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Principal Practical Applications of Ferrocene and Its Derivatives

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A little more than 20 years have elapsed since the discovery of ferrocene (dicyclopentadienyliron) and during this period its chemistry has developed quite extensively. The present authors have seen the beginning of practical studies on the applications of ferrocene and its compounds.
The review does not deal with the applications of ferrocene-containing polymers.
The bibliography includes 81 references.

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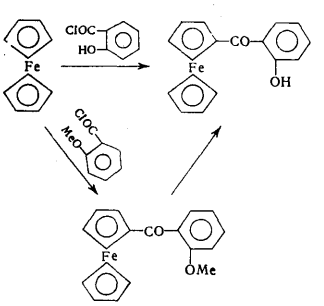
I. INTRODUCTION

The practical applications of ferrocene and its derivatives[1-4] can be grouped in the following main classes: absorbers of different types of radiation, including cosmic rays, regulators of combustion processes, highly effective non-toxic medicinal substances, components of various redox systems, and certain others.

At the present time many different ferrocene derivatives can be obtained in amounts necessary for practical applications. The wide assortment of commercial ferrocene derivatives which are available, for example, in the USA, is indicated by the advertisements of the American firm Research Organic Inorganic Chemical Corporation[5]. Ferrocene homologues, mono- and di-acylferrocenes, ferrocenecarboxylic acids, and many other compounds are quoted as available to a prospective buyer. The possibility of carrying out classical organic reactions with ferrocene[1-4] and the possibility of employing normal chemical apparatus give rise to the hope that the industrial chemistry of ferrocene derivatives will develop in the immediate future on the widest possible scale. A brief survey of the principal practical applications of ferrocene and its derivatives is given below.

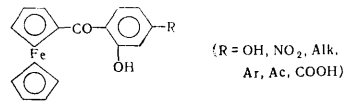
II. RADIATION ABSORBERS: AGENTS ENHANCING THERMAL STABILITY AND LIGHT RESISTANCE

Many aroylferrocene derivatives containing OH groups and other substituents in the *ortho*- or *para*-position of the aromatic ring proved to be effective inhibitors of the light-induced ageing of polymers. The best of these—*o*-hydroxybenzoylferrocene—was obtained by the present authors[6] from salicyl chloride and by Schaaf[7] from methoxysalicyl chloride with subsequent replacement of the methoxy-group by the hydroxy-group:



An interesting report has been published[8] according to which polymers containing *o*-hydroxybenzoylferrocene can be used to coat space ships to protect them from various types of radiation. The Table shows that the best effect is achieved when the inhibitor is introduced into a melamine-alkyd resin. The authors suggest that the action of this inhibitor is associated with its capacity to absorb radiation strongly in the range 200—500 nm; possibly the stabilising role is ensured not only by the ferrocene moiety of the molecule but also by the *o*-ketophenol residue, since agents enhancing light resistance, consisting of derivatives of benzoylbenzene and salicylic acid, are generally known. The replacement of one of the benzene rings of benzoylbenzene by the ferrocene residue enhances the inhibiting capacity of these substances.

Substituted *o*-hydroxybenzoylferrocenes with the substituent in the *para*-position are used to stabilise polyolefins[9].



(R = OH, NO_2, Alk, Ar, Ac, COOH)

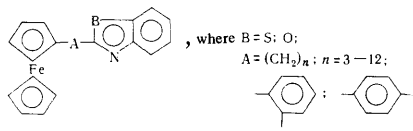
Products obtained by the condensation of ferrocene with ethyl methyl ketone[10] and many others[11] have also been proposed.

Agents enhancing the light resistance of polymers.

