The combination of BSTFA (N,O-bis(trimethylsilyl) trifluoroacetamide) and TMCS (trimethylchlorosilane) is the preferred reagent for trimethylsilylation of alcohols, alkaloids, amines, biogenic amines, carboxylic acids, phenols, and steroids. BSTFA will readily silylate a wide range of non-sterically hindered functional groups. TMCS is a silylation catalyst, rarely used alone in analytical applications but typically mixed with other silylation reagents to increase their reactivity (e.g., HMDS+TMCS+pyridine, BSTFA+TMCS, BSA+TMCS) in derivatization. Compounds derivatized with BSTFA+TMCS include opiates, PPC (PCP metabolite) and THC metabolites.

Features/Benefits
BSTFA is very versatile, reacting with a range of polar organic compounds and replacing active hydrogen with a –Si(CH₃)₃ (trimethylsilyl) group. Reacts rapidly and more completely than BSA. TMS derivatives are thermally stable but more susceptible to hydrolysis than their parent compounds.

BSTFA and its by-products (trimethylsilyl trifluoroacetamide and trifluoroacetic acid) are more volatile than many other silylating reagents, causing less chromatographic interference. Hydrogen fluoride, a by-product of silylation with BSTFA (see Mechanism), reduces detector (FID) fouling.

TMCS increases the reactivity of BSTFA (or other silylation reagents). Amides and many secondary amines and hindered hydroxyls, incompletely derivatized by BSTFA alone, can be derivatized by adding 1-20% TMCS to BSTFA.

BSTFA+TMCS has good solvent properties and can function as a silylation reagent without additional solvents. Alternatively, the mixture is very soluble in most commonly used silylation solvents.

Typical Procedure
This procedure is intended to be a guideline and may be adapted as necessary to meet the needs of a specific application. Always take proper safety precautions when using a silylating reagent – consult MSDS for specific handling information. BSTFA + TMCS is extremely sensitive to moisture and should be handled under dry conditions.

Prepare a reagent blank (all components, solvents, etc., except sample), following the same procedure as used for the sample.

1. Weigh 1-10mg of sample into a 5mL reaction vessel. If appropriate, dissolve sample in solvent (see below). If sample is in aqueous solution, evaporate to dryness, then use neat or add solvent.

2. Add excess silylating reagent (e.g., BSTFA + 1% TMCS). The reagent can be used at full strength or with a solvent.* In most applications it is advisable to use an excess of the silylating reagent – at least a 2:1 molar ratio of reagent to active hydrogen. In most cases 1% TMCS in BSTFA is sufficient to achieve the desired derivatization.

3. Allow the mixture to stand until silylation is complete. To determine when derivatization is complete, analyze aliquots of the sample at selected time intervals until no further increase in product peak(s) is observed. Derivatization times vary widely, depending upon the specific compound(s) being derivatized. Many compounds are completely derivatized as soon as they dissolve in the reagent. Compounds with poor solubility may require warming. A few compounds will require heating at 70°C for 20-30 minutes. Under extreme conditions, compounds may require heating for up to 16 hours to drive the reaction to completion. Amino acids may require reaction in a sealed tube or vial. Heat samples cautiously, near the boiling point of the mixture, until a clear solution is obtained.

If derivatization is not complete, the addition of a catalyst, use of an appropriate solvent, higher temperature, longer time and/or higher reagent concentration should be evaluated.

Use a glass injection port liner or direct on column injection when working with silylating reagents. Erratic and irreproducible results are more common when stainless steel injection ports are used. TMS derivatives and silylating reagents react with and are sensitive to active hydrogen atoms. Do not analyze BSTFA + TMCS derivatives on stationary phases with these functional groups (e.g., polyethylene glycol phases). Silicones are the most useful phases for TMS derivatives – they combine inertness and stability with excellent separating characteristics for these derivatives. Nonpolar silicone phases include SPB™-1 and SPB-5. Normal hydrocarbons (carbon-hydrogen analytes with single bonds) are separated by these phases. More polar phases, SPB-1701 and SP-2250, separate carbon-hydrogen analytes that also contain Br, Cl, F, N, O, P, or S atoms or groups. A highly polar cyanopropylphenylsiloxane phase, SP™-2330, is useful for separating fatty acid methyl esters or aromatics.

