compounds as acetylene dicarboxylic acid-2-C^{14} and *meso*-tartaric acid-2-C^{14}.

Experimental[4]

***meso*-Dibromosuccinic Acid-2-C^{14}.**—By modification of the excellent method of Hughes and Watson,[5] the yield of the dibromosuccinic acid was increased to 90–96%. Bromination of succinic acid-2-C^{14} was carried out on a 2.5-millimole scale and after the reaction was complete the contents of four tubes were combined. When the bromination was carried out on a 10-millimole scale in a single tube, unsafe pressures developed during the reaction. Each Pyrex combustion tube (15 × 20 × 250 mm.) was charged with 295 mg. (2.5 millimoles) of succinic acid-2-C^{14}, 0.24 cc. of water, 0.06 cc. of 48% hydrobromic acid and 0.28 cc. of bromine. Then the tubes were sealed, placed in a steel jacket, heated at 95–100° for 96 hours, cooled to room temperature, and opened. After placing the tubes in a vacuum desiccator containing calcium hydride, the system was evacuated (1 mm.) for two hours.

Fumaric Acid-2-C^{14}.—The *meso*-dibromosuccinic acid-2-C^{14} in each tube was removed by adding three 4-cc. portions of acetone, and the extracts from the four tubes combined. Next the acetone solution containing the bromoacid was heated under reflux with a solution of 4.5 g. (30 millimoles) of sodium iodide in 20 cc. of acetone for 75 minutes. After cooling the mixture to room temperature the liberated iodine was titrated with 1 *N* sodium thiosulfate. Five cc. of glacial acetic acid was added and the solution continuously extracted with ether for 24 hours. This solution was evaporated to dryness on a boiling water-bath by sweeping a stream of air over the surface of the liquid. The residue was dissolved in boiling water and the water extracts acidified with 5 cc. of glacial acetic acid before continuously extracting with ether for 24 hours. Following removal of the solvent, the product was dried *in vacuo* over calcium hydride. Then the crude product was dissolved in 50 cc. of boiling water, 50 mg. of Darco S-51 added, and after 20 minutes the solution heated to boiling, and the charcoal removed by suction filtration. After concentrating the solution to 9 cc., the tube was allowed to stand at 0° for 8 hours, and then the crystals of fumaric acid were collected by filtration through a sintered glass funnel. This material was dried *in vacuo* over calcium hydride and weighed 935 mg. The mother liquor was concentrated to 2 cc. and the second crop of fumaric acid-2-C^{14} collected which weighed 60 mg. The over-all yield was 86% based on succinic acid-2-C^{14} and the material melted at 268°.[4] However, the melting point of fumaric acid-2-C^{14} determined in a sealed tube and in the conventional way was 287°. A semi-micro quantitative hydrogenation was carried out with an 83-mg. sample (0.715 millimole) of fumaric acid-2-C^{14} and it was found that 0.72 millimole of hydrogen was consumed. The dimethyl fumarate derivative was prepared and melted at 104°.[6] Another check on the purity of the fumaric acid-2-C^{14} involved the preparation of a paper chromatogram using a 70% phenol–water–formic acid system.[7] By use of an alkaline brom cresol green spray and a radioautograph only fumaric acid-2-C^{14}, R_f = 0.62, was found.

Maleic Anhydride-2-C^{14}.[8]—A 50-ml. round-bottom flask equipped with a 24/40 male joint was attached to an apparatus containing a 24/40 female joint, a small U-type trap, a small collection trap, and finally a high-vacuum stopcock. A layer of 4 g. of phosphorus pentoxide was placed in the flask, then 804 mg. (6.93 millimoles) of fumaric acid-2-C^{14} added, and next 4 g. of phosphorus pentoxide were placed over the fumaric acid. The system was evacuated to 1 mm. and then isolated. The entire reaction flask was immersed in an oil-bath and the bath temperature raised to 155–160° and held there for three hours. The liberated maleic anhydride-2-C^{14} was collected by cooling the small U-type trap with liquid nitrogen. After the collection was complete the reaction vessel was sealed off from the traps. The U-type trap containing the product was allowed to warm to room temperature and then immersed in an oil-bath at 100° and the maleic anhydride vacuum-distilled into the small collection trap which was cooled by liquid nitrogen. Dry air was then admitted to the system and the maleic anhydride collected. A 651-mg. yield of maleic anhydride-2-C^{14} was obtained (96% based on fumaric acid-2-C^{14}), m.p. 53.5–54°. A sample of this material was titrated with alkali and furnished a neutral equivalent of 49.5 (theoretical 49.0). Another sample was converted to *cis*-Δ^4-tetrahydrophthalic anhydride in almost quantitative yield, m.p. 104.5–105.5°.[9] This material was recrystallized until the assay for C^{14} gave a constant specific activity.