Polymeric resin	Inhibitor	Expt. PE*
Melamine-alkyd	1% 2-hydroxybenzoylferrocene	5000
Melamine-formaldehyde	5% 2-methoxybenzoylferrocene	375
Polyvinylbutyral	5% 2-hydroxybenzoylferrocene	320
Melamine-modified polyvinylbutyral	5% 2-hydroxybenzoylferrocene	275
Melamine-alkyd	1% dibenzoylferrocene	260
Silicone-alkyd	1% 2-hydroxybenzoylferrocene	200
Silicone-alkyd	5% 2-hydroxybenzoylferrocene	200
Silicone-alkyd	5% dibenzoylferrocene	200
Melamine-formaldehyde	5% 2-hydroxy-4-methoxybenzoylferrocene	154
Melamine-formaldehyde	5% dibenzoylferrocene	160

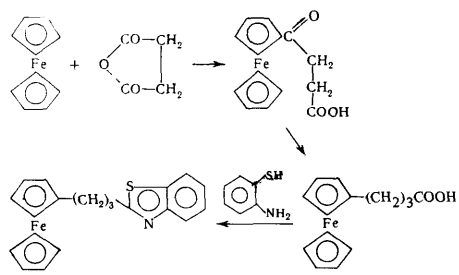
* PE are relative units of the efficiency of the ultraviolet light absorber, expressing its capacity to inhibit the decomposition of polymeric materials.

Heterocyclic ferrocene derivatives can be used as bleaching agents in the textile industry and as scintillators. For example, a number of patents[12] deal with compounds having the general formula



, where B = S; O;
$A = (CH_2)_n$; $n = 3-12$;

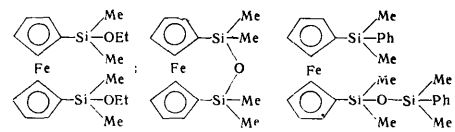
An example of the synthesis of one of them—1-ferrocenyl-3-benzothiazolylpropane—is given below:



The compounds indicated in Rei's Patent[12] include substituted naphthothiazoles, naphthoxazoles, anthrothiazoles, and anthroxazoles.

Stabilisers of another type are ferrocene derivatives of a number of elements. For example, tetraferrocenyl derivatives of Group IV elements are used as stabilisers (antioxidants)[13].

Organosilicon derivatives of ferrocene are used to enhance the thermal stability of organosilicon polymers[14].



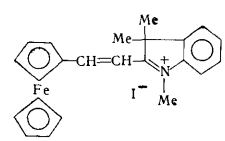
In their presence organosilicon materials withstand longer heating without appreciable signs of decomposition. A number of reports on this field were published recently[15-18].

III. FERROCENE DYES

1. Cyanine and Indolenine Dyes

Substances capable of absorbing light in the far visible region are of greatest interest among cyanine dyes: compounds of this kind are effective sensitisers, increasing the sensitivity of photographic materials with respect to light at longer wavelengths. These dyes contain as a rule fairly long polymethine chains and their stability in air is low; the period during which photographic materials based on them are serviceable does not amount to years, as is usually the case, but to days and even hours. These factors present considerable difficulties both in the synthesis and in the application of photographic materials of this kind. The introduction of a ferrocene chromophore into the molecule of a cyanine dye results in an appreciable bathochromic shift of the absorption bands in their spectra, which leads to new prospects for the development of the chemistry of ferrocene-containing organic sensitisers.

Titov et al. synthesised a green indolenine dye[19]:

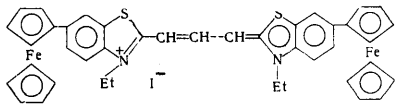


Possibly the α-ferrocenylcarbon atom of the conjugated chain plays the role of the second positively charged atom in the conjugated system, as was shown in studies by Nesmeyanov, Sazonova, and Postnov[20-22].

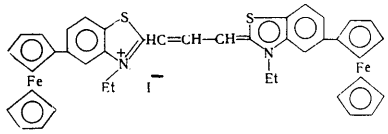
The interest in dyes of this type (sensitisers for light-sensitive layers) is illustrated by French and American patents[23,24].

Cyanine dyes (thiacarbocyanines) containing a ferrocenyl substituent in the benzene ring of benzothiazole and also dyes containing such a substituent in the main chain are known. These are blue-green substances, the spectra of

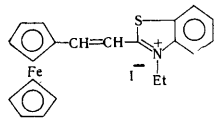
whose solutions contain absorption bands in the visible region (600–610 nm).[25]



λ = 608 nm;



λ = 592 nm;

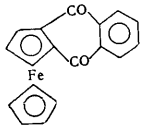


λ = 601 nm.

