

# **Thermodynamics of Enzyme-Catalyzed Reactions:**

## **Part 5. Isomerases and Ligases**

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Equilibrium constants and enthalpy changes for reactions catalyzed by the isomerase and ligase classes of enzymes have been compiled. For each reaction the following information is given: the reference for the data; the reaction studied; the name of the enzyme used and its Enzyme Commission number; the method of measurement; the conditions of measurement (temperature, pH, ionic strength, and the buffer(s) and cofactor(s) used); the data and an evaluation of it; and, sometimes, commentary on the data and on any corrections which have been applied to it or any calculations for which the data have been used. The data from 176 references have been examined and evaluated. Chemical Abstract Service registry numbers are given for the substances involved in these various reactions. There is a cross reference between the substances and the Enzyme Commission numbers of the enzymes used to catalyze the reactions in which the substances participate. © 1995 American Institute of Physics and American Chemical Society.

Key words: apparent equilibrium constants; enthalpies of reaction; enzyme-catalyzed reactions; evaluated data; isomerases; ligases; transformed thermodynamic properties.

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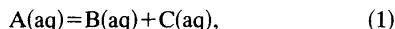
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## 1. Introduction

This paper completes a series of reviews<sup>1-4</sup> on the thermodynamics of enzyme-catalyzed reactions. The first four reviews dealt with the thermodynamics of the reactions catalyzed by the oxidoreductases, transferases, hydrolases, and lyases. These are the first four classes of enzymes classified by the Nomenclature Committee of the International Union of Biochemistry.<sup>5</sup> In the current review a critical compilation of thermodynamic data is provided for the reactions catalyzed by the fifth and sixth classes of enzymes—the isomerases and the ligases. These reactions play significant roles in many biological processes such as glycolysis, the anabolism and catabolism of carbohydrates, fermentation, and vision. Several of these reactions are also of current or potential importance for the production of bulk commodity chemicals such as ethanol and fructose. The data presented herein are limited to equilibrium and calorimetric measurements performed on these reactions under *in vitro* conditions. Thus, the thermodynamic quantities which are generally given are apparent equilibrium constants  $K'$  and calorimetrically determined enthalpies of reaction  $\Delta_f H(\text{cal})$ . Apparent equilibrium constants calculated from kinetic data are also tabulated. If the change in binding of the hydrogen ion  $\Delta_f N(H^+)$  in a biochemical reaction is known, the standard transformed enthalpy of reaction  $\Delta_f H^\circ$  can be calculated from the calorimetrically determined enthalpy of reaction.<sup>6</sup> Equilibrium constants  $K$  and standard molar enthalpies of reaction  $\Delta_f H^\circ$  for chemical reference reactions are also given if they have been reported in the literature. The standard transformed enthalpy of reaction  $\Delta_f H^\circ$  can be used to calculate the temperature dependence of apparent equilibrium constants  $K'$  in the same way that the standard enthalpy of reaction  $\Delta_f H^\circ$  is used to calculate the temperature dependence of the equilibrium constant  $K$ .

The data are presented in the same format as in Parts 1 to 4.<sup>1-4</sup> Thus, the following information is given for each entry in this review: the reference for the data; the biochemical reaction studied; the name of the enzyme used and its Enzyme Commission number; the method of measurement; the conditions of measurement (temperature, pH, ionic strength, and the buffer(s) and cofactor(s) used); the data and an evaluation of it; and, sometimes, commentary on the data and on any corrections which have been applied to it or any calculations for which the data have been used. The absence of a piece of information indicates that it was not found in

the paper cited. The arrangement of the data, its evaluation, and the thermodynamic conventions have been discussed previously.<sup>1</sup> In this regard one should note that equilibrium constants should be expressed as dimensionless quantities. However, the numerical value obtained for the equilibrium constant of an unsymmetrical reaction will depend upon the measure of composition and standard concentration selected for the reactants and products. Thus, for the chemical reaction



$K_c = c(B)c(C)/\{c(A)c^\circ\}$ ,  $K_m = m(B)m(C)/\{m(A)m^\circ\}$ , and  $K_x = x(B)x(C)/x(A)$ . Here,  $c$ ,  $m$ , and  $x$  are, respectively, concentration, molality, and mole fraction,  $c^\circ = 1 \text{ mol dm}^{-3}$ , and  $m^\circ = 1 \text{ mol kg}^{-1}$ . The equilibrium constant expressed in terms of mole fractions is automatically dimensionless. Similar definitions and considerations apply to the apparent equilibrium constant  $K'$ . The symbols used in this review are given in the Glossary (see Section 7).

The subjective evaluation of the data in this review consisted of the assignment of a rating: A (high quality), B (good), C (average), or D (low quality). In making these assignments we considered the various experimental details which were provided in the study. These details include the method of measurement, the number of data points determined, and the extent to which the effects of varying temperature, pH, and ionic strength were investigated. A low rating was generally given when few details of the investigation were reported. For example, in many of the papers cited, the major aim of the study was the isolation and purification of the enzyme of interest. Thus, the equilibrium data were obtained as only a small part of an investigation to characterize many of the properties of that enzyme and the reaction it catalyzes.

This effort began several years ago with an extensive search of the literature to locate the papers containing the relevant data. This search was based on a carefully designed computer search of Chemical Abstracts, a manual search of Methods in Enzymology, and the examination of references found in earlier reviews that dealt with the thermodynamics of enzyme-catalyzed reactions.<sup>7-18</sup> The references obtained from these sources were in turn examined for additional references relevant to this effort. The authors would be most grateful if references that contain data on the thermodynamics of enzyme-catalyzed reactions that were not included in these reviews were brought to their attention.

This effort has been given additional impetus by the recent completion of the IUBMB-IUPAC document "Recommendations for Nomenclature and Tables in Biochemical Thermodynamics."<sup>19</sup> The work described in this review paper has also been accepted by the Thermodynamics Commission (I.2) and by the Steering Committee on Biophysical Chemistry of IUPAC as a project of particular timeliness and importance. The project has therefore been conducted under the auspices of these bodies, has been endorsed by them, and has been written to be consistent with recommended IUPAC nomenclature.

## 2. Acknowledgments

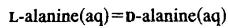
We thank Drs. Ellen Anderson and Edgar Etz for their assistance with the papers written in German and Drs. Mikhail V. Rekharsky and Vytaus Reipa for their help with the papers in Russian. Continuing discussions with Dr. Robert A. Alberty on various aspects of biochemical thermodynamics have been very helpful. Helpful comments on the biochemical nomenclature were received from Drs. A. D. McNaught and David Vanderah. Ms. Kari Fazio and Donna Bell provided valuable assistance in the early collection of the references containing the data and in the preliminary abstracting of information. Support given to this project by the Offices of Industrial Technologies and Transportation Technologies in the U.S. Department of Energy is gratefully acknowledged.

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#### 4. Table of Equilibrium Constants and Enthalpies of Reaction

##### 4.1. Enzyme: alanine racemase (EC 5.1.1.1)



$\frac{T}{K}$	pH	$K'$
310.15	8.1	1.0

Reference: 52NAR/WOO

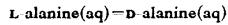
Method: enzymatic assay and manometry

Buffer: phosphate ( $0.1 \text{ mol dm}^{-3}$ )

pH: 8.1

Evaluation: B

This equilibrium constant must equal 1.0.



$\frac{T}{K}$	pH	$K'$
307.15	8.0	1.0

Reference: 54MAR/WIL

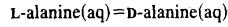
Method: enzymatic assay

Buffer: Tris ( $0.067 \text{ mol dm}^{-3}$ )

pH: 8.0

Evaluation: B

The equilibrium constant must equal 1.0.



$\frac{T}{K}$	pH	$K'$
310.15	7.4	1.0

Reference: 55THO/GOM

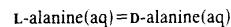
Method: manometry and enzymatic assay

Buffer: phosphate ( $0.01 \text{ mol dm}^{-3}$ )

pH: 7.4

Evaluation: B

This equilibrium constant must equal 1.0.



$\frac{T}{K}$	pH	$K'$
310.15	9.2	1.0

Reference: 81WAS/DAU

Method: enzymatic assay and spectrophotometry

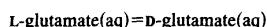
Buffer: Ches ( $0.1 \text{ mol dm}^{-3}$ )

pH: 9.2

Evaluation: B

This equilibrium constant must equal 1.0.

##### 4.2. Enzyme: glutamate racemase (EC 5.1.1.3)



$\frac{T}{K}$	pH	$K'$
310.15	6.8	1.0

Reference: 52NAR/WOO

Method: enzymatic assay

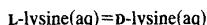
Buffer: phosphate ( $0.1 \text{ mol dm}^{-3}$ )

pH: 6.8

Evaluation: B

This equilibrium constant must equal 1.0.

##### 4.3. Enzyme: lysine racemase (EC 5.1.1.5)



$\frac{T}{K}$	pH	$K'$
303.15	8.0	1.0

Reference: 60ICH/FUR

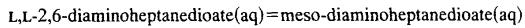
Buffer: phosphate ( $0.04 \text{ mol dm}^{-3}$ )

pH: 8.0

Evaluation: B

This equilibrium constant must equal 1.0.

##### 4.4. Enzyme: diaminopimelate epimerase (EC 5.1.1.7)



$\frac{T}{K}$	pH	$K'$
310.15	7.0	1.9

Reference: 69WHI/LEJ

Method: manometry and spectrophotometry

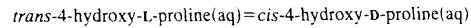
Buffer: phosphate ( $0.1 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: B

The theoretical value of  $K'$  is 2.0. White *et al.* found, as is to be expected, that the value of the apparent equilibrium constant was constant over the temperature range 298 K to 318 K at pH=7.0.

