Organic Chemistry I

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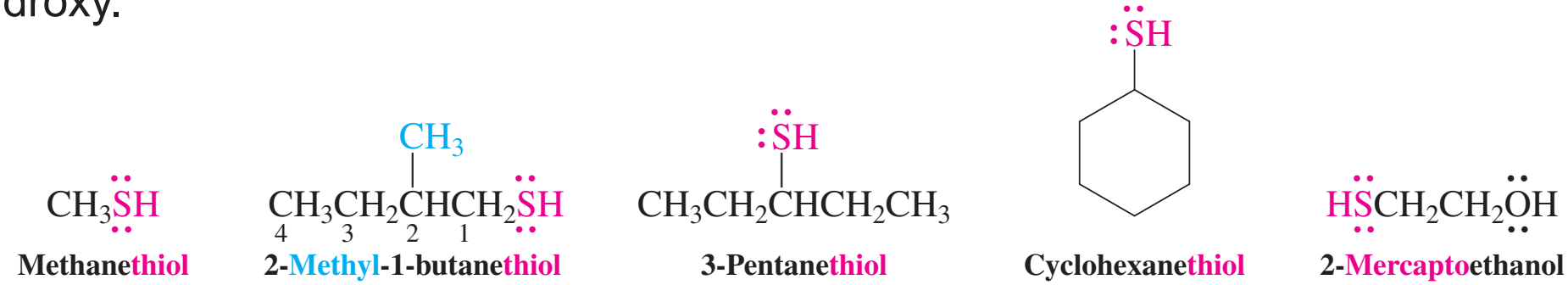
9.10 SULFUR ANALOGS OF ALCOHOLS AND ETHERS

Sulfur is located directly below oxygen in the periodic table, and therefore one might expect the sulfur analogs of alcohols and ethers to behave in a rather similar manner.

The sulfur analogs of alcohols and ethers are thiols and sulfides

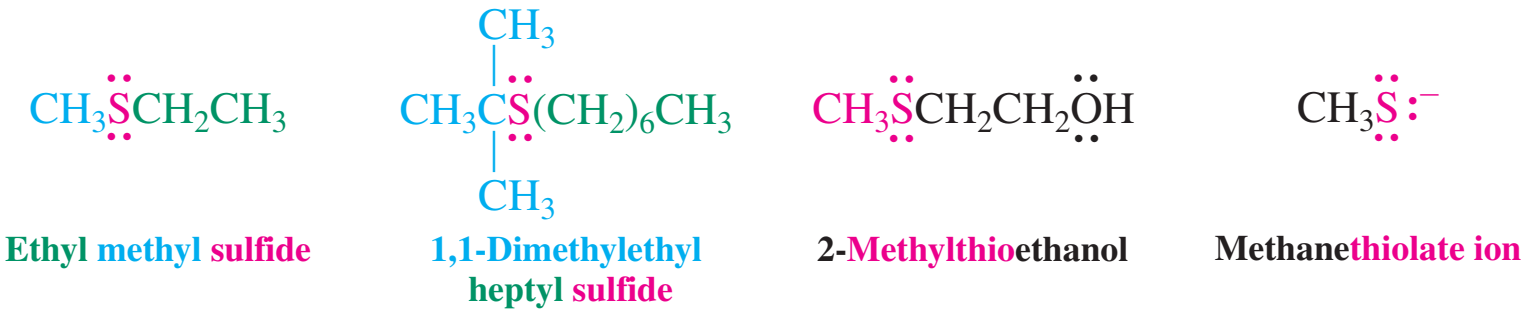
The sulfur analogs of alcohols, R–SH, are called **thiols** in the IUPAC system (*theion,* Greek, brimstone—an older name for sulfur). The ending *thiol* is added to the alkane stem to yield the alkanethiol name.

The SH group is referred to as **mercapto**. Its location is indicated by numbering the longest chain, as in alkanol nomenclature. The mercapto functional group has lower precedence than hydroxy.



The sulfur analogs of ethers (common name, thioethers) are called **sulfides,** as in alkyl ether nomenclature.

The RS group is named **alkylthio,** the RS^- group **alkanethiolate.**



Thiols are less hydrogen bonded and more acidic than alcohols

Sulfur, because of its large size, its diffuse orbitals, and the relatively nonpolarized S–H bond, does not enter into hydrogen bonding very efficiently.

