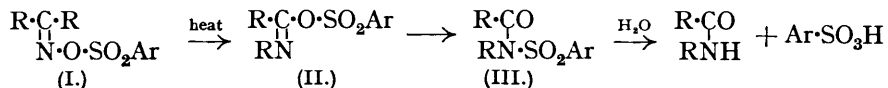


197. Studies of the Beckmann Change. Part I. The Spontaneous Rearrangement of Oxime Picryl Ethers.

By ARTHUR W. CHAPMAN and CYRIL C. HOWIS.

ALTHOUGH the Beckmann transformation of oximes has been known for many years, the precise mode of action of the various reagents employed to bring it about has remained obscure.

An observation of special interest, however, was made by Kuhara and his co-workers (Kuhara, Matsumiya, and Matsunami, *Mem. Coll. Sci. Kyoto*, 1914, **1**, 105; Kuhara and Watanabe, *ibid.*, p. 349; Kuhara, Agatsuma, and Araki, *ibid.*, 1917, **3**, 1), who found that, when the arylsulphonyl esters of certain ketoximes (I) were heated alone or in inert solvents, they underwent rearrangement to substances that could be hydrolysed to the corresponding amides. Kuhara pointed out that this rearrangement was a Beckmann change which differed from the classical type only in being apparently independent of a reagent, and suggested that in many cases the function of the reagent employed to bring about the transformation of an oxime was essentially to produce an ester, which, if derived from a sufficiently strong acid, then underwent spontaneous rearrangement (compare also Sluiter, *Rec. trav. chim.*, 1905, **24**, 372; Meisenheimer and Theilacker, Freudenberg's "Stereochemie," Leipzig, 1933, p. 1013). To the rearrangement products of the sulphonic esters Kuhara assigned the formula (II), but as this represents an imino-ester derived from a strong acid, and such compounds are known to undergo intramolecular change to the *N*-acyl compounds with extreme ease, formula (III) represents the more probable structure (compare Mumm, Hesse, and Volquartz, *Ber.*, 1915, **48**, 379; Chapman, J., 1927, 1743, and later observations in this paper).

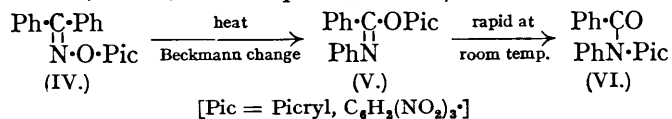


A further investigation of this spontaneous change seemed very desirable, for, if the Beckmann transformation could be studied in the absence of the complicating factors introduced by the reagents, some elucidation of its mechanism might be possible. Search was first made for a suitable oxime derivative. The transformation products from the sulphonic esters were oily substances which did not admit of complete identification, and

* Prentice (*Annalen*, 1896, **292**, 275) described the chlorohydrin obtainable from $\beta\beta$ -dimethylacrylic acid as a liquid having the constitution $\text{CMe}_2(\text{OH})\cdot\text{CHCl}\cdot\text{CO}_2\text{H}$; no isomeric chlorohydrin or neutral product is mentioned.

for detailed investigation it was necessary to find compounds that underwent a similar change but yielded crystalline products which could be identified with certainty, tested for purity, and estimated quantitatively. Although the *benzoyl* ester of benzophenone-oxime was rearranged to dibenzanilide when heated above 200°, yet considerable decomposition accompanied the change; the compounds desired were, however, finally discovered in the oxime picryl ethers.

Benzophenoneoxime picryl ether (IV) was transformed almost explosively at its m. p. into benz-*N*-picrylanilide (VI), and, in a suitable solvent, complete change took place, the only by-product being a trace of coloured substance too small to affect the m. p. of the benz-*N*-picrylanilide or to be detected in a solubility determination. *N*-Phenylbenziminopicryl ether (V) is no doubt an intermediate product but is too unstable to be isolated; reactions that should lead to its formation yield benz-*N*-picrylanilide even at room temperature (compare Mumm, Hesse, and Volquartz, *loc. cit.*).