Radioactive and Chemical Assays.—The compounds listed in Table I were burned to carbon dioxide and the radioactive gas collected in traps cooled by liquid nitrogen. After the oxidation was complete, the amount of carbon dioxide was determined manometrically (the carbon content of all compounds was within 0.3% of the theoretical values) and then transferred to an evacuated ionization chamber using vacuum-line technique. All radioactivity measurements were made by using an ion-chamber in conjunction with a vibrating reed electrometer.[10]

TABLE I

Compound	Microcuries of C^{14} per millimole of compound
Succinic acid-2-C^{14}	3.33
Fumaric acid-2-C^{14}	3.34
Maleic anhydride-2-C^{14}	3.35
cis-Δ^4-Tetrahydrophthalic anhydride-1-C^{14}	3.34

---

[4] All melting points were obtained using polarized light and the Kofler micro melting point technique.

[5] E. D. Hughes and H. B. Watson, *J. Chem. Soc.*, 1733 (1930).

[6] J. DeWolf and L. Van de Straete, *Bull. soc. chim. Belg.*, **44**, 288 (1935).

[7] J. B. Stark, A. E. Goodban and H. S. Owen, *Anal. Chem.*, **23**, 413 (1951).

[8] S. Tanatar, *Ann.*, **273**, 31 (1893).

[9] E. H. Farmer and F. L. Warren, *J. Chem. Soc.*, 897 (1929).

[10] H. Palevsky, R. K. Swank and R. Grenchik, *Rev. Sci. Instruments*, **18**, 298 (1947).

DEPARTMENT OF CHEMISTRY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

The Heats of Solution of Erythritol, Mannitol and Dulcitol; Combustion Values for Liquid Polyhydroxy Alcohols

BY GEORGE S. PARKS AND KENNETH E. MANCHESTER

RECEIVED FEBRUARY 25, 1952

The heats of solution of crystalline *i*-erythritol, *d*-mannitol and dulcitol in water at 25° constitute thermal data of considerable intrinsic interest. Moreover, the presence of the hydroxyl group in both solute and solvent is conducive to solutions which are almost "perfect." Hence, the heats of solution in these cases should approximate the theoretical heats of fusion of the crystalline substances at the temperature of the solution process.[1]

Thermal data of this sort can then be combined with the heats of combustion and enthalpies of formation of the crystalline substances so as to yield corresponding values at 25° for the hypothetical liquid state. Such a procedure is frequently advantageous, since regularities are more pronounced in any homologous series, or related group, of organic compounds if the comparisons are based upon the liquid state rather than upon the more individualistic crystalline forms.

Experimental

Method and Materials.—The calorimeter and method which Rowe and Parks[2] developed for measuring the heats of solution of various forms of glucose in water were used for the present determinations.

---

[1] J. H. Hildebrand, "Solubility," second edition, Reinhold Publishing Corp., New York, N. Y., 1936, p. 57.

[2] R. D. Rowe and G. S. Parks, *J. Chem. Phys.*, **14**, 383 (1946).

The experimental procedure involved the dissolving of suitable amounts of the crystalline solute in 250-ml. portions of water. The initial temperature of this water was generally in the 22–23° region and the subsequent temperature lowerings varied in the different experiments from 1.578° down to 0.236°. The values for the heats of solution thus obtained were then adjusted to the standard temperature of 25° by use of Kirchhoff's law with a suitable estimate for ΔC_p, the difference between the heat capacity of the dissolved and crystalline solute. In making this estimate the specific heat of the dissolved solute was assumed to be the same as that found by Gibson and Giauque[3] for liquid glycerol, while the specific heats for the crystalline alcohols were derived from the measurements of Parks and co-workers.[4]

The samples of polyhydroxy alcohols were C.P. products of the Pfanstiehl Chemical Co. The *d*-mannitol material was recrystallized from distilled water, then dried in an electric oven for two days at 100°, and finally subjected to vacuum desiccation over anhydrous magnesium perchlorate for two weeks. The melting point of the product thus obtained and that of the original sample were both 166.1°. The samples of *i*-erythritol and dulcitol were similarly treated, without recrystallization, to this oven-drying process and vacuum desiccation.

Heats of Solution.—Mannitol samples were dissolved in water in an initial series of eight experiments. The solutions thereby obtained varied from 0.3634 to 0.1140 molal. The experimental results are summarized in Table I, with the observed temperature lowerings in column 3 and the ΔH_{298} of solution values, expressed in calories per gram of solute, in the last column. An estimated maximum error of 0.002° in ΔT here introduces uncertainties of 0.04 to 0.12 cal. in the individual ΔH_{298} results. With due allowance for such uncertainties, the heat of solution of mannitol is evidently independent of the concentration in conformity with the requirements of a perfect solution.