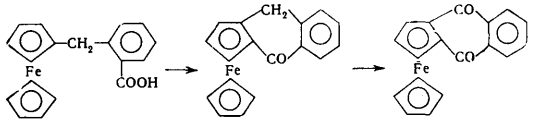
A negative reproduction material based on unsubstituted or substituted ferrocene has also been mentioned[26].

2. Ferrocene anthraquinone

Another type of ferrocene-containing dyes are compounds of the ferrocene anthraquinone series: here the anthraquinone molecule is modified by replacing one benzene ring by one cyclopentadiene ring of the ferrocene system:



Such compounds have been synthesised by Vil'chevskaya and the present authors[27–29] by the cyclisation of *o*-carboxybenzylferrocene with polyphosphoric acid,

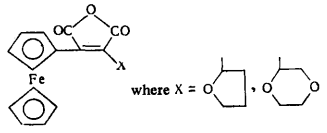


followed by oxidation using activated manganese dioxide. These compounds dye wool, silk, and artificial fabrics, giving various pink and brown shades without the use of a mordant, which is of great interest in the last instance.

3. Other Dyes

A United States patent[30] describes yellow pigments consisting of products of the condensation of ferrocene with phthalic anhydride which are insoluble and infusible up to 360°C.

Unusual compounds, described in a patent[31], were obtained by the condensation of ferrocene with maleic anhydride in tetrahydrofuran, dioxane, and other solvents in the presence of peroxides:



Possibly a polyrecombination reaction, similar to that achieved by Korshak and Sosin[32], takes place in this case.

It is interesting that the above substances have been patented not only as inks soluble in organic solvents but also as anticorrosion agents, pesticides, fungicides, and even as antidetonators.

IV. COMBUSTION REGULATORS (ANTIKNOCK-, ANTIFOULING-, AND ANTISMOKE-AGENTS, AND COMBUSTION CATALYSTS)

There is a fairly extensive, mainly patent literature on these applications of ferrocene and its derivatives. It is noteworthy that antismoke[33], antifouling and antiknock[34], and catalytic properties[34–37] are characteristic of the same compounds.

Various classes of organic derivatives of ferrocene have been mentioned in patents: ferrocene[34,35], ferrocene homologues[39–41], vinylferrocene[42], cyclopentenylferrocene[42], carbinols[35], formylferrocene[35], alkenylferrocenes[36,38], ferrocenecarboxylic acid[35], and certain other compounds[35]. Apart from data on individual compounds, mixtures with two and more components have been described[36]. For example, mixtures of ferrocene or its homologues with cyclopentadienylnitrosylnickel containing 85–50% $C_{10}H_8R_2Fe$ (where R = H, Me, or Et) and 15–50% C_5H_5NiNO and a mixture of ferrocene with cyclopentadienylthallium[38] are used as antidetonators. However, so far ferrocene and its derivatives have not yet been generally recognised as antiknock agents. The reason for this is that they all suffer from a common disadvantage—the *deposition* of iron(III) oxide as the combustion product on the components of the engine and primarily on the sparking plugs of a carburator engine greatly impairs the working parameters and accelerates the wear of such components[41].

Fuel compositions based on nitrocellulose with added ferrocene (1–2%), which exhibit a high plasticity[43], and also compositions containing 30–70% of ferrocene, benzoylferrocene, or dibenzoylferrocene in the presence of nitric acid[44] have been proposed in British patents.

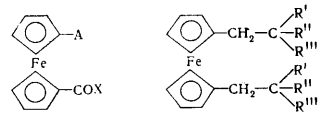
Pyrotechnic compositions based on triferrocenylphosphine and mercury nitrate have been obtained[45].

V. MEDICINAL SUBSTANCES

Iron enters into the composition of haemoglobin—the basis of the vital activity of the organism. For this reason various inorganic iron preparations were used previously to treat diseases associated with iron deficiency in the organism. However, most of these are relatively inefficient and have many side effects (irritation of the gastrointestinal tract and others).

