter as well as tendency for tarnishing unless a protective layer was applied. Hydrazine sulphate has been added to some of these solutions in order to prevent anodic oxidation. Chromium-molybdenum alloys have been deposited from sulphate solutions[75].

Athough the electrodeposition of tungsten or molybdenum with other metals is rather expensive, it might find application in specialized cases where the unusual properties, namely, brightness, hardness and corrosion resistance is needed.

ALLOYS OF PRECIOUS METALS

Cyanide baths have been used for the codeposition of gold with cobalt[76], nickel[76, 77], copper[77-79], silver[76, 80, 81], zinc[82] and cadmium[82]. Alloys with bismuth and lead have been obtained from cyanide solutions containing bismuth nitrate and lead carbonate respectively[83]. Gold-tungsten alloy deposits containing inclusions have been obtained from chloride-tungstate solutions[84], and fused salt baths have been mentioned for alloys containing germanium and antimony[13]. Gold-copper deposits containing 80 per cent gold are suitable for decorative purposes as well as corrosion resistance, and are 2 to 3 times harder than pure gold plate. This method has been utilized for plating on watch cases[77]. The microhardness of the alloys increased with copper content passing through a maximum of 240-270 kg/mm² at 30-70 per cent copper. The resistance to wear of alloys containing 30-40 per cent copper was 3 to 4 times that of gold. The internal stress of 3·4 μ thick film on a 1mm. thick brass plate decreased as the copper content increased[78]. Gold alloys with 1 per cent silver have been reported to be hard and bright[80, 81].

Alloys of silver with tin have been deposited from fused salt baths[79]; with 46-71 per cent palladium from ammoniacal solutions[85]; with cobalt[86] from silver cyanide-cobalt hexammonium carbonate solutions. The last alloy is reported to have improved hardness as well as resistance to wear and corrosion. There is a report on the deposition of palladium-copper alloy from palladium ammino complex and alkali hydroxide solutions[87].

OTHER ALLOYS

Chromium Alloys: Chromium-nickel alloys containing up to 20 per cent chromium have been deposited from the fluoborate bath at an efficiency of 60-70 per cent[88]. The sulphate bath with chromium as a glycine complex has been operated at 17-20 per cent efficiency[19]. The plates are bright, up to 10 μ thickness with a microhardness of 350-450 kg/mm². Alloys with iron have been obtained from sulphate solutions[90, 91] which have an improved throwing power and give deposits which retain their hardness at elevated temperatures. This bath has been modified with additions of sulphamate[92], urea[93] and glycine[94]. Bright deposits have been obtained from the sulphate-urea bath. The solutions containing glycine gave deposits with 10-90 per cent chromium at 20-40 per cent efficiency. They were resistant to oxidation at higher temperatures and had a hardness of 100 kg/in². It has been stated that these alloy coatings can replace those of chromium. Coatings from the fluoborate bath[95] contained 35 per cent chromium with a maximum thickness of 10 μ. They were bright and brittle, but superior to iron coatings for wear and corrosion resistance. Black chromium-vanadium deposits have been obtained from sulphate-vanadate solutions and are stated to be suitable for heat and ultraviolet resistance as in fluorescent lamps[96]. There is a mention of the codeposition of chromium with thorium from the oxalate

bath[97]. It appears that more developmental work is necessary in the field of chromium alloy deposition.

Indium Alloys: Fluoborate[98], tartrate[99] and cyanide[100] baths have been employed for the plating of indium-lead alloys. The tartrate bath gives plates containing 5-50 per cent indium. Smooth alloy coatings containing 5-26 per cent indium have been electrodeposited on automotive engine and other bearings from solutions containing indium chloride, lead nitrate and potassium cyanide with additions of dextrose and gelatin. Antimony has been codeposited with indium from chloride[101] and sulphate[102] solutions, and cadmium from fused salt[33] and sulphamate[103] electrolytes. The microhardness of the alloys from sulphamate solutions increased from 126 to 164 kg/mm^2 as the cadmium content increased from 35 to 70 per cent. Alloys containing 20-60 per cent indium retained the luster after 30 hours at 120-130°C in an oxidizing lubricating oil. Indium-gallium deposits have been obtained from fused chloride baths[104] for the preparation of leads for microalloy transistors. Sulphamate[103] and sulphate-tartrate baths[105] have been tried, for codeposition with zinc. The microhardness of the alloys from sulphamate bath increased from 44 to 194 kg/mm^2 as the zinc content increased from 20 to 75 per cent. The latter bath gives adherent plates with high corrosion resistance. Alloys of indium with rhodium have been electrodeposited from sulphate and perchlorate baths[106]. Alloys containing up to 1 per cent indium are softer than rhodium alone but not brittle, thereby facilitating use on contacts.