##### 4.5 Enzyme: 4-hydroxyproline epimerase (EC 5.1.1.8)



$\frac{T}{K}$	pH	$K'$
298.15	8.1	0.99

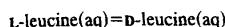
Reference: 64ADA/NOR

Method: ion exchange chromatography

Buffer: Tris ( $0.05 \text{ mol dm}^{-3}$ )

pH: 8.1

Evaluation: B

**4.6. Enzyme: amino-acid racemase (EC 5.1.1.10)**

$\frac{T}{K}$	pH	$K'$
310.15	8.3	1.0

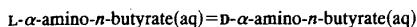
Reference: 67SOD/OSU

Method: manometry and enzymatic assay

Buffer: diphosphate ( $0.03 \text{ mol dm}^{-3}$ )

Evaluation: B

This equilibrium constant must equal 1.0



$\frac{T}{K}$	pH	$K'$
310.15	8.3	1.0

Reference: 67SOD/OSU

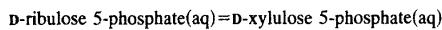
Method: manometry and enzymatic assay

Buffer: diphosphate ( $0.03 \text{ mol dm}^{-3}$ )

pH: 8.3

Evaluation: B

This equilibrium constant must equal 1.0

**4.7. Enzyme: ribulose-phosphate 3-epimerase (EC 5.1.3.1)**

$\frac{T}{K}$	pH	$K'$
298.15	7.5	1.5

Reference: 56HUR/HOR

Method: Enzymatic assay and spectrophotometry

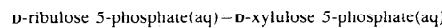
Buffer: Tris ( $0.078 \text{ mol dm}^{-3}$ )

pH: 7.5

Cofactor(s):  $\text{MgCl}_2$ 

Evaluation: B

The apparent equilibrium constant given here was calculated from the percent conversion data given by Hurwitz and Horecker.



$\frac{T}{K}$	pH	$K'$
310.15	7.5	0.83

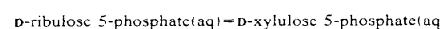
Reference: 56STU/HOR

Method: spectrophotometry

Buffer: Tris ( $0.025 \text{ mol dm}^{-3}$ )

pH: 7.5

Evaluation: C



$\frac{T}{K}$	pH	$K'$
310.15	7.5	1.4

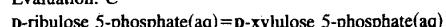
Reference: 57ASH/HIC

Method: spectrophotometry

Buffer: imidazole ( $0.01 \text{ mol dm}^{-3}$ )

pH: 7.5

Evaluation: C



$\frac{T}{K}$	pH	$K'$
310.15	7.5	3.0

Reference: 58TAB/SRE

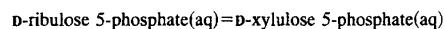
Method: enzymatic assay and spectrophotometry

Buffer: glycylglycine ( $0.056 \text{ mol dm}^{-3}$ )

pH: 7.5

Evaluation: B

The value of the apparent equilibrium constant given here was calculated from percent conversion data.



$\frac{T}{K}$	pH	$c(\text{Mg}^{2+})$ $\text{mol dm}^{-3}$	$I_c$ $\text{mol dm}^{-3}$	$K'$
311.15	7.0	0.001	0.25	1.82

Reference: 86CAS/VEE

Method: enzymatic assay and spectrophotometry

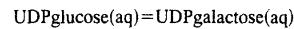
Buffer: phosphate ( $0.020 \text{ mol dm}^{-3}$ )

pH: 7.0

Cofactor(s):  $\text{MgCl}_2$ 

Evaluation: A

Also see data given under EC 5.1.3.4.

**4.8. Enzyme: UDPglucose 4-epimerase (EC 5.1.3.2)**

$\frac{T}{K}$	pH	$K'$
298.15	8.7	0.33

Reference: 57MAX

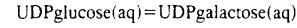
Method: spectrophotometry

Buffer: glycine ( $0.1 \text{ mol dm}^{-3}$ )

pH: 8.7

Evaluation: C

The apparent equilibrium constant given here was calculated from percent conversion data.



$\frac{T}{K}$	pH	$K'$
298.15	8.7	0.29

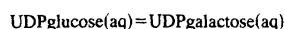
Reference: 64IMA/MOR

Method: spectrophotometry

Buffer: glycine ( $0.1 \text{ mol dm}^{-3}$ ) + NaOH

pH: 8.7

Evaluation: A



$\frac{T}{K}$	pH	$K'$
300.15	7.1	0.289
300.15	8.7	0.278

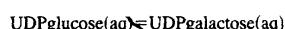
Reference: 64WIL/HOG

Method: spectrophotometry

Buffer: potassium phosphate ( $0.05 \text{ mol dm}^{-3}$ ) and glycine ( $0.05 \text{ mol dm}^{-3}$ )

pH: 7.1 and 8.7

Evaluation: B



$\frac{T}{K}$	pH	$K'$
310.15	8.7	0.35

Reference: 68SAL/NOR

Method: chromatography and spectrophotometry

Buffer: glycine ( $0.24 \text{ mol dm}^{-3}$ ) + NaOH

pH: 8.7

Evaluation: C



$\frac{T}{K}$	pH	$K'$
303.15	9.0	0.32

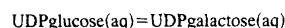
Reference: 69FAN/FEI

Method: radioactivity and spectrophotometry

Buffer: glycine ( $0.12 \text{ mol dm}^{-3}$ ) + NaOH

pH: 9.0

Evaluation: B



$\frac{T}{K}$	pH	$K'$
303.15	8.0	0.31

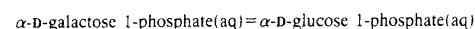
Reference: 84DEY

Method: spectrophotometry

Buffer: glycine ( $0.1 \text{ mol dm}^{-3}$ )

pH: 9.5

Evaluation: C



$\frac{T}{K}$	pH	$K'$
310.15	7.4	3

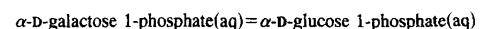
Reference: 52LEL/CAR

Method: paper chromatography and chemical analysis

pH: 7.4

Evaluation: C

UDPglucose-hexose 1-phosphate uridylyltransferase (EC 2.7.7.12) was also present. This is an approximate result obtained from percent conversion data.



$\frac{T}{K}$	pH	$K'$
298.15	7.1	3

Reference: 54IAN/CRA

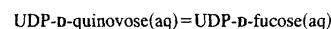
Method: paper chromatography

Buffer: acetate ( $0.005 \text{ mol dm}^{-3}$ ) + cacodylate ( $0.005 \text{ mol dm}^{-3}$ )

pH: 7.1

Evaluation: C

UDPglucose-hexose 1-phosphate uridylyltransferase (EC 2.7.7.12) was also present. The approximate value of the apparent equilibrium constant given here was calculated from the percent conversion data given by Hansen and Crane. The temperature of reaction was not stated and was assumed to be 298.15 K.



$\frac{T}{K}$	pH	$K'$
310.15	8.7	1.62

Reference: 68SAL/NOR

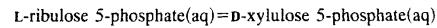
Method: chromatography and spectrophotometry

Buffer: glycine ( $0.24 \text{ mol dm}^{-3}$ ) + NaOH

pH: 8.7

Evaluation: C

#### 4.9. Enzyme: L-ribulose-phosphate 4-epimerase (EC 5.1.3.4)



$\frac{T}{K}$	pH	$K'$
310.15	7.6	1.2

Reference: 56DIC/WIL

Method: chromatography and spectrophotometry

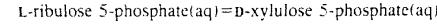
Buffer: glycylglycine ( $0.06 \text{ mol dm}^{-3}$ )

pH: 7.6

Cofactor(s):  $\text{MgCl}_2$  ( $0.01 \text{ mol dm}^{-3}$ )

Evaluation: C

The apparent equilibrium constant given here was calculated from the data given in Dickens and Williamson's Table 5. Also see data under EC 5.1.3.1.



$\frac{T}{K}$	pH	$K'$
308.15	7.0	~1.0

Reference: 57BUR/HOR

Method: enzymatic assay

Buffer: Tris ( $0.2 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: C

$L\text{-ribulose 5-phosphate(aq)} \rightleftharpoons D\text{-xylulose 5-phosphate(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	7.0	1.2

Reference: 58BUR/HOR

Method: enzymatic assay

Buffer: Tris ( $0.042 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: B

 $L\text{-ribulose 5-phosphate(aq)} \rightleftharpoons D\text{-xylulose 5-phosphate(aq)}$ 

$\frac{T}{K}$	pH	$K'$
297.15	8.4	1.86

Reference: 58WOL/SIM

Method: enzymatic assay

Buffer: glycylglycine ( $0.1 \text{ mol dm}^{-3}$ )

pH: 8.4

Evaluation: B

 $L\text{-ribulose 5-phosphate(aq)} \rightleftharpoons D\text{-xylulose 5-phosphate(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	6.0	$\approx 1.0$

Reference: 62HOR

Method: radioactivity

Buffer: succinate ( $0.092 \text{ mol dm}^{-3}$ ) + NaOH

pH: 6.0

Cofactor(s):  $MgCl_2$  ( $0.013 \text{ mol dm}^{-3}$ )

Evaluation: C

**4.10. Enzyme: UDParabinose 4-epimerase (EC 5.1.3.5)** $UDP\text{-L-arabinose(aq)} \rightleftharpoons UDP\text{-D-xylose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	7.5	1.0

Reference: 60FEL/NEU

Method: electrophoresis and radioactivity

Buffer: Tris ( $0.08 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.5

Evaluation: B

 $UDP\text{-L-arabinose(aq)} \rightleftharpoons UDP\text{-D-xylose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	8.7	0.94

Reference: 68SAL/NOR

Method: chromatography and spectrophotometry

Buffer: glycine ( $0.24 \text{ mol dm}^{-3}$ ) + NaOH

pH: 8.7

Evaluation: C

 $UDP\text{-L-arabinose(aq)} \rightleftharpoons UDP\text{-D-xylose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
303.15	8.0	1.25

Reference: 70FAN/FEI

Method: gas-liquid chromatography

Buffer: phosphate ( $0.075 \text{ mol dm}^{-3}$ )

pH: 8.0

Evaluation: B

**4.11. Enzyme: UDPglucuronate 4-epimerase (EC 5.1.3.6)** $UDP\text{-D-glucuronate(aq)} \rightleftharpoons UDP\text{-D-galacturonate(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	7.5	1.1

Reference: 60FEI/NEU

Method: electrophoresis and radioactivity

Buffer: Tris ( $0.08 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.5

Evaluation: B

 $UDP\text{-D-glucuronate(aq)} \rightleftharpoons UDP\text{-D-galacturonate(aq)}$ 

$\frac{T}{K}$	pH	$K'$
298.15	7.5	2.6

Reference: 74GAU/MAI

Method: radioactivity

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.5

Evaluation: B

**4.12. Enzyme: N-acylglucosamine 2-epimerase (EC 5.1.3.8)** $N\text{-acetyl-D-glucosamine(aq)} \rightleftharpoons N\text{-acetyl-D-mannosamine(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	7.6	0.26

Reference: 65GHO/ROS2

Method: radioactivity

Buffer: Tris ( $0.063 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.6

Cofactor(s): ATP ( $0.025 \text{ mol dm}^{-3}$ ) and  $MgCl_2$  ( $0.0125 \text{ mol dm}^{-3}$ )

Evaluation: C

**4.13. Enzyme: N-acylglucosamine-6-phosphate 2-epimerase (EC 5.1.3.9)** $N\text{-acetyl-D-glucosamine 6-phosphate(aq)} \rightleftharpoons N\text{-acetyl-D-mannosamine 6-phosphate(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	7.6	0.43

Reference: 65GHO/ROS

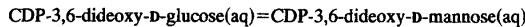
Method: spectrophotometry and radioactivity

Buffer: Tris maleate ( $0.018 \text{ mol dm}^{-3}$ )

pH: 7.6

Evaluation: C

**4.14. Enzyme: CDP-*D*-glucopyranose epimerase  
(EC 5.1.3.10)**



$\frac{T}{K}$	pH	$K'$
310.15	8.4	1.3

Reference: 66MAT

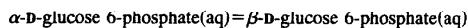
Method: chromatography and radioactivity

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + HCl

Evaluation: B

The apparent equilibrium constant given here was calculated from percent conversion data.