The *picryl* ether of acetophenoneoxime yielded pure *acet-N-picrylanilide*, and the picryl and trinitro-*m*-tolyl ethers of a number of other ketoximes underwent a similar rearrangement.

To complete the qualitative observations, the transformation of a pair of stereoisomeric oxime picryl ethers was examined. When treated with phosphorus pentachloride and then with water, the α -oxime of *p*-chlorobenzophenone yields *p*-chlorobenzanilide, and the β -compound benz-*p*-chloroanilide with a little *p*-chlorobenzanilide (Hantzsch, *Ber.*, 1891, 24, 56). The picryl ethers of these oximes were found to undergo rearrangement to *p*-chlorobenz-*N*-picrylanilide and benz-*N*-picryl-*p*-chloroanilide respectively. The relationship between the spatial configuration of an oxime and the constitution of its change product is therefore the same for the oxime itself and for its picryl ether, and the conclusion is inevitable that the spontaneous rearrangement of the oxime picryl ethers is a true Beckmann change.

Measurements of the rates of change of the picryl ethers of benzo- and aceto-phenone-oximes were made in several solvents at temperatures from 40° to 116°. The lability of *N*-phenylbenziminopicryl ether (V) ensured that the values obtained represented the speeds of the first (Beckmann) stage.

The rearrangement followed a course represented by the formula for a unimolecular reaction, the following being a typical series of observations:

Benzophenoneoxime picryl ether in chloroform at 50°.

Time (min.)	30.5	60	90	120	180	240
% Changed	25.5	41	56	66	82	90
$k \times 10^3$	4.2	3.8	3.95	3.9	4.15	4.1; mean 4.0

The values of the velocity constants obtained are given in the following tables, time being expressed in minutes with Briggsian logarithms.

*Values of $k \times 10^3$ for the rearrangement of benzophenoneoxime picryl ether into benz-*N*-picrylanilide.*

Solvent.	Temp.	40°.	45°.	50°.	55°.	60°.	70°.	75°.	79°.	85°.	99.7°.
CCl ₄								0.83		2.5	12.6
				0.24			3.1	6.0†	8.8		
CHCl ₃		1.18	2.3	4.0	6.2	10.5					
			1.9	3.9	6.25	9.0§					
				4.0*	4.0†						
C ₂ H ₄ Cl ₂		2.25		7.75¶							
				8.35							

* Ether twice reppd. from acetone-alcohol.

† Ether reppd. from CCl₄ and light petroleum.

‡ Ether reppd. from CHCl₃ and light petroleum, solvent purified by method of Lowry and Trill.

§ Old sample of CHCl₃ containing a large quantity of COCl₂.

|| At 39.7°.

¶ At 49.7°.

Values of $k \times 10^3$ for the rearrangement of acetophenoneoxime picryl ether into acet-N-picrylanilide.

Solvent.	Temp.	60°.	65°.	75°.	85°.	99.1°.	99.3°.	116°.
CCl ₄								
C ₆ H ₆					0.75	3.3	0.34	1.7
CHCl ₃				1.7	5.0			
C ₂ H ₄ Cl ₂			1.77	5.3	5.0†			
CH ₃ CN ...	2.7*				15.2			

* Approximate only, change accompanied by some decomposition.

† Ether repptd. from CHCl₃ and light petroleum; solvent reperfired.

The values of $\log k$ when plotted against $1/T$ fell upon a straight line in every case in which measurements were made at three or more temperatures, except for benzophenone-oxime picryl ether in chloroform for which the relationship was only approximate. The values calculated for the energies of activation with both compounds in all the solvents were between 25.5 and 28.5 kg.-cal. per g.-mol. with the same exception for which the most probable value was approximately 23 kg.-cal.