Iron Alloys: Detailed studies have been made on the deposition of iron-zinc alloys from pyrophosphate[107] and sulphamate[108] solutions. It was possible to obtain alloys over a wide composition range in both cases, and there were sudden changes in plate composition at low current densities due to the deposition of alloys of different phases. During deposition from the pyrophosphate bath these changes were also associated with sudden changes in cathode potential. In the high current density range, the deposit composition was practically constant. Chloride solutions have been used for the codeposition of iron with manganese[109]. Iron—vanadium alloys have been obtained from the sulphate-vanadate bath[110] at 5-8 amp/dm^2, and from chloride—vanadate bath[111] at 5—12.5 amp/dm^2 to give alloys containing 5-12 per cent vanadium. Cadmium has been codeposited with iron from the sulphamate bath[112] at current densities as high as 25 amp/dm^2. The plates contained up to 93 per cent iron, and were mechanical mixtures of the two metals as shown by x-ray studies. Chloride solutions[113] have been reported to give aluminium-iron alloys containing 12 per cent aluminium.

Alloys with cobalt have been obtained from sulphate[114], sulphamate[115] and pyrophosphate[116] solutions. Deposits containing up to about 90 per cent iron could be obtained from sulphamate and pyrophosphate baths as shown by work done in this laboratory. In the high current density range the composition was practically constant. X-ray patterns showed the existence of the b.c.c. structure for deposits from the sulphamate, and b.c.c., b.c.c. plus h.c.p., and h.c.p. structures for deposits from the pyrophosphate bath. Rotinyan and coworkers[117] found that alloys obtained from sulphate bath containing 72 per cent cobalt had the f.c.c. structure, and a mixture of f.c.c. and b.c.c. structures in the range 70-72 per cent cobalt. The electrodeposition of iron alloys has been recently reviewed in this laboratory[118].

Cadmium Alloys: Cadminm has been codeposited with other metals: copper from sulphate[119, 120]; lead from fused salt[33]; titanium from cyanide-pertitanate[121, 122]; tellurium from cyanide[123]; zirconium from cyanide-perzirconate[121]; and zinc from sulphamate[125] baths. The cadmium-titanium solution possessed high throwing power and could deposit plates containing 0.3 per cent titanium up to a thickness of 20μ and corrosion resistancemuch superior to cadmium alone[121]. Alloys containing up to 80 per cent zinc could be deposited from sulphamate solutions, and they were mechanical mixtures of two h.c.p. structures.

Miscellaneous Alloys: Cobalt-titanium alloys containing 5-30 per cent titanium have been deposited from cobalt sulphate-pertitanate-hydrofluoric acid solutions[123] up to a thickness of 5-10μ and current density of 25.0-37.5 amp/dm^2. Detailed studies have been made in this laboratory on the codeposition of cobalt with tin[127], copper[128] and zinc[129] from the pyrophosphate bath. The tin alloys contained up to 87 per cent cobalt, and had the b.c.t., b.c.t. plus hexagonal, hexagonal and h.c.p. structures. The bath gave alloys containing 6-99 per cent copper at a limiting current density of 6 amp/dm^2 and had the f.c.c. structure. Alloys with zinc could be deposited over a wide range of composition. In the low current density range there were sudden changes in plate composition and cathode potential corresponding more or less to the deposition of alloys of

different phases — h.c.p., b.c.c plus cubic, and b.c.c.

