

*Handbook of Reagents
for Organic Synthesis*

*Oxidizing and
Reducing Agents*

Edited by

Steven D. Burke

University of Wisconsin at Madison

and

Rick L. Danheiser

Massachusetts Institute of Technology, Cambridge, MA

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Preface

As stated in its Preface, the major motivation for our undertaking publication of the *Encyclopedia of Reagents for Organic Synthesis* was "to incorporate into a single work a genuinely authoritative and systematic description of the utility of all reagents used in organic chemistry." By all accounts, this reference compendium has succeeded admirably in attaining this objective. Experts from around the globe contributed many relevant facts that define the various uses characteristic of each reagent. The choice of a masthead format for providing relevant information about each entry, the highlighting of key transformations with illustrative equations, and the incorporation of detailed indexes serve in tandem to facilitate the retrieval of desired information.

Notwithstanding these accomplishments, the editors have since recognized that the large size of this eight-volume work and its cost of purchase have often served to deter the placement of copies of the *Encyclopedia* in or near laboratories where the need for this type of insight is most critically needed. In an effort to meet this demand in a cost-effective manner, the decision was made to cull from the major work that information having the highest probability for repeated consultation and to incorporate same into a set of handbooks. The latter would also be purchasable on a single unit basis.

The ultimate result of these deliberations is the publication of the *Handbook of Reagents for Organic Synthesis* consisting of the following four volumes:

Reagents, Auxiliaries and Catalysts for C-C Bond Formation

Edited by Robert M. Coates and Scott E. Denmark

Oxidizing and Reducing Agents

Edited by Steven D. Burke and Rick L. Danheiser

Acidic and Basic Reagents

Edited by Hans J. Reich and James H. Rigby

Activating Agents and Protecting Groups

Edited by Anthony J. Pearson and William R. Roush

Each of the volumes contains a complete compilation of those entries from the original *Encyclopedia* that bear on the specific topic. Ample listings can be found to functionally related reagents contained in the original work. For the sake of current awareness, references to recent reviews and monographs have been included, as have relevant new procedures from *Organic Syntheses*.

The end product of this effort by eight of the original editors of the *Encyclopedia* is an affordable, enlightening set of books that should find their way into the laboratories of all practicing synthetic chemists. Every attempt has been made to be of the broadest synthetic relevance and our expectation is that our colleagues will share this opinion.

Leo A. Paquette
Columbus, Ohio USA

Introduction

The aim of this volume of the *Handbook of Reagents for Organic Synthesis* ("HROS") is to provide the practicing synthetic chemist with a convenient compendium of information concerning the most important and frequently employed reagents for the oxidation and reduction of organic compounds. Modification of the oxidation state of organic compounds constitutes one of the most common transformations encountered in synthetic schemes, and literally hundreds of reagents are available for this purpose. For this volume, we have selected the 145 most important oxidizing and reducing agents that were previously included in the *Encyclopedia of Reagents for Organic Synthesis* ("EROS"). Reproduced in this Handbook is the full EROS article for each reagent, including the discussion of synthetic transformations effected by that reagent that do not involve oxidation or reduction.

The usefulness of each article in HROS has been enhanced by the incorporation of a new **Related Reagents** section which focuses on alternative reagents that have been employed and found to be effective for similar oxidative and reductive transformations. In these Related Reagents sections, reference is made not to individual reagents, but rather to classes of reagents which are defined in the listings found at the end of this Introduction. Each of these classes represents a general type of oxidation or reduction of importance in organic synthesis. For each class are listed (alphabetically) all of the reagents included in EROS that have utility for that particular transformation. These focused classifications will directly guide the user to alternative reagents in both this Volume and EROS. Those reagents that are included among the 145 reagents in this

Handbook are highlighted by having their names printed in boldface type.

Also included in this Handbook is a Bibliography of Reviews and Monographs covering the period 1993–1997. All important review articles and monographs on the subject of oxidizing and reducing agents are listed here in order of their date of publication. Most of these articles appeared subsequent to the publication of EROS and hence are not referenced in the individual reagent articles found in the Handbook. Following this bibliography is a compilation of *Organic Syntheses* procedures that illustrate, with tested experimental details, oxidations and reductions by reagents included in this volume. The *Organic Syntheses* procedures are presented in alphabetical order, with separate sections for oxidizing and reducing agents. All references to oxidizing and reducing agents in volumes 69 through 75 of *Organic Syntheses* are included in this section.

We hope you will find this to be a useful and convenient Handbook, describing the most widely employed reagents for oxidation and reduction of organic compounds. The selected original EROS articles, augmented by the Related Reagents Classifications, the Recent Review and Monograph bibliographies, and the *Organic Syntheses* illustrations, should provide a unique resource for the practicing organic chemist.

Steven D. Burke
University of Wisconsin-Madison

Rick L. Danheiser
Massachusetts Institute of Technology

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Classification of Oxidizing Agents

- Class O-1: Reagents for the Oxidation of Alcohols to Aldehydes and Ketones.**
- Class O-2: Reagents for the Oxidation of Alcohols and Aldehydes to Carboxylic Acids.**
- Class O-3: Reagents for the Oxidation of Aldehydes to Carboxylic Esters.**
- Class O-4: Reagents for the Oxidation of Organohalogen Compounds to Carbonyl Compounds.**
- Class O-5: Reagents for the Oxidation of Phenols to Quinones.**
- Class O-6: Reagents for the Oxidation of Phenol Ethers to Quinones.**
- Class O-7: Reagents for the Oxidation of Thiols to Disulfides.**
- Class O-8: Reagents for the Oxidation of Sulfides to Sulfoxides and Sulfones.**
- Class O-9: Reagents for the Oxidation of Amines to Nitro Compounds.**
- Class O-10: Reagents for the Oxidation of Amines to Azo Compounds.**
- Class O-11: Reagents for the Oxidation of Amines to Amine Oxides.**
- Class O-12: Reagents for Dehydrogenation to Form Aromatic Compounds.**
- Class O-13: Reagents for Dehydrogenation to Form Unsaturated Carbonyl Compounds.**
- Class O-14: Reagents for Epoxidation.**
- Class O-15: Reagents for Baeyer-Villiger Oxidation of Ketones and Aldehydes.**
- Class O-16: Reagents for the Oxidation of Alkenes to 1,2-Diols.**
- Class O-17: Reagents for the Oxidative Cleavage of Alkenes.**
- Class O-18: Reagents for the Oxidative Cleavage of 1,2-Diols.**
- Class O-19: Reagents for the Oxidation of Alkenes to Ketones.**
- Class O-20: Reagents for the Oxidation of Enol Derivatives to α -Hydroxy Ketones and Derivatives.**
- Class O-21: Reagents for Oxidation at Allylic and Benzylic C-H Bonds.**
- Class O-22: Reagents for the Oxidative Cyclization of Alcohols to Cyclic Ethers.**
- Class O-23: Reagents for the Oxidation of Unactivated C-H Bonds.**

Class O-24: Reagents for the Oxidation of Carbanions and Organometallic Compounds to Alcohols.

Class O-1: Reagents for the Oxidation of Alcohols to Aldehydes and Ketones.

