40 mc, and was made possible by grants from the National Research Council of Canada and the National Cancer Institute of Canada.

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RECEIVED MAY 1, 1956

ANOMALOUS REDUCTION OF EPOXIDES WITH LITHIUM ALUMINUM HYDRIDE

Sir:

Lithium aluminum hydride attacks unsymmetrically substituted epoxides predominantly at the least substituted carbon atom to give the more highly substituted alcohol.[1–3] Thus primary–secondary epoxides (I, R_1 = alkyl, $R_2 = R_3$ = H) give secondary alcohols (II, same), and primary–tertiary or secondary–tertiary epoxides (I, R_1, R_2 = alkyl, R_3 = H or alkyl) give tertiary alcohols (II, same). Representative examples from the literature and from our own work are listed in the table (entries 1, 3, 4, 5, 8, 10, 12).

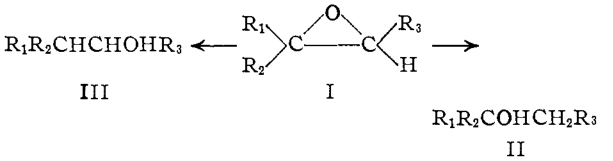

TABLE I

REDUCTION OF EPOXIDES WITH LITHIUM ALUMINUM HYDRIDE

					Moles			Products		
	Entry compound	R_1	R_2	R_3	LAH	AlX_3	Yield, %	% II	% III	Ref.
1	Propylene oxide	Me	H	H	0.3	0	60	100	0	*a*
2	Propylene oxide	Me	H	H	.25	1[b]	*ca.* 42	*ca.* 80	*ca.* 20	*a*
3	1,2-Epoxydecane	Oct	H	H	.25	0	90	100	0	2
4	Styrene oxide	Ph	H	H	.25+	0	94	100	0	3
5	Styrene oxide	Ph	H	H	.3	0	82	90–95	5–10	*a*
6	Styrene oxide	Ph	H	H	.25	1[b]	87	2–10	90–98	*a*
7	Styrene oxide	Ph	H	H	1.5	*c*	80	71	28	*a*
8	Isobutylene oxide	Me	Me	H	0.3	0	26	95–98	2–5	*a*
9	Isobutylene oxide	Me	Me	H	.25	1[b]	55	5–7	93–95	*a*
10	1,1-Diphenylethylene oxide	Ph	Ph	H	.4	0	97	100	0	*a*
11	1,1-Diphenylethylene oxide	Ph	Ph	H	2.4	*c*	85	14	86	*a*
12	1,1,2-Triphenylethylene oxide	Ph	Ph	Ph	2.2	0	11.5[d]	100	0	*a*
13	1,1,2-Triphenylethylene oxide	Ph	Ph	Ph	2.4	*c*	91	0	100	*a*

[a] This work. [b] Aluminum chloride. [c] Generated *in situ* from 1 mole of allyl bromide. [d] Also recovered 81% starting material.

In contrast, we have now found that *reversal* of the direction of ring opening occurs (I → III) when the reduction is carried out in the presence of aluminum chloride or bromide. Substantially complete reversal is achieved in phenyl-substituted epoxides (entries 6, 11, 13) and in isobutylene oxide (entry 9). With propylene oxide (entry 2) only partial reversal occurred and the crude reaction product contained halohydrins. No aliphatic secondary–tertiary epoxide has as yet been studied.

The reductions were carried out in the customary way.[1] Water-soluble products were isolated by continuous ether extraction. Mixtures of solid products (entries 10–13) were analyzed by chromatographic separation. Liquid mixtures (entries 1, 2, 5–9) were analyzed by mass spectrometry; in most cases the analyses were checked by infrared comparison with synthetic mixtures. The reduction mixture for experiments 2, 6, 7, 9, 11 and 13 was obtained by adding standardized ethereal lithium aluminum hydride to cold ethereal aluminum chloride, or by adding allyl bromide in ether to the standardized hydride solution prior to addition of the epoxide.

We are presently studying the mechanism of the abnormal ring opening as well as extensions of the method to other epoxides, including alicyclic and steroid cases.

This work is supported in part under Atomic Energy Commission contract AT(11-1)-38.

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(4) Shell Research Fellow, 1955–1956.

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RECEIVED MAY 21, 1956

THE RADIATION CHEMISTRY OF WATER VAPOR. THE INDIRECT EFFECT ON DEUTERIUM[1]

Sir:

The rate of formation of hydrogen deuteride in gaseous mixtures of tritium–water (0.284 hydrogen-atom % tritium) and deuterium is a direct measure of the rate of formation of hydrogen atoms. Samples containing 0.185 g. of tritium–water vapor and deuterium gas at mole fractions in the range 10^{-3} to 10^{-2} were heated in sealed Pyrex tubes (238 ml., 47 mm. i.d.) at temperatures from 120 to 165° and total pressures of 1000 millimeters. Evolution of foreign gases from the tube walls was kept negligibly small by heating and pumping on the tubes for at least 12 hours at 510° followed by 12 hours at 440° before admission of the reactants. Isotopic analysis of the hydrogen was performed on a mass spectrometer. No exchange was observed in the absence of tritium–water. G(HD)

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(1) Based on work performed under the auspices of the U. S. Atomic Energy Commission.

(molecules of HD/100 e.v.) was observed to be equal to $G(-D_2)$ in samples irradiated to 10 per cent. exchange, at least. G(HD) values for such samples averaged 11 ± 1 molecules per 100 e.v. and were independent of deuterium pressure and virtually independent of temperature in the ranges employed.