Amongst other alloys, mention may be made of zirconium-zinc[121] alloys plated from the cyanide-perzirconate bath up to a thickness of 13.5 μ. Alloys of zirconium with niobium[130] and titanium[131] have been obtained from fused chloride-fluoride, and cyanide-metal hydroxide-pyrophosphate baths respectively. Antimony-germanium deposits having high corrosion resistance have been obtained from sulphide solutions with good throwing power[71]. The copper sulphate-potassium antimonyl tartrate[132] solution has been studied for the deposition of antimony-copper alloys containing up to 4.5 per cent antimony. Alloys of rhenium with nickel, cobalt and chromium, on copper or copper-nickel alloy, have been deposited from the sulphate-perrhenate baths[133]. Manganese-bismuth plates with magnetic properties have been obtained from chloride solutions[134] containing urea and glycerol, but the composition remained unaffected in the current density range 5-30 amp/dm^2. Alloys of lead-thallium with a low thallium content have been deposited from tartrate-carbonate solutions[135], and polarization studies have also been made.

CONCLUSION

Alloy deposition holds interesting possibilities in the field of metal finishing. Tin alloys appear quite attractive, and one can expect greater usage of nickel for alloy plating since the metal is no longer in shortage today. In addition to the special advantages from the practical viewpoint, there are many points of theoretical interest during the codeposition of tungsten or molybdenum with other metals. Another system which needs thorough investigation from the electrochemical and metallurgical aspects is the deposition of zinc with nickel, cobalt or iron. The codeposition of a precious metal with a cheaper one is another important field. Alloys of iron or cobalt find greater applications in the electronic field in view of their magnetic and other properties. It is needless to stress the necessity of developmental work in the case of many alloy systems where codeposition between two metals has been shown to be feasible. It can be hoped that alloy plating will find greater application during the next decade or two.

REFERENCES

1. D. V. Subrahmanyam, (Miss) M. Sarojamma and T. L. Rama Char, J. Electrochem. Soc., India, **14**, 63 (1965).
2. (Miss) M. Sarojamma and T. L. Rama Char, Electroplating and Metal Finishing, **18**, 51 (1965).
3. R. Taylor and R. R. Phillips, U.S. Patent, 2,926,124 (1960).
4. J. Vanacek, Korose Ochrana Mater., 105 (1962); Chem. Abs., **58**, 13,439 (1963).
5. N. T. Kudryavtsev and K. M. Tyutina, Zashchitno-Dekorativ. i Spetsial. Pokrytiva Metal.. Nauch-Tekh. Obshchestvo. Mashinostroitel. Prom., 5 (1959); Chem. Abs., 55, 17,298 (1961).
6. N. T. Kudryavtsev and K. M. Tyutina, Elekrolit. Osazhdenie Splavov, Mosk. Dom Nauchn.-Tekhn Propagandy, 76 (1961); Chem. Abs., **58**, 13,437 (1963).
7. N. T. Kudryavtsev, K. M. Tyutina and S. M. Firger, Internat. Symp. Anti-Corrosion Protection, Bratislava, **2**, No. 4, 21 pp. (1962).
8. N. T. Kudryavtsev et al , Tr. Mosk. Khim.-Tekhnol. Inst., No. 32,283 (1961); Chem. Abs., **57**, 4,459 (1962).
9. T. L. Rama Char and J. Vaid, Electroplating and Metal Finishing, **14**, 367 (1961).
10. P. Granovesova, Ze Tekh, Progress, Byull. Novosibirsk. Sovet. Narod. Khoz. i Oblast. Sovet. Professional. Soyuza., No. 9, 62 (1958); Chem. Abs., **54**, 18,121 (1960).
11. P. Csokán, Fémipari Kutató Intézet Közleményei, **4**, 309 (1960); Chem. Abs., **55**, 21,910 (1961).
12. Zh. M. Mostovaya, U.S.S.R. Patent 160,066 (1964).
13. S. Fazekas and A. Veres, Kohasz. Lapok. **96**, No. 9,408 (1963); Chem. Abs., **61**, 302 (1964).
14. T. L. Rama Char and J. Vaid, Plating, **48**, 871 (1961).
15. E. I. Ruzalep, Tr. Tallinsk. Politekhn. Inst., Ser. A, No. 204, 31 (1963); Chem. Abs., **61**, 5,194 (1964).
16. C. R. Krishnamurthy, J. Balachandra and A. A. Krishnan, J. Sci. and Ind. Res., **21D**, 414 (1961).
17. C. R. Krishnamurthy, A. V. Ramana Rao and A. A. Krishnan, Indian J. Technol.. **1**, 170 (1963).
18. T. Ishiguro, Kogyo Kagaku Zasshi, **64**, 1,763 (1961); Chem. Abs., **57**, 4,458 (1962).
19. S. Scinteie, Met. Constructia Masini, **12**,