**4.15. Enzyme: glucose-6-phosphate 1-epimerase  
(EC 5.1.3.15)**



$\frac{T}{K}$	pH	$K'$
298.15	7.6	1.7

Reference: 72WUR/HES

Method: enzymatic assay and spectrophotometry

Buffer: imidazole (0.050 M) + HCl

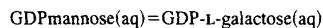
pH: 7.6

Cofactor(s):  $\text{MgSO}_4$  ( $0.008 \text{ mol dm}^{-3}$ )

Evaluation: C

The apparent equilibrium constant given here was calculated from the percentages of these isomers present at equilibrium as given by Wurster and Hess.

**4.16. Enzyme: GDP-D-mannose 3, 5-epimerase  
(EC 5.1.3.18)**



$\frac{T}{K}$	pH	$K'$
310.15	8.0	0.52

Reference: 82BAR/HEB

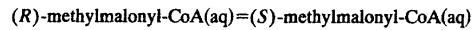
Buffer: Tris ( $0.04 \text{ mol dm}^{-3}$ ) + HCl

pH: 8.0

Evaluation: C

The apparent equilibrium constant given here was calculated from the percentages of the reactant and product at equilibrium.

**4.17. Enzyme: methylmalonyl-CoA epimerase  
(EC 5.1.99.1)**



$\frac{T}{K}$	pH	$K'$
303.15	7.4	1.0

Reference: 63ALL/KEL

Method: spectrophotometry

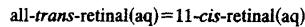
Buffer: Tris ( $0.05 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.4

Evaluation: B

This equilibrium constant must equal 1.0.

**4.18. Enzyme: retinal isomerase (EC 5.2.1.3)**



$\frac{T}{K}$	pH	$K'$
309.15	7.0	$\approx 0.05$

Reference: 56HUB

Method: spectrophotometry

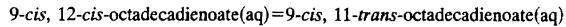
Buffer: phosphate

pH: 7.0

Evaluation: C

The apparent equilibrium constant given here refers to the reaction that occurs under dim red light.

**4.19. Enzyme: linoleate isomerase (EC 5.2.1.5)**



$\frac{T}{K}$	pH	$K'$
308.15	7.0	61

Reference: 67KEP/TOV

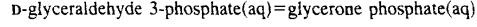
Method: radioactivity

Buffer: phosphate ( $0.1 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: B

**4.20. Enzyme: triose-phosphate isomerase  
(EC 5.3.1.1)**



$\frac{T}{K}$	pH	$K'$
303.15	7.0	24
312.15	7.0	21
333.15	7.0	25

Reference: 43MEY/JUN

Method: chemical analysis and polarimetry

pH: 7.0

Evaluation: C

These measurements were performed in the absence of buffers but near pH = 7.0. From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $T=318 \text{ K}$ , pH  $\approx 7$ )  $\approx 2 \text{ kJ mol}^{-1}$ .

**D-glyceraldehyde 3-phosphate(aq)=glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$K'$
298.15	8.0	≈17

Reference: 47MEY/OES

Method: chemical analysis and polarimetry

Buffer: barbital+acetate

pH: 8.0

Evaluation: C

This is an approximate result. The temperature was assumed to be 298.15 K.

**D-glyceraldehyde 3-phosphate(aq)=glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$K'$
311.15	≈7.3	22

Reference: 50OES/MEY

Method: spectrophotometry

Buffer: barbital+acetate

pH: 7.0–7.5

Evaluation: C

**D-glyceraldehyde 3-phosphate(aq)=glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$K'$
298.15	7.8	22

Reference: 68BUR/WAL

Method: enzymatic assay

Buffer: triethanolamine ( $0.021 \text{ mol dm}^{-3}$ )

pH: 7.8

Evaluation: C

The approximate value of the apparent equilibrium constant given here is based upon kinetic data. Few details were given in this short communication.

**D-glyceraldehyde 3-phosphate(aq)=glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$K'$
298.15	7.5	19

Reference: 75KRI

Method: spectrophotometry

Buffer: triethanolamine ( $0.093 \text{ mol dm}^{-3}$ )+HCl

pH: 7.5

Evaluation: C

**D-glyceraldehyde 3-phosphate(aq)=glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$I_c$ $\text{mol dm}^{-3}$	$K'$
311.15	7.0	0.25	22.0

Reference: 69VEE/RAI

Method: spectrophotometry

Buffer: sodium phosphate ( $0.010 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: A

Veech *et al.* stated that the addition of  $Mg^{2+}$  ( $0.005 \text{ mol dm}^{-3}$ ) had no effect on the value of the apparent equilibrium constant.

**D-glyceraldehyde 3-phosphate(aq)=glycerone phosphate(aq)**

$\frac{T}{K}$	pH	Cosolvent	$K'$
303.15	7.6	none	22
303.15	7.6	glycerol (9 mass percent)	20
303.15	7.6	glycerol (10 mass percent)	19
303.15	7.6	glycerol (18 mass percent)	16
303.15	7.6	glycerol (27 mass percent)	11
303.15	7.6	glycerole (34 mass percent)	14
303.15	7.6	glycerol (36 mass percent)	10
303.15	7.6	poly(ethylene glycol) (18 mass percent)	19
303.15	7.6	2-propanol (14 mass percent)	21

Reference: 88LIM/RAI

Method: enzymatic assay and spectrophotometry; NMR  
Buffer: triethanolamine ( $0.1 \text{ mol dm}^{-3}$ )

pH: 7.6

Evaluation: B

The results obtained by direct measurement of  $K'$  were generally in agreement with results obtained from kinetic data. Two series of measurements were done; one used an enzymatic assay method and the second used NMR.

**D-fructose 1,6-bisphosphate(aq)=2 glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$K'_c$
266.15	7	0.00018
273.15	7	0.00030
293.15	7	0.0015
333.15	7	0.013
343.15	7	0.022

Reference: 34MEY/LOH

Method: spectrophotometry

pH: ≈7

Evaluation: C

Fructose-bisphosphate aldolase (EC 4.1.2.13) was also present. From the temperature dependence of  $K'$  we calculate  $\Delta_f H^\circ$  ( $\bar{T}=255 \text{ K}$ , pH=7) = 47 kJ mol<sup>-1</sup>.

**D-fructose 1,6-bisphosphate(aq)=2 glycerone phosphate(aq)**

$\frac{T}{K}$	pH	Salt	$c(\text{salt}) \text{ mol dm}^{-3}$	$K'_c$
273.15	7	none	--	0.00032
293.15	7	none	--	0.0015
313.15	7	none	--	0.0064
333.15	7	none	--	0.019
293.15	7	NaCl	0.043	0.0011
293.15	7	NaCl	0.21	0.00075
293.15	7	NaCl	0.90	0.00047
293.15	7	Na <sub>2</sub> SO <sub>4</sub>	0.2	0.00055
293.15	7	MgCl <sub>2</sub>	0.06	0.00035
293.15	7	MgCl <sub>2</sub>	0.12	0.00035
293.15	7	MgCl <sub>2</sub>	0.24	0.00035
273.15	7	MgCl <sub>2</sub>	0.12	0.000071
293.15	7	MgCl <sub>2</sub>	0.12	0.00029
333.15	7	MgCl <sub>2</sub>	0.12	0.0012
273.15	7	MgCl <sub>2</sub>	0.006	0.00014
293.15	7	MgCl <sub>2</sub>	0.06	0.00037
293.15	7	MgCl <sub>2</sub>	0.031	0.00031
293.15	7	MgCl <sub>2</sub>	0.012	0.00051
293.15	7	MgCl <sub>2</sub>	0.006	0.00064
293.15	7	MgCl <sub>2</sub>	0.0025	0.0011
293.15	7	MgCl <sub>2</sub>	0.0012	0.0014
313.15	7	MgCl <sub>2</sub>	0.031	0.0014
313.15	7	MgCl <sub>2</sub>	0.012	0.0020
313.15	7	MgCl <sub>2</sub>	0.006	0.0025
313.15	7	MgCl <sub>2</sub>	0.0012	0.0056
333.15	7	MgCl <sub>2</sub>	0.031	0.0046
333.15	7	MgCl <sub>2</sub>	0.012	0.0056
333.15	7	MgCl <sub>2</sub>	0.006	0.0082
333.15	7	MgCl <sub>2</sub>	0.0012	0.015

Reference: 35MEY

Method: spectrophotometry

pH:  $\approx 7$ 

Evaluation: C

Fructose-bisphosphate aldolase (EC 4.1.2.13) was also present. The pH was not well controlled in this study. From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $\bar{T}=303$  K, pH=7)=52 kJ mol<sup>-1</sup>.

**D-fructose 1,6-bisphosphate(aq)=2 glycerone phosphate(aq)**

$\frac{T}{K}$	$\Delta H(\text{cal}) \text{ kJ mol}^{-1}$
293.15	58
313.15	64

Reference: 35MEY/LOH

Method: calorimetry

Buffer: phosphate

Evaluation: C

Fructose-bisphosphate aldolase (EC 4.1.2.13) was also present.

**D-fructose 1,6-bisphosphate(aq)=2 glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$K'_c$
278.15	9.0	4.35E-4
298.15	9.0	1.82E-3
313.15	9.0	6.37E-3

Reference: 41UTT/WER

Method: chemical analysis

Buffer: glycine + NaOH

pH: 9.0

Cofactor(s): MgCl<sub>2</sub>**Evaluation: B**

Fructose-bisphosphate aldolase (EC 4.1.2.13) was also present. From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $T=296$  K, pH=9.0)≈55 kJ mol<sup>-1</sup>.

