When contamination by diphenylurea was detected, which was formed by the presence of traces of moisture in the reaction mixture, the product was recrystallized from absolute isopropyl alcohol.

The specific activity of ^{14}C-sydnocarb was 28 mCi/g. Total activity was 17.78 mCi. The radiochemical yield was 36.3% calculated on ^{14}C sodium cyanide.

LITERATURE CITED

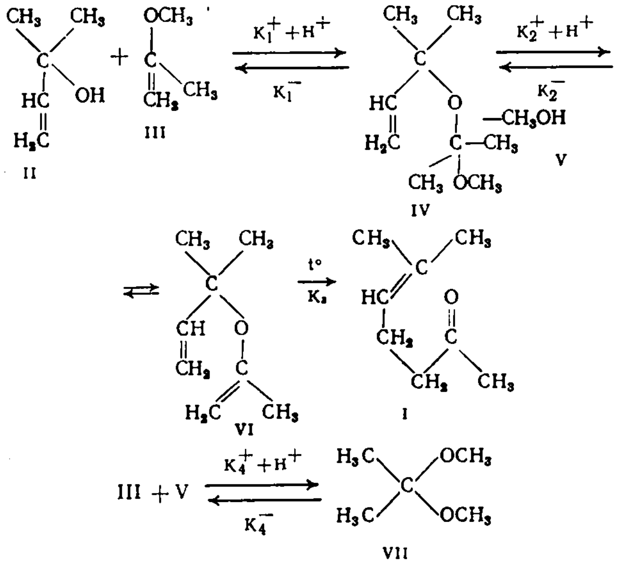
1. A. D. Bulat, L. E. Kholodov, Yu. Ya. Usaevich, et al., Khim. Farm. Zh., No. 12, 9 (1975).
2. L. E. Kholodov, N. F. Tishchenko, Z. A. Pankina, et al., Zh. Org. Khim., 3, 1513 (1967).
3. V. G. Yashunskii, Z. A. Olovyanishnikova, V. V. Ogorodnikova, et al., Khim. Geterosikl. Soedin., No. 1, 117 (1980).

INVESTIGATION OF THE KINETICS OF THE SYNTHESIS OF METHYLHEPTENONE UNDER CONDITIONS OF HOMOGENEOUS ACID CATALYSIS

M. M. Avrutskii, M. A. Miropol'skaya,
M. G. Romanyuk, I. B. Tikhova, N. I. Zakharova,
V. V. Beregovykh, and G. I. Samokhvalov

UDC 547.384:615.015

Methylheptenone (I) is an intermediate in the synthesis of pseudo- and beta-ionones used in the manufacture of vitamins A and E. A method for obtaining (I) is known from dimethylvinylcarbinol (II) and methylisopropenyl ether (III) under conditions of homogeneous acid catalysis [1]. According to the data of [1] and in agreement with our results by methods described previously [2] the synthesis proceeds in the presence of orthophosphoric acid according to the following scheme:



(1)

In the absence of kinetic studies on this reaction we have investigated these.

According to the accepted experimental procedure a prepared mixture (about 2 ml) of compounds (II), (III), and orthophosphoric acid in definite proportions is placed at a temperature of −5 to 0°C in glass ampuls. The sealed ampuls of about 10 ml capacity each were transferred to a thermostat at the reaction temperature. One ampul was taken out after definite time intervals, cooled to −5 to 0°C and the contents analyzed. Analysis of the

---

"Vitaminy" Scientific-Industrial Association, Moscow. Translated from Khimiko-Farmatsevticheskii Zhurnal, Vol. 15, No. 11, pp. 80-83, November, 1981. Original article submitted March 30, 1981.

TABLE 1. Values of Correlation Coefficients and Effective Reaction Constants at the Studied Temperatures

Parameter	Temperature		
	90	105	120
$r\,[\tau, F_I\,(c_{II})]$	0,900	0,950	0,918
$r\,[\tau, F_2\,(c_{II})]$	0,990	0,994	0,984
$K\cdot 10^4$ liter$^2\cdot$ mole$^{-2}\cdot$ min^{-1}	1,32±0,28	2,64±0,64	4,92±2,19

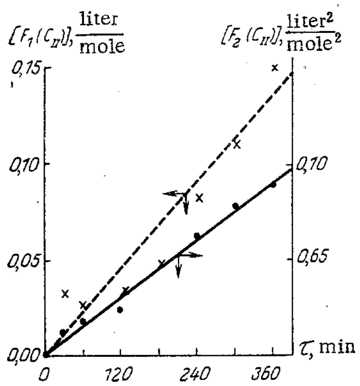


Fig. 1

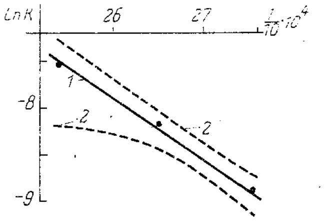


Fig. 2

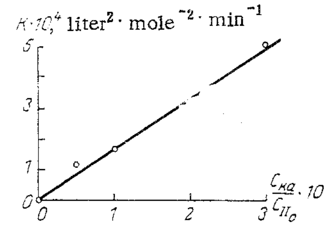


Fig. 3

Fig. 1. Comparison of results of processing experimental data at 105°C and $c_K\, c_{II_0}$ 0.03. Crosses were calculated from formula (7); small circles were calculated from formula (10); $[F_1\,(c_{II})]$ and $[F_2\,(c_{II})]$ are coefficients from the left hand portions of equations (7) and (10) respectively.