Ferrocene derivatives proved to be much more effective and relatively non-toxic medicinal substances.

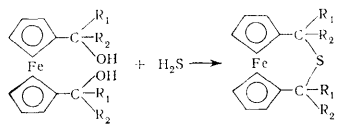
Ferrocene homologues described in patents possess anti-anaemic properties[46–48]. Homologues containing secondary and tertiary alkyl and cyclohexyl groups joined to ferrocene via a methylene unit have been obtained from the corresponding ketones:



(A = H or COX)
(X = s- or t-alkyl or C_6H_{12})

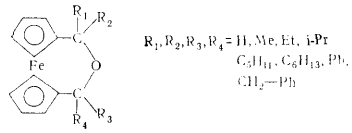
Homologues with the same alkyl substituents linked directly via a secondary or tertiary carbon atom to the cyclopentadiene ring have been obtained by the direct alkylation of ferrocene[49]. These are thick reddish liquids, which are introduced into the organism in the form of capsules, oil emulsions, and other medicinal forms; the application of ferrocene derivatives together with anticoagulants (nitro-compounds, tetrahydrofuran, and others) has also been mentioned in a patent[48].

Ethers and thioethers derived from ferrocene have been proposed in the USA for the same purposes. For example thioepoxyferrocene[50] obtained by the reaction of carbinols with hydrogen sulphide,



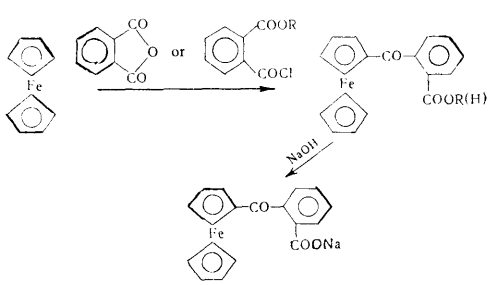
and a number of other compounds[51,52] have been suggested.

Epoxyferrocene[53,54], which combines simultaneously anti-anaemic and anticoagulant activities in the organism, has been recommended:



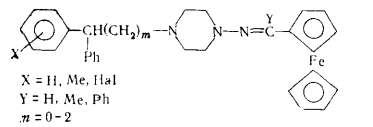
A characteristic feature of the ferrocene derivatives listed above is their insolubility in water. Possibly this is why they require the simultaneous employment of anticoagulants, very toxic compounds such as nitro-derivatives, tetrahydrofuran, and others being recommended.

Until recently medicinal preparations derived from ferrocene were unknown in the world market. The first such preparation is *"ferrocerone"*, which was synthesised in the USSR. It is the sodium salt of *o*-carboxybenzoylferrocene and was developed by Vil'chevskaya and Palitsyn together with ourselves at the Leningrad Institute of Haematology and Blood Transfusion[55-61]. It was synthesised from ferrocene and the half-ester half-chloride of phthalic acid and also from ferrocene and phthalic anhydride[58,59] according to the following scheme:

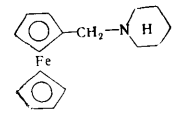


Ferrocerone is soluble in water, is non-toxic, and is readily assimilated by the organism; it exhibits a wide therapeutic spectrum. It can be used to treat various forms of iron deficiency anaemia[55,57], a severe infection of the nasopharynx[56], and others. Ferrocerone is manufactured in the form of tablets and is administered orally, which is very convenient for the patient, particularly when the gastrointestinal tract is affected.

Ferrocene derivatives have not been recommended solely for the treatment of various iron deficiency diseases. It has been suggested that many other diseases be treated with ferrocene derivatives. For example, an antiulcer preparation has been recommended[62]:



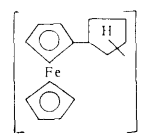
The physiological activity of aminoferrocene derivatives[63] having the composition



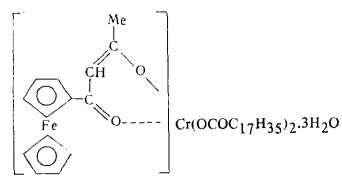
has also been briefly mentioned.