**D-fructose 1,6-bisphosphate(aq)=2 glycerone phosphate(aq)**

$\frac{T}{K}$	pH	$K'_c$
303.15	7	0.0020
311.15	7	0.0024
313.15	7	0.0030
333.15	7	0.011

Reference: 43MEY/JUN

Method: chemical analysis and polarimetry

pH: 7

Evaluation: B

Fructose-bisphosphate aldolase (EC 4.1.2.13) was also present. These measurements were performed in the absence of a buffer but near pH=7. From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $\bar{T}=318$  K, pH≈7)=50 kJ mol<sup>-1</sup>.

**4.21. Enzyme: erythrose isomerase (EC 5.3.1.2)****D-erythrose(aq)=D-erythrulose(aq)**

$\frac{T}{K}$	pH	$K'$
308.15	5.8	2.3

Reference: 62UEH

Method: chemical analysis

Buffer: phosphate (0.04 mol dm<sup>-3</sup>)

pH: 5.8

Evaluation: C

This is an approximate result calculated from percent conversion data. The enzyme commission number given here is now a deleted entry.

**4.22. Enzyme: arabinose isomerase (EC 5.3.1.3)****D-arabinose(aq)=D-ribulose(aq)**

$\frac{T}{K}$	$K'$
310.15	≈0.18

Reference: 53COH

Method: spectrophotometry

Buffer: glycylglycine (0.1 mol dm<sup>-3</sup>)

pH: 6.0–8.0

Evaluation: C

The approximate value of the apparent equilibrium constant given here was calculated from percent conversion data. Also see data given under EC 5.3.1.4.

$\text{D}-\text{arabinose(aq)} = \text{D}-\text{ribulose(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
320.25	7.4	0.146
325.25	7.4	0.170
328.15	7.4	0.169
331.95	7.4	0.199
338.15	7.4	0.226
343.75	7.4	0.246

Reference: 85TEW/GOL2

Method: HPLC

Buffer: phosphate ( $0.039 \text{ mol dm}^{-3}$ )

pH: 7.4

Cofactor(s):  $\text{Mg}(\text{NO}_3)_2$  ( $\approx 0.013 \text{ mol dm}^{-3}$ )

Evaluation: A

From the temperature dependence of the apparent equilibrium constant Tewari and Goldberg calculated  $\Delta_f H^\circ(T=332 \text{ K}, \text{pH}=7.4) = -20.9 \text{ kJ mol}^{-1}$ .

 $\text{L}-\text{fucose(aq)} = \text{L}-\text{fuculose(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
310.15	8.0	0.12

Reference: 56GRE/COH

Method: chemical analysis

Buffer: phosphate ( $0.050 \text{ mol dm}^{-3}$ )

pH: 8.0

Evaluation: B

**4.23. Enzyme: L-arabinose isomerase (EC 5.3.1.4)** $\text{L}-\text{arabinose(aq)} = \text{L}-\text{ribulose(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
298.15	7.0	0.11
310.15	7.0	0.16
326.15	7.0	0.19

Reference: 58HEA/HOR

Method: polarimetry

Buffer: triethanolamine ( $0.10 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: C

The values of the apparent equilibrium constants given here were calculated from the percent conversion data given by Heath *et al.* Also see data given under EC 5.3.1.3.

**4.24. Enzyme: xylose isomerase (EC 5.3.1.5)** $\text{D}-\text{glucose(aq)} = \text{D}-\text{fructose(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
323.15	7.65	1.0

Reference: 64SAT/TSU

Method: polarimetry

Buffer: phosphate and barbital

pH: 7.6–7.7

Cofactor(s):  $\text{MgSO}_4$ 

Evaluation: C

This is an approximate result.

 $\text{D}-\text{glucose(aq)} = \text{D}-\text{fructose(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
343.15	8.0	1.08

Reference: 65ICH/HIR

Method: spectrophotometry

Buffer: phosphate

pH: 8.0

Cofactor(s):  $\text{CoSO}_4$ 

Evaluation: B

The apparent equilibrium constant given here was calculated from the percent conversion data given by Ichimura *et al.*

 $\text{D}-\text{glucose(aq)} = \text{D}-\text{glucose(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
333.15	9.0	1.08

Reference: 65TSU/SAT

Method: spectrophotometry

Buffer: ammonium ( $0.05 \text{ mol dm}^{-3}$ )

pH: 9.0

Cofactor(s):  $\text{Mg}^{2+}(0.001 \text{ mol dm}^{-3})$  and  $\text{Co}^{2+}(0.001 \text{ mol dm}^{-3})$ 

Evaluation: C

This is an approximate result calculated from percent conversion data.

 $\text{D}-\text{glucose(aq)} = \text{D}-\text{fructose(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
313.15	7.0	0.82

Reference: 66NAT

Method: chromatography

Buffer: arsenate + HCl

pH: 7.0

Evaluation: C

This is an approximate result calculated from percent conversion data.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
333.15	6.5	1.0
343.15	6.5	1.0

Reference: 67DAN/YOS

Method: spectrophotometry

Buffer: phosphate ( $0.01 \text{ mol dm}^{-3}$ )

pH: 6.5

Cofactor(s):  $\text{CoCl}_2$  ( $0.001 \text{ mol dm}^{-3}$ )

Evaluation: B

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
298.15	7.0	0.74
313.15	7.0	0.92
333.15	7.0	1.15
343.15	7.0	1.30

Reference: 67TAK

Method: chemical analysis and polarimetry

Buffer: phosphate ( $0.045 \text{ mol dm}^{-3}$ )

pH: 7.0

Cofactor(s):  $\text{MgSO}_4$  ( $0.009 \text{ mol dm}^{-3}$ )

Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $T=321 \text{ K}$ , pH=7.0)= $10.5 \text{ kJ mol}^{-1}$ .

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
333.15	6.85	1.02
343.15	6.85	1.06
352.65	6.85	1.10

Reference: 73HAV/PIT

Method: polarimetry

Buffer: sodium maleate ( $0.2 \text{ mol dm}^{-3}$ )

pH: 6.85

Cofactor(s):  $\text{MgSO}_4$  ( $0.02 \text{ mol dm}^{-3}$ )+ $\text{CoCl}_2$  ( $0.001 \text{ mol dm}^{-3}$ )

Evaluation: C

The values of the apparent equilibrium constants given here were calculated from the percent conversion data given by Havewala and Pitcher.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
323.15	7.8	1.00
333.15	7.8	1.08
338.15	7.8	1.14
343.15	7.8	1.21

Reference: 73LAN

pH: 7.8

Cofactor(s):  $\text{Co}^{2+}$  and  $\text{Mg}^{2+}$ 

Evaluation: C

Few details were given in this study. From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $T=302 \text{ K}$ , pH=7.8)= $8.7 \text{ kJ mol}^{-1}$ .

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
323.15	7.0	1.03

Reference: 74FRA/LEE

Buffer:  $\beta$ -glycerophosphate ( $0.05 \text{ mol dm}^{-3}$ )

pH: 7.0

Cofactor(s):  $\text{Mg}^{2+}$  and  $\text{Co}^{2+}$ 

Evaluation: C

The value of the apparent equilibrium constant given here is based upon kinetic data.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
333.15	7.2	1.13
343.15	7.2	1.33
323.15	7.0	0.83
333.15	7.0	1.32
343.15	7.0	1.05
353.15	7.0	1.10

Reference: 74MCK

Method: polarimetry and chemical analysis

pH: 7.0–7.2

Cofactor(s):  $\text{Mg}^{2+}$ 

Evaluation: B

The results at pH=7.0 were obtained from kinetic data.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
340.15	7.1	1.04
350.15	7.1	1.09
360.15	7.1	1.16

Reference: 74SCA/SII

Buffer: phosphate ( $0.03 \text{ mol dm}^{-3}$ )

pH: 7.0–7.2

Cofactor(s):  $\text{Mg}^{2+}$  and  $\text{Co}^{2+}$ 

Evaluation: C

The values of the apparent equilibrium constant given here were calculated from percent conversion data.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
303.15	7.3	0.869
318.15	7.3	0.931
333.15	7.3	0.996
343.15	7.3	1.101

Reference: 76LLO/KHA

Method: polarimetry and HPLC

Buffer: sodium sulfite+sodium hydrogen sulfite

pH: 7.3

Cofactor(s):  $\text{MgSO}_4$  ( $0.005 \text{ mol dm}^{-3}$ )

Evaluation: A

The result given here was calculated from percent conversion data. From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $\bar{T}=323 \text{ K}$ , pH=7.3)= $4.9 \text{ kJ mol}^{-1}$ .

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
303.15	7.0	0.828
318.15	7.0	0.957
333.15	7.0	1.141
343.15	7.0	1.283
353.15	7.0	1.381

Reference: 76SPR/LIM

Method: enzymatic assay and chemical analysis

pH: 7.0

Cofactor(s):  $\text{Co}^{2+}$  and  $\text{Mg}^{2+}$ 

Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $\bar{T}=328$  K, pH=7.0)=9.4 kJ mol<sup>-1</sup>.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
323.15	7.0	0.84
333.15	7.0	1.33
343.15	7.0	1.06
353.15	7.0	1.12

Reference: 79MCK/TAV

Method: polarimetry

pH: 7.0

Cofactor(s):  $\text{Mg}^{2+}$ 

Evaluation: C

We calculated the values of the apparent equilibrium constant given here from the kinetic data given in McKay and Tavlarides' Table 2.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
323.15	7.5	0.99
328.15	7.5	1.01
333.15	7.5	1.05
338.15	7.5	1.07
333.15	7.5	1.11
338.15	7.5	1.14

Reference: 83TIL

Method: polarimetry and HPLC

pH: 7.5

Cofactor(s):  $\text{MgSO}_4$  (0.003 mol dm<sup>-3</sup>)

Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $\bar{T}=331$  K, pH=7.5)=7.1 kJ mol<sup>-1</sup>.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
333.15	7.0	1.039
338.15	7.0	1.062
343.15	7.0	1.103
348.15	7.0	1.131
353.15	7.0	1.182
358.15	7.0	1.209

Reference: 84LLO/CHA

Method: HPLC

Buffer: sodium sulfite + sodium hydrogen sulfite

pH: 7.0

Cofactor(s):  $\text{Mg}^{2+}$  and  $\text{Co}^{2+}$ 

Evaluation: A

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ$  ( $\bar{T}=346$  K, pH=7.0)=6.3 kJ mol<sup>-3</sup>.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
298.15	7.5	0.866
306.15	7.5	0.892
313.15	7.5	0.936
322.15	7.5	0.964
331.85	7.5	1.004
344.15	7.5	1.094
353.15	7.5	1.157
358.15	7.5	1.199

Reference: 84TEW/GOL

Method: HPLC

Buffer: phosphate (0.039 mol dm<sup>-3</sup>) and {Tris (0.050 mol dm<sup>-3</sup>) + HCl}

pH: 7.5

Cofactor(s):  $\text{MgSO}_4$ 

Evaluation: A

Tewari and Goldberg used their combined equilibrium and calorimetric data to calculate  $K=0.869$ ,  $\Delta_f G^\circ=0.35$  kJ mol<sup>-1</sup>, and  $\Delta_f H^\circ=2.78$  kJ mol<sup>-1</sup>, and  $\Delta_f C_p^\circ=76.1 \text{ K}^{-1} \text{ mol}^{-1}$  at  $T=298.15$  K for the chemical reference reaction: D-glucose(aq)=D-fructose(aq). This is the predominant chemical reaction at neutral pHs. These results were also published in [85TEW/GOL].

