



A Publication
of Reliable Methods
for the Preparation
of Organic Compounds

Working with Hazardous Chemicals

The procedures in *Organic Syntheses* are intended for use only by persons with proper training in experimental organic chemistry. All hazardous materials should be handled using the standard procedures for work with chemicals described in references such as "Prudent Practices in the Laboratory" (The National Academies Press, Washington, D.C., 2011; the full text can be accessed free of charge at http://www.nap.edu/catalog.php?record_id=12654). All chemical waste should be disposed of in accordance with local regulations. For general guidelines for the management of chemical waste, see Chapter 8 of Prudent Practices.

In some articles in *Organic Syntheses*, chemical-specific hazards are highlighted in red "Caution Notes" within a procedure. It is important to recognize that the absence of a caution note does not imply that no significant hazards are associated with the chemicals involved in that procedure. Prior to performing a reaction, a thorough risk assessment should be carried out that includes a review of the potential hazards associated with each chemical and experimental operation on the scale that is planned for the procedure. Guidelines for carrying out a risk assessment and for analyzing the hazards associated with chemicals can be found in Chapter 4 of Prudent Practices.

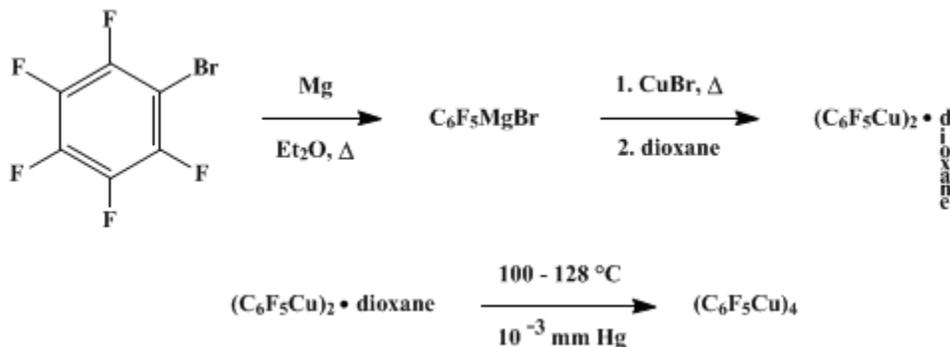
The procedures described in *Organic Syntheses* are provided as published and are conducted at one's own risk. *Organic Syntheses, Inc.*, its Editors, and its Board of Directors do not warrant or guarantee the safety of individuals using these procedures and hereby disclaim any liability for any injuries or damages claimed to have resulted from or related in any way to the procedures herein.

These paragraphs were added in September 2014. The statements above do not supersede any specific hazard caution notes and safety instructions included in the procedure.

Organic Syntheses, Coll. Vol. 6, p.875 (1988); Vol. 59, p.122 (1979).

PENTAFLUOROPHENYLCOPPER TETRAMER, A REAGENT FOR SYNTHESIS OF FLUORINATED AROMATIC COMPOUNDS

[Copper, tetrakis(pentafluorophenyl)tetra]



Submitted by Allan Cairncross¹, William A. Sheppard², and Edward Wonchoba.
Checked by William J. Guilford, Cynthia B. House, and Robert M. Coates.

1. Procedure

Caution! Benzene has been identified as a carcinogen; OSHA has issued emergency standards on its use. All procedures involving benzene should be carried out in a well-ventilated hood, and glove protection is required.