4-Acetamido-2,2,6,6-tetramethyl-1-piperidinyloxy; Ammonium Peroxydisulfate; 1,1'-(Azodicarbonyl)dipiperidine; Barium Manganate; Benzeneseleninic Acid; **1,4-Benzoquinone**; Benzyltriethylammonium Chlorochromate; Benzyltriethylammonium Permanganate; 2,2'-Bipyridinium Chlorochromate; Bismuth(III) Oxide; Bis(pyridine)silver(I) Permanganate; Bis(tetrabutylammonium) Dichromate; **Bis(tri-*n*-butyltin) Oxide**; Bis(trichloromethyl) Carbonate; **Bis(trimethylsilyl) Peroxide**; **Bromine**; Bromine-1,4-Diazabicyclo[2.2.2]octane; Bromine Trifluoride; *N*-Bromoacetamide; *N*-Bromosuccinimide; *N*-Bromosuccinimide-Dimethyl Sulfide; *t*-Butyl Hydroperoxide; *t*-Butyl Hypochlorite; Calcium Hypochlorite; **Cerium(IV) Ammonium Nitrate**; **Cerium(IV) Ammonium Nitrate-Sodium Bromate**; **Cerium(IV)-Nafion 511**; **Cerium(IV) Trifluoromethanesulfonate**; **Cerium(IV) Trihydroxide Hydroperoxide**; **Cerium(IV) Trifluoroacetate**; Chloramine; **Chlorine**; Chlorine-Pyridine; 1-Chlorobenzotriazole; *m*-Chloroperbenzoic Acid-2,2,6,6-Tetramethylpiperidine Hydrochloride; *N*-Chlorosuccinimide-Dimethyl Sulfide; **Chromic Acid**; **Chromium(VI) Oxide**; **Chromium(VI) Oxide-3,5-Dimethylpyrazole**; **Chromium(VI) Oxide-Quinoline**; **Chromium(VI) Oxide-Silica Gel**; **Copper(II) Bromide**; **Copper(I) Chloride-Oxygen**; **Copper(II) Permanganate**; **Copper(II) Sulfate-Pyridine**; Di-*t*-butyl Chromate; Di-*t*-butyl Chromate-Pyridine; **2,3-Dichloro-5,6-dicyano-1,4-benzoquinone**; 4-(Dimethylamino)pyridinium Chlorochromate; Dimethyldioxirane; Dimethyl Sulfide-Chlorine; **Dimethyl Sulfoxide-Acetic Anhydride**; Dimethyl Sulfoxide-Dicyclohexylcarbodiimide; Dimethyl Sulfoxide-Oxalyl Chloride; Dimethyl Sulfoxide-Methanesulfonic Anhydride; **Dimethyl Sulfoxide-Oxalyl Chloride**; Dimethyl Sulfoxide-Phosgene; Dimethyl Sulfoxide-Phosphorus Pentoxide; Dimethyl Sulfoxide-Sulfur Trioxide-Pyridine; Dimethyl Sulfoxide-Trifluoroacetic Anhydride; Dimethyl Sulfoxide-Triphosgene; Dinitratoceric(IV) Chromate Dihydrate; **Dipyridine Chromium(VI) Oxide**; Hydrogen Peroxide-Ammonium Heptamolybdate; Imidazolium Dichromate; Iron(III) Nitrate-K10 Montmorillonite Clay; **Manganese Dioxide**; *N*-Methylmorpholine *N*-Oxide; Methyl-(trifluoromethyl)dioxirane; Nickel(II) Peroxide; μ -Oxobis(chlorotriphenylbismuth); **Oxygen-Platinum Catalyst**; **Ozone**; Phenyliodine(III) Dichloride; Poly(4-vinylpyridinium dichromate); Potassium *t*-Butoxide-Benzophenone; Potassium Dichromate; Potassium Ferrate; **Potassium Permanganate**; Potassium Ruthenate; **Pyridinium Chlorochromate**; Pyridinium Chlorochromate-Alumina; **Pyridinium Dichromate**; Pyridinium Fluorochromate; **Ruthenium(VIII) Oxide**; **Silver(I) Carbonate on Celite**; Sodium Bromate; Sodium Bromite; Sodium Dichromate; **Sodium Hypochlorite**; Sodium Permanganate; Tetra-*n*-butylammonium Chlorochromate; 2,2,6,6-Tetramethylpiperidin-1-oxyl; Tetra-*n*-propylammonium Perruthenate; 1,1,1-Triacetoxo-1,1-dihydro-1,2-benziodoxol-3(1*H*)-one; Triphenylbismuth Dichloride; Tris(trinitratoceric(IV))Paraperiodate.

Class O-2: Reagents for the Oxidation of Alcohols and Aldehydes to Carboxylic Acids.

Benzyltriethylammonium Permanganate; **Chromic Acid**; **Chromium(VI) Oxide**; 2-Hydroperoxyhexafluoro-2-propanol; **Oxygen-Platinum Catalyst**; Peroxyacetyl Nitrate; **Potassium Permanganate**; Potassium Ruthenate; **Pyridinium Dichromate**; Ruthenium(VIII) Oxide; **Silver(I) Oxide**; **Silver(II) Oxide**; Sodium Chlorite; Sodium Hypochlorite; 2,2,6,6-Tetramethylpiperidin-1-oxyl.

Class O-3: Reagents for the Oxidation of Aldehydes to Carboxylic Esters.

3-Benzylthiazolium Bromide; **Bromine**; *t*-Butyl Hydroperoxide; **Chromic Acid**; **Manganese Dioxide**; Monoperoxydisulfuric Acid; **Ozone**; **Silver(I) Carbonate on Celite**; **Silver(II) Oxide**; Sodium Cyanide.

Class O-4: Reagents for the Oxidation of Organohalogen Compounds to Carbonyl Compounds.

Bis(tetrabutylammonium)Dichromate; Dimethyl Selenoxide; Dimethyl Sulfoxide-Silver Tetrafluoroborate; Hexamethylene-tetramine; *N*-Methylmorpholine *N*-Oxide; Potassium Chromate; Potassium Ruthenate; Pyridine *N*-Oxide; **Ruthenium(VIII) Oxide**; Sodium 4,6-Diphenyl-1-oxido-2-pyridone; Trimethylamine *N*-Oxide.

Class O-5: Reagents for the Oxidation of Phenols to Quinones.

Ammonium Peroxydisulfate; Benzeneseleninic Acid; Benzenetellurinic Anhydride; Bis(*N*-propylsalicylideneaminato)copper(II); Bis(*N*-propylsalicylideneaminato)cobalt(II); Bromine Trifluoride; *N*-Bromosuccinimide-Dimethylformamide; Cerium(IV) Ammonium Sulfate; Cerium(IV) Trihydroxide Hydroperoxide; *N*-Chlorosuccinimide-Dimethyl Sulfide; Chromyl Chloride; **Copper(II) Chloride**; Copper(I) Chloride-Oxygen; (Diacetoxiodo)benzene; Dimethylsuccinimidodisulfonium Tetrafluoroborate; Dinitratocesium(IV) Chromate Dihydrate; Diphenylselenium Bis(trifluoroacetate); Iodosylbenzene-Dichlorotris(triphenylphosphine)ruthenium; Lead(IV) Oxide; **Mercury(II) Oxide**; Methyl(trifluoromethyl)dioxirane; **Phenyliodine(III) Bis(trifluoroacetate)**; **Potassium Nitrosodisulfonate**; **Potassium Superoxide**; Salcomine; **Silver(I) Oxide**; **Silver(II) Oxide**; Sodium Bromate; **Sodium Hypochlorite**; **Sodium Periodate**; Thallium(III) Perchlorate Hexahydrate; **Thallium(III) Trifluoroacetate**.

Class O-6: Reagents for the Oxidation of Phenol Ethers to Quinones.

Cerium(IV) Ammonium Nitrate; Nitric Acid; **Silver(II) Oxide**; **Thallium(III) Trifluoroacetate**.

Class O-7: Reagents for the Oxidation of Thiols to Disulfides.

Ammonium Peroxy disulfate; Barium Manganate; Benzenetellurinic Anhydride; Benzoyl Nitrate; Bis(2,2'-bipyridyl)cop-

per(II) Permanganate; Copper(II) Nitrate-K10 Bentonite Clay; Dimethyl Dithiobis(thioformate); Dinitratocesium(IV) Chromate Dihydrate; Iron(III) Nitrate-K10 Montmorillonite Clay; **Oxygen**; **Potassium Superoxide**; **Pyridinium Chlorochromate**; 2,4,4,6-Tetrabromo-2,5-cyclohexadienone; Tetra-*n*-butylammonium Chlorochromate; Thallium(III) Acetate.

Class O-8: Reagents for the Oxidation of Sulfides to Sulfoxides and Sulfones.

Acetyl Nitrate; Ammonium Peroxydisulfate; Benzyltriethylammonium Permanganate; 2,2-Bipyridinium Chlorochromate; **Bis(tri-*n*-butyltin) Oxide**; Bis(trimethylsilyl) Monoperoxydisulfate; **Bis(trimethylsilyl) Peroxide**; Bromine-1,4-Diazabicyclo[2.2.2]octane; *t*-Butyl Hydroperoxide; *t*-Butyl Hypochlorite; (Camphorylsulfonyl)oxaziridine; **Cerium(IV) Ammonium Nitrate**; 1-Chlorobenzotriazole; *m*-Chloroperbenzoic Acid; Cumyl Hydroperoxide; Dimethyldioxirane; **Hydrogen Peroxide**; Hydrogen Peroxide-Tellurium Dioxide; Hydrogen Peroxide-Tungstic Acid; 2-Hydroperoxyhexafluoro-2-propanol; Iodosylbenzene-Dichlorotris(triphenylphosphine)ruthenium; **Monoperoxyphthalic Acid**; Nitronium Tetrafluoroborate; **Ozone**; **Perbenzoic Acid**; Phenyliodine(III) Dichloride; *N*-(Phenylsulfonyl)(3,3-dichlorocamphoryl)oxaziridine; ($\pm$)-*trans*-2-(Phenylsulfonyl)-3-phenyloxaziridine; **Potassium Permanganate**; **Potassium Monoperoxydisulfate**; **Potassium Superoxide**; **Pyridinium Chlorochromate**; **Ruthenium(VIII) Oxide**; Singlet Oxygen; Sodium Bromite; **Sodium Periodate**; Tetra-*n*-butylammonium Periodate; **Tetra-*n*-propylammonium Perruthenate**; **Thallium(III) Nitrate Trihydrate**; **Trifluoroperacetic acid**; Triphenylmethyl Hydroperoxide; **Vanadyl Bis(acetylacetonate)**.

Class O-9: Reagents for the Oxidation of Amines to Nitro Compounds.

Dimethyldioxirane; **Fluorine**; Hypofluorous Acid; Ozone-silica gel; Peroxymaleic Acid; **Potassium Permanganate**; **Potassium Monoperoxydisulfate**; Sodium Perborate; **Trifluoroperacetic Acid**; **Vanadyl Bis(acetylacetonate)**.

Class O-10: Reagents for the Oxidation of Amines to Azo Compounds.