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$\frac{\Delta_f H(\text{cal})}{\text{kJ mol}^{-1}}$
298.15	≈7.4	2.76
313.25	≈7.4	4.01
331.85	≈7.4	5.21
344.15	≈7.4	6.34

Reference: 84TEW/GOL

Method: microcalorimetry

Buffer: Tris + HCl

pH: 6.8 to 8.0

Cofactor(s):  $\text{MgSO}_4$  and  $\text{CoCl}_2$ 

Evaluation: A

**D-glucose(aq)=D-fructose**

$\frac{T}{K}$	pH	c (total substrate)	$K'$
343.35	7.1	0.278	1.110
343.35	7.1	0.555	1.109
343.35	7.1	0.617	1.107
343.35	7.1	0.833	1.114
343.35	7.1	1.111	1.104
343.35	7.1	1.667	1.104
343.35	7.1	2.222	1.105

Reference: 85MAK/KIE

Method: HPLC

pH: 7.1

Cofactor(s):  $Mg^{2+}$  and  $Ca^{2+}$ 

Evaluation: B

Makkee *et al.* reported the apparent equilibrium constant as a function of the total concentration of substrate (glucose+fructose).

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
310.6	7.00	0.895
318.2	7.00	0.936
326.5	7.00	0.992
333.2	7.00	1.037
341.6	7.00	1.083
345.2	7.00	1.120

Reference: 86OLI/TOI

Method: HPLC

pH: 7.00

Cofactor(s):  $MgSO_4$  (0.01 mol dm<sup>-3</sup>) and  $CoCl_2$  (0.001 mol dm<sup>-3</sup>)

Evaluation: B

The values of the apparent equilibrium constant given here were obtained from Olivier and du Toits' Fig. 10 that contains percent conversion data as a function of temperature. Olivier and du Toit also calculated  $\Delta_fH^\circ$  ( $T=328$  K, pH=7.0)=6.0 kJ mol<sup>-1</sup> for the above reaction.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
303.15	7.0	1.060
313.15	7.0	1.080
323.15	7.0	1.093
333.15	7.0	1.162

Reference: 86POL/MEN

Method: polarimetry

pH: 7.0

Evaluation: C

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_fH^\circ$  ( $T=318$  K, pH=7.0)=2.4 kJ mol<sup>-1</sup>.

**D-glucose(aq)=D-fructose(aq)**

$\frac{T}{K}$	pH	$K'$
333.15	7.5	1.08

Reference: 92DEM/ATT

Buffer: Tris (0.05 mol dm<sup>-3</sup>)+HCl

pH: 7.5

Cofactor(s):  $Co^{2+}$  (0.001 mol dm<sup>-3</sup>) and  $Mg^{2+}$  (0.070 mol dm<sup>-3</sup>)

Evaluation: C

The apparent equilibrium constant was calculated from the percent conversion data given by Demerdash and Attia.

**D-psicose(aq)= $\beta$ -D-allose(aq)**

$\frac{T}{K}$	pH	$K'$
317.25	7.4	2.15
325.15	7.4	2.32
333.15	7.4	2.55
341.55	7.4	2.77
349.25	7.4	3.01

Reference: 86TEW/GOL

Method: HPLC

Buffer: phosphate (0.039 mol dm<sup>-3</sup>)

pH: 7.4

Evaluation: A

Tewari and Goldberg also calculated  $\Delta_fH^\circ$  ( $T=298.15$  K)=7.4 kJ mol<sup>-1</sup> and  $\Delta_fC_p^\circ \approx 67$  J K<sup>-1</sup> mol<sup>-1</sup> for the chemical reference reaction:

**D-psicose(aq)= $\beta$ -D-allose(aq)**

$\frac{T}{K}$	pH	$K'$
333.15	7.4	≈ 0.30

Reference: 86TEW/GOL

Method: HPLC

Buffer: phosphate

pH: 7.4

Cofactor(s):  $Mg(NO_3)_2$ 

Evaluation: B

This is an approximate result. It is likely that this reaction was catalyzed by an enzymatic impurity present in the sample of xylose isomerase used in this study.

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$K'$
300.15	7.5	0.19

Reference: 53HOC/WAT

Method: chemical analysis and paper chromatography

Buffer: phosphate

pH: 7.5

Cofactor(s):  $Mg^{2+}$  and  $Mn^{2+}$ 

Evaluation: C

The apparent equilibrium constant given here was calculated from the percent conversion data given by Hochster and Watson. The same result was also reported by [54HOC/WAT].

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$K'$
310.15	7.0	0.16

Reference: 53MIT/LAM

Method: chromatography and spectrophotometry

Buffer: phosphate ( $0.05 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: C

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$K'$
298.35	8.7	0.172
306.15	8.7	0.204
313.25	8.7	0.237
314.05	8.7	0.224
320.15	8.7	0.272
328.15	8.7	0.315
335.05	8.7	0.374
342.15	8.7	0.424

Reference: 85TEW/STE

Method: HPLC

Buffer: phosphate ( $0.039 \text{ mol dm}^{-3}$ )

pH: 8.7

Cofactor(s):  $\text{MgSO}_4$  ( $\approx 0.013 \text{ mol dm}^{-3}$ )

Evaluation: A

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$K'$
303.15	7.5	0.19

Reference: 55SLE

Method: spectrophotometry

Buffer: phosphate ( $0.05 \text{ mol dm}^{-3}$ )

pH: 7.5

Cofactor(s):  $\text{MgCl}_2$  ( $0.0004 \text{ mol dm}^{-3}$ )

Evaluation: B

The value of the apparent equilibrium constant given here was calculated from percent conversion data.

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$K'$
313.15	6.0	0.20

Reference: 81GON/CHE

Method: chemical analysis

Buffer: sodium phosphate ( $0.05 \text{ mol dm}^{-3}$ )

pH: 6.0

Cofactor(s):  $\text{MgCl}_2$  ( $0.001 \text{ mol dm}^{-3}$ )

Evaluation: C

The apparent equilibrium constant given here was calculated from the data given in Gong *et al.*'s Fig. 4

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$K'$
313.15	7.5	0.18
323.15	7.5	0.22
334.15	7.5	0.31
343.15	7.5	0.39
345.15	7.5	0.41

Reference: 82HSL/CHI

Method: liquid chromatography

Buffer:  $\beta$ -glycerophosphate ( $0.1 \text{ mol dm}^{-3}$ )

pH: 7.5

Cofactor(s):  $\text{MgSO}_4$  ( $0.001 \text{ mol dm}^{-3}$ )

Evaluation: C

The apparent equilibrium constants given here were calculated from the percent conversion data given by Hsiao *et al.* From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta H^\circ$  ( $T=329 \text{ K}$ , pH=7.5)=24 kJ mol<sup>-1</sup>.

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$\frac{\Delta H^\circ}{\text{kJ mol}^{-1}}$
313.15	7.4	16.85
320.15	7.4	16.55
325.35	7.4	17.26
331.65	7.4	17.57
338.15	7.4	17.64

Reference: 85TEW/STE

Method: calorimetry

Buffer: phosphate ( $\approx 0.025 \text{ mol dm}^{-3}$ )

pH: 7.4

Cofactor(s):  $\text{MgSO}_4$ 

Evaluation: A

**D-xylose(aq)=D-xylulose(aq)**

$\frac{T}{K}$	pH	$K'$
311.15	7.00	0.176
318.15	7.00	0.209
325.15	7.00	0.246
331.15	7.00	0.282
341.15	7.00	0.347
348.15	7.00	0.400

Reference: 86OLI/TOI

Method: HPLC

Buffer: Tris + maleate

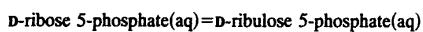
pH: 7.00

Cofactor(s):  $\text{MgSO}_4$  ( $0.01 \text{ mol dm}^{-3}$ )

Evaluation: B

The values of the apparent equilibrium constant given here were obtained from Olivier and du Toits' Fig. 9 that contains percent conversion data as a function of temperature. Oliver and du Toit also calculated  $\Delta H^\circ$  ( $T=330 \text{ K}$ , pH=7.0)=20.2 kJ mol<sup>-1</sup> for the above reaction.

**4.25. Enzyme: ribose-5-phosphate isomerase  
(EC 5.3.1.6)**



$\frac{T}{K}$	pH	$K'$
273.15	7.0	0.164
298.65	7.0	0.264
310.15	7.0	0.323

Reference: 54AXE/JAN

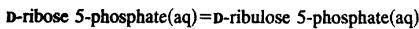
Method: enzymatic assay and spectrophotometry

Buffer: Tris (0.1 mol dm<sup>-3</sup>)

pH: 7.0

Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_H^{\circ} (\bar{T}=292 \text{ K}, \text{pH}=7.0) \approx 13 \text{ kJ mol}^{-1}$



$\frac{T}{K}$	pH	$K'$
310.15	7.0	$\approx 0.59$

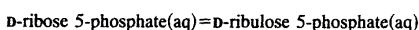
Reference: 56DIC/WIL

Method: chromatography and spectrophotometry

pH: 7.0

Evaluation: C

The apparent equilibrium constant given here was calculated from the percent conversion data given by Dickens and Williamson. This is an approximate result.



$\frac{T}{K}$	pH	$K'$
310.15	7.4	0.67

Reference: 56DIC/WIL

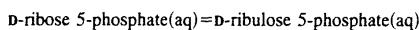
Method: chromatography and spectrophotometry

Buffer: Tris (0.1 mol dm<sup>-3</sup>)

pH: 7.4

Evaluation: C

The apparent equilibrium constant given here was calculated from the percent conversion data given by Dickens and Williamson.



