THE DECOMPOSITION OF SULPHONYL-HYDRAZONE SALTS---I

MECHANISM AND STEREOCHEMISTRY

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Abstract—The rate-determining stage in the Bamford-Stevens reaction is shown to be a unimolecular elimination from the anion of the sulphonylhydrazone. This gives, apparently in all cases, a secondary aliphatic diazo-compound, which then undergoes thermal decomposition. Such diazo-compounds may decompose in solvents rich in available protons, such as were originally used by Bamford and Stevens, mainly via the diazonium cation, and the reaction then degenerates into a variant of the normal deamination reaction. Acetamide is a convenient solvent for minimizing this effect, and gives higher yields of hydrocarbon products.

BAMFORD and Stevens¹ recently described a reaction in which toluene-p-sulphonylhydrazones were heated with the sodium derivative of ethylene glycol, in glycol, giving olefines. Skeletal rearrangements were observed^{1,2} of a type that might be useful in the synthesis of some terpenoid systems, and in any case are of interest in view of the basic reaction medium, unfavourable to carbonium-ion intermediates.

We now describe experiments designed to characterize this potentially useful reaction.

Since sulphinate anions are formed, electron-attracting groups were expected to increase its rate. Accordingly, attempts were made to prepare hydrazides of trifluoromethane- and 2,4-dinitrobenzenesulphonic acids, using the corresponding fluoride³ and chloride,⁴ repectively. With hydrazine, the former gave only gaseous products, and the latter, according to conditions, gave either the hydrazine arylsulphonate or 2,4-dinitrophenylhydrazine. Methanesulphonylhydrazine, however, was readily obtained, and proved on the whole a more satisfactory reagent (though actually rather slower reacting) than the aromatic derivative.

Acetone methanesulphonylhydrazone has pK_a ca. 8.5, as found by potentiometric titration. Accordingly, sulphonylhydrazones are very largely ionized under the basic conditions used for the reaction. The decomposition of the methane and p-toluene derivatives of cyclohexanone and camphor was studied kinetically, using a gas-burette to measure the evolved nitrogen; although results of high accuracy were not sought, good first-order plots were obtained, and rates were consistent from one run to another and independent of the surface area of the solid phase in contact with the solution.⁵ A fourfold change in initial alkali concentration had no effect on the rate; as the hydrazone was present essentially as the anion, a reaction rate proportional to

¹ W. R. Bamford and T. S. Stevens, J. Chem. Soc. 4735 (1952).

² J. Elks, G. H. Phillipps, D. A. H. Taylor and L. J. Wyman, J. Chem. Soc. 1739 (1954). ³ T. Gramstad and R. N. Haszeldine, J. Chem. Soc. 173 (1956).

⁴ H. Meerwein, G. Dittmar, R. Göllner, K. Hafner, F. Mensch and O. Steinfort, Chem. Ber. 90, 841 (1957).

⁵ M. S. Newman and E. G. Caflisch, J. Amer. Chem. Soc. 80, 862 (1958).

[anion] [H⁺] is ruled out. The reaction may thus be classed as of mechanism E_1cb . There are, however, three general ways in which the conjugate anion of a sulphonylhydrazone might break down, in an initial, rate-determining stage:-

- (a) to give an aliphatic diazo-compound, plus sulphinate;
- (b) to give a carbene, plus either nitrogen and sulphinate or an unstable anion $N = N \cdot SO_2 R$, or
- (c) to give an olefine directly, most plausibly via a cyclic transition state in which a β -hydrogen atom is removed by the departing sulphinate residue.

There is no doubt that mechanism (a) is often followed, as the aliphatic diazocompounds can frequently be isolated. Bamford and Stevens¹ rejected the view that this was always the chosen route as the camphor derivative gave optically active camphene, whereas diazocamphane had been stated⁶ to give tricyclene (which might decompose to camphene but must then give optically inactive material). We therefore chose cyclohexanone and camphor for kinetic study. Route (b) would require, in all probability, that the camphor derivative would react faster, because the formation of a carbene should be anchimerically assisted,⁷ while route (c) would imply that the camphor derivative, apparently being unable to use the two β -hydrogen atoms to form the cyclic transition state for steric reasons, had to employ a different route and would thus be slower than the cyclohexanone derivative. In point of fact, the camphor and cyclohexanone derivatives reacted at virtually the same rate, and had, within experimental error, the same activation energies. This strongly suggests that the ratedetermining stage precedes that at which skeletal rearrangement takes place in the camphor derivative; that is, it supports mechanism (a) even in this case. Accordingly, the evidence from product composition was re-examined, using gas-liquid chromatography. This at once revealed that the product from camphor was not pure camphene, but an 80 : 20 mixture with tricyclene. On the other hand, Meerwein and van Emster report^{6a} the formation, along with tricyclene, of a small amount of camphene when diazocamphane decomposes. If it could be shown that changing the solvent markedly changed the camphene: tricyclene ratios in either reaction, the negative evidence against route (a) would be invalidated. As Table 1 shows, this was readily done.