Fig. 2. Representation of experimental data in Arrhenius coordinates for $c_K\, c_{II}$ 0.03. 1) Approximated straight line (small circles are calculated points); 2) limits of variation of log K corresponding to the confidence limit for K.

Fig. 3. Dependence of effective rate constant K on c_K/c_{II_0} at 105°C. Approximated straight line (small circles are calculated points).

reaction mixture was carried out by GLC on an LKhM-7A chromatograph using internal standards. The chromatographic column had a length of 2 m. The stationary phase (SE-30) was applied at 5 wt.% to carrier (chromaton NA-W) of particle size 0.16-0.20 mm. Column temperatures were 50-100°C (changed by program at a rate of 8°C per min), detector 125°C, evaporator 170°C, carrier gas was helium, and octane was the internal standard. Experiments were carried out at 90, 105, and 120°C with molar proportions $c_{III_0}\, c_{II_0}$ of 1-3 and $c_K\, c_{II_0}$ 0.005-0.030 (here c_{II_0}, c_{III_0}, and c_K are the initial concentrations of (II), (III), and catalyst respectively in moles per liter).

Two variants of the mathematical description were considered when developing the kinetic model.

The first variant started from the reaction scheme (1). Assuming that all stages are first order to a component the complete system of kinetic equations at a fixed concentration of catalyst will have the form

$$\frac{dc_{II}}{d\tau} = -K_1^+ c_{II} c_{III} + K_1^- c_{IV};$$

$$\frac{dc_{IV}}{d\tau} = -K_2^+ c_{IV} + K_2^- c_V c_{VI} - K_1^- c_{IV} + K_1^+ c_{II} c_{III};$$

$$\frac{dc_{VI}}{d\tau} = -K_3 c_{VI} + K_2^+ c_{IV} - K_2^- c_V c_{VI};$$

$$\frac{dc_{III}}{d\tau} = -K_4^+ c_{III} c_V + K_4^- c_{VII} - K_1^+ c_{II} c_{III} + K_1^- c_{IV};$$

$$\frac{dc_V}{d\tau} = -K_4^+ c_{III} c_V + K_4^- c_{VII} + K_2^+ c_{IV} - K_2^- c_V c_{VI};$$

$$\frac{dc_I}{d\tau} = K_3 c_{VI};$$

$$\frac{dc_{VII}}{d\tau} = K_4^+ c_{III} c_V - K_4^- c_{VII}, \qquad (2)$$

where c_i is the running concentration of component i (i = I,..., VII) in mole/liter; K_j^+, K_j^- are the effective constants of the forward and reverse j reactions in min^{-1} or in liter · mole^{-1} min^{-1}; K_3 is the effective reaction constant of the thermal rearrangement (in min^{-1}); τ is time (min).

It was established by us that the intermediate compounds, viz. the mixed ketal (IV), the vinyl ether (VI), and methanol (V) do not accumulate in the reaction mixture at temperatures above 60°C. Seemingly acceleration of the Claisen rearrangement (compound VI to I) occurs with increasing temperature, and the reversible interaction between (III) and (V) is shifted in the direction of forming acetone dimethylketal (VII).

In view of this we assume

$$\frac{dc_{IV}}{d\tau} = \frac{dc_V}{d\tau} = \frac{dc_{VI}}{d\tau} = 0. \qquad (3)$$

Substituting equation (3) into the system of equations (2) and since the concentrations c_{IV}, c_V, and c_{VI} are close to zero from the analytical data, we obtain:

$$\frac{dc_{II}}{d\tau} = -K_1^+ c_{II} c_{IV}; \qquad (4)$$

$$\frac{dc_{II}}{d\tau} = \frac{1}{2} \cdot \frac{dc_{III}}{d\tau} = -\frac{dc_I}{d\tau} = -\frac{dc_{VII}}{d\tau}. \qquad (5)$$

The material balance between components (II) and (III) is expressed by the relationship

$$c_{III_0} - c_{III} = 2(c_{II_0} - c_{II}). \qquad (6)$$

Solving Eq. (4) allowing for the relationship (6) we find:

$$F_1(c_{II}) = \frac{1}{c_{III_0} - 2c_{II_0}} \ln\left[\frac{c_{II_0}(c_{III_0} - 2c_{II_0} + 2c_{II})}{c_{II} c_{II_0}}\right] = -K_1^+ \tau. \qquad (7)$$