$\frac{T}{K}$	pH	$K'$
273.15	7.5	0.31
310.15	7.5	0.28

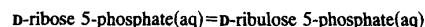
Reference: 58BRU/NOL

Method: spectrophotometry

Buffer: Tris

pH: 7.5

Evaluation: C



$\frac{T}{K}$	pH	$K'$
310.15	7.5	0.32

Reference: 58TAB/SRE

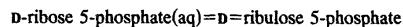
Method: enzymatic assay and spectrophotometry

Buffer: glycylglycine (0.056 mol dm<sup>-3</sup>)

pH: 7.5

Evaluation: B

The value of the apparent equilibrium constant given here was calculated from percent conversion data.



$\frac{T}{K}$	pH	$K'$
298.15	7.5	0.179
304.15	7.5	0.227
311.15	7.5	0.312

Reference: 60AGO/ARA

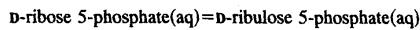
Method: spectrophotometry

Buffer: Tris (0.05 mol dm<sup>-3</sup>) + HCl

pH: 7.5

Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_H^{\circ} (\bar{T}=305 \text{ K}, \text{pH}=7.5) \approx 33 \text{ kJ mol}^{-1}$



$\frac{T}{K}$	pH	$K'$
310.15	7.6	0.30

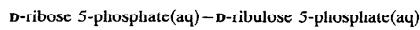
Reference: 63DOB/DEM

Method: spectrophotometry

Buffer: Tris (0.020 mol dm<sup>-3</sup>) + HCl

pH: 7.6

Evaluation: C



$\frac{T}{K}$	pH	$\frac{c(\text{Mg}^{2+})}{\text{mol dm}^{-3}}$	$\frac{I_c}{\text{mol dm}^{-3}}$	$K'$
311.15	7.0	0.001	0.25	0.83

Reference: 86CAS/VEE

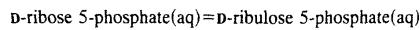
Method: enzymatic assay and spectrophotometry

Buffer: phosphate (0.020 mol dm<sup>-3</sup>)

pH: 7.0

Cofactor(s): MgCl<sub>2</sub>

Evaluation: A



$\frac{T}{K}$	pH	$\frac{\Delta H(\text{cal})}{\text{kJ mol}^{-1}}$
298.15	8.52	$\approx 14$

Reference: 88TEW/STE

Method: calorimetry

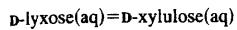
Buffer: Tris (0.1 mol dm<sup>-3</sup>)

pH: 8.52

Cofactor(s): MgCl<sub>2</sub> (0.00010 mol dm<sup>-3</sup>)

Evaluation: B

This is an approximate result.

**4.26. Enzyme: mannose isomerase (EC 5.3.1.7)**

$\frac{T}{\text{K}}$	pH	$K'$
303.15	7.4	0.39

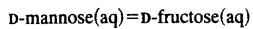
Reference: 56PAL/DOU

Method: chemical analysis and spectrophotometry

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + HClCofactor(s):  $\text{MgCl}_2$  ( $0.01 \text{ mol dm}^{-3}$ )

Evaluation: C

This same result was also given in [62DOU]. Also see data given under EC 5.3.1.15.



$\frac{T}{\text{K}}$	pH	$K'$
303.15	7.4	2.45

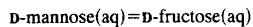
Reference: 56PAL/DOU

Method: chemical analysis and spectrophotometry

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + HClCofactor(s):  $\text{MgCl}_2$  ( $0.01 \text{ mol dm}^{-3}$ )

Evaluation: C

This same result was also given in [62DOU].



$\frac{T}{\text{K}}$	pH	$K'$
274.15	7.0	3.1
279.15	7.0	3.1
284.15	7.0	3.0
298.15	7.0	3.0
308.15	7.0	2.9
313.15	7.0	3.0

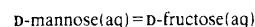
Reference 67TAK2

Method: chemical analysis and polarimetry

Buffer: phosphate ( $0.05 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation B

From the temperature dependence of the apparent equilibrium constant  $\Delta_f H^\circ (T=321 \text{ K}, \text{pH}=7.0)$  is approximately zero.

$\frac{T}{\text{K}}$	pH	$K'$
310.15	7.5	$\approx 1.9$

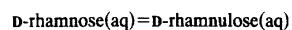
Reference: 70HEY/ELB

Method: spectrophotometry and chemical analysis

Buffer: Tris + maleate

pH: 7.5

Evaluation C



$\frac{T}{\text{K}}$	pH	$K'$
303.15	7.4	0.58

Reference: 56PAL/DOU

Method: chemical analysis and spectrophotometry

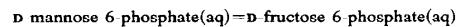
Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.4

Cofactor(s):  $\text{MgCl}_2$  ( $0.01 \text{ mol dm}^{-3}$ )

Evaluation: C

This same result was also given in [62DOU]. Also see data given under EC 5.3.1.14.

**4.27. Enzyme: mannose-6-phosphate isomerase (EC 5.3.1.8)**

$\frac{T}{\text{K}}$	pH	$K'$
303.15	7.4	1.5

Reference 50SLE

Method: spectrophotometry

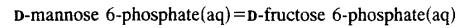
Buffer: barbital ( $0.05 \text{ mol dm}^{-3}$ )

pH: 7.4

Cofactor(s):  $\text{MgCl}_2$  ( $0.07 \text{ mol dm}^{-3}$ )

Evaluation: B

The value of the apparent equilibrium constant given here was calculated from percent conversion data.



$\frac{T}{\text{K}}$	pH	$K'$
310.15	5.9	1.8

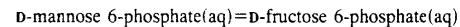
Reference: 58NOL/BRU

Method: spectrophotometry

Buffer: acetate

pH: 5.9

Evaluation: C



$\frac{T}{\text{K}}$	pH	$K'$
298.15	8.50	0.99
304.75	8.50	1.03

Reference: 88TEW/STE

Method: calorimetry

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ )

pH: 8.50

Cofactor(s):  $\text{MgCl}_2$  ( $0.00010 \text{ mol dm}^{-3}$ )

Evaluation: A

Tewari *et al.* also calculated  $K(T=298.15 \text{ K}, I=0)=0.99$  for the chemical reference reaction:  $\text{D-mannose 6-phosphate}^{2-}(\text{aq}) = \text{D-fructose 6-phosphate}^{2-}(\text{aq})$ .

$\text{D-mannose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$\Delta_f H(\text{cal})$ $\text{kJ mol}^{-1}$
298.15	8.50	8.46
304.74	8.50	8.71

Reference: 88TEW/STE

Method: calorimetry

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ )

pH: 8.50

Cofactor(s):  $\text{MgCl}_2$  ( $0.00010 \text{ mol dm}^{-3}$ )

Evaluation: A

Tewari *et al.* calculated  $\Delta_f H^\circ = 8.46 \text{ kJ mol}^{-1}$  and  $\Delta_f C_p^\circ \approx 38 \text{ J K}^{-1} \text{ mol}^{-1}$  at  $T = 298.15 \text{ K}$  and  $I = 0$  for the chemical reference reaction: D-mannose 6-phosphate<sup>2-</sup>(aq) = D-fructose 6-phosphate<sup>2-</sup>(aq).

#### 4.28. Enzyme: glucose-6-phosphate isomerase (EC 5.3.1.9)

 $\text{6-amino-D-glucose 6-phosphate(aq)} = \text{6-amino-D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
278.85	8.7	0.202

Reference: 91SEM/CLE

Method: NMR and spectrophotometry

Buffer: Ches ( $0.10 \text{ mol dm}^{-3}$ )

pH: 8.7

Evaluation: B

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
303.15	7.4	0.45

Reference: 50SLE

Method: spectrophotometry

Buffer: barbital ( $0.05 \text{ mol dm}^{-3}$ )

pH: 7.4

Cofactor(s):  $\text{MgCl}_2$  ( $0.07 \text{ mol dm}^{-3}$ )

Evaluation: B

The value of the apparent equilibrium constant given here was calculated from percent conversion data.

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
310.15	7.4	0.67

Reference: 53BOD

Method: spectrophotometry

Buffer: sodium acetate + diethyl barbiturate

pH: 7.4

Evaluation: B

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
310.15	$\approx 7.65$	0.67

Reference: 56RAM/GIR

Method: chemical analysis

Buffer: barbital ( $0.02 \text{ mol dm}^{-3}$ )

pH: 7.5–7.8

Evaluation: C

The value of the apparent equilibrium constant given here was calculated from percent conversion data.

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
310.15	7.5	0.67

Reference: 58NOL/BRU

Method: spectrophotometry

Buffer: barbital

pH: 7.5

Evaluation: C

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
293.15	8.0	0.260
303.15	8.0	0.298
311.15	8.0	0.327

Reference: 60KAH/LOW

Method: enzymatic assay; fluorimetry

Buffer: Tris ( $0.05 \text{ mol dm}^{-3}$ )

pH: 8.0

Evaluation: A

From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ (\bar{T} = 302 \text{ K}, \text{pH} = 8.0) = 9.7 \text{ kJ mol}^{-1}$ .

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$\frac{I_\epsilon}{\text{mol dm}^{-3}}$	$K'$
303.15	8.0	0.1	0.32

Reference: 63HIN/WOL

Method: spectrophotometry

Buffer: Tris + acetate

pH: 8.0

Evaluation: B

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$\frac{T}{\text{K}}$	pH	$K'$
303.15	8.0	0.32

Reference: 66REI

Method: spectrophotometry

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + acetate

pH: 8.0

Evaluation: C

$\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$T$ K	pH	$K'$
310.15	7.5	0.54

Reference: 67TAK/HIZ

Method: spectrophotometry

Buffer: Tris ( $0.040 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.5

Evaluation: C

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$T$ K	pH	$c(\text{MgCl}_2)$ $\text{mol dm}^{-3}$	$c(\text{Tris})$ $\text{mol dm}^{-3}$	$K'$
298.15	8.7	0.0010	0.10	0.293
298.15	8.7	0.0010	0.30	0.299
298.15	8.7	0.0010	0.64	0.302
298.15	8.7	0.00010	0.10	0.287
298.15	8.7	0.0025	0.10	0.308
304.95	8.7	0.00010	0.10	0.310
310.15	8.7	0.00010	0.10	0.329
316.15	8.7	0.00010	0.10	0.357

Reference: 88TEW/STE

Method: calorimetry

Buffer: Tris

pH: 8.7

Cofactor(s):  $\text{MgCl}_2$ 

Evaluation: A

Tewari *et al.* also calculated  $K(T=298.15 \text{ K}, I=0)=0.285$  for the chemical reference reaction:  $\text{D-glucose 6-phosphate}^{2-}(\text{aq}) = \text{D-fructose 6-phosphate}^{2-}(\text{aq})$ .

