THIONES AS SUPERDIPOLAROPHILES [1]

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Summary According to kinetic measurements, the 1,3-cycloadditions of diphenyl-
diazomethane to thioketones are much faster than those to α,β-unsatu-
rated carbonyl compounds and nitriles previously regarded as *record
dipolarophiles*. The primary cycloadducts are tetrasubstituted 1,3,4-
thiadiazolines which extrude N_2 and furnish thiiranes via thiocarbo-
nyl ylides.

In the 1960s, we studied reactivity scales of dipolarophiles versus
various 1,3-dipoles, but neglected thiones.[2] In the cycloadditions of thioben-
zophenone S-methylide, an electron-rich 1,3-dipole, dipolarophiles with C=S
bond ranked at the top; e.g., the cycloadditions to thiofluorenone and thio-
benzophenone proceed 78,000,000 and 1,150,000 times faster than that to methyl
propiolate.[3] Cycloaddition rate constants of diphenyldiazomethane (1) now con-
firm thiones as front runners among dipolarophilic multiple bonds.
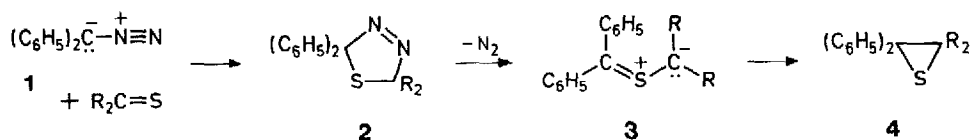
The formation of tetraphenylthiirane (4, R = C_6H_5) from 1 and thio-
benzophenone, discovered by Staudinger and Siegwart,[4] is initiated by a 1,3-
cycloaddition; reaction in dichloromethane at -78°C afforded the crystalline
1,3,4-thiadiazoline 2; R = C_6H_5,[5] which loses nitrogen in a 1,3-dipolar cyclo-
reversion. The thiocarbonyl ylide 3, R = C_6H_5, furnishes 4, R = C_6H_5, on elec-
trocyclization. At room temperature, the bimolecular cycloaddition is the ra-
te-determining step. We secured an analogous reaction course for the other
thiones of Table 1.

The second-order rates were measured by VIS spectrophotometry. The
reactant with the higher molar extinction coefficient ε at the chosen wave-
length (440-628 nm) was used in lower concentration. Reactant ratios were
adapted to ε and k_2 in order to boost extinction changes in the course of the
cycloaddition. The evaluation by linear regression was based on

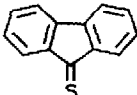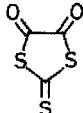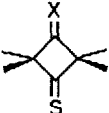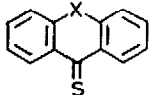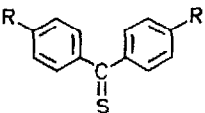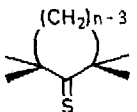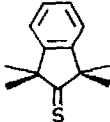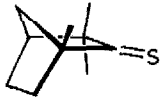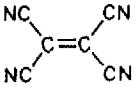$$\frac{1}{c_D^o - c_T^o} \ln\left[\frac{c_T^o}{c_D^o}\left(\frac{c_D^o - c_T^o}{c_T^o} + 1\right)\right] = k_2 t$$

with $E = \epsilon_T c_T + \epsilon_D c_D$ and $c_T = \dfrac{E - \epsilon_D (c_D^o - c_T^o)}{\epsilon_T + \epsilon_D}$

Index T refers to thione and D to diphenyldiazomethane. Correlation coefficients r were >0.996; Table 1 lists averaged k_2 values of 2-6 independent runs.

DMF at 40°C was chosen to allow comparison with kinetic data for the cycloadditions of diphenyldiazomethane to α,β-unsat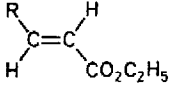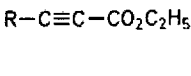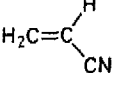urated carbonyl compounds and nitriles.[6] 2-Thioxo-1,3-dithiolane-4,5-dione and tetracyanoethylene (for comparison) are not stable to DMF and their cycloaddition rates were measured in $CHCl_3$. Thiobenzophenone reacts with $\underline{1}$ in DMF 2.5 times faster than in $CHCl_3$.