Bis(pyridine)silver(I) Permanganate; (Diacetoxiodo)benzene; **Lead(IV) Acetate**; **Manganese Dioxide**; **Potassium Superoxide**; **Silver(I) Carbonate on Celite**; **Silver(II) Oxide**.

Class O-11: Reagents for the Oxidation of Amines to Amine Oxides.

Bis(trimethylsilyl) Monoperoxydisulfate; *t*-Butyl Hydroperoxide-*m*-Chloroperbenzoic Acid; *m*-Chloroperbenzoic Acid; **Hydrogen Peroxide**; Hydrogen Peroxide-Urea; 2-Hydroperoxyhexafluoro-2-propanol; **Monoperoxyphthalic Acid**; **Peracetic Acid**; ($\pm$)-*trans*-2-(Phenylsulfonyl)-3-phenyloxaziridine; **Potassium Monoperoxydisulfate**; **Trifluoroperacetic Acid**; **Vanadyl Bis(acetylacetonate)**.

Class O-12: Reagents for Dehydrogenation to Form Aromatic Compounds.

Barium Manganate; Cadmium Chloride; Cerium(IV) Ammonium Sulfate; 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone; Manganese Dioxide; Nitrosylsulfuric Acid; Palladium on Carbon; Sulfur; Triphenylcarbenium Tetrafluoroborate.

Class O-13: Reagents for Dehydrogenation to Form Unsaturated Carbonyl Compounds.

Benzeneseleninic Acid; Chloranil; Copper(II) Bromide; 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone; Iodylbenzene; Thallium(III) Acetate.

Class O-14: Reagents for Epoxidation.

Benzeneperoxseleninic Acid; Bis(acetonitrile)chloronitropalladium(II); *N,N*-Bis(salicylidene)ethylenediaminenickel(II); *t*-Butyl Hydroperoxide; *m*-Chloroperbenzoic Acid; *m*-Chloroperbenzoic Acid-2,2,6,6-Tetramethylpiperidine Hydrochloride; Chromyl Acetate; Cumyl Hydroperoxide; 1,1-Di-*t*-butyl Peroxide; Dimethyldioxirane; 2,4-Dinitrobenzeneseleninic Acid; *O*-Ethylperoxycarbonic Acid; Fluorine; Hydrogen Peroxide; Hydrogen Peroxide-Ammonium Heptamolybdate; Hydrogen Peroxide-Tungstic Acid; Hydrogen Peroxide-Urea; Hypofluorous Acid; Iodosylbenzene; *p*-Methoxycarbonylperbenzoic Acid; Methyl(trifluoromethyl)dioxirane; Monoperoxyphosphoric Acid; Monoperoxyphthalic Acid; *o*-Nitrobenzeneseleninic Acid; *p*-Nitroperbenzoic Acid; Peracetic Acid; Perbenzoic Acid; Peroxyacetimidic Acid; Peroxyacetyl Nitrate; Potassium *o*-Nitrobenzeneperoxyulfonate; Potassium Permanganate; Potassium Monoperoxyulfate; Sodium Hypochlorite; Sodium Hypochlorite-*N,N*-Bis(3,5-di-*t*-butylsalicylidene)-1,2-cyclohexane-diaminomanganese(III) Chloride; Sodium Perborate; Trifluoroperacetic Acid; Triphenylmethyl Hydroperoxide; Vanadyl Bis(acetylacetonate).

Class O-15: Reagents for Baeyer-Villiger Oxidation of Ketones and Aldehydes.

Benzeneperoxseleninic Acid; Bis(trimethylsilyl) Monoperoxyulfate; Bis(trimethylsilyl) Peroxide; Cerium(IV) Ammonium Nitrate; Cerium(IV) Ammonium Sulfate; *m*-Chloroperbenzoic Acid; Hydrogen Peroxide; Hydrogen Peroxide-Boron Trifluoride; Hydrogen Peroxide-Urea; 2-Hydroperoxyhexafluoro-2-propanol; Hypofluorous Acid; *p*-Methoxycarbonylperbenzoic Acid; Monoperoxyphosphoric Acid; Monoperoxyphthalic Acid; Monoperoxyphthalic Acid; *p*-Nitroperbenzoic acid; Peracetic Acid; Perbenzoic Acid; Peroxymaleic Acid; Potassium Dichromate; Potassium Monoperoxyulfate; Sodium Perborate; Trifluoroacetic Acid; Trifluoroperacetic Acid.

Class O-16: Reagents for the Oxidation of Alkenes to 1,2-Diols.

t-Butyl Hydroperoxide; Hydrogen Peroxide; Iodine-Copper(II) Acetate; Iodine-Silver Benzoate; *N*-Methylmorpholine

N-Oxide; Osmium Tetroxide; Osmium Tetroxide-*t*-Butyl Hydroperoxide; Osmium Tetroxide-*N*-Methylmorpholine *N*-Oxide; Osmium Tetroxide-Potassium Ferricyanide; Potassium Permanganate; Selenium(IV) Oxide; *o*-Sulfoferbenzoic Acid; Trifluoroperacetic Acid.

Class O-17: Reagents for the Oxidative Cleavage of Alkenes.

Bis(2,2'-bipyridyl)copper(II) Permanganate; Chromium(VI) Oxide; Hydrogen Peroxide-Tungstic Acid; Ozone; Osmium Tetroxide-*N*-Methylmorpholine *N*-Oxide; Singlet Oxygen; Sodium Periodate-Osmium Tetroxide; Sodium Periodate-Potassium Permanganate.

Class O-18: Reagents for the Oxidative Cleavage of 1,2-Diols.

Calcium Hypochlorite; Chromic Acid; Lead(IV) Acetate; Manganese Dioxide; Pyridinium Chlorochromate; Ruthenium(VIII) Oxide; Silver(I) Carbonate on Celite; Sodium Bismuthate; Sodium Periodate; Tetra-*n*-propylammonium Perruthenate; Triphenylbismuth Carbonate.

Class O-19: Reagents for the Oxidation of Alkenes to Ketones.

Bis(acetonitrile)chloronitropalladium(II); Bis(acetonitrile)dinitropalladium(II); Bis(trimethylsilyl) Monoperoxyulfate; Palladium *t*-Butyl Peroxide Trifluoroacetate; Palladium(II) Chloride; Palladium(II) Chloride-Copper(I) Chloride; Palladium(II)-Trifluoroacetate; Rhodium(III) Chloride; Thallium(III) Nitrate Trihydrate.

Class O-20: Reagents for the Oxidation of Enol Derivatives to α -Hydroxy Ketones and Derivatives.

(Camphorylsulfonyl)oxaziridine; *m*-Chloroperbenzoic Acid; Chromyl Chloride; (Diacetoxyiodo)benzene; Dimethyldioxirane; Iodosylbenzene; Iodosylbenzene-Boron Trifluoride; Lead(IV) Acetate; μ -Oxobis(chlorotriphenylbismuth); Oxodiperoxyxymolybdenum(Pyridine)-(hexamethylphosphoric triamide); Oxygen; (Phenyliodine(III) Bis(trifluoroacetate).

Class O-21: Reagents for Oxidation at Allylic and Benzylic C-H Bonds.

2,2-Bipyridinium Chlorochromate; *t*-Butyl Hydroperoxide; Cerium(III) Methanesulfonate; Cerium(IV) Pyridinium Chloride; Chromium(VI) Oxide; Chromium(VI) Oxide-3,5-Dimethylpyrazole; Copper(II) Acetate; Copper(I) Chloride-Oxygen; Di-*t*-Butyl Chromate; 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone; Dipyrindine Chromium(VI) Oxide; Iodylbenzene; Iron(II) Phthalocyanine; Lead(IV) Acetate; Mercury(II) Acetate; Nitric Acid; Potassium *o*-Nitrobenzeneperoxyulfonate; Potassium Permanganate; Potassium Superoxide; Pyridinium Chlorochromate; Pyridinium Dichromate; Selenium(IV) Oxide; Selenium(IV) Oxide-Butyl Hydroperoxide; Singlet Oxygen; Sodium Dichromate.

Class O-22: Reagents for the Oxidative Cyclization of Alcohols to Cyclic Ethers.

Bromine; Bromine-Silver(I) Oxide; Cerium(IV) Ammonium Nitrate; Di-*t*-butyl Chromate; Lead(IV) Acetate; Lead(IV) Acetate-Iodine; Mercury(II) Oxide; Mercury(II) Oxide-Iodine.

Class O-23: Reagents for the Oxidation of Unactivated C-H Bonds.

Ammonium Peroxydisulfate; Benzyltriethylammonium Permanganate; Chromium(VI) Oxide; Chromyl Acetate; Dichlorotris(triphenylphosphine)-ruthenium(II); Dimethyldioxirane; Disodium Tetrachloroplatinate(II); Fluorodimethoxyborane Diethyl Etherate; Hypofluorous Acid; Iodine Tris(trifluoroacetate); Iron(II) Chloride; Iron(II) Sulfate-Oxygen; Lead(IV) Trifluoroacetate; Methyl(trifluoromethyl)dioxirane; *p*-Nitroperbenzoic acid; Ozone-Silica Gel; Potassium Monoperoxyulfate; Ruthenium(VIII) Oxide.