In addition, the finding that diazocamphane and camphor methane and p-toluenesulphonylhydrazones gave these products in the same ratio would constitute positive evidence for such a mechanism. An attempt was made to use this test, employing 2-ethoxyethanol as solvent. Diazocamphane was readily obtained from N-nitroso-Ncarbethoxybornylamine and sodium β -ethoxyethoxide, ^{6b} and allowed to decompose at various temperatures.

The tricyclene percentage rose with the temperature (Table 2), but it could not be raised to that obtained in the very slow reaction at high temperatures from the methanesulphonylhydrazone. The values attributed to temperatures of 100° and 135° were in reality representative of lower temperatures, as the rate of decomposition was comparable to that of heating; however, in spite of these limitations, we think that the results of Table 2 do add useful confirmatory evidence. Under all conditions investigated the methane- and toluenesulphonylhydrazones gave identical results.

⁴⁶ H. Meerwein and K. van Emster, Ber. Dtsch. Chem. Ges. 53, 1815 (1920); ^b U. Heubaum and W. A. Noyes, J. Amer. Chem. Soc. 52, 5070 (1930). ⁷ S.Winstein, B. K. Morse, E. Grunwald, H. W. Jones, J. Course, D. Trifan and H. Marshall, J. Amer.

Chem. Soc. 74, 1127 (1952).

Hydrazone	Solvent	Temperature	% Tricyclene
		<u> </u>	! !
Ts	Glycerol	132°	12
Ts	Ethylene glycol	124	15
Ts	Ethylene glycol	139	20
Ms	Ethylene glycol	139	21
Ts	Ethylene glycol	195	23
Ts	Trimethylene glycol	132	46
Ms	Diethylene glycol	139	53
Ts	Ethanolamine	132	91
Ts	2-Ethoxyethanol	132	92
Ms	Acetamide	181	. 97
Ts	Acetamide	181	97
Ms	Acetamide	156	98
Ts	Acetamide	156	99

TABLE 1. PRODUCT FROM CAMPHOR SULPHONYLHYDRAZONE DECOMPOSITION

The following abbreviations are employed throughout: Cm = camphor, Hx = cyclohexanone, Ts = toluene-p-sulphonyl, Ms = methanesulphonyl.

It remains to explain (a) the solvent effects on the rate of the rate-determining initial decomposition, and (b) the fact that the decomposition of diazocamphane gives the two hydrocarbons in a ratio that varies so much with solvent. Formally, the elimination involves an increase in polarity in the transition state:-

and would be expected to proceed faster in polar solvents. Actually the reverse is the case; but perhaps the system is so complex, in that in all stages hydrogen-bonded species predominate, that predictions would be intrinsically unreliable.

TABLE 2. VARIATION OF PRODUCT COMPOSITION WITH DECOMPOSITION TEMPERATURE FOR DIAZOCAMPHANE IN 2-ETHOXYETHANOL

Temperature	20	52	100	135°	
% Tricyclene	36	38	56	65%	
78 1110 June		50			

The effect of solvent upon product composition is more interesting; generally, the formation of camphene is promoted by a high concentration of acidic protons (Cram et al.8 have observed a similar effect on the steric course of aliphatic electrophilic substitution). Apparently-NH-groups are ineffective in this sense. The

⁸ D. J. Cram, Private Communication.

simplest explanation is that a diazo-compound can decompose either without or with acid catalysis:----

$$R_{s}CH_CR=\stackrel{+}{N}=\stackrel{-}{N}\xrightarrow{\longrightarrow} R_{2}C_CHR + N_{s}$$

$$H^{+}$$
or
$$R_{s}CH_CR=\stackrel{+}{N}=\stackrel{-}{N}\xrightarrow{\longrightarrow} [R_{2}CH_CHR_\stackrel{+}{N}\equiv N] \longrightarrow [R_{2}CH_\stackrel{+}{C}HR] + N_{s}$$

$$-H^{+}$$

$$R_{3}C=CHR, etc$$

In proton-rich solvents, the latter course predominates, and the sulphonyl-hydrazone decomposition then leads to products similar to those obtained in deamination with nitrous acid; whereas in, e.g. acetamide, most of the diazo-compound decomposes as such. In point of fact bornylamine does give mainly camphene, rather than tricyclene, with nitrous acid;⁹ however, one would anticipate that if diazonium ions were indeed intermediates in, e.g., ethylene glycol, substitution products would be formed along with olefines. As Bamford and Stevens¹ reported a virtually quantitative yield of cyclohexene from the toluenesulphonylhydrazone of cyclohexanone in ethylene glycol, we repeated their experiment. They isolated the cyclohexene after transformation, via the dibromide, to the picrate of piperidinocyclohexene. We did not use this method, or try to weigh the volatile hydrocarbon, but noted that, either under our preferred conditions (methanesulphonylhydrazone at 156°) or theirs (toluene-psulphonylhydrazone at ca. 190°), β -cyclohexyloxyethanol was isolable in yields of 20-35 per cent. Although this implies a lower substitution/elimination ratio than that found for aqueous deamination at room temperature, the difference is no larger than would be expected.