Nonpolar organic solvents such as hexane, ether, benzene, and toluene are excellent solvents for the reagent and the reaction products; they do not accelerate the rate of reaction. Polar solvents such as pyridine, dimethylformamide (DMF), dimethyl sulfoxide (DMSO), tetrahydrofuran (THF), and acetone are more often used because they can facilitate the reaction. Pyridine is an especially useful solvent because it can act as an HCl acceptor in silylation reactions involving * organochlorosilanes.
Silylation is the most widely used derivatization procedure for GC analysis. In silylation, an active hydrogen is replaced by an alkylsilyl group, most often trimethylsilyl (TMS). Compared to the parent compounds, silyl derivatives generally are more volatile, less polar, and more thermally stable.

Silyl derivatives are formed by the displacement of the active proton in –OH, –COOH, =NH, =N–H, and =SH groups. The general reaction for the formation of trialkylsilyl derivatives is shown above.

The reaction is viewed as a nucleophilic attack upon the silicon atom of the silyl donor, producing a bimolecular transition state. The silyl compound leaving group (X) must possess low basicity, the ability to stabilize a negative charge in the transition state, and little or no tendency for a (p-d) back bonding between itself and the silicon atom.

The ideal silyl compound leaving group (X) must be such that it is readily lost from the transition state during reaction, but possesses sufficient chemical stability in combination with the alkyl silyl group to allow long term storage of the derivatizing agent for use as required. As the formation of the transition state is reversible, the derivatization will only proceed to completion if the basicity of the leaving group X exceeds that of the group it replaces. The ease of derivatization of various functional groups for a given silylating agent follows this order: alcohol > phenol > carboxylic acid > amine > amide. Within this sequence reactivity towards a particular silylating reagent will also be influenced by steric hindrance, hence the ease of reactivity for alcohols follows the order: primary > secondary > tertiary, and for amines: primary > secondary.

The addition of TMCS, which is a relatively weak silyl donor, to BSTFA will enhance the donor strength of the stronger donor, BSTFA. The byproduct of TMCS reactions is HCl.

Toxicity – Hazards – Storage – Stability
BSTFA + TMCS is a flammable, moisture-sensitive liquid. It may irritate eyes, skin, and/or the respiratory system. Store in a brown bottle or amber ampul at room temperature, in a dry, well ventilated area away from ignition sources. Use only in a well ventilated area and keep away from ignition sources.

Properly stored, this reagent is stable indefinitely. Recommended storage conditions for the unopened product are stated on the label. Moisture will decompose both TMS reagents and derivatives. To exclude moisture, Supelco packages this product under nitrogen. If you store an opened container or transfer the contents to another container, exclude moisture, Supelco packages this product under nitrogen. If you

For BSTFA,

\[
X = CF_3 + \text{C} = \text{N} - \text{Si(CH}_3)_3
\]

For TMCS,

\[
X = \text{Cl}
\]

References

Additional Reading
C. Cocolo and C. Delfino Simultaneous Determination By GC of Free and Combined Fatty Acids and Sterols in Grape Musts and Yeasts as Silanized Compounds Food-Hyphen 20 (3) 297-305 (1994).

Ordering Information

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For information about individual reagents, refer to Product Specification 496020 (BSTFA) and 496028 (TMCS).

Microreaction Vessels with Hole Caps and Septa

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Books

Handbook of Derivatives for Chromatography K. Blau and J. Halket Z246220
Handbook of Analytical Derivatization Reactions D.R. Knapp 23561

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