Class O-24: Reagents for the Oxidation of Carbanions and Organometallic Compounds to Alcohols.

Bis(trimethylsilyl) Peroxide; *t*-Butyl Hydroperoxide; (Camphorylsulfonyl)oxaziridine; Cerium(IV) Ammonium Nitrate; Copper(II) Acetate; Oxygen; ($\pm$)-*trans*-2-(Phenylsulfonyl)-3-phenyloxaziridine.

Classification of Reducing Agents**Class R-1: Reagents for Reduction of Acetals.****Class R-2: Reagents for Reduction of Aldehydes or Ketones to Alcohols.****Class R-3: Reagents for Reduction of Alkenes.****Class R-4: Reagents for Reduction of Alkynes.****Class R-5: Reagents for Reduction of Amides, Imines, or Iminium Ions to Amines.****Class R-6: Reagents for Reduction of Anhydrides or Imides.****Class R-7: Reagents for Reduction of Aromatic Carbocycles.****Class R-8: Reagents for Reduction of Aromatic Heterocycles.****Class R-9: Reagents for Reduction of Azides, Azo Compounds, Hydrazones, or Oximes to Amines.****Class R-10: Reagents for Chemoselective Reduction of Carbonyl Compounds.****Class R-11: Reagents for Enantioselective Reduction of Carbonyl Compounds.****Class R-12: Reagents for Stereoselective Reduction of Carbonyl Compounds.****Class R-13: Reagents for Reduction of Carboxylic Acids, Esters or Derivatives to Alcohols.****Class R-14: Reagents for Reduction of Carboxylic Acids, Esters or Derivatives to Aldehydes or Hemiacetals.****Class R-15: Reagents for Conjugate Reduction of α,β -Unsaturated Carbonyl Compounds.****Class R-16: Reagents for Reductive Deoxygenation of Epoxides to Alkenes.****Class R-17: Reagents for Reduction via Hydroboration.****Class R-18: Reagents for Enantioselective Hydrogenation.****Class R-19: Reagents for Catalysis of Hydrogenation or Hydrogenolysis.****Class R-20: Reagents for Reduction of Nitriles to Imines or Amines.****Class R-21: Reagents for Reduction of Nitro Compounds to Amines or Oximes.****Class R-22: Reagents for Reduction of Quinones.****Class R-23: Reagents for Reductive Cleavage of Allylic, Benzylic or α -Carbonyl Functionality.****Class R-24: Reagents for Reductive Cleavage of N-O, N-N, O-O, O-S or S-S Bonds.****Class R-25: Reagents for Reductive Coupling or Cyclization.****Class R-26: Reagents for Reductive Decarbonylation, Decarboxylation or Decyanation.****Class R-27: Reagents for Reductive Dehalogenation.****Class R-28: Reagents for Reductive Deoxygenation of Alcohols or Derivatives.****Class R-29: Reagents for Reductive Deoxygenation of Aldehydes or Ketones.****Class R-30: Reagents for Reductive Desulfurization.****Class R-31: Reagents for Reductive Elimination or Fragmentation.****Class R-32: Reagents for Reductive Cleavage of Epoxides or Ethers to Alcohols.****Class R-33: Reagents for Reductive Metallation.****Class R-34: Reagents for Reduction of Sulfoxides or Sulfones to Sulfides.****Class R-35: Reagents for Reductive Amination of Carbonyls.****Class R-1: Reagents for Reduction of Acetals.**

Aluminum Amalgam; Aluminum Hydride; Aluminum Isopropoxide; Borane-Tetrahydrofuran; Dibromoalane; Dichloroalane; Dichloroborane Diethyl Etherate; Diiodosilane; Diisobutylaluminum Hydride; Lithium Aluminum Hydride; Lithium Aluminum Hydride-Boron Trifluoride Etherate; Lithium Triethylborohydride; Monochloroalane; Monochloroborane-Dimethyl Sulfide; Potassium Naphthalenide; Sodium Cyanoborohydride; Tin(II) Bromide; Triethylsilane; Zinc Borohydride.

Class R-2: Reagents for Reduction of Aldehydes or Ketones to Alcohols.

Aluminum Amalgam; Aluminum Ethoxide; Aluminum Hydride; Ammonium Formate; Ammonium Sulfide; (S)-2-

(Anilinoethyl)pyrrolidine; Bis(bicyclo[2.2.1]hepta-2,5-diene)-rhodium Perchlorate; Bis(η^5 -cyclopentadienyl)dihydrido-zirconium; 2,6-Bis[(*S*)-4'-isopropylloxazolin-2'-yl](pyridine)rhodium Trichloride; 9-Borabicyclo[3.3.1]nonane Dimer; Bis(trifluoroacetoxy)borane; Bis(triphenylphosphine)copper(I) Borohydride; Bis(triphenylphosphine)copper(I) Cyanoborohydride; **Borane-Dimethyl Sulfide**; **Borane-Tetrahydrofuran**; **Catecholborane**; (+)-*B*-Chlorodiisopinocampheylborane; Chloro(thexyl)borane-Dimethyl Sulfide; Copper Chromite; Diborane; Dichloroalane; Dichlorotris(triphenylphosphine)ruthenium(II); Dicyclohexylborane; **Diisobutylaluminum Hydride**; **Diisopinocampheylborane**; 9-*O*-(1,2,5,6-Di-*O*-isopropylidene- α -*D*-glucofuranosyl)-9-boratabicyclo[3.3.1]nonane, Potassium Salt; Dimethyl(phenyl)silane; Diphenylsilane-Cesium Fluoride; Diphenylstannane; **Disiamylborane**; Hexadecacarbonylhexarhodium; Hydrogen Selenide; Iron(III) Chloride-Sodium Hydride; (2,3-*O*-Isopropylidene)-2,3-dihydroxy-1,4-bis(diphenylphosphino)butane; Lithium; Lithium Aluminum Hydride; Lithium Aluminum Hydride-2,2'-Dihydroxy-1,1'-binaphthyl; Lithium 9-boratabicyclo[3.3.1]nonane; Lithium 9-boratabicyclo[3.3.1]nonane; **Lithium Borohydride**; Lithium *t*-Butyl(diisobutyl)aluminum Hydride; Lithium *n*-Butyl(hydrido)cuprate; **Lithium 4,4'-Di-*t*-butylbiphenylide**; Lithium 9,9-Dibutyl-9-borabicyclo[3.3.1]nonane; **Lithium-Ethylamine**; Lithium Pyrrolidine; **Lithium Tri-*t*-butoxyaluminum Hydride**; **Lithium Triethylborohydride**; Lithium Triisiamylborohydride; Monochloroalane; Monoisopinocampheylborane; **Nickel Boride**; **Nickel(II) Chloride**; **Palladium on Carbon**; *B*-3-Pinanyl-9-borabicyclo[3.3.1]nonane; **Platinum on Carbon**; Potassium; Potassium-Graphite Laminate; Potassium Tri-*s*-butylborohydride; Potassium Triisopropoxyborohydride; Raney Nickel; Rhodium on Alumina; Ruthenium Catalysts; Samarium(II) Iodide; Sodium; Sodium-Alcohol; Sodium-Ammonia; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Cyanoborohydride; Sodium Dithionite; Sodium Hydride-Nickel(II) Acetate-Sodium *t*-Pentoxide; Sodium Hydroxymethanesulfinate; Sodium Hypophosphite; Sodium Triacetoxylborohydride; Sodium Trimethoxyborohydride; Tetra-*n*-butylammonium Borohydride; Tetra-*n*-butylammonium Cyanoborohydride; Tetrahydro-1-methyl-3,3-diphenyl-1*H*,3*H*-pyrrolo[1,2-*c*][1,3,2]oxazaborole; Tetramethylammonium Triacetoxylborohydride; **Thexylborane**; Thiourea Dioxide; Trichlorosilane; Triethoxysilane; Triethylsilane; Triisobutylaluminum; Triphenylstannane; **Tris(trimethylsilyl)silane**; Urushibara Nickel; **Zinc**; **Zinc Borohydride**; Zinc-Copper(II) Acetate-Silver Nitrate; Zinc Chloride Etherate in Dichloromethane; Zinc-Dimethylformamide.

Class R-3: Reagents for Reduction of Alkenes.