The rearrangement did not appear to require an external catalyst (except in so far as the solvent may be regarded as such) or to depend on the action of light, for not only was the unimolecular law obeyed throughout the whole course of the transformation, but the rates of change were not affected by repeated purification of the picryl ethers or of the solvents, by the introduction into the solution of sufficient broken glass to double the effective area of the vessel, or by carrying out the transformation in a blackened tube. Exposure of a benzene solution of benzophenoneoxime picryl ether to the light of a mercury-vapour lamp caused some decomposition of the material but no rearrangement.

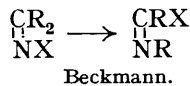
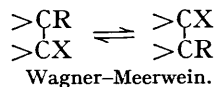
The effect of the solvent on the rate of change, however, is striking, and the velocities increase in the same order as the cohesions, the dielectric constants, and the dipole moments of the solvents. They do not appear to be connected with the relative solubilities of the ethers in the different solvents, but in benzene solutions the rate of change may also be affected by solvation.

At this stage it is not possible to state the mechanism of the rearrangement precisely, but the conception of the transformation as an intramolecular exchange of positions by the hydrocarbon radical and the picrate group is fully consistent with the ascertained facts. It might be expected that such a change would be facilitated by the presence of polar solvent molecules even though the preliminary dissociation within the rearranging molecule never reached the stage of true ionisation.

Suggestions (cf. Kuhara and Todo, *Mem. Coll. Sci. Eng. Kyoto*, 1910, **2**, 387; Stieglitz, private communication in Porter, "Molecular Rearrangements," New York, 1928, p. 42) involving the preliminary dissociation of the molecule into two ions introduce both stereochemical and valency difficulties, and appear inherently improbable. Provisionally, therefore, the rearrangement is regarded as intramolecular.

It may nevertheless be noted that it is only the esters of strong acids (of which picric acid is one) that undergo the Beckmann rearrangement spontaneously at moderate temperatures. Although probably not ionised, these esters lie on the border-line between completely covalent substances and salts, and so conform with the opinion expressed by Brady and Dunn (J., 1926, 2412) that one condition requisite for a Beckmann change is that "the rearranging compound must be a salt or salt-like substance."

The study of these oxime esters has revealed the close analogy, which does not seem to have been previously pointed out, between the Beckmann change and the Wagner-Meerwein rearrangement (compare for latter change, Meerwein and van Emster, *Ber.*, 1922, **55**, 2500; Meerwein and Wortmann, *Annalen*, 1924, **435**, 190; Meerwein, Hammel, Serini, and Vorster, *ibid.*, 1927, **453**, 16). Both of these transformations, reduced to their simplest terms, involve an exchange of positions on two adjacent atoms by a hydrocarbon radical (R) and a potentially anionic group (X):



The exchange takes place between two carbon atoms in one case and between a carbon and a nitrogen atom in the other, but in both cases the transformation occurs spontaneously under suitable conditions, the rate of change is greatly increased by the substitution of a more polar solvent for a less polar one, and the more negative the group X (as measured by the strength of the acid HX) the more readily does the rearrangement take place. It is possible that the compounds which undergo the Wagner-Meerwein rearrangement may actually reach the stage of ionic dissociation, but the evidence for a true ionisation is indirect, being based on effects of change of solvent and of X on the rate of transformation which are similar to those which have now been found for the Beckmann change, and the facts could also be accounted for if the rearrangement were intramolecular. In both cases, however, the compounds that rearrange spontaneously belong to the class of salt-like esters of strong acids. It therefore seems probable that these two changes are examples of the same phenomenon, being essentially similar in mechanism, and differing mainly in the system in which migration takes place.

Kuhara's observations on the oxime sulphonic esters and some preliminary measurements made in the course of the present research have shown that the ease of rearrangement is greatly modified by substitution in all parts of the oxime ester molecule, and a systematic study of these effects is being undertaken.

EXPERIMENTAL.

All analyses were micro-determinations carried out by Dr. A. Schoeller.

Benzophenoneoxime benzoyl ester was prepared from the oxime by the Schotten-Baumann reaction; needles from alcohol, m. p. 99° (Found: C, 79.3; H, 4.95. $C_{20}H_{15}O_2N$ requires C, 79.7; H, 5.0%). When heated at 230—235° for 2 hours and crystallised from benzene and light petroleum, this gave dibenzanilide, m. p. and mixed m. p. 160—161°.