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$T$ K	pH	$I_c$ $\text{mol dm}^{-3}$	$K'$
273.3	8.5	0.12	0.19
274.9	8.5	0.12	0.19
278.2	8.5	0.12	0.20
279.3	8.5	0.12	0.20
283.4	8.5	0.12	0.22
284.7	8.5	0.12	0.22
288.4	8.5	0.12	0.24
289.9	8.5	0.12	0.25
293.3	8.5	0.12	0.26
294.3	8.5	0.12	0.26
298.2	8.5	0.12	0.29
299.0	8.5	0.12	0.27
303.6	8.5	0.12	0.30
303.6	8.5	0.12	0.31
308.6	8.5	0.12	0.33
308.2	8.5	0.12	0.33
313.3	8.5	0.12	0.36
317.5	8.5	0.12	0.38
313.7	8.5	0.12	0.34
318.7	8.5	0.12	0.38
322.0	8.5	0.12	0.41
322.8	8.5	0.12	0.41

Reference: 68 DYS/NOL

Method: spectrophotometry

Buffer: Tris ( $0.050 \text{ mol dm}^{-3}$ ) + HCl

pH: 8.5

Evaluation: A

The values of the apparent equilibrium constants given here were taken from Dyson and Noltmann's Fig. 13. From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_f H^\circ(T=298 \text{ K}, \text{pH}=8.5, I_c=0.12 \text{ mol dm}^{-3})=11.8 \text{ kJ mol}^{-1}$  and  $\Delta_f C_p^\circ \approx 59 \text{ J K}^{-1} \text{ mol}^{-1}$ . Dyson and Noltmann also reported that the apparent equilibrium constant at  $T=303.15 \text{ K}$  was independent of pH for  $6.0 \leq \text{pH} \leq 10.0$ .

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$T$ K	pH	$K'$
298.15	6.4	0.28

Reference: 70WUR/SCH

Method: enzymatic assay

Buffer: imidazole ( $0.050 \text{ mol dm}^{-3}$ ) + HCl

pH: 6.4

Cofactor(s):  $\text{MgSO}_4$ 

Evaluation: B

 $\text{D-glucose 6-phosphate(aq)} = \text{D-fructose 6-phosphate(aq)}$ 

$T$ K	pH	$K'$
303.15	8.1	0.37

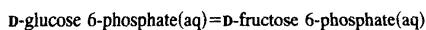
Reference: 89SAN/SIN

Method: enzymatic assay + spectrophotometry

Buffer: Tris ( $0.05 \text{ mol dm}^{-3}$ ) + HCl

pH: 8.1

Evaluation: C



$\frac{T}{K}$	pH	$K'$
303.15	8.6	0.30

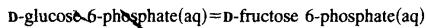
Reference: 90SAN/SIN

Method: enzymatic assay + spectrophotometry

Buffer: Tris ( $0.05 \text{ mol dm}^{-3}$ ) + HCl

pH: 8.6

Evaluation: C



$\frac{T}{K}$	pH	$K'$
278.85	8.7	0.214
295.15	8.7	0.264

Reference: 91SEM/CLE

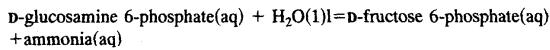
Method: NMR and spectrophotometry

Buffer: Chex ( $0.10 \text{ mol dm}^{-3}$ )

pH: 8.7

Evaluation: B

#### 4.29. Enzyme: glucosamine-6-phosphate isomerase (EC 5.3.1.10)



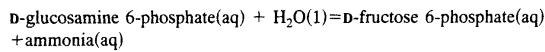
$\frac{T}{K}$	pH	$K'_c$
310.15	8.4	0.15

Reference: 56LEL/CAR

Buffer: Tris ( $0.4 \text{ mol dm}^{-3}$ )

pH: 8.4

Evaluation: B



$\frac{T}{K}$	pH	$K'_c$
310.15	8.5	$\approx 0.15$

Reference: 70BEN/FRI

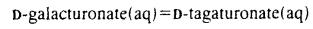
Method: spectrophotometry

Buffer: Tris ( $0.050 \text{ mol dm}^{-3}$ ) + HCl

pH: 8.5

Evaluation: B

#### 4.30. Enzyme: glucuronate isomerase (EC 5.3.1.12)



$\frac{T}{K}$	pH	Buffer	$K'$
310.15	8.0	phosphate	0.25
310.15	8.0	borate	$\approx 1.4$

Reference: 60ASH/WAH

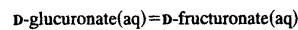
Method: enzymatic assay and spectrophotometry

Buffer: phosphate and borate

pH: 8.0

Evaluation: C

The apparent equilibrium constants given here were calculated from the percent conversion data given by Ashwell *et al.*



$\frac{T}{K}$	pH	Buffer	$K'$
310.15	8.0	phosphate	0.82

Reference: 60ASH/WAH

Method: enzymatic assay and spectrophotometry

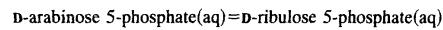
Buffer: phosphate and borate

pH: 8.0

Evaluation: B

The apparent equilibrium constant given here was calculated from the percent conversion data given by Ashwell *et al.* They also state that, in borate buffer at  $T=310.15 \text{ K}$  and pH=8.0, more than 98 percent of the D-glucuronate was converted to D-fructuronate and that the reverse reaction could not be detected. This indicates that, under these conditions, a different reaction has occurred.

#### 4.31. Enzyme: arabinose-5-phosphate isomerase (EC 5.3.1.13)



$\frac{T}{K}$	pH	$K'$
310.15	8.0	0.295

Reference: 60VOL

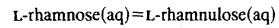
Method: spectrophotometry

Buffer: glycylglycine ( $0.0033 \text{ mol dm}^{-3}$ )

pH: 8.0

Evaluation: B

#### 4.32. Enzyme: L-rhamnose isomerase (EC 5.3.14)

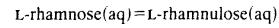


$\frac{T}{K}$	$K'$
298.15	1.5

Reference: 56ENG

Evaluation: C

Few details were given in this Federation Proceedings abstract. The temperature was assumed to be  $298.15 \text{ K}$ . Also see data given under EC 5.3.1.7.



$\frac{T}{K}$	pH	$K'$
310.15	8.5	0.75

Reference: 63DOM/ZEC

Method: spectrophotometry

Buffer: Tris ( $0.0063 \text{ mol dm}^{-3}$ ) + HCl

pH: 8.5

Cofactor(s):  $\text{MnCl}_2$  ( $0.0013 \text{ mol dm}^{-3}$ )

Evaluation: C

The apparent equilibrium constant given here was calculated from the percent conversion data given by Domagk and Zech.

$L\text{-rhamnose(aq)} \rightleftharpoons L\text{-rhamnulose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	7.6	1.5

Reference: 64TAK/SAW  
 Method: spectrophotometry  
 Buffer: Tris ( $0.01 \text{ mol dm}^{-3}$ )  
 pH: 7.6  
 Cofactor(s):  $\text{MnCl}_2$  ( $0.01 \text{ mol dm}^{-3}$ )  
 Evaluation: B

 $L\text{-rhamnose(aq)} \rightleftharpoons L\text{-rhamnulose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	8.5	0.75

Reference: 66DOM/ZEC  
 Method: spectrophotometry  
 Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + HCl  
 pH: 8.5  
 Evaluation: C

The apparent equilibrium constant given here was calculated from the percent conversion data given by Domagk and Zech.

### 4.33. Enzyme: $D\text{-lyxose ketol-isomerase}$ (EC 5.3.1.15)

 $D\text{-lyxose(aq)} \rightleftharpoons D\text{-xylulose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
298.15	7.0	0.23

Reference: 65AND/ALL  
 Method: spectrophotometry  
 Buffer: sodium cacodylate ( $0.06 \text{ mol dm}^{-3}$ )  
 pH: 7.0  
 Cofactor(s):  $\text{MnCl}_2$  ( $0.01 \text{ mol dm}^{-3}$ )  
 Evaluation: B

Also see data given under EC 5.3.1.7.

### 4.34. Enzyme: ribose isomerase (EC 5.3.1.20)

 $D\text{-ribose(aq)} \rightleftharpoons D\text{-ribulose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
310.15	7.5	0.39

Reference: 75IZU/REE  
 Buffer: Tris ( $0.025 \text{ mol dm}^{-3}$ )  
 pH: 7.5  
 Cofactor(s):  $\text{MnCl}_2$  ( $0.0025 \text{ mol dm}^{-3}$ )  
 Evaluation: B

The apparent equilibrium constant given here was calculated from the percent conversion data given in Izumori *et al.*'s Fig. 6.

 $D\text{-ribose(aq)} \rightleftharpoons D\text{-ribulose(aq)}$ 

$\frac{T}{K}$	pH	$K'$
313.15	7.4	0.391
320.25	7.4	0.446
325.25	7.4	0.484
328.15	7.4	0.489
331.95	7.4	0.521
338.15	7.4	0.563
343.75	7.4	0.591

Reference: 85TEW/GOL2

Method: HPLC  
 Buffer: phosphate ( $0.039 \text{ mol dm}^{-3}$ )  
 pH: 7.4  
 Cofactor(s):  $\text{Mg}(\text{NO}_3)_2$  ( $\approx 0.013 \text{ mol dm}^{-3}$ )  
 Evaluation: A

Tewari and Goldberg used their combined equilibrium and calorimetric data to calculate  $K=0.317$ ,  $\Delta_f G^\circ=2.85 \text{ kJ mol}^{-1}$ ,  $\Delta_f H^\circ=11.0 \text{ kJ mol}^{-1}$ , and  $\Delta_f C_p \approx 75 \text{ J K}^{-1} \text{ mol}^{-1}$  at  $T=298.15 \text{ K}$  for the chemical reference reaction:  $D\text{-ribose(aq)} \rightleftharpoons D\text{-ribulose(aq)}$ . This is the predominant reaction at neutral pHs.