1,132 (1960); Chem. Abs., **56,** 8,454 (1962).

20. N. N. Bibikov and L. K. Gurevich, Zashchitno-Dekorativ. Spetsial. Pokrytiya Metal., Nauch.-Tekh. Obshchestvo Mashinostroitel. Prom., 146 (1959); Chem. Abs., **55,** 18,388 (1961).
21. V. Sourek and V. Holpuch, Czech. Patent, 103,286 (1962).
22. T. L. Rama Char and J. Vaid, Metal Finishing, **59**, No. 12, 44 (1961).
23. E. A. Prandetskaya and L. P. Nosova, Izvest. Vysshik Ucheb. Zavedenii, Tsvetnaya Met., **4,** No. 3, 136 (1961); Chem. Abs., **56,** 2,271 (1962).
24. T. L. Rama Char and J. Vaid, Metalloberfläche, **16,** 70 (1962).
25. G. Häensel, Elektrie, **17,** No. 8, 264 (1963).
26. N. T. Kudryavtsev, K. M. Tyutina and M. M. Yarlykov, Trudy Moskov. Khim. — Tekhnol. Inst. im. D. I. Mendeleeva No. 26, 120 (1959); Chem. Abs., **55,** 18,381 (1961).
27. N. T. Kudryavtsev, Elektrolit. Osazhdenie Splavov, Mosk. Dom Nauchn.-Tekhn. Propagandy, 94 (1961); Chem. Abs., 57, 4,460 (1962).
28. N. T. Kudryavtsev, K. M. Tyutina and M. M. Yarlykov, U. S. S. R. Patent, 161,603 (1964).
29. N. T. Kudryavtsev, K. M. Tyutina and N. K. Baraboshkina, Trudy. Moskov. Khim.—Tekhnol. Inst. im. D. I. Mendeleeva, No. 26, 113 (1959); Chem. Abs., **55,** 23,119 (1961).
30. N. P. Fedot'ev et al., Trudy Leningrad. Tekhnol. Inst. im. Lensoveta, No. **53,** 72 (1959); Chem. Abs., **55,** 24,320 (1961).
31. S. I. Sklyarenko, I. I. Lavrov and S. V. Yakobson, Izv. Vysshikh Uchebn. Zavedenii, Tsvetn. Met., **5,** No. 2, 129 (1962); Chem. Abs., **57,** 10,915 (1962).
32. A. V. Izmailov and N. D. Chernysheva, Izv. Vysshikh. Uchebn. Zavedenii, Khim. i Khim. Tekhnol., **7,** No. 2, 269 (1964); Chem. Abs., **61,** 11,613 (1964).
33. G. L. Schnable and J. G. Javes, Electrochem. Technol., **2,** 201 (1964).
34. S. Venkatachalam and T. L. Rama Char, Current Engineering Practice, **3,** No. 12, 18 (1961).
35. V. M. Zhogina and B. Ya. Kaznachei, Trudy Chetvertogo Soveshchaniya po Elektrokhimii, Moscow, 506 (1956); Chem. Abs., **54,** 8,356 (1960).