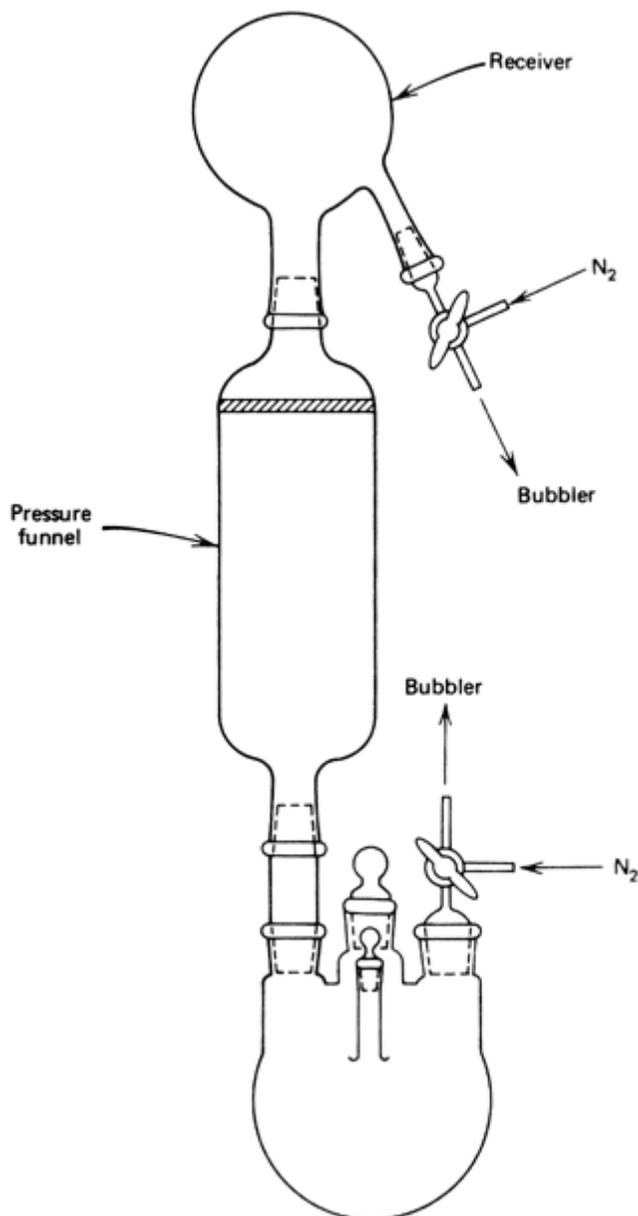
A 1-l., four-necked, round-bottomed flask fitted with a condenser bearing a nitrogen inlet, a pressure-equalizing dropping funnel, a thermometer, and a mechanical stirrer is charged with 5.40 g. (0.222 g.-atom) of magnesium turnings (Note 1). The flask is flame dried while being flushed with nitrogen and kept dry and oxygen-free with a static nitrogen atmosphere throughout the preparation (Note 2). After 150 ml. of diethyl ether (Note 3) is introduced into the flask with a syringe, 54.9 g. (28.2 ml., 0.222 mole) of bromopentafluorobenzene (Note 4) is added dropwise over *ca.* 45 minutes at a rate that maintains a gentle reflux. The reflux is maintained for another 15 minutes by heating at 35° (Note 1). The resulting black solution is cooled to room temperature, and 63.1 g. (0.440 mole) of powdered, anhydrous copper(I) bromide (Note 5) is added in three 21-g. portions at 1-minute intervals. An exothermic reaction occurs after each addition (Note 6).

The brown mixture is stirred for 30 minutes, 100 ml. of ether is added, and the mixture heated at reflux for another 30 minutes. The brown suspension is diluted with 400 ml. of ether, after which 100 ml. of 1,4-dioxane (Note 7) is added carefully over 15 minutes, moderating the mildly exothermic reaction. The light-gray suspension is stirred for 30 minutes.

The dropping funnel is replaced with a three-way stopcock with an attached nitrogen source and a bubbler open to the system (see Figure 1). The thermometer and mechanical stirrer are replaced with ground-glass plugs (Note 8), and the condenser is replaced with a 1-l., 90-mm., medium-porosity fritted-disk nitrogen pressure funnel attached to a 1-l., round-bottomed, two-necked flask fitted with a three-way stopcock on the side arm (Figure 1). All joints are either clamped or taped together, and the apparatus is carefully inverted, pouring the slurry into the funnel. The mixture is filtered with nitrogen pressure into the 1-l. receiving flask (Note 9), which is maintained under a nitrogen atmosphere. The solid filter cake is rinsed with three 50-ml. portions of 4:1 (v/v) ether-dioxane injected with a long needle syringe through the three-way stopcock. The four-necked flask is rinsed by manipulation of the needle, and the apparatus and the solids are dispersed in each rinse. The pale-yellow filtrate is evaporated to dryness under reduced pressure with a warm water bath at 40°, and the powdery white solid is dried at 10-mm. pressure for 4 hours at 25°, yielding 38.3–48.8 g. (63–80%) of bis

(pentafluorophenylcopper)dioxane complex (Note 10). The color of this dioxane complex varies from tan to white. The complex is transferred to a 200-ml., round-bottomed flask under a nitrogen atmosphere. The flask is evacuated to a pressure of 0.001 mm., immersed in an oil bath, and slowly heated to 100° over 1 hour (Note 11). The temperature is slowly and constantly increased to 128° during a second hour and maintained at 128° for 4 hours (Note 12). Pure pentafluorophenylcopper tetramer is obtained as a gray to tan powder weighing 29.8–34.7 g. (58–68%) (Note 13).