VI. ELECTRON-EXCHANGE RESINS AND OTHER REDOX SYSTEMS

The capacity of ferrocene to undergo reversible oxidation-reduction made possible the practical application of this system in various redox processes. The first example of organoiron electron-exchange resins was polyferrocenylcyclopentene, which we obtained by the decomposition of ferrocene in the presence of aluminium chloride[64,65]:



This oligomer is insoluble in water. In oxidation by potassium dichromate in the presence of sulphuric acid the capacity of this redox resin under static conditions proved to be 2.00—2.38 milliequivalents per gm. of air-dry resin. It was reduced with ascorbic acid. The cycle was repeated three times without appreciable effect on the capacity. At the present time the chemistry of ferrocene-containing polymeric redox resins has developed fairly extensively[66-71]. A ferrocene electrode[72-76] as well as ferrocene-containing antistatic agents are known. A mixed chromium chelate salt derived from ferrocenoylacetone,



has been proposed as an antistatic agent[77,78]. The possible applications of organometallic compounds in electronics are described in a monograph[79].

Thus the known practical applications of ferrocene and its derivatives can be grouped in a number of classes. In one of them the applications are based on the ability of ferrocene and its derivatives to absorb various types of radiation. A ferrocene chromophore imparts a bright

colour ranging from yellow-orange to blue-green and as a rule these products are firmly fixed on various materials, including synthetic fabrics. All this makes it possible to employ ferrocene derivatives as dyes of a new type and also as photographic materials and light sensitisers.

Another important application is based on the ability of ferrocene and its derivatives to regulate various combustion processes. This leads to the possibility of using them as antismoke, antifouling, and antidetonation agents and also as combustion catalysts.

Iron is a component of the organism important for its vital activity. A deficiency of this element leads to severe illnesses. The low toxicity of ferrocene and its derivatives and their ability to treat diseases associated with iron deficiency in the organism as well as many other ailments gives rise to the third important practical application—medicinal preparations based on ferrocene derivatives.

Ferrocene is capable of undergoing reversible oxidation–reduction under mild conditions. As a result of this property, ferrocene derivatives sparingly soluble in water have been proposed as electron-exchange resins (redox resins) and also as other redox systems.

In conclusion of this brief review, we may mention that cyclopentadienyl and other derivatives of almost all transition and non-transition metals are now known. Many of these compounds are quite stable in air and there are easy methods for their synthesis.

Thus there are very many possible practical applications of these compounds in a wide variety of fields[80,81].