36. V. V. Bondarev and V. V. Stender, Zhur. Priklad. Khim., **37,** No. 4, 784 (1964); Chem. Abs. **61,** 3,920 (1964).
37. (Miss) Vasanta Sree and T. L. Rama Char, J. Electrochem. Soc., **108,** 64 (1961).
38. S. Venkatachalam and T. L. Rama Char, Electroplating and Metal Finishing, **15,** 233, 270 (1962).
39. N. T. Kudryavtsev, K. M. Tyutina and S. M. Firger, Zhur. Priklad. Khim., **35,** 1,035 (1962); Chem. Abs., **57,** 9,573 (1962).
40. N. T. Kudryavtsev, K. M. Tyutina and S. M. Firger, Trudy Moskov. Khim.-Tekhnol. Inst. im. D. I. Mendeleeva, No. 26, 96 (1959); Chem. Abs., **55,** 24,321 (1961).
41. M. B. Hammond and G. B. Bowman, U.S. Patent, 2,989,446 (applied in 1956).
42. M. B. Hammond and G. B. Bowman, U.S. Patent, 3,064,337 (1962).
43. Zh. V. Batyuk and N. A. Marchenko, Tr. Kharkovsk. Politekhn. Inst., **45,** 48 (1963); Chem. Abs., **61,** 10,312 (1964).
44. N. A. Marchenko and Zh. V. Batyuk, Zhur. Priklad. Khim., **37,** No. 3, 595 (1964); Chem. Abs., **61,** 2,716 (1964).
45. S. Venkatachalam, Bull. India Section, Electrochem. Soc., **10,** 93 (1961).
46. T. L. Rama Char and S. K. Panikkar, Electroplating and Metal Finishing, **13,** 405 (1960).
47. M. P. Melkov, U.S.S.R. Patent, 128,249 (1960).
48. M. E. Henstock and E. S. Spencer-Timms, Trans. Inst. Metal Finishing, **40,** 179 (1963).
49. (Miss) Vasanta Sree and T. L. Rama Char, Metal Finishing, **59,** No. 8, 49 (1961).
50. S. S. Misra and T. L. Rama Char, Sixth International Conference on Electrodeposition and Metal Finishing, London (1964); Proceedings under publication.
51. S. K. Panikkar and T. L. Rama Char, J. Sci. and Ind. Res., **19A,** 510 (1960).
52. N. Ya. Fedotova and P. S. Titov, Izvest. Vysshikh Uchebn. Zavedenii, Tsvetnaya Met., **3,** No. 5, 126 (1960); Chem. Abs., **55,** 13,219 (1961).
53. N. V. Korovin, Zhur. Fiz. Khim., **34,**