Figure 1.



2. Notes

1. Magnesium metal turnings, from Fisher Scientific Company or Mallinckrodt Chemical Works, were used. Excess magnesium or incomplete formation of the Grignard must be avoided, since any free magnesium reacts when the copper salts are added, producing a dark product in lower yield and of questionable purity.
2. All glassware must be flame dried, and an absolute nitrogen atmosphere must be maintained during each step, since pentafluorophenylcopper hydrolyzes easily and undergoes oxidative coupling in air. The checkers used dry grade nitrogen from a cylinder, supplied by the Linde Division, Union Carbide

Corporation.

3. Anhydrous ether, purchased from Fisher Scientific Company or Mallinckrodt Chemical Works, was dried over Linde type 3A molecular sieves. The checkers degassed the solvent immediately before use by evacuating and filling the container with nitrogen three times.

4. Bromopentafluorobenzene, obtained from either PCR, Inc., or Columbia Organic Chemicals Company, Inc., was used without purification.

5. Anhydrous copper(I) bromide, from Fisher Scientific Company, was powdered and used without drying by the submitters. The checkers dried the copper(I) bromide at 140° for 2 hours under reduced pressure before use.

6. The copper(I) bromide can also be added gradually from a solid addition apparatus such as a 50-ml. Erlenmeyer flask connected to a ground-glass adapter with a short piece of gooch tubing.

7. Spectral grade 1,4-dioxane, from MC and B Manufacturing Chemists or Mallinckrodt Chemical Works, was dried over Linde type 4A molecular sieves. The checkers degassed the solvent prior to use as described in (Note 3).

8. The checkers used rubber septa, secured with wire bands.

9. The filtering operation can also be conveniently done in a high-quality nitrogen atmosphere dry box by vacuum filtration through a 90-mm., 60-ml., medium-porosity, fritted-disk Büchner funnel.

10. Pentafluorophenylcopper is first isolated as a 1:1 complex with dioxane and is usually white. Half of the complexed dioxane is very labile and is usually lost during vacuum drying, giving the 2:1 complex. Excessive heating can cause loss of additional dioxane (lower apparent yield) and eventual decomposition of the product.

If the product is isolated in a nitrogen dry box, the filtrate is evaporated without heat until a small amount of solvent remains. The precipitate is collected cold and rinsed with cold ether. The nearly white 1:1 pentafluorophenylcopper-dioxane complex is obtained with no significant loss of yield.

11. The rate of heating is critical. The temperature must be increased very gradually to remove the dioxane without causing decomposition of the product. A vacuum of 0.1 to 1.0 mm is sufficient to remove the last of the dioxane although 0.001 mm was usually used by the submitters. Occasionally, cold traps become plugged with frozen dioxane (m.p. 12°), resulting in loss of vacuum, overheating, and decomposition of the pentafluorophenyl dioxane complexes.

12. If the product is heated to 130° or higher, decomposition of product occurs with the formation of a copper mirror.

13. The spectral properties of pentafluorophenylcopper tetramer are as follows: IR (Nujol) cm^{-1} : 1630 medium; 1391 medium; 1353 medium; 1275 medium; 1090, 1081, and 1071 strong triplet; 978 strong; 785 medium; ^{19}F NMR (tetrahydrofuran with CFCl_3 as internal reference): δ (multiplicity, coupling constant J in Hz., number of fluorines, assignment): 107.2 (20-line m, 2F, *ortho* F), 153.4 (t of t, $J = \sim 1.3$ and 20, 1F, *para* F), 162.3 (17-line m, 2F, *meta* F). Absorptions at 820–900, 1100–1125, and 1290 cm^{-1} in the IR spectrum and at δ 3.05 in the ^1H NMR spectrum indicate that dioxane is still present.

The pentafluorophenylcopper tetramer is usually analytically pure as isolated and melts at 200° with decomposition. If any significant decomposition occurs during the final drying, the product can be purified by dissolution in ether, filtration to remove copper metal, and precipitation by addition of hexane. It can also be recrystallized from benzene. When kept in a sealed container under nitrogen at room temperature, pentafluorophenyl copper tetramer appears to be stable for reasonable periods. It can be stored indefinitely at -78° under an atmosphere of carbon dioxide.