Aluminum Amalgam; **Baker's Yeast**; (Bicyclo[2.2.1]hepta-2,5-diene)[1,4-bis(diphenylphosphino)butane]rhodium(I) Tetrafluoroborate; Bis(η^5 -cyclopentadienyl)dihydrido-zirconium; 1,2-Bis(2,5-diethylphospholano)benzene; (+)-*trans*-(2*S*,3*S*)-Bis(diphenylphosphino)bicyclo[2.2.1]hept-5-ene; (*R*)- & (*S*)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl; **Borane-Tetrahydrofuran**; Calcium-Ammonia; **Catecholborane**; Chlorotris(triphenylphosphine)cobalt; **Chlorotris(triphenylphosphine)rhodium(I)**; Chromium(II) Sulfate; Cobalt Boride; (*R*)-

(+)-Cyclohexyl(2-anisyl)methylphosphine; (1,5-Cyclooctadiene)(tricyclohexylphosphine)(pyridine)iridium(I) Hexafluorophosphate; Diborane; **Diimide**; **Diisopinocampheylborane**; **Disiamylborane**; (*R,R*)-[Ethylene-1,2-bis(η^5 -4,5,6,7-tetrahydro-1-indenyl)]titanium (*R*)-1,1'-Bi-2,2'-naphtholate; (-)-[Ethylene-1,2-bis(η^5 -4,5,6,7-tetrahydro-1-indenyl)]zirconium (*R*)-1,1'-Bi-2,2'-naphtholate; ($\pm$)-1,1'-Ethylenebis(4,5,6,7-tetrahydro-1-indenyl)zirconium Dichloride; Hexadecacarbonylhexarhodium; **Hydrazine**; Iron(III) Chloride-Sodium Hydride; (2,3-*O*-Isopropylidene)-2,3-dihydroxy-1,4-bis(diphenylphosphino)butane; **Lithium Aluminum Hydride**; Lithium Aluminum Hydride-Nickel(II) Chloride; Lithium Aluminum Hydride-Titanium(IV) Chloride; Lithium Aluminum Hydride-Cobalt(II) Chloride; **Lithium-Ethylamine**; **Lithium Naphthalenide**; **Lithium Triethylborohydride**; **Nickel Boride**; Nickel-Graphite; Nickel(II) Chloride; **Palladium on Barium Sulfate**; **Palladium on Carbon**; **Palladium-Graphite**; Palladium-Triethylamine-Formic Acid; **Platinum on Carbon**; **Platinum(IV) Oxide**; Rhodium on Alumina; **Ruthenium Catalysts**; Sodium; Sodium-Alcohol; Sodium Hypophosphite; Sodium Hydride-Nickel(II) Acetate-Sodium *t*-Pentoxide; **Sodium Triacetoxylborohydride**; **Titanium**; **Triethylsilane**; 2,4,6-Triisopropylbenzenesulfonylhydrazide; Urushibara Nickel.

Class R-4: Reagents for Reduction of Alkynes.

Aluminum Hydride; Bis(η^5 -cyclopentadienyl)dihydrido-zirconium; Bis(diisopropylamino)aluminum Hydride; **Borane-Dimethyl Sulfide**; Calcium-Ammonia; **Catecholborane**; Chloro(thexyl)borane-Dimethyl Sulfide; **Chlorotris(triphenylphosphine)rhodium(I)**; **Chromium(II) Chloride**; Chromium(II) Sulfate; Cobalt Boride; Diborane; **Dibromoborane-Dimethyl Sulfide**; Dicarbonylbis(cyclopentadienyl)titanium; Dichloroborane Diethyl Etherate; Dicyclohexylborane; **Diimide**; **Diisobutylaluminum Hydride**; **Disiamylborane**; Ethylmagnesium Bromide-Copper(I) Iodide; **Hexa- μ -hydrohexakis(triphenylphosphine)hexacopper**; **Hydrazine**; Iron(III) Chloride-Sodium Hydride; Lithium; **Lithium Aluminum Hydride**; Lithium Aluminum Hydride-Cobalt(II) Chloride; Lithium Aluminum Hydride-Nickel(II) Chloride; Lithium Diisobutyl(methyl)aluminum Hydride; **Lithium-Ethylamine**; **Lithium Tri-*t*-butoxyaluminum Hydride**; Magnesium Hydride-Copper(I) Iodide; Nickel(II) Acetate; **Nickel Boride**; Nickel Catalysts (Heterogeneous); Nickel(II) Chloride; Nickel-Graphite; Niobium(V) Chloride-Zinc; Palladium(II) Acetate; **Palladium on Barium Sulfate**; **Palladium on Calcium Carbonate (Lead Poisoned)**; **Palladium on Carbon**; Palladium-Graphite; Palladium on Poly(ethylenimine); Palladium-Triethylamine-Formic Acid; **Platinum on Carbon**; **Potassium Tri-*s*-butylborohydride**; Raney Nickel; Rhodium on Alumina; Sodium; Sodium-Ammonia; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Hydride-Nickel(II) Acetate-Sodium *t*-Pentoxide; Sodium Hydride-Palladium(II) Acetate-Sodium *t*-Pentoxide; Sodium Hypophosphite; **Sodium-Potassium Alloy**; **Thexylborane**; Tri-carbonyl-(naphthalene)chromium; Urushibara Nickel; Ytterbium(0); **Zinc**; Zinc-Copper(II) Acetate-Silver Nitrate; **Zinc/Copper Couple**; Zinc-1,2-Dibromoethane.

Class R-5: Reagents for Reduction of Amides, Imines, or Iminium Ions to Amines.

Aluminum Amalgam; Aluminum Hydride; Bis(trifluoroacetoxy)borane; Borane-Ammonia; Borane-Dimethyl Sulfide; Dichlorotris(triphenylphosphine)ruthenium(II); Diisobutylaluminum Hydride; Dodecacarbonyltriiron; (*R,R*)-[Ethylene-1,2-bis(η^5 -4,5,6,7-tetrahydro-1-indenyl)]titanium (*R*)-1,1'-Bi-2,2'-naphtholate; (2,3-*O*-Isopropylidene)-2,3-dihydroxy-1,4-bis(diphenylphosphino)butane; Lithium Aluminum Hydride; Lithium Aluminum Hydride-2,2'-Dihydroxy-1,1'-binaphthyl; Lithium 9-boratabicyclo[3.3.1]nonane; Lithium Borohydride; Lithium Tri-*t*-butoxyaluminum Hydride; Lithium Tri-*s*-butylborohydride; Lithium Triethylborohydride; Monochloroalane; Palladium on Calcium Carbonate (Lead Poisoned); Platinum on Carbon; Sodium; Sodium Borohydride; Sodium Cyanoborohydride; Sodium Dithionite; Sodium Telluride; Sodium Triacetoxyborohydride; Sodium Trifluoroacetoxyborohydride; Sodium Tris(trifluoroacetoxy)borohydride; Tetrahydro-1-methyl-3,3-diphenyl-1*H*, 3*H*-pyrrolo[1,2-*c*][1,3,2]oxazaborole; Tetramethylammonium Triacetoxyborohydride; Tin(IV) Chloride; Titanium(IV) Chloride; Trichlorosilane; Triethoxysilane; Ytterbium(0); Zinc.

Class R-6: Reagents for Reduction of Anhydrides or Imides.

Aluminum Amalgam; Lithium Aluminum Hydride; Lithium Tri-*s*-butylborohydride; Lithium Triethylborohydride; Lithium Trisiamylborohydride; Potassium Tri-*s*-butylborohydride; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Triacetoxyborohydride; Tetramethylammonium Triacetoxyborohydride; Zinc-Acetic Acid.

Class R-7: Reagents for Reduction of Aromatic Carbocycles.

Calcium-Ammonia; Lithium; Lithium-Ethylamine; Palladium on Carbon; Platinum(IV) Oxide; Potassium; Potassium-Graphite Laminate; Rhodium on Alumina; Ruthenium Catalysts; Sodium-Alcohol; Sodium-Ammonia; Triethylsilane; Ytterbium(0).

Class R-8: Reagents for Reduction of Aromatic Heterocycles.

Bis(trifluoroacetoxy)borane; Copper Chromite; Lithium Borohydride; Lithium Triethylborohydride; Nickel Boride; Palladium on Carbon; Platinum on Carbon; Platinum(IV) Oxide; Raney Nickel; Rhodium on Alumina; Ruthenium Catalysts; Sodium-Alcohol; Sodium Amalgam; Sodium Dithionite; Sodium Triacetoxyborohydride; Sodium Tris(trifluoroacetoxy)borohydride; Triethylsilane-Trifluoroacetic Acid.

Class R-9: Reagents for Reduction of Azides, Azo Compounds, Hydrazones, or Oximes to Amines.

Aluminum Amalgam; 1,2-Bis(2,5-diethylphospholano)benzene; Borane-Dimethyl Sulfide; Borane-Tetrahydrofuran;

Diisobutylaluminum Hydride; Hydrogen Sulfide; Magnesium-Methanol; Monochloroalane; Nickel Boride; Nickel(II) Chloride; Norephedrine-Borane; Palladium on Calcium Carbonate (Lead Poisoned); Palladium on Carbon; Palladium(II) Hydroxide on Carbon; Platinum(IV) Oxide; 1,3-Propanedithiol; Rhodium on Alumina; Sodium; Sodium-Alcohol; Sodium Amalgam; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Cyanoborohydride; Sodium Dithionite; Sodium Hydride; Sodium Hypophosphite; Sodium Telluride; Sodium Thiosulfate; Sodium Tris(trifluoroacetoxy)borohydride; Tetrahydro-1-methyl-3,3-diphenyl-1*H*,3*H*-pyrrolo[1,2-*c*][1,3,2]oxazaborole; Tetramethylammonium Triacetoxyborohydride; Tin(II) Chloride; Tri-*n*-butylhexadecylphosphonium Bromide; Triphenylphosphine; Vanadium(II) Chloride; Zinc; Zinc-Acetic Acid; Zinc/Copper Couple; Zinc-Dimethylformamide.