1,351 (1960); Chem. Abs., **57,** 7,007 (1962).

54. P. L. Hawkes and F. G. Tarbin, Brit. Patent, 957,808 (1964).
55. N. V Korovin and M. N. Ronzhin, Zhur. Priklad. Khim., **33,** 2,734 (1960); Chem. Abs., **55,** 9,109 (1961).
56. T. Morita, Jap. Patent, 20,704 (1963).
57. S. A. Gantman, U.S.S.R. Patent, 160,411 (1964).
58. A. T. Vassko and D. P. Zosimovich, Zhur. Priklad. Khim., **35,** 1,302 (1962); Metal Finishing, **62,** No. 4, 68 (1964).
59. T. L. Rama Char, Electroplating and Metal Finishing, **15,** 40 (1962).
60. N. P. Fedot'ev et al., Zhur. Priklad. Khim.; **32,** 2,235 (1959); Chem. Abs., **54,** 7,371 (1960).
61. N. T. Kudryavtsev and N. M. Alpatova, Tr. Mosk. Khim.-Tekhnol. Inst., No. 32, 293 (1961); Chem. Abs., **57,** 4,459 (1962).
62. D. L. Roy et al., Symp. on Electrodeposition and Metal Finishing, Karaikudi — 1957, Proceedings, 42 (1960).
63. K. I. Vasu and T. L. Rama Char, Plating, **49,** 60 (1962).
64. K. I. Vasu and T. L. Rama Char, Metalloberflache, **16,** 349 (1962).
65. J. I. Green, U.S. Patent, 3, 097,148 (1963).
66. D. V Subrahmanyam and T. L. Rama Char, Bull. India Section, Electrochem. Soc., **12,** 42 (1963).
67. H. Imanaga, Kogyo Kagaku Zasshi, **63.** 1,336 (1960); Chem. Abs., **56,** 13,950 (1962).
68. H. Imanaga, ibid., **67,** 803 (1964); Chem. Abs., **61,** 7,938 (1964).
69. N. W. Hovey, A. Krohn and G. M. Hanneken Jr., J. Electrochem. Soc., **110,** 362 (1963).
70. T. F. Frantsevich-Zabludovskaya and N. A. Fominskaya, Zhur. Priklad. Khim., **36,** 578 (1963); Chem. Abs., **59,** 1,278 (1963).
71. A. I. Lisogor, U.S.S.R. Patent, 161, 604 (1964).
72. T. F. Frantsevich-Zabludovskaya, Ukrain. Khim. Zhur., **25,** 463 (1959); Chem Abs., **54,** 8,360 (1960).
73. A. Krohn and T. M. Brown, J. Electrochem. Soc., **108,** 60 (1961).
74. P. C. Rydel and S. C. Barnes, ibid, **109,** 206C (1962).
75. G. N. Tomashova and A. T. Vagramyan, Zhur. Fiz. Khim., **36,** 1,445 (1962); Chem. Abs., **57,** 13,529 (1962).
76. E.F. Harlow, Brit. Patent, 931,638 (1963).
77. N. A. Smagunova, Elektrolit. Osazhdenie Splavov, Mosk. Dom Nauchn.—Tekhn. Propagandy, 125 (1961); Chem. Abs., **57,** 1,968 (1962).
78. N. P. Fedot'ev, E.G. Kruglova and P.M. Vyacheslavov, Zhur. Priklad. Khim., **32,** 2,014 (1959); Chem. Abs., **54,** 7,373 (1960).
79. M Murat, Fr. Patent, 1,259,407.
80. E. C. Rinker, Ger. Patent, 1,089,612 (1960).
81. E. C. Rinker, Ger. Patent, 1,120,238 (1961).
82. E. Raub and A. Disam, Metalloberfläche, **17,** 17 (1963).
83. E. Raub and A. Disam, ibid, **16,** 317 (1962).
84. R. F. Walton., Tech. Proc. Am. Electroplaters' Soc., **49,** 62 (1962).
85. V. E. Medina, U. S. Patent, 3,053,741 (1962).
86. L. D. Petrov, U.S.S.R. Patent, 152,995 (1963).
87. S. Ya. Grilikhes, N. P. Fedot'ev and L. I. Kulikova, U.S.S.R. Patent, 160,067 (1964).
88. S. G. Stepanov and S. N. Mal'kova, U.S.S.R. Patent, 136,992 (1961).
89. N. T. Kudryavtsev and T.E. Tsupak, Izv Vysshikh. Ucheba. Zavedenii, Khim i Khim. Tekhnol., 7, No. 1, 84 (1964): Chem. Abs., **61,** 6,630 (1964).
90. G. R. Schaer, U.S. Patent, 2,927,066 (1960).
91. V. Skominas and J. Matulis, Lietuvos TSR Mokslu Akad. Darbai, Ser B., No. 1, 73 (1963); Chem. Abs., **61,** 3,920 (1964).
92. W. H. Safranek Jr., J. G. Beach and C. L. Faust, U. S. Patent, 3,111,464 (1963).
93. H. Nitto, U. S. Patent, 2,938,842 (1960).
94. J. Przyluski, Przemysl Chem., **43,** No. 2, 83 (1964); Chem. Abs., **60,** 15,433 (1964)
95. N. T. Kudryavtsev, M. M. Mel'nikova and V. Sh. Palanker, Tr. Mosk. Khim.—Tekhnol. Inst., No. 32, 278 (1961); Chem. Abs., **57,** 7007 (1962).
96. A. A. Latawiec and G. H. Lockwood, U. S. Patent, 3,074,859 (1963).