Thus, the boiling points of thiols are not as abnormally high as those of alcohols; rather, their volatilities lie close to those of the analogous haloalkanes.

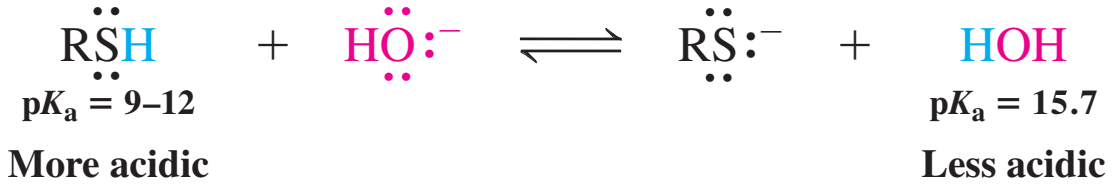
Table 9-2 Comparison of the Boiling Points of Thiols, Haloalkanes, and Alcohols

Compound	Boiling point (°C)
CH_3SH	6.2
CH_3Br	3.6
CH_3Cl	−24.2
CH_3OH	65.0
CH_3CH_2SH	37
CH_3CH_2Br	38.4
CH_3CH_2Cl	12.3
CH_3CH_2OH	78.5

Partly because of the relatively weak S–H bond, thiols are also more acidic than water, with pK_a values ranging from 9 to 12.

They can therefore be more readily deprotonated by hydroxide and alkoxide ions.

Acidity of Thiols



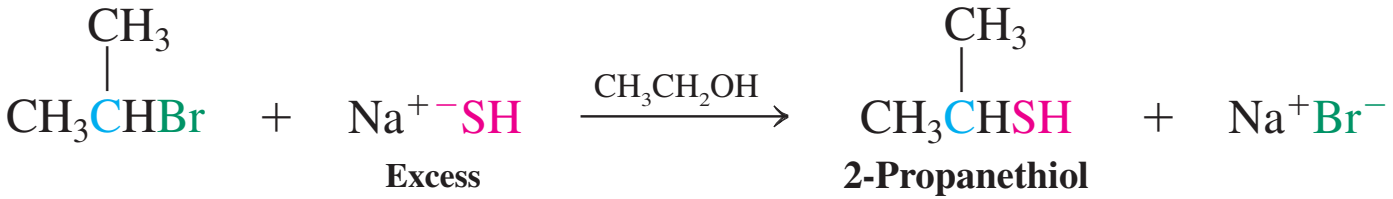
Thiols and sulfides react much like alcohols and ethers

Many reactions of thiols and sulfides resemble those of their oxygen analogs.

The sulfur in these compounds is even more nucleophilic and much less basic than the oxygen in alcohols and ethers.

Thiols and sulfides are readily made through nucleophilic attack by RS^- or HS^- on haloalkanes, with little competing elimination.

A large excess of the HS^- is used in the preparation of thiols to ensure that the product does not react with the starting halide to give the dialkyl sulfide.

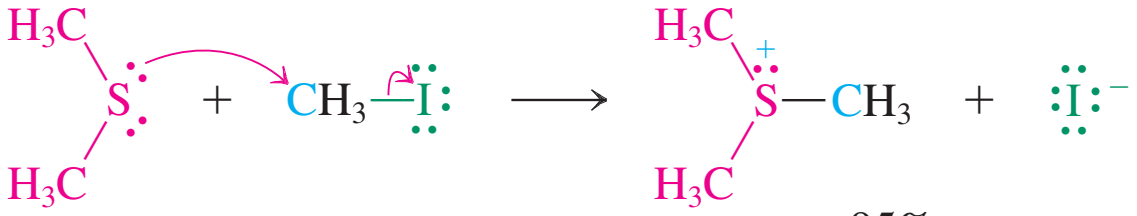


Sulfides are prepared in an analogous way by alkylation of thiols in the presence of base, such as hydroxide. The base generates the alkanethiolate, which reacts with the haloalkane by an S_N2 process.

Because of the strong nucleophilicity of thiolates, there is no competition from hydroxide in this displacement.