Class R-10: Reagents for Chemoselective Reduction of Carbonyl Compounds.

Aluminum Amalgam; Aluminum Isopropoxide; 1,2-Bis(2,5-diethylphospholano)benzene; (*R*)- & (*S*)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl; 9-Borabicyclo[3.3.1]nonane Dimer; Borane-Dimethyl Sulfide; Borane-Tetrahydrofuran; Catecholborane; Cerium(III) Chloride; Chlorotris(triphenylphosphine)rhodium(I); Cobalt Boride; Diisobutylaluminum 2,6-Di-*t*-butyl-4-methylphenoxide; Diisobutylaluminum Hydride; Hexa- μ -hydrohexakis(triphenylphosphine)hexacopper; Lanthanum(III) Chloride; Lithium Borohydride; Lithium *t*-Butyl(diisobutyl)aluminum Hydride; Lithium *n*-Butyl(diisobutyl)aluminum Hydride; Lithium 9,9-Dibutyl-9-borabicyclo[3.3.1]nonane; Lithium Tri-*t*-butoxyaluminum Hydride; Lithium Tri-*s*-butylborohydride; Lithium Triethylborohydride; Lithium Trisiamylborohydride; Nickel Boride; Potassium Tri-*s*-butylborohydride; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Dithionite; Sodium Triacetoxyborohydride; Sodium Trimethoxyborohydride; Tetra-*n*-butylammonium Borohydride; Tetrahydro-1-methyl-3,3-diphenyl-1*H*,3*H*-pyrrolo[1,2-*c*][1,3,2]oxazaborole; Tetramethylammonium Triacetoxyborohydride; Triethoxysilane; Zinc Borohydride.

Class R-11: Reagents for Enantioselective Reduction of Carbonyl Compounds.

2-Amino-3-methyl-1,1-diphenyl-1-butanol; (*S*)-4-Anilino-3-methylamino-1-butanol; (*S*)-2-(Anilinomethyl)pyrrolidine; Baker's Yeast; 2-[2-[(Benzyloxy)ethyl]-6,6-dimethylbicyclo[3.3.1]-3-nonyl]-9-borabicyclo[3.3.1]nonane; 1,2-Bis(2,5-diethylphospholano)benzene; (+)-*trans*-(2*S*,3*S*)-Bis(diphenylphosphino)bicyclo[2.2.1]hept-5-ene; (*R*)- & (*S*)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl; 2,6-Bis[(*S*)-4'-isopropylloxazolin-2'-yl](pyridine)rhodium Trichloride; Borane-Dimethyl Sulfide; Borane-Tetrahydrofuran; Catecholborane; (+)-*B*-Chlorodiisopinocampheylborane; Diborane; Diisobutylaluminum Hydride; Diisopinocampheylborane; 9-*O*-(1,2,5,6-Di-*O*-isopropylidene- α -*D*-glucofuranosyl)-9-boratabicyclo[3.3.1]nonane; Potassium Salt; (*R,R*)-2,5-Dimethylborolane; Ephedrine-borane; Lithium Aluminum Hydride; Lithium Aluminum Hydride-2,2'-Dihydroxy-1,1'-binaphthyl;

Lithium Tri-*t*-butoxyaluminum Hydride; Monoisopinocampheylborane; Norephedrine-Borane; Potassium Triisopropoxyborohydride; Raney Nickel; Sodium Borohydride; Tetrahydro-1-methyl-3,3-diphenyl-1*H*,3*H*-pyrrolo[1,2-*c*][1,3,2]oxazaborole; Tin(II) Chloride.

Class R-12: Reagents for Stereoselective Reduction of Carbonyl Compounds.

Aluminum Hydride; Aluminum Isopropoxide; Baker's Yeast; *trans*-2,5-Bis(methoxymethyl)pyrrolidine; Borane-Tetrahydrofuran; Catecholborane; Chlorodiisopropylsilane; Chlorotris(triphenylphosphine)rhodium(I); Dicyclohexylborane; Diisobutylaluminum 2,6-Di-*t*-butyl-4-methylphenoxide; Diisobutylaluminum Hydride; (*R,R*)-2,5-Dimethylborolane; Dimethyl(phenyl)silane; Disiamylborane; Erbium(III) Chloride; Hexa- μ -hydrohexakis(triphenylphosphine)hexacopper; Lithium; Lithium Aluminum Hydride; Lithium Aluminum Hydride-2,2'-Dihydroxy-1,1'-binaphthyl; Lithium Aluminum Hydride-Titanium(IV) Chloride; Lithium 9-boratabicyclo[3.3.1]nonane; Lithium Borohydride; Lithium *n*-Butyl(diisobutyl)aluminum Hydride; Lithium 9,9-Dibutyl-9-borabicyclo[3.3.1]nonanate; Lithium-Ethylamine; Lithium Tri-*t*-butoxyaluminum Hydride; Lithium Tri-*s*-butylborohydride; Lithium Triethylborohydride; Lithium Trisiamylborohydride; Palladium on Carbon; Platinum on Carbon; Potassium 9-Siamyl-9-boratabicyclo[3.3.1]nonane; Potassium Tri-*s*-butylborohydride; Raney Nickel; Rhodium on Alumina; Ruthenium Catalysts; Sodium-Alcohol; Sodium-Ammonia; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Dithionite; Sodium Triacetoxyborohydride; Tetrahydro-1-methyl-3,3-diphenyl-1*H*,3*H*-pyrrolo[1,2-*c*][1,3,2]oxazaborole; Tetramethylammonium Triacetoxyborohydride; Thexylborane; Triisobutylaluminum; Tris(trimethylsilyl)silane; Urushibara Nickel; Zinc Borohydride; Zinc Complex Reducing Agents.

Class R-13: Reagents for Reduction of Carboxylic Acids, Esters or Derivatives to Alcohols.

Aluminum Hydride; Borane-Dimethyl Sulfide; Borane-Tetrahydrofuran; Copper Chromite; Diborane; Diisobutylaluminum Hydride; Diphenylsilane-Cesium Fluoride; Ethyl Chloroformate; *N*-Ethyl-5-phenylisoxazolium-3'-sulfonate; Lithium Aluminum Hydride; Lithium Aluminum Hydride-2,2'-Dihydroxy-1,1'-binaphthyl; Lithium Tri-*t*-butoxyaluminum Hydride; Lithium Tri-*s*-butylborohydride; Lithium Triethylborohydride; Lithium 9-boratabicyclo[3.3.1]nonane; Lithium *t*-Butyl(diisobutyl)aluminum Hydride; Monochloroalane; Potassium Tri-*s*-butylborohydride; Sodium; Sodium-Ammonia; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Triacetoxyborohydride; Titanium(IV) Chloride; Titanium Tetraisopropoxide; Triethoxysilane; Trimethyl Borate.

Class R-14: Reagents for Reduction of Carboxylic Acids, Esters or Derivatives to Aldehydes or Hemiacetals.

Borane-Dimethyl Sulfide; Chlorodiisopropylsilane; Chloro(thexyl)borane-Dimethyl Sulfide; Dichlorobis(cyclopentadi-

nyl)titanium; Diisobutylaluminum Hydride; (2-Dimethylaminomethylphenyl)phenylsilane; Disiamylborane; Lithium; Lithium Aluminum Hydride; Lithium 9-boratabicyclo[3.3.1]nonane; Lithium Borohydride; Lithium *t*-Butyl(diisobutyl)aluminum Hydride; Lithium *n*-Butyl(diisobutyl)aluminum Hydride; Lithium-Ethylamine; Lithium Tri-*s*-butylborohydride; Lithium Trisiamylborohydride; Nickel Boride; Palladium on Barium Sulfate; Sodium Amalgam; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Tetrakis(triphenylphosphine)palladium(0); Thexylborane; Tri-*n*-butylstannane; Triethylsilane; Zinc Borohydride.

Class R-15: Reagents for Conjugate Reduction of α,β -Unsaturated Carbonyl Compounds.