3. Discussion

Pentafluorophenylcopper is representative of a series of fluorinated organocopper compounds that are highly soluble in organic solvents, more thermally stable than their hydrocarbon analogs, and useful as synthetic intermediates.^{3,4,5,6} Pentafluorophenylcopper has been used to introduce the pentafluorophenyl group^{7,8,9} and as a reagent for an improved, Ullman diphenyl ether synthesis.¹⁰ It is also an effective catalyst for decarboxylation of aromatic acids,^{11,12} rearrangement of bicyclic hydrocarbons,¹³ and decomposition of alkyldiazo compounds.^{3,4,5} It also is an excellent reagent for the preparation of anhydrous copper salts of carboxylic acids¹¹ and can be used for coating substrates with copper by thermal decomposition.¹⁴

Pentafluorophenylcopper exists as a tetramer.¹⁵ It forms complexes with a variety of reagents and solvents as well as “ate” complexes; a representative list is given in Table I. For many syntheses the

crude reaction mixtures of copper(I) halide with either [pentafluorophenylmagnesium bromide](#), or [pentafluorophenyllithium](#),^{8,9} or the pentafluorophenylcopper-dioxane complex⁷ react as well as the solvent-free tetramer.

TABLE I
COMPLEXES OF PENTAFLUOROPHENYLCOPPER^{3,4,5}

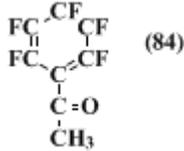
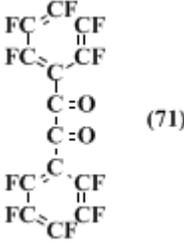
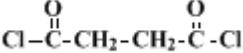
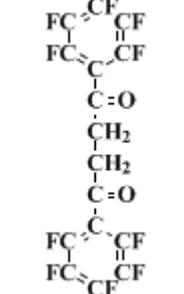
Complex	Properties
C ₆ F ₅ Cu-benzonitrile	m.p. 101°
C ₆ F ₅ Cu-tributylamine	liquid at room temperature
(C ₆ F ₅ Cu) ₂ ·dioxane	m.p. 200–220° (dec.)
C ₆ F ₅ Cu-quinoline	m.p. 170–176°
(C ₆ F ₅ Cu) ₂ ·1,5-cycloöctadiene	dec. 160°
C ₆ F ₅ Cu-dimethylacetylene	dec. 145°
(C ₆ F ₅ Cu) ₂ ·butadiene	dec. 215°
C ₆ F ₅ Cu-tetraethylammonium cyanide	dec. 160°

^a A, (C₆F₅Cu)₄; B, (C₆F₅Cu)₂·dioxane; C, reagent prepared *in situ* from C₆F₅MgX and CuX; D, reagent prepared *in situ* from C₆F₅Li and CuX.

A selection of synthetic uses of [pentafluorophenylcopper](#) is given in Table II. Two unchecked experimental procedures illustrating the use of pentafluorophenylcopper tetramer and the dioxane complex to introduce the pentafluorophenyl group are given below. In coupling reactions [hexane](#) is usually the preferred solvent, particularly with alkyl halides that can readily form carbonium ion intermediates. Aromatic solvents are often alkylated during coupling, giving undesired by-products.

TABLE II
SUMMARY OF REACTIONS OF PENTAFLUOROPHENYLCOPPER

Reactant	Form of C ₆ F ₅ Cu ^a	Conditions	Product (% yield)	Reference
H ₂ O	B	ether , 25°, 1 hour	C ₆ F ₅ H (87)	5
None	B	200°	C ₆ F ₅ -C ₆ F ₅ (60)	5
Br ₂	B	hexane , 0°	C ₆ F ₅ Br(4) + C ₆ F ₅ -C ₆ F ₅ (47)	3
CuBr ₂	B	hexane , reflux	C ₆ F ₅ -C ₆ F ₅ (68)	3
CO ₂	A or B	neat or aprotic solvent, -78° to 25°	no reaction	3
CH ₃ I	A	hexane , 25°, 5 days	CH ₃ -C ₆ F ₅ (39)	3
C ₆ H ₅ CH ₂ Br	B	ether , 25°, 4 hours	C ₆ H ₅ CH ₂ C ₆ F ₅ (40)	3
1-Bromobicyclo-[2.2.2]octane	A	hexane , reflux, 20 hours	1-pentafluorophenylbicyclo-[2.2.2]octane (83)	3,4
C ₂ H ₅ O ₂ CCHN ₂	A	tetrahydrofuran , 0°; hydrolysis	(C ₂ H ₅ O ₂)CCH ₂ C ₆ F ₅ (43)	3
C ₆ H ₅ I	A	benzene , reflux, 2 hours	C ₆ F ₅ -C ₆ H ₅ (87)	3
3-FC ₆ H ₄ I	B	benzene , reflux, 2 hours	3-FC ₆ H ₄ -C ₆ F ₅ (73)	7
O ₂ NC ₆ H ₄ I	B	<i>meta</i> : benzene , reflux, 2 hours <i>para</i> : benzene , reflux, 2 hours	O ₂ NC ₆ H ₄ C ₆ F ₅ <i>meta</i> (85) <i>para</i> (85)	7 7