REFERENCES

1. A. N. Nesmeyanov, "Khimiya Ferrotsena" (The Chemistry of Ferrocene), Izd. Nauka, Moscow, 1969.
2. M. Rosenblum, "Chemistry of the Iron Group Metallocenes. Ferrocene, Ruthenocene, Osmocene", Wiley, New York–London, 1965.
3. M. I. Bruce, Organometal. Chem. Rev., 5, 379 (1965); 6, 665 (1970); 10, 75 (1972).
4. E. G. Perevalova and T. V. Nikitina, Organometal. React., 4, 165 (1972).
5. See, for example, J. Organometal. Chem., 35, No. 2, 38, No. 2, 40, No. 2 (1972).
6. A. N. Nesmeyanov, N. S. Kochetkova, V. D. Vil'chevskaya, Yu. N. Shneinker, L. V. Senyavina, and M. I. Struchkova, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 1911 (1962).
7. R. L. Schaaf, J. Org. Chem., 27, 107 (1962).
8. R. L. Schaaf, Chem. Eng. News, 39, 21 (1961).
9. G. Newland and G. Lappin, Def. Publ. U. S. Pat. Office 666 502, Offic. Gaz., (3) 695 (1968); Chem. Abs., 71, 31 044 (1969).
10. T. P. Vishnyakova, Ya. M. Paushkin, T. A. Sokolinskaya, I. P. Losev, and A. I. Sokolov, USSR P. 248 200 (1969); Byul. Izobret., No. 23 (1969).
11. L. Dauksaite, Z. Kaikaciene, N. S. Kochetkova, V. D. Vil'chevskaya, and Yu. A. Ershov, "Materialy 13-i Respublikanskoi Nauchno-Tekhnicheskoi Konferentsii, Vil'nyus, 1973" (Proceedings of the 13th All-Republic Scientific and Technical Conference, Vilna, 1973), No. 13, p. 79.
12. C. Rei, US P. 3 461 287 (1969); Chem. Abs., 71, 81 541 (1969).
13. H. Rosenberg, US P. 3 410 885 (1968); Chem. Abs., 70, 29 052g (1969).
14. T. S. Tubyanskaya, R. I. Kobzova, E. M. Oparina, V. A. Zaitsev, A. A. Egorov, and B. K. Kabanov, Plast. Massy, 69, No. 10, 21 (1969).
15. A. I. Sidnev, B. K. Kabanov, V. A. Zaitsev, N. A. Kondratova, T. A. Agapova, and L. M. Konstantinenko, Vysokomol. Soed., A13, 2526 (1971).
16. M. V. Sobolevskii, A. I. Skorokhodov, V. E. Ditsent, and L. V. Sobolevskaya, "Sintez i Issledovanie Effektivnosti Khimikatov dlya Polimernykh Materialov" (The Synthesis and Investigation of the Efficiency of Chemical Agents for Polymeric Materials), NIIKhimpolimer, Tambov, 1970, Vol. 4, p. 195.
17. C. Jouiu, M. Bert, and A. Gugot, J. Chim. Phys. Physicochim. Biol., 69, 810 (1972).
18. H. R. Lucas, US P. 3 655 606 (1972); Chem. Abs., 77, 35 585 (1972).
19. A. I. Titov, E. S. Lisitsyna, and M. R. Shemtova, Dokl. Akad. Nauk SSSR, 130, 341 (1960).
20. A. N. Nesmeyanov, V. N. Postnov, V. A. Sazonova, and V. A. Dobryak, Izv. Akad. Nauk SSSR, Ser. Khim., 2371 (1968).
21. A. N. Nesmeyanov, V. A. Sazonova, V. N. Postnov, I. F. Leshcheva, and O. P. Yurchenko, Dokl. Akad. Nauk SSSR, 186, 555 (1968).
22. A. N. Nesmeyanov, V. N. Postnov, I. F. Leshcheva, B. A. Surkov, and V. A. Sazonova, Dokl. Akad. Nauk SSSR, 200, 858 (1971).
23. French P. 19 584 042 (1970); Chem. Abs., 73, 82 523 (1970).
24. US P. 3 577 238 (1970); Chem. Abs., 75, 50 436 (1971).
25. I. K. Ushenko, K. D. Zhikhareva, and F. Z. Rodova, Zhur. Obshch. Khim., 33, 798 (1969).
26. G. O. Schenck, E. A. Hackmann, A. Arnst, and J. Munder, US P 3 490 970 (1970); Chem. Abs., 72, 105 872 (1970):
27. A. N. Nesmeyanov, V. D. Vil'chevskaya, N. S. Kochetkova, and Yu. Yu. Gorelikova, USSR P. 176 923 (1965); Byul. Izobret., No. 24 (1965).
28. A. N. Nesmeyanov, V. D. Vil'chevskaya, N. S. Kochetkova, and Yu. Yu. Gorelikova, USSR P. 183 768 (1965); Byul. Izobret., No. 14 (1966); USSR P. 184 879 (1966); Byul. Izobret., No. 16 (1966).
29. A. N. Nesmeyanov, V. D. Vil'chevskaya, and N. S. Kochetkova, Izv. Akad. Nauk SSSR, Ser. Khim., 938 (1966).
30. W. B. Hardy and E. Klingsberg, US P. 2 900 401 (1959); Chem. Abs., 54, 569c (1960).
31. R. E. Bazak, US P. 3 322 793 (1967); Chem. Abs., 67, 64 546g (1967).
32. V. V. Korshak, S. L. Sosin, and V. P. Alekseeva, Dokl. Akad. Nauk SSSR, 132, 360 (1960).
33. A. N. Sidorov, I. P. Kravchenko, B. M. Antonov, and V. M. Sukharetskii, USSR P. 210 720; Byul. Izobret., No. 6, 171 (1968).
34. W. Uhlmann and R. Gelius, Wiss. Z. Tech. Univ. Dresden, 17, 15 (1968); Chem. Abs., 70, 116 837 (1969).
35. D. C. Sayls, US P. 3 447 981 (1969); Chem. Abs., 71, 40 924 (1969).
36. US P. 3 353 938 (1967); Chem. Abs., 68, 61 470d (1968).
37. V. Z. Makhov, Izv. Vys. Ucheb. Zaved., Mashinostroenie, 8, 82 (1969).
38. US P. 3 336 751 (1967); Chem. Abs., 67, 101 571 (1967).
39. B. P. 2 763 550 (1956); Chem. Abs., 51, 3334 (1957).
40. BRD P. 961 916 (1957); Chem. Abs., 54, 15 921 (1960).
41. V. Vesely, S. Toma, J. Gursky, and L. Patzele, Ropa a uhlie, 15, No. 4, 194 (1973).