G(HD) corresponds to that for dissociation of one water molecule according to the stoichiometry implicit in $D_2 + H_2O = HD + DOH$. A reasonable mechanism can be written as

$$H_2O \rightsquigarrow H + OH \qquad (1)$$

$$H + D_2 \longrightarrow HD + D \qquad (2)$$

$$OH + D_2 \longrightarrow DOH + D \qquad (3)$$

$$D + D \xrightarrow{M} D_2 \qquad (4)$$

Thus, $-d(D_2)/dt = d(HD)/dt = k_1(H_2O) = k_0$. G(HD) is directly proportional to k_0, since the energy absorbed by the water is proportional to time. At vapor densities employed (0.78 g./cc.) over 99% of the tritium β-particles are absorbed by the water.[2] G(HD)'s were calculated using 12.46 years for the tritium half-life and 5.69 kev. for the average β-particle energy. Virtual absence of a temperature coefficient is good evidence against the possible chain-propagating step, $D + H_2O \rightarrow H + DOH$. Absence of dependence of G(HD) on deuterium pressure indicates that deuterium at mole fractions of 10^{-3} to 10^{-2} is a completely efficient scavenger for the reactive species involved.

Comparison of G(HD) in this work with that obtained by Gordon and Hart[3] in Co^{60}-irradiated liquid water saturated with deuterium shows that approximately four times as many hydrogen atoms are available for reaction with deuterium when water vapor is irradiated. Hart's measurement of the water decomposition yield in liquid tritium–water using formic acid and oxygen as free-radical scavengers provided $G(-H_2O) = 3.8$.[4] Assuming a similar mechanism for formation of reactive species in water vapor, as above, an average value of 9 e.v. per radical pair is obtained in the present work. If roughly 30 e.v. are required per ion pair formed in water vapor, a total of three measurable radical pairs appear to be formed per ionization. It is suggested that the two additional pairs measurable in the vapor recombine in liquid water via $H + OH \xrightarrow{M} H_2O$ in track regions inaccessible to solute molecules in times necessary for recombination.

The author is indebted to E. J. Hart and S. Gordon for helpful discussion and for preparation of the tritium–water and to L. Pobo and H. Rest for the mass spectrometer analyses.

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RECEIVED MAY 7, 1956

HETEROGENEITY IN THE DINITROPHENOL UNCOUPLING OF MITOCHONDRIAL OXIDATIVE PHOSPHORYLATION[1]

Sir:

Previous experiments by Ochoa,[2] Lehninger,[3] Copenhaver and Lardy,[4] and others, established that phosphorylations are coupled with the transport of electrons by the respiratory enzyme chain localized in mitochondria. Concurrently, Loomis and Lipmann,[5] Hunter and Hixon,[6] and others demonstrated that dinitrophenol uncouples these phosphorylations. We have now observed that the sensitivity of the phosphorylation mechanism to a given dinitrophenol concentration is not uniform.

The mitochondria for the present experiments were obtained from flight muscle of house flies, *Musca domestica*, by a modification[7] of techniques previously described.[8] The isolation medium was 0.25 *M* sucrose–0.005 *M* EDTA, *p*H 7.2. Table I shows the effect of two concentrations of dinitrophenol on oxidative phosphorylation with four respiratory substrates.

TABLE I

HETEROGENEITY OF DNP ACTION DEMONSTRATED BY THE OXIDATION OF DIFFERENT SUBSTRATES

Substrate	DNP added, *M*	Δ*O* μ atoms	Δ*P* μ moles	*P/O*
α-Ketoglutarate	......	5.5	11.6	2.1
	5×10^{-5}	5.4	6.5	1.2
	1×10^{-4}	5.0	1.2	0.2
α-Glycerophosphate	......	6.7	9.6	1.4
	5×10^{-5}	6.3	7.7	1.2
	1×10^{-4}	6.8	5.7	0.8
Succinate	......	5.7	8.5	1.5
	5×10^{-5}	5.5	6.7	1.2
	1×10^{-4}	5.1	2.5	0.5
Glutamate	......	4.9	11.0	2.2
	5×10^{-5}	4.9	10.1	2.1
	1×10^{-4}	5.2	9.0	1.7

Measurements for oxygen consumption and inorganic phosphate uptake were made by the methods reported in an earlier paper.[8] The reaction mixtures contained 30 μM. K phosphate buffer, *p*H 7.4; 20 μM. $MgCl_2$; 10 μM. ADP; 50 μM. glucose; 2% bovine serum albumin; 150 K.M. units hexokinase; and 0.5 ml. of mitochondrial suspension. The quantities of substrate used in their respective experiments were as follows: α-ketoglutarate, 30 μM.; glutamate, 30 μM.; succinate, 90 μM.; α-glycerophosphate, 100 μM.; 0.15 ml. of 5 *N* KOH placed in center well. Total fluid volume of Warburg flask made to 2.5 ml. with 0.25 *M* sucrose; time 30 minutes, temperature 25°. Each set of comparative *P/O* values for the various substrates was obtained with the same mitochondrial suspension. The mito-

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[1] The following abbreviations have been used: DNP for 2,4-dinitrophenol, ADP for adenosine diphosphate, EDTA for ethylenediaminetetraacetate, P/O for the ratio of the micromoles of inorganic phosphate esterified to the microatoms of oxygen utilized.

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