Benzophenoneoxime o-nitrobenzoyl ester, m. p. 185—188° (Found: C, 69.6; H, 4.3. $C_{20}H_{14}O_4N_2$ requires C, 69.4; H, 4.05%), charred on heating.

The various oxime picryl ethers were prepared by a modification of the Schotten-Baumann technique as follows: To a solution of the oxime (5 g.) in acetone (25 c.c.) were added alternately in small portions 1 molecular proportion each of *N*/2-sodium hydroxide and picryl chloride with vigorous shaking. The mixture was diluted with water (*ca.* 250 c.c.) and the precipitated ether filtered off. Several batches were combined and dissolved in the minimum quantity of cold benzene, chloroform, or acetone, and precipitated by addition of 2—4 vols. of methyl or ethyl alcohol. The yield at this stage was about 60% of the theoretical. Purification was completed by at least one more precipitation from acetone solution with absolute alcohol, and the material dried in a vacuum over sulphuric acid. Further reprecipitation from other pairs of solvents was employed in some cases indicated in the tables of results. The change products were, unless otherwise stated, crystallised from a mixture of acetone and absolute alcohol.

Benzophenoneoxime picryl ether was a very pale yellow crystalline powder (Found: C, 56.0; H, 3.1; N, 13.8. $C_{19}H_{12}O_7N_4$ requires C, 55.8; H, 2.95; N, 13.7%). It melted very suddenly between 103° and 105°, crystallised on continued heating, and remelted at 195—197° (m. p. of benz-*N*-picrylanilide 198—199°). The rearrangement was accompanied by considerable evolution of heat, for when 1 g. was heated slowly in a small tube an almost explosive reaction took place when the oil-bath reached 106°, and a small maximum thermometer enclosed in the tube registered a temperature of over 140°. Solutions of the ether and of benz-*N*-picrylanilide (each 1 g. in 25 c.c. of benzene) were evaporated to dryness on the water-bath. The m. p.'s of the products, determined with that of an unheated specimen, were 197—199°, 199—200°, and 198—199° respectively. The bulk of the residue from each evaporation was made up to 100 c.c. with carbon tetrachloride, and the two mixtures kept in a bath of cold water for 3 hours to come to equilibrium. Evaporation of 25 c.c. of each solution gave residues weighing 20 and 19 mg. respectively. Both m. p. and solubility differences fall within the limits of experimental error.

Benzophenoneoxime picryl ether yielded benzophenone (m. p. and mixed m. p. 140—142°) on hydrolysis with cold alcoholic potash. From benzene solution it crystallised in fine needles containing benzene, which was slowly lost even in the cold. A specimen dried in a vacuum contained 15.8% of benzene ($C_{19}H_{12}O_7N_4 \cdot C_6H_6$ requires C_6H_6 , 17.7%). Saturated solutions of the oxime ether in various solvents at 25° contained the following amounts per 100 c.c. of solution: CCl_4 , 2.05 g.; C_6H_6 , 5.5 g.; $CHCl_3$, 39.2 g.; $C_2H_4Cl_2$, 36.5 g.

A solution of benzanilideiminochloride (11 g.) in ether (100 c.c.) was shaken with sodium

picrate (25 g.) and water (500 c.c.) for 1½ hours. After evaporation of the ether at room temperature, the yellow precipitate was reprecipitated once from cold acetone solution by alcohol to remove benzanilide. The product (m. p. 196°) had the same solubility in carbon tetrachloride as benz-*N*-picrylanilide and was insoluble in a saturated solution of that substance in the same solvent.