		<i>ortho</i> : ether, reflux (exothermic)	<i>ortho</i> (73)	5
4-(CH ₃) ₂ NC ₆ H ₄ I	B	benzene, reflux, 2 hours	4-(CH ₃) ₂ NC ₆ H ₄ C ₆ F ₅ (26)	7
4-C ₂ H ₅ O ₂ CC ₆ H ₄ I	B	benzene, reflux, 2 hours	4-C ₂ H ₅ O ₂ CC ₆ H ₄ C ₆ F ₅ (97)	7
CF ₂ =CFI	C	tetrahydrofuran, 25– 55°, 5 hours	C ₆ F ₅ CF=CF ₂ (55)	16
CBr ₂ =CHBr	C	tetrahydrofuran, –5°, 3 hours	C ₆ F ₅ C≡CC ₆ F ₅ (43)	17
	D	tetrahydrofuran– hexane, 0°, several hours	 (84)	9
	D	tetrahydrofuran, 0° (exothermic)	 (71)	18
	C	tetrahydrofuran, –5°, 3 hours	 (71)	17
C ₆ H ₅ I	C	tetrahydrofuran, 66°, 10 hours	C ₆ H ₅ -C ₆ F ₅ (74)	16
	C	tetrahydrofuran, –5°, 3 hours	 (77)	17
(C ₂ H ₅) ₃ SiC≡CBr	C	tetrahydrofuran, 25°, 1 hour; reflux, 10 hours	(C ₂ H ₅) ₃ SiC≡CC ₆ F ₅ (85)	19

A. (*Pentafluorophenyl*)benzene. A 100-ml., round-bottomed flask equipped with a magnetic stirring bar and a reflux condenser bearing a nitrogen inlet is flushed with nitrogen and charged with a solution of 2.40 g. (0.00259 mole) of pentafluorophenylcopper tetramer in 25 ml. of benzene; 2.12 g. (0.0104 mole) of iodobenzene is then added. A static nitrogen atmosphere is maintained in the flask as the solution is heated to reflux. Copper(I) iodide starts to precipitate almost immediately. After 2 hours at

reflux, the mixture is cooled and filtered, separating 1.67 g. of copper(I) iodide. The filtrate is evaporated, and the remaining pale-brown residue is sublimed at 100° (0.1 mm.), affording 2.01 g. (79%) of (pentafluorophenyl)benzene as a colorless solid, m.p. 110.0–112.4°. The presence of about 3% of decafluorobiphenyl in the product is revealed by GC analysis. (Pentafluorophenyl)benzene may be further purified by column chromatography on acid-washed alumina (Woelm, activity grade I) with hexane as an eluent, the decafluorobiphenyl impurity being eluted first. The purified product melts at 111.3–112.0°.

B. 1-(Pentafluorophenyl)adamantane. A 500 ml., three-necked flask equipped with a thermometer, a magnetic stirring bar, and a reflux condenser bearing a nitrogen inlet is maintained under nitrogen, and charged with 32.5 g. (0.00590 mole) of bis(pentafluorophenylcopper)-dioxane complex, 24.9 g. (0.116 mole) of 1-bromoadamantane, and 175 ml. of spectral grade hexane. The mixture is stirred and slowly warmed until the onset of an exothermic reaction which causes the mixture to reflux for approximately 15 minutes. After the exothermic reaction subsides, the mixture is heated at reflux overnight, stirred briefly with 3 ml. of water, and filtered, separating 17.0 g. of copper(I) bromide. The filtrate is concentrated, and the residue is recrystallized from ethanol, affording 32.6 g. (93%) of colorless crystals of 1-pentafluorophenyladamantane. After sublimation at 100° (0.1 mm.) the product melts at 109.9–111.0°.