EXPERIMENTAL

Treatment of 2,4-dinitrobenzenesulphonyl chloride with hydrazine hydrate. 2,4-Dinitrobenzenesulphonyl chloride⁴ (5·3 g, 0·02 mole) in warm ethanol (25 ml) was added dropwise to an ice-cooled, well-shaken solution of hydrazine hydrate (2·5 g, 0·05 mole) in ethanol (25 ml). After standing 2 hr the precipitate was filtered off, and recrystallized from ethanol, giving hydrazine 2,4-dinitrobenzenesulphonate (1·4 g, m.p. (decomp) 155-160°), freely soluble in water. (Found: C, 25·8; H, 3·0; N, 20·4. C₄H₈O₇N₄S requires: C, 25·7; H, 2·9; N, 20·0%).

Treatment of 2,4-dinitrobenzenesulphonyl chloride with anhydrous hydrazine. Anhydrous hydrazine (0.48 g, 0.015 mole) in N,N-dimethylformamide (5 ml) was added to the sulphonyl chloride (1 g, 0.0038 mole) in N,N-dimethylformamide (10 ml), the mixture turning deep red. Water (20 ml) was added, and after standing 1 hr, the product (0.53 g, m.p. 198°) was filtered off. This product was shown by mixed m.p., and comparison of infra-red spectra, to be 2,4-dinitrophenylhydrazine.

Methanesulphonyl hydrazine. To a vigorously stirred solution of hydrazine hydrate (108 g) in ethanol (50 ml) a solution of methanesulphonyl chloride (96 g) in ethanol (50 ml) was added dropwise (about 60 min), the reaction vessel being cooled in running water (12°). After stirring a further 15 min, ethanol was removed under reduced pressure until a homogeneous solution was obtained. This solution was acidified with phosphoric acid (to pH 5) to hold in the aqueous phase the unchanged hydrazine, and the required hydrazine was separated by continuous ether extraction (96 hr). On removal of ether, a syrup (n_D^{14} 1·497) was obtained, which slowly solidified on seeding (63·5 g, 68%, m.p. 49°). Recrystallization from ethyl acetate gave cubic crystals, m.p. 50·5°. (Found: C, 11·5; H, 5·5; N, 25·7. CH₆O₂N₉S requires: C, 10·9; H, 5·5; N, 25·4%). (Seed crystals were obtained only after several weeks at 15°; decomposition prevented distillation even at 10⁻³ mm.)

* Von W. Huckel and F. Nerdel, Liebigs Ann. 528, 57 (1937).

Acetone methanesulphonylhydrazone. Acetone (3 ml) was added to a solution of methanesulphonylhydrazine $(2 \cdot 2 \text{ g})$ in hot water (5 ml). On cooling, acetone methanesulphonylhydrazone $(1 \cdot 8 \text{ g}, 61 \%)$ separated. Recrystallization from ethanol gave needles, m.p. 120° . (Found: C, $32 \cdot 2$; H, $6 \cdot 7$.

 $C_4H_{10}N_3O_3S$ requires: C, 32.0; H, 6.7%). Titration of an N/100 aqueous solution of the sulphonylhydrazone with N/10 sodium hydroxide solution, using a Cambridge pH meter, gave the approximate value of pK_a as 8.5.

Camptor methanesulphonylhydrazone. Using the method of Bamford and Stevens,¹ methanesulphonylhydrazine (6·1 g), camptor (4·4 g) and 1% ethanolic hydrochloric acid (25 ml) were heated under reflux for 30 min, and cooled, when the sulphonylhydrazone separated (6·3 g, 60%, m.p. 126°). Recrystallization from ethanol gave needles, m.p. 129° (Found C, 54·1; N, 8·2; N, 11·4. $C_{11}H_{20}N_2$ O₂S requires: C, 54·05; H, 8·25; N, 11·5%).

Cyclohexanone methanesulphonylhydrazone. Methanesulphonylhydrazone (11 g) was dissolved in hot ethanol (50 ml) and cyclohexanone (10 ml) was added. On cooling and seeding, the sulphonyl-hydrazone separated (10.75 g, 60%). Recrystallization from ethanol gave needles, m.p. 103-104 (Found: C, 44.6; H, 7.4; N, 14.7. $C_7H_{14}N_2O_2S$ requires: C, 44.2; H, 7.4; N, 14.7%).

