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FURTHER OBSERVATIONS ON THE GUERBET REACTION

CH. WEIZMANN, ERNST BERGMANN, AND MAX SULZBACHER

Received June 20, 1949

In previous papers (1, 2) the "Guerbet Reaction" which, *e.g.*, converts butyl alcohol into 2-ethylhexanol (and butyric acid) was formulated as follows:

A. $2\ CH_3CH_2CH_2CH_2OH \rightarrow 2\ CH_3CH_2CH_2CHO$

B. $2\ CH_3CH_2CH_2CHO \rightarrow CH_3CH_2CH_2CH{=}C(C_2H_5)CHO$

C. $3\ CH_3CH_2CH_2CH{=}C(C_2H_5)CHO \rightarrow CH_3CH_2CH_2CH_2OH +$
$CH_3CH_2CH_2COOH + CH_3CH_2CH_2CH_2CH(C_2H_5)CH_2OH.$

Primary alcohols, which are branched in α-position, should, therefore, be incapable of this reaction (incapable of step B). We have observed that 2-ethylhexanol $C_8H_{18}O$ gives, when heated with its sodium derivative, a compound of the expected formula $C_{16}H_{34}O$. This, however, is not a higher alcohol, but *bis*-2-ethylhexyl ether, as it contains no hydroxyl group and is split by hydriodic acid into 2-ethylhexane and 2-ethylhexyl iodide. A similar reaction was observed before (1) for cinnamyl alcohol, which has also no methylene group in the immediate vicinity of the hydroxyl. These observations recall the occasional formation of isopropyl ethers in the reduction of ketones with aluminum isopropoxide (3). In contradistinction to 2-ethylhexanol, the isomeric 1-octanol undergoes the Guerbet reaction to give an alcohol $C_{16}H_{34}O$ which is assumed to be 2-hexyldecanol, and caprylic acid.

"Mixed" Guerbet reactions between a primary alcohol carrying an α-methylene group, and a primary alcohol which does not conform to this requirement, take place as expected, according to the following scheme:

A′. $R_1CH_2OH \rightarrow R_1CHO$
$R_2CH_2CH_2OH \rightarrow R_2CH_2CHO$
B′. $R_1CHO + R_2CH_2CHO \rightarrow R_1CH{=}C(R_2)CHO$
C′. $R_1CH{=}C(R_2)CHO \rightarrow R_1CH_2CH(R_2)CH_2OH$

To the examples reported previously (1), we have added the condensation between benzyl and β-phenylethyl alcohols which leads to 2,3-diphenylpropanol, $C_6H_5CH_2CH(C_6H_5)CH_2OH$. In this case, the benzoic acid formed in step C′ was not isolated as such, but in the form of its reduction product, toluene. A similar method of synthesis of this alcohol has been described by Mastagli (4).

Likewise, the course of the Guerbet reaction between a primary and a secondary alcohol is predetermined by the fact that an aldehyde condenses with a ketone always to give an alkylidene-ketone [for a remarkable exception, see Kuzin and Nevraeva (5)]. Primary alcohols and cyclohexanol, therefore, give 2-alkylcyclohexanols. This fact, established previously (1), has now been confirmed for the pair isobutyl alcohol-cyclohexanol, which condense to give 2-isobutylcyclohexanol.

Guerbet (6) already has observed that two molecules of secondary alcohols react analogously. In this case, the third molecule of the alcohol cannot supply the four hydrogen atoms required in step C in the same manner as a primary alcohol. As a matter of fact, a deep-seated destruction occurs, reminiscent of the oxidative splitting of the corresponding ketone (from isopropanol, isovaleric, acetic, and formic acids and from *sec*-butanol, propionic and formic acids were obtained).

In the Experimental part some data are reported showing the beneficial effect of small amounts of copper-bronze on the course of the Guerbet reaction, which has been mentioned previously (1). It helps to suppress the undesirable oxidation of the alcohol to the corresponding acid under the influence of the sodium alkoxide.

EXPERIMENTAL

All experiments were carried out in an autoclave. The reaction mixture was heated to the desired temperature; then the excess pressure was released and the mixture heated for the time required at a pressure of about 50–60 atm.