42. US P. 2 694 721 (1954); Chem. Abs., 49, 15 955B (1955).
43. E. M. Prince, B. P. 1 279 961 (1972); Chem. Abs., 77, 141 976 (1972).
44. B. P. 1 282 271 (1972); Chem. Abs., 78, 6089 (1973).
45. G. P. Sollott and W. R. Peterson, US P. 3 673 015 (1972); Chem. Abs., 77, 128 636 (1972).
46. T. Leigh, B. P. 819 108 (1959); Chem. Abs., 54, 7732 (1960).
47. T. Leigh, B. P. 828 965 (1960); Chem. Abs., 54, 15 402 (1960).
48. T. Leigh, B. P. 858 078 (1961); Chem. Abs., 55, 17 537 (1961).
49. T. Leigh, J. Chem. Soc., 3294 (1964).
50. J. T. Suh, US P. 3 382 267 (1968); Chem. Abs., 69, 59 378 (1968).
51. J. T. Suh, US P. 3 557 143 (1971); Chem. Abs., 75, 6111 (1971).
52. J. T. Suh, US P. 3 553 241 (1971); Chem. Abs., 75, 493 440 (1971).
53. J. E. Robertson, US P. 3 377 248 (1968); Chem. Abs., 69, 96 878c (1968).
54. J. E. Robertson, US P. 3 370 248 (1968); Chem. Abs., 69 (1968).
55. A. N. Nesmeyanov and I. G. Andrianova, "Materialy Itogovoi Nauchnoi Sessii Leningradskogo Instituta Gematologii i Perelivaniya Krovi" (Proceedings of the Concluding Scientific Session at the Leningrad Institute of Haematology and Blood Transfusion), Leningrad, 1969, p. 93.
56. T. M. Ostroukhova and E. O. Dembo, "Materialy Itogovoi Nauchnoi Sessii Leningradskogo Instituta Gematologii i Perelivaniya Krovi" (Proceedings of the Concluding Scientific Session at the Leningrad Institute of Haematology and Blood Transfusion), Leningrad, 1969, p. 95.
57. A. N. Filatov, I. G. Andrianova, V. D. Vil'chevskaya, and N. S. Kochetkova, Khim.-Farm. Zhur., 6, 61 (1972).
58. A. N. Nesmeyanov, V. D. Vil'chevskaya, N. S. Kochetkova, N. P. Palitsyn, Yu. Yu. Gorelikova, and V. Kh. Syundikova, USSR P. 400 597 (1971); Otkryt. Izobret. Pr. Obraztsy Tov. Znaki, 40, 70 (1973).
59. A. N. Nesmeyanov, L. G. Bogomolova, N. S. Kochetkova, V. D. Vil'chevskaya, N. P. Palitsyn, Yu. Yu. Gorelikova, I. G. Andrianova, O. P. Belozerova, and V. Kh. Syundyukova, B. P. 1 320 046 (1973); Chem. Abs., 79, 78 966 (1973).
60. N. P. Palitsyn, A. N. Nesmeyanov, V. D. Vil'chevskaya, and N. S. Kochetkova, USSR P. 179 309 (1966); Byul. Izobret., No. 5 (1966).
61. BRD P. 1 287 740 (1969); Chem. Abs., 70, 80 851m (1969).
62. US P. 3 265 687 (1966); Chem. Abs., 65, 13 764 (1966).
63. R. D. Srivastava, Labdev Pharm A.C.C., 74, 128 564 (1971).
64. A. N. Nesmeyanov and N. S. Kochetkova, Dokl. Akad. Nauk SSSR, 109, 543 (1956).