Kinetic investigations. For each run, the sulphonylhydrazone (ca. 0.003 mole) was added to 10 ml of reagent, this being, unless otherwise specified, a 1.3 N solution of sodium in ethylene glycol, the glycol having been purified by distillation over sodium. The reaction mixture was contained in a test-tube fitted with ground-glass joint, and was connected, via a water-condenser, to a simple gasburette. The reaction vessel was heated by vapour-bath. First-order rate constants and activation energies were determined graphically, and are probably reliable to -5% and +2 kcal, respectively.

In addition to the results summarized in Table 3, the following observations were made: The rate of decomposition of camphor toluene-*p*-sulphonylhydrazone at 139° is given by $10^4k = 21 \pm 1 \text{ sec}^{-1}$, when treated with 1.3 N reagent, 0.65 N reagent, or 0.325 N reagent; and the rate remains within these limits whether the reaction is carried out in the absence of added surface area, or in a tube packed with porous pot. In formamide solution, no visible reaction took place at 180°, whilst in 2 N aqueous sodium hydroxide, heated to ca. 135° in an autoclave, several hours were needed for appreciable reaction to take place.

Hydrazone		$10^4 k (sec^{-1})$				E	
	Solvent	124°	132°	139°	156°	165°	(kcal/mol)
HxMs	Ethylene glycol			3.4	24	48	28
HxTs	Ethylene glycol		15	26	120		31
CmMs	Ethylene glycol		4.9	8.6	34	85	30
CmTs	Ethylene glycol		12	21	78	160	28
CmTs	Amyl alcohol	8.3	18				
CmTs	2-Methyl cyclo- hexanol				250		

TABLE 3.	REACTION	RATES
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Abbreviations as in footnote to Table 1.

Product composition investigations. The camphor sulphonylhydrazone (0.0015 mole) was mixed with a 1.3 N solution of sodium in the specified solvent (5 ml), the solvent having been purified by distillation over sodium. The reaction mixture was heated by vapour-bath until nitrogen evolution ceased. After cooling, water (5 ml) and pentane (2 ml) were added. After shaking, a portion of the pentane layer was withdrawn, and submitted to gas-liquid chromatography. By using a solution of silver nitrate in diethylene glycol¹¹ as stationary phase a clear separation was obtained between camphene and tricyclene. Early runs were carried out using a katharometer detector, but a flame ionisation detector was used for the later work, thus giving a higher sensitivity, and less trouble from the relative volatility of diethylene glycol at 80°, the column temperature used. In either case, it was assumed that the area under the peak should be approximately proportional to the amount of hydrocarbon present, a reasonable assumption for isomeric compounds.

Diazocamphane. Ethyl bornylcarbamate¹⁰ (4 g) in dry ether (20 ml) was cooled to -15° , and nitrogen sesquioxide (generated by the action of conc. nitric acid on arsenious oxide) was passed in until the solution was strongly coloured green. This solution was kept at -15° for a further 2 hr; it was then washed rapidly with water and saturated sodium hydrogen carbonate solution at 0°. It was immediately cooled to -60° , and the precipitated ice filtered off. After addition of 2-ethoxyethanol (15 ml), the required solvent for the next stage, the ether was removed at 0° under reduced pressure, and the resulting solution of the N-nitrosourethane kept at -60° until required.

To about 2.5 ml of this solution was added a 1.3 N solution of sodium β -ethoxyethoxide in 2-ethoxyethanol (2.5 ml). The solution became cherry-red, indicating the formation of diazocamphane. This was decomposed *in situ* by heating rapidly to the appropriate temperature, and maintaining it there until the colour had faded. After cooling, water (5 ml) and pentane (2 ml) were added, and a sample of the pentane extract used for the G.L.C. process. The results are outlined in Table 2.

 β -Cyclohexyloxyethanol. Cyclohexanone methanesulphonylhydrazone (7.55 g) was dissolved in 1.3 N sodium in ethylene glycol solution (75 ml), and the mixture was heated by oil-bath (maximum bath-temperature 175°) until nitrogen evolution subsided (ca. 15 min). After cooling, water (100 ml), was added, and the mixture extracted with ether (25 + 4 × 15 ml). The extract was washed, dried and evaporated on the water-bath and the residue was distilled under reduced pressure, the β -cyclohexyloxyethanol (2.0 g, 35%, n_{20}^{20} 1.4630) distilling at 93–95° (11 mm). (Found: C, 66.5; H,11.1. C₈H₁₈O₂ requires: C, 66.6; H, 11.2%).

¹⁰ A. Neville and R. H. Pickard, J. Chem. Soc. 686 (1904).

¹¹ B. W. Bradford, D. Harvey and D. E. Chalkey, J. Inst. Pet. 41, 80 (1955).