97. E. Cerrari, R. D. Lonati and F. Gazzarrini, Energia Nucl., 9, 200 (1962).

98. M.A. Shluger and A.I. Lipin, Zashchitno. Dekorativ. i Spetsial. Pokrytiya Metal., Nauch.—Tekh. Obshchestvo Mashinostroitel. Prom., 139 (1959); Chem. Abs., 55, 18,388 (1961).

99. Yu. V. Zaitsev and P. S. Titov, Izv. Vysshikh. Uchebn Zavedenii, Tsvetn. Met., 5, No. 6, 136 (1962); Chem. Abs., 2,391 (1963).

100. W. J. Waterman and N. P. Mallet, Brit. Patent, 959, 553 (1964).

101. G. Busch, R. Kern and E. Steigmeier, Proc. Intern. Comm. Electrochem. Thermodynam. and Kinet., 9th Meeting 1957; Proceedings, 425 (1959).

102. V. V. Ostroumov and A. D. Styrkas, Vestn. Leningr. Univ., 18, No. 10, Ser. Fiz. i Khim., No. 2, 101 (1963); Chem. Abs., 59, 12,403 (1963).

103. S. I. Sklyarenko, I. I. Lavrov and L. A. Mansurova, Zhur. Priklad. Khim., 35, 2017 (1962): Chem. Abs., 58, 2,136 (1963).

104. E. M. Zimmerman, U. S. Patent, 2,931,758 (1960).

105. N. A. Marchenko, L. S. Ionycheva and Zh. V. Batyuk, U.S.S.R. Patent, 160,410 (1964).

106. R. R. Benham, Brit. Patent, 959,052 (1964).

107. (Miss) Vasanta Sree and T. L. Rama Char, Plating, 48, 50 (1961).

108. S. S. Misra and T. L. Rama Char, Metal Finishing, 62, No. 6, 88 (1964).

109. V. P. Revyakin, Izvest. Irkutsk. Sel'skokhoz. Inst., No. 8, 16 (1958); Chem. Abs., 54, 18,125 (1960).

110. L. I. Antropov, A. A. Trchunyan and Ya. I. Satin, U.S.S.R. Patent, 127,402 (1960).

111. A. M. Kunaev, Izvest. Akad. Nauk Kazakh. S.S.R., Ser. Met., Obogashchen. i Ogneuporov., No. 2, 52 (1960); Chem. Abs., 55, 17,295 (1961).

112. S. S. Misra and T. L. Rama Char, Metalloberfläche, 18, 164 (1964).

113. Y. Anayama and K. Uejima, Jap. Patent, 6,870 (1963).

114. A. L. Rotinyan and E. N. Molotkova, Zhur. Fiz. Khim., 34, 2336 (1960); ibid, 35, 158 (1961); Chem. Abs., 55, 10,145, 11,137 (1961).

115. S. S. Misra and T. L. Rama Char, Plating, 51, 423 (1964).

116. D. V. Subrahmanyam and T. L. Rama Char, ibid., 52, No. 10 (1965).

117. A. L. Rotinyan, E. N. Molotkova and O. M. Donilovich, Izvest. Vysshikh. Ucheb. Zavedenii, Tsvetnaya Met., 3, No. 4, 49 (1960); Chem. Abs., 55, 3,239 (1961).

118. S. S. Misra and T. L. Rama Char, Bull. India Section, Electrochem. Soc., 11, 64 (1962).

119. A. Lange and D. Schab, Neue Huette, 7, 291 (1962); Chem. Abs., 57, 13,532 (1962).

120. L. A. Belyakova and N. V. Gudin, Teoriya i Prakt. Blestyashchikh Gal'vanopokrytii, Akad. Nauk Lit. SSR, Inst. Khim. i Khim. Tekhnol., Osnovnye Materialy Vses. Soveshch., Vilnyus, 227 (1963); Chem. Abs., 61, 2,718 (1964).

121. K. Takada and T. K. Kabushikikaisha, Brit. Patent, 918,904 (1963).

122. Y. Takada, Jap. Patent, 20,703 (1963).

123. V. G. Trusova and D. M. Chizhikov, Tr. Inst. Met. im., A. A. Baikova, Akad. Nauk. SSSR, No. 12, 49 (1963); Chem. Abs., 59, 8,356 (1963).