100 C.c. of a saturated solution of benz-*N*-picrylanilide in carbon tetrachloride at 25° contained 0.10 g. of solute.

Acetophenoneoxime picryl ether formed pale yellow plates, m. p. 112° (Found: C, 48.5; H, 3.0. C₁₄H₁₀O₇N₄ requires C, 48.55; H, 2.9%). Saturated solutions at 25° contained the following amounts per 100 c.c. of solution: CCl₄, 0.65 g.; C₆H₆, 21.3 g.; CHCl₃, 15.8 g.; C₂H₄Cl₂, 17.3 g. Rearrangement took place on heating alone or in solvents to *acet-N-picrylanilide*, bright yellow flakes, m. p. 198° (Found: C, 48.8; H, 3.05%); 100 c.c. of saturated solution in carbon tetrachloride at 25° contained 0.07 g.

The two oximes of *p*-chlorobenzophenone were separated as described by Demuth and Dittrich (*Ber.*, 1890, 23, 3610). The α -compound melted at 163° (Demuth and Dittrich give 155—156°). The β -oxime (m. p. 91—95°) seemed still to be somewhat impure, but it changed into the α -compound when heated and attempts at further purification were unsuccessful.

p-Chlorobenzophenone- α -oxime *picryl ether* formed a pale yellow crystalline powder, m. p. 117° (Found: C, 51.8; H, 2.7. C₁₉H₁₁O₇N₄Cl requires C, 51.5; H, 2.5%). A benzene solution heated under reflux for 4 hours and evaporated gave pale yellow crystals, m. p. 220—221°, m. p. after recrystallisation 223—224°, of *p*-chlorobenz-*N*-picrylanilide, identical (mixed m. p.) with a sample prepared from *p*-chlorobenzoylanilideiminochloride and sodium picrate (Found: C, 51.7; H, 2.65%).

p-Chlorobenzophenone- β -oxime *picryl ether*, long needles from acetone and absolute methyl alcohol, had m. p. 109—110° (Found: C, 51.5; H, 2.55%), and similarly gave benz-*N*-picryl-*p*-chloroanilide, yellow leaves, m. p. 204—209°, m. p. after recrystallisation 208—210°, identical with a sample prepared from benz-*p*-chloroanilideiminochloride and sodium picrate (Found: C, 51.8; H, 2.7%). Two recrystallisations of the picryl ether were required before a pure change product was obtained, confirming the doubt as to the purity of the β -oxime, but the quantity available did not allow of an attempt to regenerate the pure β -oxime from the picryl ether.

Dynamical Experiments.—Solvents. Commercially pure carbon tetrachloride was washed with sodium hydroxide, dried over calcium chloride, and redistilled. A.R. Benzene was dried over either calcium chloride or sodium and redistilled. Chloroform and ethylene dichloride were boiled under reflux with phosphoric oxide to remove water and alcoholic impurities and redistilled. In the later stages of the work, chloroform was purified by the method of Lowry and Traill (*Proc. Roy. Soc.*, 1931, 132, 404) and dried over phosphoric oxide. Acetonitrile was purified by boiling under reflux with phosphoric oxide and fractionated, but in spite of repeated treatments some decomposition always took place in this solvent. The picryl ethers were completely decomposed when heated in alcoholic solution, and considerable decomposition occurred in carefully purified acetone; these solvents could therefore not be used for velocity measurements.

Velocity determinations. Glass tubes, each containing about 28 c.c. of a solution of the oxime ether (generally about 3.2% for the benzophenone and 1.5% for the acetophenone compounds) were heated in a water thermostat. (A butyl alcohol vapour bath was used for 116°.) Two tubes were heated in boiling water for 4 hours to provide values for complete rearrangement, allowing for any slight decomposition that might have taken place. On withdrawal from the thermostat, the tubes were at once chilled in cold water and 25 c.c. of the liquid were withdrawn and evaporated at room temperature in a gentle blast of air. To assist the removal of the last traces of solvent, 5 c.c. of acetone were added when the residue was apparently dry, and the mixture was again evaporated and finally kept in an evacuated desiccator for 15 min.