References and Notes

1. Central Research & Development Department, E. I. du Pont de Nemours and Company, Experimental Station, Wilmington, Delaware 19898.
2. Deceased Nov. 2, 1978.
3. A. Cairncross and W. A. Sheppard, *J. Am. Chem. Soc.*, **90**, 2186 (1968);
4. A. Cairncross and W. A. Sheppard, U.S. Pat. 3,700,693 (1972) [*Chem. Abstr.*, **78**, 30001d (1973)];
5. A. Cairncross and W. A. Sheppard, Abstract P152, Division of Organic Chemistry, 155th National American Chemical Society Meeting, San Francisco, California, April 1968.
6. For recent reviews of organocopper reagents, see A. E. Jukes, *Adv. Organomet. Chem.*, **12**, 215 (1974); G. H. Posner, *Org. React.*, **22**, 253 (1975).
7. W. A. Sheppard, *J. Am. Chem. Soc.*, **92**, 5419 (1970).
8. C. Tamborski, E. J. Soloski, and R. J. DePasquale, *J. Organomet. Chem.*, **15**, 494 (1968);
9. A. E. Jukes, S. S. Dua, and H. Gilman, *J. Organomet. Chem.*, **21**, 241 (1970); A. E. Jukes, S. S. Dua, and H. Gilman, *J. Organomet. Chem.*, **24**, 791 (1970).
10. M. P. Cava and A. Afzali, *J. Org. Chem.*, **40**, 1553 (1975).
11. A. Cairncross, J. R. Roland, R. M. Henderson, and W. A. Sheppard, *J. Am. Chem. Soc.*, **92**, 3187 (1970).
12. B. M. Trost and P. L. Kineson, *J. Org. Chem.*, **37**, 1273 (1972).
13. P. G. Gassman, G. R. Meyer, and F. J. Williams, *J. Am. Chem. Soc.*, **94**, 7741 (1972).
14. A. Cairncross and W. A. Sheppard, U.S. Pat. 3,817,784 (1974) [*Chem. Abstr.*, **81**, 128814h (1975)].
15. A. Cairncross, H. Omura, and W. A. Sheppard, *J. Am. Chem. Soc.*, **93**, 248 (1971).
16. R. J. DePasquale and C. Tamborski, *J. Org. Chem.*, **34**, 1736 (1969).
17. A. F. Webb and H. Gilman, *J. Organomet. Chem.*, **20**, 281 (1969).
18. S. S. Dua, A. E. Jukes, and H. Gilman, *Organomet. Chem. Synth.* **1**, 87 (1970/1971).
19. F. Waugh and D. R. M. Walton, *J. Organomet. Chem.*, **39**, 275 (1972).

Appendix

Chemical Abstracts Nomenclature (Collective Index Number); (Registry Number)

H₂O

Pentafluorophenylcopper tetramer

Copper, tetrakis(pentafluorophenyl)tetra
bis(pentafluorophenylcopper)dioxane complex

pentafluorophenylcopper·dioxane complex

pentafluorophenyl copper tetramer

C₆F₅Cu·benzotrile

C₆F₅Cu·tributylamine

C₆F₅Cu·quinoline

C₆F₅Cu·dimethylacetylene

(C₆F₅Cu)₂·butadiene

C₆F₅Cu·tetraethylammonium cyanide

bis(pentafluorophenylcopper)·dioxane complex

(C₆F₅Cu)₂·1,5-cyclooctadiene

[ethanol \(64-17-5\)](#)

[Benzene \(71-43-2\)](#)

[ether,](#)
[diethyl ether \(60-29-7\)](#)

[magnesium,](#)
[magnesium turnings,](#)
[Magnesium metal turnings \(7439-95-4\)](#)

[nitrogen \(7727-37-9\)](#)

[carbon dioxide \(124-38-9\)](#)

[copper \(7440-50-8\)](#)

[copper\(I\) bromide \(7787-70-4\)](#)

[Iodobenzene \(591-50-4\)](#)

[copper\(I\) iodide \(7681-65-4\)](#)

Tetrahydrofuran (109-99-9)

hexane (110-54-3)

1-bromoadamantane (768-90-1)

1,4-dioxane (123-91-1)

PENTAFLUOROPHENYLCOPPER

bromopentafluorobenzene (344-04-7)

pentafluorophenylmagnesium bromide

pentafluorophenyllithium

(pentafluorophenyl)benzene (784-14-5)

decafluorobiphenyl (434-90-2)

1-Bromobicyclo-[2.2.2]octane
(7697-09-8)

1-pentafluorophenylbicyclo[2.2.2]octane

1-pentafluorophenyladamantane,
1-(Pentafluorophenyl)adamantane