TABLE I

HEATS OF SOLUTION OF *d*-MANNITOL IN WATER AT 25°

Experiment no.	Molality of resulting solution	$-\Delta T$ of solution	ΔH_{298} of solution (cal. per gram)
1	0.3634	1.496	29.59
2	.2960	1.219	29.57
3	.2817	1.153	29.56
4	.2726	1.119	29.53
5	.2531	1.040	29.53
6	.1313	0.550	29.65
7	.1212	0.503	29.62
8	.1140	0.474	29.70
Mean result			29.59 (±0.05)

Similarly, the heats of solution of *i*-erythritol and dulcitol were measured in six and eight experiments, respectively. Again the resulting data showed no change of the heat effect with the concentration of the solution. The molal heats of solution for these three polyhydroxy alcohols are now reported in Table II.

TABLE II

SUMMARY OF HEATS OF SOLUTION IN WATER AT 25°

Substance	Formula	No. of experiments	Mean ΔH_{298} of solution, kcal. per mole
i-Erythritol	$C_4H_6(OH)_4$	6	5.57 (±0.01)
d-Mannitol	$C_6H_8(OH)_6$	8	5.39 (±0.01)
Dulcitol	$C_6H_8(OH)_6$	8	7.09 (±0.04)

For comparison with our present results the literature contains only early values obtained for all three substances by Berthelot[5] and a value obtained for mannitol by Speyer.[6] The Berthelot data, when computed to 25°, differ from ours by +0.4, −3.7 and −8.5%, respectively. Speyer's value is 0.6% lower than our mannitol result.

Discussion

The heats of combustion of crystalline erythritol, mannitol and dulcitol, as well as of liquid ethylene glycol and glycerol, have been measured previously in this Laboratory.[7] These experimental results are here recorded in columns 2 and 3 of Table III.

TABLE III

HEATS OF COMBUSTION, $-\Delta H_c$, FOR FIVE POLYHYDROXY ALCOHOLS (IN KCAL. PER MOLE AT 25°)

Substance	$-\Delta H_c$, experimental Crystals	Liquid	$-\Delta H_c$, calcd Liquid
Ethylene glycol	....	284.32	284.47
Glycerol	....	395.63	395.34
i-Erythritol	500.18	(505.75)	506.21
d-Mannitol	722.93	(728.32)	727.95
Dulcitol	720.63	(727.72)	727.95

Our present data for the heats of solution can now be combined with such combustion values for the crystalline alcohols so as to yield the heats of combustion for the hypothetical liquid forms at 25°, which are given parenthetically in Col. 3. Thus we have comparable data, with uncertainties of not over 0.07% in any case, for five polyhydroxy alcohols, and from a study of these results we have deduced the empirical general equation to express

$$-\Delta H_c = 62.73 + 110.87n$$

the heat of combustion, in kilocalories, of such compounds as a function of the number of carbon atoms n. The values thereby calculated for the five alcohols are recorded in column 4.

In this connection it should be noted that the experimental data in Table III show a difference of only 0.60 kcal. for the heats of combustion of the isomers, mannitol and dulcitol, in the liquid form, although the values for the respective crystals differ by 2.30 kcal. This situation is striking evidence as to how greatly crystal forces may influence such thermal data, and supports our general conclusion that comparisons in any homologous series should preferably be based on data referring to the liquid state.

---

[3] G. E. Gibson and W. F. Giauque, THIS JOURNAL, **45**, 93 (1923).

[4] G. S. Parks and C. T. Anderson, *ibid.*, **48**, 1506 (1926); G. S. Parks and H. M. Huffman, *ibid.*, **48**, 2788 (1926).

[5] M. Berthelot, *Ann. chim. phys.*, [6] **21**, 409 (1890); *ibid.*, [5] **9**, 313 (1876).

[6] C. L. Speyer, THIS JOURNAL, **18**, 146 (1896).

[7] G. S. Parks, T. J. West, B. F. Naylor, P. S. Fujii and L. A. McClaine, *ibid.*, **68**, 2524 (1946).

DEPARTMENT OF CHEMISTRY
STANFORD UNIVERSITY
STANFORD, CALIFORNIA

Steroids. XXXIII.[1] Δ^7-Allopregnene-3β,17α-diol-20-one and Related Compounds

BY J. PATAKI, G. ROSENKRANZ AND CARL DJERASSI[2]

RECEIVED JANUARY 28, 1952

Kritchevsky and Gallagher's method[3] for the introduction of a 17α-hydroxy group, which involves formation of an enol acetate of a 20-keto steroid followed by treatment with perbenzoic acid, has so far not been applied to a 20-keto steroid which possesses a double bond. Since Δ^7-allopregnene-3β,17α-diol-20-one (Ia) was required for biological

---

[1] Paper XXXII, C. Djerassi, O. Mancera, M. Velasco, G. Stork and G. Rosenkranz, THIS JOURNAL, **74**, 3321 (1952).

[2] Department of Chemistry, Wayne University, Detroit, Michigan.

[3] T. H. Kritchevsky and T. F. Gallagher, *J. Biol. Chem.*, **179**, 507 (1949); THIS JOURNAL, **73**, 184 (1951).