Aluminum Amalgam; Baker's Yeast; Benzeneselenol; (1*S*,9*S*)-1,9-Bis[[(*t*-butyl)dimethylsiloxy]methyl]-5-cyanosemicorin; 1,2-Bis(2,5-diethylphospholano)benzene; Bis(diisopropylamino)aluminum Hydride; (*R*)- & (*S*)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl; Calcium-Ammonia; Catecholborane; Chlorotris(triphenylphosphine)rhodium(I); Copper(I) Bromide-Lithium Trimethoxyaluminum Hydride; Copper(I) Bromide-Sodium Bis(2-methoxyethoxy)aluminum Hydride; (1,5-Cyclooctadiene)(tricyclohexylphosphine)(pyridine)iridium(I) Hexafluorophosphate; Diimide; Diisobutylaluminum Hydride; 1,3-Dimethyl-2-phenylbenzimidazolone; Dimethyl(phenyl)silane; Diphenylsilane-Tetrakis(triphenylphosphine)palladium(0)-Zinc Chloride; Disiamylborane; Disodium Tetracarbonylferrate(-II); Hexa- μ -hydrohexakis(triphenylphosphine)hexacopper; Hydrogen Sulfide; Lithium; Lithium Aluminum Hydride-Copper(I) Iodide; Lithium *n*-Butyl(diisobutyl)aluminum Hydride; Lithium *n*-Butyl(hydrido)cuprate; Lithium Diisobutyl(methyl)aluminum Hydride; Lithium Tri-*t*-butoxyaluminum Hydride; Lithium Tri-*s*-butylborohydride; Lithium Triethylborohydride; Magnesium-Methanol; Mesitylcopper(I); Nickel Boride; Nickel(II) Chloride; Nickel-Graphite; Potassium; Potassium-Graphite Lamine; Potassium Tri-*s*-butylborohydride; Sodium; Sodium Amalgam; Sodium-Ammonia; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Cyanoborohydride; Sodium Dithionite; Sodium Tetracarbonylcobaltate; Sodium Tetracarbonylhydridoferrate; Sodium Thiosulfate; Tetra-*n*-butylammonium Borohydride; Tin; Titanium; Titanium(III) Chloride; Tri-*n*-butylstannane; Tri-*n*-butyltin Trifluoromethanesulfonate; Triethylborane; Triethylsilane; Triethylsilane-Trifluoroacetic Acid; Triisobutylaluminum; Ytterbium(0); Ytterbium(II) Iodide; Zinc; Zinc-Acetic Acid; Zinc/Copper Couple; Zinc/Nickel Couple.

Class R-16: Reagents for Reductive Deoxygenation of Epoxides to Alkenes.

Aluminum Amalgam; Aluminum Iodide; Diethyl[diethyl(phenyl)silyl]aluminum; Diethyl Phosphonite; Dimethyl Diazo-malonate; Dimethylphenylsilyllithium; Diphosphorus Tetraiodide; Iodotrimethylsilane; Lithium Aluminum Hydride-Titanium(IV) Chloride; Methyltriphenoxyposphonium Iodide; Phosphorus(III) Iodide; Potassium Selenocyanate; Sodium

O,O-Diethyl Phosphorotelluroate; Trifluoroacetic Anhydride; Sodium Iodide; Trimethylsilylpotassium; **Triphenylphosphine**; Triphenylphosphine-Iodine; Triphenylphosphine-Iodoform-Imidazole; Triphenylphosphine Selenide; Triphenylphosphine-2,4,5-Triiodoimidazole; Tungsten(VI) Chloride-*n*-Butyllithium; Zinc-Acetic Acid.

Class R-17: Reagents for Reduction via Hydroboration.

Borane-Dimethyl Sulfide; **Borane-Tetrahydrofuran**; **Catecholborane**; Chloro(thexyl)borane-Dimethyl Sulfide; **Chlorotris(triphenylphosphine)rhodium(I)**; **Diborane**; **Dibromoborane-Dimethyl Sulfide**; Dichloroborane Diethyl Etherate; Dicyclohexylborane; **Lithium Borohydride**; **Lithium Tri-*s*-butylborohydride**; **Lithium Triethylborohydride**; **Sodium Triacetoxylborohydride**; **Tetrahydro-1-methyl-3,3-diphenyl-1H,3H-pyrrolo[1,2-*c*][1,3,2]oxazaborole**; **Thexylborane**.

Class R-18: Reagents for Enantioselective Hydrogenation.

(Bicyclo[2.2.1]hepta-2,5-diene)[1,4-bis(diphenylphosphino)butane]rhodium(I) Tetrafluoroborate; Bis(bicyclo[2.2.1]hepta-2,5-diene)dichlorodirrhodium; Bis(1,5-cyclooctadiene)rhodium Tetrafluoroborate-(*R*)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl; **1,2-Bis(2,5-diethylphospholano)benzene**; (+)-*trans*-(2*S*,3*S*)-Bis(diphenylphosphino)bicyclo[2.2.1]hept-5-ene; (*R*)- & (*S*)-2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl; 10-Camphorsulfonic Acid; (*R*)-(+)-Cyclohexyl(2-anisyl)methylphosphine; (*R*)-*N*-[2-(*N,N*-Dimethylamino)ethyl]-*N*-methyl-1-[(*S*)-1',2-bis(diphenylphosphino)ferrocenyl]ethylamine; (*R,R*)-[Ethylene-1,2-bis(η⁵-4,5,6,7-tetrahydro-1-indenyl)]titanium (*R*)-1,1'-Bi-2,2'-naphtholate; (-)-[Ethylene-1,2-bis(η⁵-4,5,6,7-tetrahydro-1-indenyl)]zirconium (*R*)-1,1'-Bi-2,2'-naphtholate; (±)-1,1'-Ethylenebis(4,5,6,7-tetrahydro-1-indenyl)zirconium Dichloride; (2,3-*O*-Isopropylidene)-2,3-dihydroxy-1,4-bis(diphenylphosphino)-butane; 5-Phenyl-5*H*-benzophosphindole; Pivalic Acid.

Class R-19: Reagents for Catalysis of Hydrogenation or Hydrogenolysis.

(Bicyclo[2.2.1]hepta-2,5-diene)[1,4-bis(diphenylphosphino)butane]rhodium(I) Tetrafluoroborate; (Bicyclo[2.2.1]hepta-2,5-diene)[1,4-bis(diphenylphosphino)butane]rhodium(I) Tetrafluoroborate; Bis(benzonitrile)dichloropalladium(II); Bis(bicyclo[2.2.1]hepta-2,5-diene)rhodium Perchlorate; Bis(η⁵-cyclopentadienyl)dihydrozirconium; Chlorotriethylsilane; Chlorotris(triphenylphosphine)cobalt; **Chlorotris(triphenylphosphine)rhodium(I)**; Cobalt Boride; Copper Chromite; (1,5-Cyclooctadiene)bis(methylphenylphosphine)iridium(I) Hexafluorophosphate; (1,5-Cyclooctadiene)(tricyclohexylphosphine)(pyridine)iridium(I) Hexafluorophosphate; Dicarbonylbis(cyclopentadienyl)titanium; Dichlorobis(triphenylphosphine)platinum(II)-Tin(II) Chloride; Dichlorotris(triphenylphosphine)ruthenium(II); (*R,R*)-[Ethylene-1,2-bis(η⁵-4,5,6,7-tetrahydro-1-indenyl)]titanium (*R*)-1,1'-Bi-2,2'-naphtholate; (-)-[Ethylene-1,2-bis(η⁵-4,5,6,7-tetrahydro-1-indenyl)]zirconium

(*R*)-1,1'-Bi-2,2'-naphtholate; (±)-1,1'-Ethylenebis(4,5,6,7-tetrahydro-1-indenyl)zirconium Dichloride; Hexadecacarbonylhexarhodium; Lithium Aluminum Hydride-Bis(cyclopentadienyl)nickel; Nafion-H; Nickel(II) Acetate; Nickel(II) Acetylacetonate; **Nickel Boride**; Nickel Catalysts (Heterogeneous); Nickel-Graphite; Octacarbonyldicobalt; Palladium(II) Acetate; Palladium(II) Acetylacetonate; **Palladium on Barium Sulfate**; **Palladium on Calcium Carbonate (Lead Poisoned)**; **Palladium on Carbon**; Palladium-Graphite; **Palladium(II) Hydroxide on Carbon**; Palladium on Poly(ethylenimine); Palladium-Triethylamine-Formic Acid; **Platinum on Carbon**; **Platinum(IV) Oxide**; Platinum (Sulfided) on Carbon; **Potassium-Graphite Laminar**; **Raney Nickel**; **Rhodium on Alumina**; **Ruthenium Catalysts**; Sodium Hydride-Nickel(II) Acetate-Sodium *t*-Pentoxide; Tetrachlorotris[bis(1,4-diphenylphosphino)butane]diruthenium; Tricarbonyl(naphthalene)chromium; Urushibara Nickel.

Class R-20: Reagents for Reduction of Nitriles to Imines or Amines.

Aluminum Hydride; **Borane-Dimethyl Sulfide**; **Borane-Tetrahydrofuran**; **Chlorotris(triphenylphosphine)rhodium(I)**; Cobalt Boride; Copper Chromite; **Diborane**; **Diisobutylaluminum Hydride**; **Lithium Aluminum Hydride**; **Lithium Borohydride**; **Lithium Triethylborohydride**; Monochloroalane; Nickel Catalysts (Heterogeneous); **Palladium on Carbon**; **Platinum on Carbon**; **Platinum(IV) Oxide**; **Potassium-Graphite Laminar**; Potassium 9-Siamyl-9-boratabicyclo[3.3.1]nonane; **Rhodium on Alumina**; **Ruthenium Catalysts**; **Sodium-Alcohol**; **Sodium Bis(2-methoxyethoxy)aluminum Hydride**; **Sodium Borohydride**; Sodium Hypophosphite; **Sodium Triacetoxylborohydride**; Sodium Trifluoroacetylborohydride; Sodium Trimethoxyborohydride; **Tin**; Tin(II) Chloride; Titanium; **Zinc**; Zinc/Nickel Couple.