For the estimation of the isomerides in mixtures an extraction method based on the widely different solubilities of the ethers and their change products in carbon tetrachloride was employed (compare Holleman, "Direkte Einfuhrung von Substituenten in den Benzolkern," 1910, p. 17). The dry residue from each evaporation was ground in the beaker with a saturated solution of benz- or acet-*N*-picrylanilide in carbon tetrachloride, transferred to a flask, and made up to 100 c.c. The flasks were kept for 3 hours in running water, which remained constant in temperature to $\pm 1^\circ$, and the contents were then filtered and portions of 25 c.c. evaporated in weighed beakers. The residues corresponded with the ether present plus the saturation

amount of amide. Tests with mixtures of known composition showed that the values obtained were accurate to within 2%. For experiments in carbon tetrachloride the preliminary evaporation was unnecessary and the contents of the tubes were merely transferred to bottles containing a little benz- or acet-*N*-picrylanilide as seed, allowed to stand for 3 hours, filtered, and measured quantities evaporated.

Benzophenoneoxime 2 : 4 : 6-trinitro-m-tolyl ether, prepared from the oxime and 3-chloro-2 : 4 : 6-trinitrotoluene, formed pale brown leaves, m. p. 127° (Found : C, 57·0; H, 3·45. $C_{20}H_{14}O_7N_4$ requires C, 56·9; H, 3·3%), and underwent rearrangement to *benz-2 : 4 : 6-trinitro-m-tolylanilide*, a pale yellow crystalline powder from methyl ethyl ketone, m. p. 255° (decomp.), very sparingly soluble in acetone, and almost insoluble in carbon tetrachloride (Found : C, 56·8; H, 3·4%). Rearrangement occurred at about one-seventh of the rate of the picryl ether under the same conditions..

Di-p-tolylketoxime picryl ether, pale yellow needles, m. p. 106—107° (Found : C, 57·6; H, 3·85. $C_{21}H_{16}O_7N_4$ requires C, 57·75; H, 3·65%).

p-Toluo-N-picryl-p-toluidide, lemon-yellow plates, m. p. 166—169° (Found : C, 57·8; H, 3·55%); solubility in carbon tetrachloride at 17°, 0·7%.

Di-p-tolylketoxime 2 : 4 : 6-trinitro-m-tolyl ether, almost colourless needles, m. p. 114° (Found : C, 59·0; H, 4·1. $C_{22}H_{18}O_7N_4$ requires C, 58·6; H, 4·0%). *p-Toluo-2 : 4 : 6-trinitro-m-tolyl-p-toluidide*, sheaves of yellow needles from alcohol; the crystals melt at 144°, resolidify, and melt again sharply at 168—170°; the compound is probably dimorphous (Found : C, 58·8; H, 3·9%).

Di-p-chlorophenylketoxime picryl ether, pale yellow crystals, m. p. 129° (Found : C, 48·0; H, 2·3. $C_{18}H_{10}O_7N_4Cl_2$ requires C, 47·8; H, 2·1%). This compound rearranges at about 1/20th the rate of benzophenoneoxime picryl ether. *p-Chlorobenz-N-picryl-p-chloroanilide*, m. p. 194—195° (Found : C, 48·0; H, 2·2%); solubility in carbon tetrachloride at 17°, 0·1%.

Di-p-chlorophenylketoxime 2 : 4 : 6-trinitro-m-tolyl ether, nearly colourless leaves, m. p. 129° (Found : C, 48·5; H, 2·65. $C_{20}H_{14}O_7N_4Cl_2$ requires C, 48·8; H, 2·45%).

p-Chlorobenz-2 : 4 : 6-trinitro-m-tolyl-p-chloroanilide, yellow crystals, m. p. 166—168° (Found : C, 49·0; H, 2·5%).

p-Chloroacetophenoneoxime picryl ether, pale yellow crystals, m. p. 133° (Found : C, 44·5; H, 2·5. $C_{14}H_9O_7N_4Cl$ requires C, 44·2; H, 2·35%).

p-Chloro-N-picrylacetanilide, pale yellow leaves, m. p. 191° (Found : C, 44·1; H, 2·45%).

We are grateful to the Chemical Society for a grant.