1. *Butyl alcohol.* Table I shows the effect of small amounts of copper-bronze on the product obtained from 2 moles of butyl alcohol and 0.67 atom of sodium.

2. *Isoamyl alcohol.* Table II refers to experiments with 2 moles of the alcohol and 0.67 atom of sodium. The structure of the C_{10} alcohol has been determined by Nef (7); the C_{10} acid which is obtained in small quantities and for which b.p. 249°/760; 135–136°/13 has been observed, is therefore, most proabably 2,6-dimethylheptane-5-carboxylic acid, $(CH_3)_2CHCH_2CH_2CH(COOH)CH(CH_3)_2$.

3. *2-Ethylhexanol.* When 1 mole (130 g.) of 2-ethylhexanol was heated at 300° for six hours with 0.3 mole of sodium and 0.7 g. of copper-bronze, 20% of the starting material was recovered unchanged. The neutral product weighed 45 g., and boiled at 144–146°/13. It is di-2-ethylhexyl ether.

The acidic reaction product (48 g.) was mainly 2-ethylhexoic acid, b.p. 118°/14, formed by oxidation of the starting material. The neutral product (5 g.) was boiled for four hours with 50 cc. of hydriodic acid (b.p. 127°). After dilution with water, the product was extracted with ether and the ethereal solution washed with sodium carbonate and sodium thiosulfate. Fractionation *in vacuo* gave a low-boiling liquid and a fraction which boiled at 122°/13 with some decomposition (liberation of iodine).

The first fraction boiled under atmospheric pressure at 120° and was saturated and halogen-free; it was 2-ethylhexane. The second fraction was 2-ethylhexyl iodide.

Anal. Calc'd for $C_8H_{17}I$: C, 40.0; H, 7.1; I, 52.9.
Found: C, 40.6; H, 7.3; I, 52.4.

It was identified by conversion into the crystalline trimethyl-(2-ethylhexyl)ammonium iodide, m.p. 208° (1).

4. *1-Octyl alcohol.* A batch of 130 g. of octyl alcohol (1 mole), in which 7.6 g. of sodium (0.33 mole) had been dissolved, was heated in the presence of 0.6 g. of copper-bronze at 295° for five hours. The reaction set in at 210°, as indicated by the sudden pressure rise in the autoclave when this temperature was reached. Treatment with water gave an organic layer, consisting of (a) 45.0 g. of octyl alcohol, b.p. 195° (34.6% recovery), (b) 42.0 g. of 2-hexyldecanol, b.p. 170–180°/24 (52%), and an aqueous layer from which (c) 34.0 g. of *n*-caprylic acid, b.p. 120–125°/10 (70.8%) was isolated. Practically no higher-boiling acidic product (hexyloctylacetic acid) was observed.

2-Hexyldecanol is a colorless, viscous oil which did not solidify at room temperature; the caprylic acid crystallized, upon cooling, and had the correct m.p., 16°.

5. *Condensation of benzyl and β-phenylethyl alcohol.* When 1.5 moles (162 g.) of benzyl alcohol and 1.5 moles (183 g.) of β-phenylethyl alcohol were heated for six hours at 310° with 1 mole of sodium metal and 1.2 g. of copper-bronze, exactly one-third of each alcohol was recovered unchanged. The β-phenylethyl alcohol was converted into polystyrene (90 g., 57.7%) [see (1)]. 2,3-Diphenylpropanol (8), b.p. 186°/14, was isolated in an amount of 25 g. (11.8%), while 32 g. (17.5%) of benzoic acid, and 10 g. of toluene (21.7%) were formed. A small amount of 2,4-diphenylbutanol, the expected Guerbet product from β-phenylethyl alcohol, was also isolated.

6. *Condensation of isobutyl alcohol and cyclohexanol.* Isobutyl alcohol (93 cc.) and 100 cc. of cyclohexanol were heated at 280° for twelve hours with 8 g. of sodium metal and 2 g. of copper-bronze. Repeated fractionation gave as a neutral product 2-isobutylcyclohexanol, b.p. 118°/22, 111°/15; yield, 56 g. (36%).

Anal. Calc'd for $C_{10}H_{20}O$: C, 76.9; H, 12.8.

Found: C, 77.0; H, 13.1.