The other mathematical model of the kinetics was obtained from the assumption that the reaction between (III) and (V) is close to being irreversible. Then summing the separate stages of route (1) we arrive at the empirical equation

$$\text{II} + 2\,\text{III} \rightarrow \text{I} + \text{VII}. \qquad (8)$$

The corresponding differential equations may be written as

$$\frac{dc_{II}}{d\tau} = -Kc_{II} \cdot c_{III}^2. \qquad (9)$$

Expressing c_{III} in this equation through c_{II} with the aid of relationship (6) and integrating we find

$$F_2(c_{II}) = \frac{1}{(c_{III_0} - 2c_{II_0})^2}$$

$$\ln\left[\frac{c_{II_0}(c_{II_0} - 2c_{II_0} + 2c_{II}}{c_{III_0} c_{II}} + \frac{2(2c_{II_0} - c_{III_0})(c_{II_0} - c_{II}}{c_{III_0}(c_{III_0} - 2c_{II_0} + 2c_{II}}\right] = -K\tau. \qquad (10)$$

Graphs are shown in Fig. 1 illustrating the treatment of the experimental results according to equations (7) and (10) for molar ratios c_{III_0} c_{II_0} 3, c_K c_{II_0} 0.03, and a temperature of 105°C. Linear approximation of the found values of F_1 (c_{II}) and F_2 (c_{II}) was carried out by a modified least squares method allowing for the fact that the straight lines must pass through the origin of coordinates [3].

With the aim of comparing the adequacy of the two considered models the appropriate correlation coefficients $r[\tau,\ F_1\ (c_{II})]$ and $r[\tau,\ F_2\ (c_{II})]$ were calculated [4].

As is evident from Table 1, on linearization the best results were achieved through equation (10) (correlation coefficient $r[\tau, F_2(c_{II})]$). On this basis the model possessing mechanism (8) with kinetic differential equation (9) and integral (10) was taken for the reaction being considered in the temperature range 90-120°C and at c_K c_{II_0} 0.03. The effective reaction constants K found as slopes are given in Table 1. Values of the constants in Arrhenius coordinates were satisfactorily disposed along straight lines (Fig. 2). The limits of the change in log K calculated from the confidence limit for K are shown as broken lines in Fig. 2 and were determined by known methods using the Student criteria [4]. The calculated energy of activation was 11.7 kcal/mole.

Analysis of the experimental results showed that the reaction rate depended appreciably on catalyst concentration. In this case the following expression is true in general:

$$K = f(c_K)\exp\left\{-\frac{11.7}{RT}\right\}, \tag{11}$$

where $f(c_K)$ is an unknown function of c_K; R is the universal gas constant (in kcal/mole · deg); T is absolute temperature (K). It was established for a temperature of 120° that in the examined concentration interval of c_K the function $f(c_K)$ was linear and passed through the origin of coordinates (since the reaction does not go when $c_K = 0$ so $f(c_K) = 0$). The relationship of K on c_K has the form (Fig. 3)

$$K = 0.016\frac{c_K}{c_{II_0}} \tag{12}$$

Substituting known values of R, T, and c_{II_0} in formula (II) and solving jointly with equation (12) we find

$$f(c_K) = 1.97\cdot 10^4\cdot c_K. \tag{13}$$

Then from formulas (9), (11), and (13) we have finally

$$\frac{dc_{II}}{d\tau} = 1.97\cdot 10^4\cdot \exp\left\{-\frac{11.7}{RT}\right\}\cdot c_K\cdot c_{II}\cdot c_{III}^2. \tag{14}$$

The experimental data make it possible to draw the conclusion that the majority of intermediate reaction stages occur at sufficiently high rates at the investigated temperatures. Evidently the limiting step is the protonation of ether (III). Then in spite of the presence of a thermal rearrangement step which occurs without catalyst participation it is possible to consider that under the experimental conditions a situation is brought about which is similar to that taking place in the case of general acid catalysis. This is also evident from formula (14) into which the catalyst concentration clearly enters.

A mathematical description has been derived as a result of the investigation and may be used for modeling a reaction for the synthesis of methylheptenone and for automating control of the process.

LITERATURE CITED

1. G. Sausy and R. Marbet, Helv. Chim. Acta, 50, 2091-2095 (1967).
2. M. A. Miropol'skaya, A. R. Bekker, M. G. Romanyuk, et al., Zh. Org. Khim., 10, 1860-1865 (1974).
3. M. M. Avrutskii, T. E. Samsonova, and V. V. Zarutskii, Khim. Farm. Zh., No. 6, 116-121 (1978).
4. D. Himmelblau, Analysis of Processes by Statistical Methods [Russian translation], Moscow (1973).