65. A. N. Nesmeyanov, N. S. Kochetkova, P. V. Petrovskii, and E. I. Fedin, Dokl. Akad. Nauk SSSR, 152, 375 (1968).
66. J. Lubach and W. Drewth, Rec. Trav. chim., 92, 403 (1973).
67. H. G. Cassidy and K. A. Kun, "Polymer Reviews", Vol. 2, "Oxidation-Reduction Polymers (Redox Polymers)" (Translated into Russian), Izd. Khimiya, Moscow, 1967.
68. E. E. Ergozhin and F. G. Shostak, "Okislitel'no Vosstanovitel'nye Polimery" (Oxidation-Reduction Polymers), Uspekhi Khim., 34, 2220 (1965) [Russ. Chem. Rev., No. 12 (1965)].
69. S. I. Zhdanov and A. Esimzhanova, Symposium, "Adsorbtsiya i Dvoinoi Elektricheskii Sloi" (Adsorption and the Electrical Double Layer), (Edited by A. N. Frumkin), Izd. Nauka, Moscow, 1972, pp. 127, 197.
70. G. A. Laitinskii, "Khimicheskii Analiz" (Chemical Analysis), "Okislitel'no-Vosstanovitel'nye Smoly" (Oxidation-Reduction Resins) Chapter, Izd. Khimiya, Leningrad, 1966, p. 390.
71. B. P. Nikol'skii, T. P. Vishnyakova, S. P. Gubin, Ya. M. Paushkin, A. A. Pendin, T. A. Sokolinskaya, and I. A. Golubeva, Dokl. Akad. Nauk SSSR, 181, 1149 (1968).
72. A. A. Abakumov, T. P. Vishnyakova, I. A. Golubeva, T. A. Kolenikova, B. P. Nikol'skii, Ya. M. Paushkin, E. V. Pal'chevskii, A. A. Pendin, and T. A. Sokolinskaya, Vysokomol. Soed., 13A, 2049 (1971).
73. N. K. Leont'evskaya, T. A. Sokolinskaya, T. P. Vishnyakova, Ya. M. Paushkin, A. A. Pendin, and T. P. Nikol'skii, Dokl. Akad. Nauk SSSR, 188, 1324 (1969).
74. A. A. Pendin, P. K. Leont'evskaya, and A. D. Korsun, Elektrokhimiya, 5, 889 (1969).
75. S. I. Zhdanov and A. Esimzhanova, Coll. Czech. Chem. Comm., 36, 3990 (1971).
76. E. M. Semenova, S. M. Maslenitskii, and A. A. Pendin, Elektrokhimiya, 7, 1446 (1971).
77. Ya. M. Paushkin, T. P. Vishnyakova, I. D. Vlasova, and F. F. Machus, Zhur. Obshch. Khim., 39, 2379 (1969).
78. Ya. M. Paushkin, T. P. Vishnyakova, I. F. Krylova, I. D. Vlasova, and F. F. Machus, USSR P. 203 126 (1967); Byul. Izobret., No. 20 (1967).
79. V. A. Razuvaev, B. G. Gribov, G. A. Domrachev, and V. A. Solomatin, "Metallorganicheskie Soedineniya v Elektronike" (Organometallic Compounds in Electronics), Izd. Nauka, Moscow, 1972.
80. A. N. Nesmeyanov (Editor), "Margantsevye Antidetonatory" (Manganese Antidetonators), Izd. Nauka, Moscow, 1971.
81. J. H. Harwood, "Industrial Applications of Metal Chelate Compounds" [Chem. Process Eng., 50 (6), 75 (1969)] (Translated into Russian), Izd. Khimiya, Leningrad, 1970.

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