The acid formed in the reaction was identified as isobutyric acid.

TABLE I

GUERBET REACTION WITH BUTYL ALCOHOL

EXPT.	TEMP., °C.	TIME, HRS.	COPPER ADDED, G.	BUTYL ALCOHOL RECOVERED G.	2-ETHYLHEXANOL		BUTYRIC ACID		2-ETHYLHEXOIC ACID G.
					G.	%	G.	%	
1	270	10	—	15	55	63.4	55	93.7	5
2	300	6	0.75	9	79	91.0	50	85.1	10
3	300	6	1.5	20	78	89.9	40	68.1	5

The % yields are calculated on the basis of the amount of sodium used without considering the recovered butyl alcohol.

TABLE II

GUERBET REACTION WITH ISOAMYL ALCOHOL

EXPT.	TEMP., °C.	TIME, HRS.	COPPER ADDED, G.	ISOAMYL ALCOHOL RECOVERED, G.	C_{10} ALCOHOL		ISOVALERIC ACID		C_{10} ACID G.
					g.	%	G.	%	
1	290	6	—	22	65	61.7	65	95.6	7
2	300	5	—	11	55	52.2	65	95.6	12
3	300	6	0.9	20	79	75.0	50	73.5	12
4	300	6	1.8	20	80	76.0	48	70.6	12
5	295	6	3.6	20	75	71.2	48	70.6	12

7. *Guerbet condensation of propyl alcohol.* In this (and the following) case, too, the addition of copper has proved beneficial. In an autoclave, 180 g. of propyl alcohol (3 moles) and 23 g. of sodium (1 mole) were refluxed until all the metal had dissolved. The solution was allowed to cool to 60°, 0.9 g. of copper-bronze was added and the mixture heated at 295° for five hours. The usual treatment of the reaction product gave as neutral products: propyl alcohol, 39.6 g. (22% recovery) and C_6 alcohol, b.p. 148°, 73.2 g. (71.7%) and as acidic products: propionic acid, b.p. 140–142°, 59.4 g. (80.2%) and residue, presumably C_6 acid. It can be assumed that the C_6 alcohol is 2-methylpentanol (9)[1] and the C_6 acid is methylpropylacetic acid.

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[1] Terentjew (9) found b.p. 147–149° for 2-methylpentanol.

8. *Guerbet condensation of pentanol-1.* In the above-described manner, 176 g. of pentanol-1, (2 moles), 15.4 g. of sodium (0.67 mole) and 0.9 g. of copper-bronze were heated at 300° for five hours. It was interesting to note that the reaction set in (rise in pressure) at 210°, *i.e.*, at a temperature 30° lower than that required for butyl alcohol. Neutral products: pentanol-1, 35.0 g. (19.9% recovery) and C_{10} alcohol, b.p. 112–115°/14, 75.0 g. (71.2%). Acidic products: valeric acid, b.p. 90–92°/14, 60.0 g. (88.2%) and C_{10} acid b.p. 145°/14, 2.0 g. Assuming that the general mechanism indicated above is correct, the C_{10} alcohol would be 2-propylheptanol; the C_{10} acid 2-propylheptanoic acid.

REHOVOTH, ISRAEL
LONDON, ENGLAND

REFERENCES

(1) WEIZMANN, BERGMANN, AND HASKELBERG, *Chemistry & Industry*, **56**, 587 (1937).
(2) WEIZMANN, SULZBACHER, AND BERGMANN, *J. Chem. Soc.*, 851 (1947).
(3) *Org. Reactions* **2**, 190 (1944).
(4) MASTAGLI, *Ann. chim.*, [11] **10**, 281 (1938).
(5) KUZIN AND NEVRAEVA, *Biokhimiya*, **6**, 261 (1941); *Chem. Abstr.*, **35**, 7427 (1941).
(6) GUERBET, *Compt. rend.*, **149**, 129 (1909).
(7) NEF, *Ann.*, **318**, 157 (1901).
(8) See, *e.g.*, RAMART-LUCAS AND AMAGAT, *Compt. rend.*, **184**, 30 (1928); *Ann. chim.*, [10] **8**, 263 (1927).
(9) TERENTJEW, *Bull. soc. chim.*, [4] **35**, 1152 (1924).