Sulfides by Alkylation of Thiols

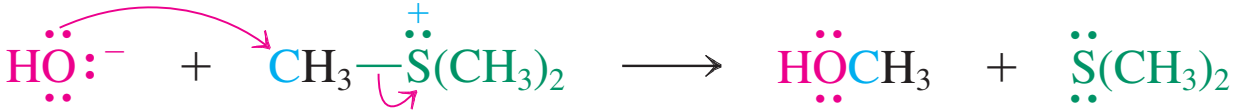
The nucleophilicity of sulfur also explains the ability of sulfides to attack haloalkanes to furnish **sulfonium ions.**



95%

Trimethylsulfonium iodide

Sulfonium salts are subject to nucleophilic attack at carbon, the sulfide functioning as the leaving group.



Valence-shell expansion of sulfur accounts for the special reactivity of thiols and sulfides

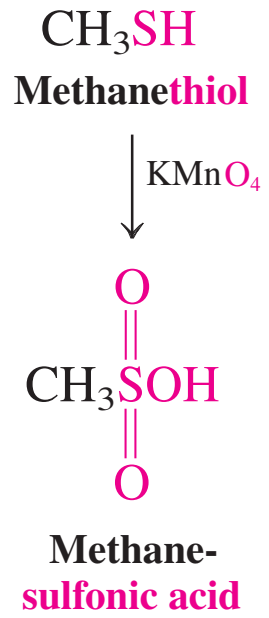
As a third-row element with *d* orbitals, sulfur's valence shell can expand to accommodate more electrons than are allowed by the octet rule.

In some of its compounds, sulfur is surrounded by 10 or even 12 valence electrons, and this capacity enables sulfur compounds to undergo reactions inaccessible to the corresponding oxygen analogs.

For example, oxidation of thiols with strong oxidizing agents, such as hydrogen peroxide or potassium permanganate, gives the corresponding sulfonic acids.

In this way, methanethiol is converted into methanesulfonic acid.

Sulfonic acids react with PCl_5 to give sulfonyl chlorides, which are used in sulfonate synthesis.



More careful oxidation of thiols, by the use of iodine, results in the formation of **disulfides,** the sulfur analogs of peroxides.

Disulfides are readily reduced back to thiols by mild reducing agents, such as aqueous sodium borohydride.

The Thiol–Disulfide Redox Reaction

Oxidation:

$$2\ CH_3CH_2CH_2S{-}H + I_2 \longrightarrow CH_3CH_2CH_2S{-}SCH_2CH_2CH_3 + 2\ HI$$

1-Propanethiol — **Dipropyl disulfide**

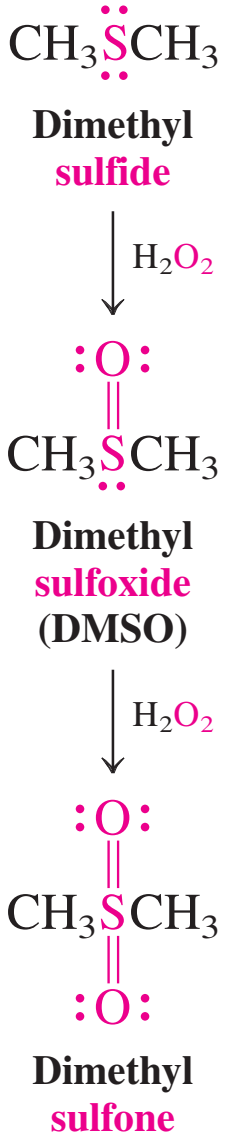
Reduction:

$$CH_3CH_2CH_2S{-}SCH_2CH_2CH_3 + NaBH_4 \xrightarrow{H_2O} 2\ CH_3CH_2CH_2SH$$

Sulfides are readily oxidized to **sulfones,** a transformation proceeding through a **sulfoxide** intermediate.

For example, oxidation of dimethyl sulfide first gives dimethyl sulfoxide (DMSO), which subsequently furnishes dimethyl sulfone.

Dimethyl sulfoxide has already been mentioned as a highly polar nonprotic solvent of great use in organic chemistry, particularly in nucleophilic substitutions.



Disulfide formation by oxidation of thiols and its reverse are important biological processes, although nature uses much milder reagents and conditions than those depicted above.

Many proteins and peptides contain free SH groups that form bridging disulfide linkages. Nature exploits this mechanism to link amino acid chains.

By thus helping to control the shape of enzymes in three dimensions, the mechanism makes biocatalysis far more efficient and selective.