124. K. Takada and S. Tanaka, Jap. Patent, 5,709 (1962).

125. S. Venkatachalam and T. L. Rama Char, Plating, 49, 872 (1962).

126. S.M. Kochergin and G. R. Pobedimskiĭ, Zhur. Priklad. Khim., 33, 238 (1960); Chem. Abs., 54, 9,547 (1960).

127. (Miss) Vasanta Sree and T. L. Rama Char, Metalloberfläche, 15, 301 (1961)

128. D. V. Subrahmanyam and T. L. Rama Char, Metal Finishing, 61, No. 5, 68 (1963); Unpublished work.

129. D. V. Subrahmanyam and T. L. Rama Char, Chemistry and Industry, 697 (1963); Unpublished work.

130. C. Decroly and R. Winand, J. Less—Common Metals, 6, No. 2, 132 (1964).

131. K. Takada, Jap. Patent, 14,051 (1962).

132. L. V. Yurinskaya and S. Ya. Popov, Mashinostr., Nauchn.—Tekhn. Sb. No. 3, 64 (1963); Chem. Abs., 59, 14,889 (1963).

(*Continued on Page* 95)

and Japan 5 per cent of the total. Nuclear power stations are in operation in USSR, U.S.A., U.K., France, West Germany, Belgium, Canada, Italy, Japan and Sweden.—UN Weekly Newsletter, Vol. 13, No. 35, 4, 1965.

Engineering and Mining Guide Book

The June 1965 issue of Engineering and Mining Journal contains the 1965 Guidebook Section: articles on processing, exploration, mining and marketing minerals; USA smelter directory; geological surveys of the world; buying directory under product classification and manufacturers' index.

Technical Books—U.S.A.

The US Information Service arranged the exhibition "Technical Books—U S.A." at New Delhi for 20 days during September 1965. It consisted of about 7.000 books and 325 professional journals in all the principal areas of science and technology.

Stainless Steel Road Tankers

The Search for higher rates of utilization of road tankers with emphasis on operational flexibility has led to a widespread use of nickel stainless steels for an immense range of transport tasks. Not only are they very often the only materials capable of maintaining the rigid standards of cleanliness required but, due to their strength and corrosion resistance, they outlast tanks made of other metals. The publication "Stainless Steel Road Tankers" issued by International Nickel and available from Nickel Information Bureau P. Ltd., Bombay, contains a survey of different types of stainless steel road tankers operating in 8 countries.

Nickel Boride in the Fuel Cell

It has been recently shown that, in a fuel cell, a performance only slightly less satisfactory than that of the noble metals can be obtained with "Teflon"—bonded nickel boride supported on a nickel screen. Data have been obtained for the nickel boride anode in the hydrogen and ethylene fuel cells.— Nature, Vol. 206, 186, 1965.

—T.L.R.

(*Concluded from Page* 105)

133. Z. M. Sominskaya et al., Renii, Tr. Vses. Soveshch. po Probl. Reniya, Akad. Nauk SSSR, Inst. Met., 209 (1958); Chem. Abs., 57, 3,186 (1962).

134. E. M. Natanson, N. N. Kozachek and V. V. Bushin, Doklady Akad. Nauk S.S.S.R., **135**, 137 (1960); Chem. Abs., **56**, 263 (1962).

135. V. T. Pustovit and N. N. Gratsianskii, Met. Gornorud'n. Prom., Nauchn.-Tekhn. Sb., No. 5, 70 (1962); Chem. Abs., 58, 10,973 (1963).

(*Concluded from Page* 110)

how virtually every calculation of chemistry can thus be simplified have been vividly brought home in this small book. Apart from the introduction the practical value of mole concept is discussed in eight other chapters with captions; gases, stoichiometry, formulae, quantitative relationship in chemical reactions, properties of liquid solutions, chemical equivalents, electrochemistry, Avagadro number and calculation of molecular quantities. This book is recommended to all students and teachers of chemistry.

—P. L. N. R.