Table 1. Rate constants for the 1,3-cycloadditions of diphenyldiazomethane to thioketones and some electrophilic alkenes and alkynes in DMF (*$CHCl_3$) at 40°C; $10^3 k_2$ ($M^{-1} s^{-1}$)

The cycloaddition rate constants of the thiones (Table 1) stretch over five powers of ten with thiofluorenone at the top and the highly sterically hindered thiofenchone at the bottom. Thiofluorenone exceeds thiobenzophenone 110fold. Diphenyldiazomethane is still an electron-rich 1,3-dipole;

not astonishing, therefore, that the introduction of electron-releasing sub-
stituents as 4-OCH$_3$ and 4-N(CH$_3$)$_2$ into thiobenzophenone decreases the dipola-
rophilic activity by factors of 27 and 2,300. For the same reason, thioxanthi-
one and xanthione lag behind thiobenzophenone 20 and 185fold.

In contrast to cycloalkanethiones, their vic-tetramethyl derivatives
are stable in the monomeric state (and nearly odorless). The dependence of the
cycloaddition constants on ring size is controlled by the change of conforma-
tional strain, and is inverse to the one observed in solvolysis of tertiary
halides.

The cycloaddition rates of thioketones dwarf those of α,β-unsaturated
carbonyl compounds and nitriles which had previously led the list of dipolaro-
philes in their reactions with diazoalkanes.[6,7] Thiobenzophenone surpasses
acrylic and propiolic ester 1,260 and 1,000fold. Even tetracyanoethylene fails
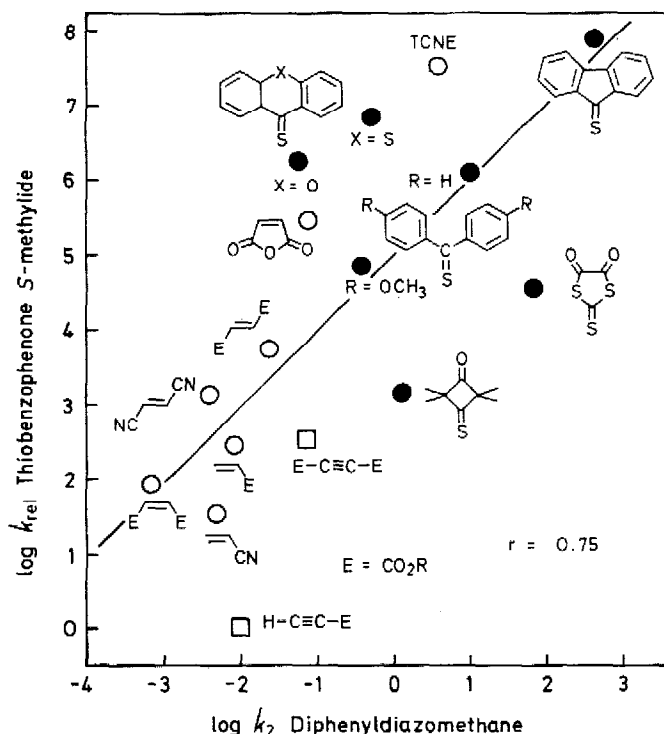to reach 1% of the thiofluorenone rate.

Fig. 1. Plot of relative rate constants of thiobenzophenone S-methylide (3,
R = H, THF, -45°C) versus k_2 of diphenyldiazomethane in DMF at 40°C

The plot of log k (Fig. 1) reveals that the reactivity sequences of
thiobenzophenone S-methylide (3, R = C$_6$H$_5$) and diphenyldiazomethane (1) are

not the same. The deviations from linearity are substantial, but the thiones' being superior as dipolarophiles is indisputable. Thermodynamic and kinetic factors are contributing.

Thermochemical values on thiones are limited to carbon disulfide, hardly a suitable model. According to high quality ab initio calculations (MP4/6-31G*), the π bond energies of C=S, C=C, and C=O sacrificed in cycloadditions amount to 56, 70, and 93 kcal mol^{-1}.[8] Kinetic phenomena are involved, too. Conjugated double bonds react faster in concerted cycloadditions than isolated ones, despite a reaction enthalpy which is diminished by the loss of conjugation energy. Polarity and polarizability play an important role. A calculation (3-21G*) showed the polarity of the double bond in $H_2C=S$ to be negligibly small; natural population analysis indicated the CS σ bond being polarized 0.57:0.43 towards C and offset by a polarization of the π bond 0.43:0.57 towards S.[9] High *polarizability* of the CS double bond may well be the major rate-increasing factor.

The rate constants of thiobenzophenone S-methylide at -45°C are much higher than those of diphenyldiazomethane at +40°C. The slope of 1.01 for the line in Tab. 1 indicates the same selectivity of the two 1,3-dipoles, but the electrophilic alkenes alone determine a line with tg α = 1.64. According to Sustmann's PMO model, the faster 1,3-dipole should be the more selective.[10]

ACKNOWLEDGMENT

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