Class R-21: Reagents for Reduction of Nitro Compounds to Amines or Oximes.

Aluminum Amalgam; Ammonium Formate; Ammonium Sulfide; Bis(benzonitrile)dichloropalladium(II); Bis(trimethylsilyl) Sulfide; **Chromium(II) Chloride**; Copper Chromite; Dichlorotris(triphenylphosphine)ruthenium(II); **Diisobutylaluminum Hydride**; Dodecacarbonyltriiron; Hexadecacarbonylhexarhodium; Hydrogen Selenide; **Hydrogen Sulfide**; Hypophosphorous Acid; **Lithium Aluminum Hydride**; Magnesium Amalgam; **Nickel Boride**; **Nickel(II) Chloride**; Palladium(II) Acetate; **Palladium on Calcium Carbonate (Lead Poisoned)**; **Palladium on Carbon**; Palladium-Graphite; **Palladium(II) Hydroxide on Carbon**; Palladium-Triethylamine-Formic Acid; **Platinum on Carbon**; **Platinum(IV) Oxide**; Platinum (Sulfided) on Carbon; **Ruthenium Catalysts**; **Sodium Bis(2-methoxyethoxy)aluminum Hydride**; **Sodium Borohydride**; Sodium Disulfide; **Sodium Dithionite**; Sodium Hydrogen Sulfide; Sodium Hypophosphite; Sodium Sulfide; Sodium Telluride; Sodium Tetracarbonylhydridoferrate; **Titanium(III) Chloride**; Zinc-Acetic Acid; Zinc Amalgam; Zinc Complex Reducing Agents; Zinc/Nickel Couple.

Class R-22: Reagents for Reduction of Quinones.

Aluminum Amalgam; Chlorotris(triphenylphosphine)rhodium(I); Hydrogen Iodide; Sodium Dithionite; Sodium Thiosulfate; Tin; Vanadium(II) Chloride; Zinc-Acetic Acid; Zinc-Zinc Chloride.

Class R-23: Reagents for Reductive Cleavage of Allylic, Benzylic or α -Carbonyl Functionality.

Aluminum Amalgam; Aluminum Hydride; Aluminum Iodide; Ammonium Formate; Borane-Tetrahydrofuran; Chromium(II) Chloride; Diiodosilane; Diisobutylaluminum Hydride; 1,3-Dimethyl-2-phenylbenzimidazoline; Diphenylsilane-Tetrakis(triphenylphosphine)palladium(0)-Zinc Chloride; Hydrogen Sulfide; Iodotrimethylsilane; Iron-Graphite; Lithium; Lithium Aluminum Hydride; Lithium-Ethylamine; Lithium Tri-*s*-butylborohydride Lithium Triethylborohydride; Methyltrichlorosilane; Nickel Boride; Nickel(II) Chloride; Nonacarbonyliron; Palladium(II) Acetate; Palladium(II) Acetylacetonate; Palladium on Barium Sulfate; Palladium on Carbon; Palladium(II) Hydroxide on Carbon; Palladium-Triethylamine-Formic Acid; Pentacarbonyliron; Platinum(IV) Oxide; Raney Nickel; Samarium(II) Iodide; Sodium Amalgam; Sodium Cyanoborohydride; Sodium *O,O*-Diethyl Phosphorotelluroate; Sodium Dithionite; Sodium Hypophosphite; Sodium Iodide; Sodium Naphthalenide; Sodium Telluride; Sodium Tris(trifluoroacetoxy)borohydride; Tetrakis(triphenylphosphine)palladium(0); Tin; Tin(II) Chloride; Titanium(III) Chloride; Triethylsilane; Triphenylphosphine; Zinc; Zinc-Acetic Acid; Zinc Borohydride; Zinc-Copper Couple.

Class R-24: Reagents for Reductive Cleavage of N-O, N-N, O-O, O-S or S-S Bonds.

Aluminum Amalgam; Aluminum Iodide; Aminoiminomethanesulfonic Acid; Chromium(II) Chloride; Dimethyl Sulfide; Hydrogen Sulfide; Iron(II) Sulfate; Lithium Aluminum Hydride; Lithium Aluminum Hydride-Nickel(II) Chloride; Lithium Tri-*t*-butoxyaluminum Hydride; Nickel(II) Chloride; Palladium on Carbon; Platinum(IV) Oxide; Platinum (Sulfided) on Carbon; Potassium Tri-*s*-butylborohydride; Potassium Triisopropoxyborohydride; Raney Nickel; Sodium; Sodium Amalgam; Sodium-Ammonia; Sodium Thiosulfate; Tin; Titanium(III) Chloride; Triphenylphosphine; Zinc; Zinc-Acetic Acid.

Class R-25: Reagents for Reductive Coupling or Cyclization.

Aluminum Amalgam; Chromium(II) Chloride; Dichlorobis(cyclopentadienyl)titanium; Diisobutylaluminum Hydride; Disiamylborane; Hydrogen Sulfide; Lithium; Lithium Aluminum Hydride-Titanium(IV) Chloride; Magnesium; Magnesium Amalgam; Nickel(II) Chloride; Potassium; Potassium-Graphite Laminate; Samarium(II) Iodide; Sodium; Sodium Hydride-Nickel(II) Acetate-Sodium *t*-Pentoxide; Sodium

Naphthalenide; Sodium-Potassium Alloy; Tin; Titanium; Titanium(III) Chloride; Titanium(III) Chloride-Potassium; Titanium(III) Chloride-Zinc/Copper Couple; Tri-*n*-butylstannane; Ytterbium(0); Ytterbium(II) Iodide; Zinc; Zinc-Copper Couple; Zinc-Zinc Chloride.

Class R-26: Reagents for Reductive Decarbonylation, Decarboxylation or Decyanation.

Bis[1,3-bis(diphenylphosphino)propane]rhodium Tetrafluoroborate; trans-Carbonyl(chloro)bis(triphenylphosphine)iridium(I); Carbonyl(chloro)bis(triphenylphosphine)rhodium(I); Chlorotris(triphenylphosphine)rhodium(I); Copper Chromite; Diphenyl Phosphorazidate; 1-Methyl-2-pyrrolidinone; Palladium on Carbon; Potassium; Potassium on Alumina; Raney Nickel; Sodium; Sodium Borohydride; Titanium; Tri-*n*-butylstannane; Tris(acetylacetonato)iron(III); Tris(trimethylsilyl)silane.

Class R-27: Reagents for Reductive Dehalogenation.

Aluminum Amalgam; Aluminum Hydride; Bis(η^5 -cyclopentadienyl)dihydrido-zirconium; Chromium(II) Chloride; Dichlorobis(cyclopentadienyl)titanium; Diisobutylaluminum Hydride; 1,3-Dimethyl-2-phenylbenzimidazoline; Hexacarbonyl-tungsten; Iron-Graphite; Lithium; Lithium Aluminum Hydride; Lithium Aluminum Hydride-Cobalt(II) Chloride; Lithium Aluminum Hydride-Nickel(II) Chloride; Lithium *n*-Butyl(hydrido)cuprate; Lithium 4,4'-Di-*t*-butylbiphenylide; Lithium 9,9-Dibutyl-9-borabicyclo[3.3.1]nonane; Lithium Naphthalenide; Lithium Tri-*t*-butoxyaluminum Hydride; Lithium Tri-*s*-butylborohydride; Lithium Triethylborohydride; Magnesium; Magnesium Amalgam; Magnesium-Methanol; Nickel Boride; Nickel(II) Chloride; Nonacarbonyliron; Palladium on Barium Sulfate; Palladium on Carbon; Pentacarbonyliron; Potassium; Potassium-Graphite Laminate; Potassium Naphthalenide; Potassium Tri-*s*-butylborohydride; Pyridine; Samarium(II) Iodide; Sodium; Sodium-Alcohol; Sodium Amalgam; Sodium-Ammonia; Sodium Bis(2-methoxyethoxy)aluminum Hydride; Sodium Borohydride; Sodium Cyanoborohydride; Sodium *O,O*-Diethyl Phosphorotelluroate; Sodium Dithionite; Sodium Hydride-Palladium(II) Acetate-Sodium *t*-Pentoxide; Sodium Iodide; Sodium Phenanthrene; Sodium-Potassium Alloy; Sodium Sulfide; Sodium Tetracarbonylcobaltate; Sodium Thiosulfate; Sodium Trimethoxyborohydride; Tetrakis(triphenylphosphine)palladium(0); Tin; Titanium; Titanium(III) Chloride; Tri-*n*-butylstannane; Triethylsilane; Trimethyl Phosphite; Triphenylphosphine; Tris(trimethylsilyl)silane; Zinc; Zinc-Acetic Acid; Zinc Borohydride; Zinc Complex Reducing Agents; Zinc/Copper Couple; Zinc/Silver Couple.

Class R-28: Reagents for Reductive Deoxygenation of Alcohols or Derivatives.

Bis(dimethylamino) Phosphorochloridate; 1,4-Bis(diphenylhydrosilyl)benzene; Bis(trifluoroacetoxy)borane; Diisobutylaluminum Hydride; *N*-Hydroxypyridine-2-thione; Lithium;