 $D\text{-ribose(aq)} \rightleftharpoons D\text{-ribulose(aq)}$ 

$\frac{T}{K}$	pH	$\frac{\Delta_f H(\text{cal})}{\text{kJ mol}^{-1}}$
320.15	$\approx 7.1$	10.97
325.35	$\approx 7.1$	11.38
331.65	$\approx 7.1$	12.11
338.15	$\approx 7.1$	12.25

Reference: 85TEW/GOL2

Method: calorimetry  
 Buffer: phosphate  
 pH: 6.8–7.4  
 Cofactor(s):  $\text{MgSO}_4$   
 Evaluation: A

### 4.35. Enzyme: $L\text{-mannose ketol-isomerase}$ (EC 5.3.1.a)

 $L\text{-mannose(aq)} \rightleftharpoons L\text{-fructose(aq)}$ 

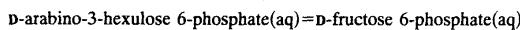
$\frac{T}{K}$	pH	$K'$
303.15	7.6	1.5

Reference: 68MAY/AND

Method: spectrophotometry and polarimetry  
 Buffer: Tris ( $0.0217 \text{ mol dm}^{-3}$ ) + HCl  
 pH: 7.6  
 Cofactor(s):  $\text{CoCl}_2$  (0.0052)  
 Evaluation: B

The apparent equilibrium constant given here was calculated from the percent conversion data given by May and Anderson. Also see data given under EC 5.3.1.7.

**4.36. Enzyme: phospho-3-hexuloisomerase  
(EC 5.3.1.b)**



$\frac{T}{K}$	pH	$K'$
303.15	7.0	188

Reference: 74FER/STR

Method: enzymatic assay and spectrophotometry

Buffer: phosphate (0.050 mol dm<sup>-3</sup>)

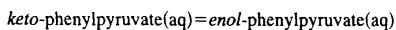
pH: 7.0

Cofactor(s): MgCl<sub>2</sub> (0.001 mol dm<sup>-3</sup>)

Evaluation: B

This result was obtained from kinetic data.

**4.37. Enzyme: phenylpyruvate tautomerase  
(EC 5.3.2.1)**



$\frac{T}{K}$	pH	$K'$
298.15	7.8	≈0.1

Reference: 69BLA/FRA

Method: spectrophotometry

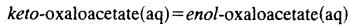
Buffer: phosphate

pH: 7.8

Evaluation: C

The temperature was assumed to be 298.15 K.

**4.38. Enzyme: oxaloacetate tautomerase  
(EC 5.3.2.2)**



$\frac{T}{K}$	$K'$
298.15	≈0.1

Reference: 65ANN/KOS

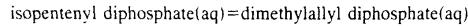
Method: NMR

pH: 5–10

Evaluation: D

The conditions of measurement were not stated. The temperature was assumed to be 298.15 K.

**4.39. Enzyme: isopentenyl-diphosphate  
Δ-isomerase (EC 5.3.3.2)**



$\frac{T}{K}$	pH	$K'$
310.15	8.0	≈6.7

Reference: 65SHA/CLE

Method: radioactivity

Buffer: Tris (0.048 mol dm<sup>-3</sup>) + HCl

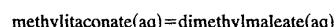
pH: 8.0

Cofactor(s): MgCl<sub>2</sub> (0.0048 mol dm<sup>-3</sup>)

Evaluation: C

The value of the apparent equilibrium constant given here was calculated from percent conversion data.

**4.40. Enzyme: methylitaconate Δ-isomerase  
(EC 5.3.3.6)**



$\frac{T}{K}$	pH	$K'$
307.15	7.9	3.4

Reference: 71KUN/STA

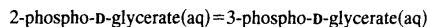
Method: spectrophotometry

Buffer: potassium phosphate

pH: 7.9

Evaluation: B

**4.41. Enzyme: phosphoglycerate mutase  
(EC 5.4.2.1)**



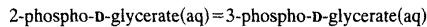
$\frac{T}{K}$	$K'$
273.15	7.3
301.15	3.85
311.15	3.45
333.15	2.3

Reference: 35MEY/KIE

Method: polarimetry

Evaluation: C

The buffer and the pH used were not reported.



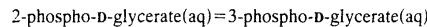
$\frac{T}{K}$	$K'$
301.15	4.0

Reference: 35MEY/KIE2

Method: polarimetry

Evaluation: B

The result given here was calculated from percent conversion data. The buffer and the pH used were not reported.



$\frac{T}{K}$	$K'$
273.15	10.8
293.15	9.5
310.15	7.9
333.15	7.6

Reference: 38MEY/SCH

Method: polarimetry

Evaluation: C

The approximate values of the apparent equilibrium constant given here were calculated from percent conversion data. The buffer and the pH used were not reported.

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	$K'$
297.15	6.0

Reference: 49MEY/OES

Method: polarimetry

Evaluation: C

The buffer and the pH used were not reported.

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	pH	$K'$
310.15	6.8	5.0

Reference: 56COW/PIZ

Method: polarimetry

Buffer: imidazole ( $0.0025 \text{ mol dm}^{-3}$ )

pII: 6.8

Evaluation: B

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	pH	$K'$
303.15	4.60	6.0
303.15	5.01	6.6
303.15	5.15	6.2
303.15	5.43	6.0
303.15	5.70	6.3
303.15	6.10	6.8
303.15	6.65	5.8

Reference: 57ROD/TOW

Method: spectrophotometry

Buffer: potassium acetate ( $0.1 \text{ mol dm}^{-3}$ )

pH: 4.60–6.65

Evaluation: B

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	pH	$K'$
298.15	5.0	4.90
298.15	5.4	5.30
298.15	5.9	5.35
298.15	6.5	5.10
298.15	7.2	5.25

Reference: 59CHI/SUG

Method: polarimetry

Buffer: acetate

pH: 5.0–7.2

Evaluation: C

Equilibrium was approached from only one direction.

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	$K'$
303.15	$\approx 8$

Reference: 59ITO/GRI

Evaluation: D

This is an approximate result. The conditions of measurement were not stated. Ito and Grisolia prefer the earlier results reported by Rodwell, Towne and Grisolia [57ROD-TOW].

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	pH	$K'$
303.15	7.0	6.1

Reference: 62GRI

Method: spectrophotometry

Buffer: Tris ( $0.033 \text{ mol dm}^{-3}$ )+HCl

pH: 7.0

Cofactor(s):  $\text{MgSO}_4$  ( $0.0033 \text{ mol dm}^{-3}$ )

Evaluation: C

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	pH	$K'$
311.15	7.0	9.8

Reference: 64 LOW/PAS

Method: fluorimetry

Buffer: phosphate ( $0.04 \text{ mol dm}^{-3}$ )

pH: 7.0

Evaluation: A

## 2-phospho-D-glycerate(aq)=3-phospho-D-glycerate(aq)

$\frac{T}{K}$	pH	Buffer	$c(\text{MgCl}_2)$ mol dm $^{-3}$	$I_c$ mol dm $^{-3}$	$K'$
303.15	5.42	maleate ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	8.65
303.15	6.20	imidazole ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	10.02
303.15	6.45	imidazole ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	10.50
303.15	6.66	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	10.72
303.15	7.10	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	11.40
303.15	7.50	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	11.59
303.15	7.89	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	11.65
303.15	6.97	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.30	10.06
303.15	7.45	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.30	10.45
303.15	7.89	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.30	11.10
303.15	7.01	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.30	10.43
303.15	7.55	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.30	10.84
303.15	7.80	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.30	11.14
303.15	8.12	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.30	11.47
293.15	6.22	imidazole ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	9.81
293.15	7.24	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	11.28
293.15	8.06	Tris ( $0.0333 \text{ mol dm}^{-3}$ )	0.0	0.065	11.74
303.15	7.40	Tris ( $0.0167 \text{ mol dm}^{-3}$ )	0.0453	0.085	11.11
303.15	7.40	Tris ( $0.0167 \text{ mol dm}^{-3}$ )	0.0453	0.059	11.64
303.15	7.40	Tris ( $0.0167 \text{ mol dm}^{-3}$ )	0.0453	0.046	11.30
303.15	7.40	Tris ( $0.0167 \text{ mol dm}^{-3}$ )	0.0333	0.038	11.36
303.15	7.40	Tris ( $0.0167 \text{ mol dm}^{-3}$ )	0.0333	0.032	11.31

Reference: 75CLA/BIR

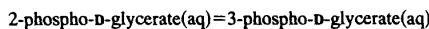
Method: spectrophotometry

Buffer: sodium maleate; imidazole+ $\text{HNO}_3$ ; and Tris+HCl

pH: 5.42–8.06

Cofactor(s):  $\text{MgCl}_2$ 

Evaluation: A



$\frac{T}{K}$	pH	$K'$
298.15	≈6	5.1
303.15	≈5.6	6.3
310.15	6.8	5.0

Reference: 75GRI/CAR

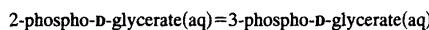
Method: polarimetry and spectrophotometry

Buffer: Tris (0.033 mol dm<sup>-3</sup>+HCl)

pH: 4.6–7.2

Cofactor(s): MgSO<sub>4</sub> (0.0033 mol dm<sup>-3</sup>)

Evaluation: C



$\frac{T}{K}$	pH	$K'$
303.15	7.3	11.3

Reference: 76 HIL/ATT

Method: enzymatic assay and spectrophotometry

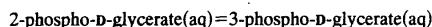
Buffer: imidazole (0.05 mol dm<sup>-3</sup>)+HCl

pH: 7.3

Cofactor(s): MgCl<sub>2</sub> (0.0018 mol dm<sup>-3</sup>)

Evaluation: B

The apparent equilibrium constant was also obtained from kinetic data. There was good agreement with the direct measurement.



$\frac{T}{K}$	pH	$c(\text{Mg}^{2+})$ mol dm <sup>-3</sup>	$I_c$ mol dm <sup>-3</sup>	$K'$
311.15	6.76	0.00059	0.25	10.7
311.15	6.78	0.00059	0.25	10.7
311.15	6.86	0.00059	0.25	10.6
311.15	6.83	0.00060	0.25	11.3
311.15	6.66	0.0046	0.25	10.5
311.15	6.65	0.0047	0.25	10.6
311.15	6.79	0.0046	0.25	10.3
311.15	6.76	0.0047	0.25	11.3
311.15	6.57	0.0093	0.25	10.8
311.15	6.68	0.0090	0.25	10.8
311.15	6.72	0.0092	0.25	10.4
311.15	6.70	0.0092	0.25	11.0
311.15	6.48	0.0144	0.25	10.8
311.15	6.48	0.0144	0.25	11.0
311.15	6.65	0.0141	0.25	10.9
311.15	6.63	0.0142	0.25	11.3

Reference: 82 GUY

Method: spectrophotometry

Buffer: potassium phosphate (0.025 mol dm<sup>-3</sup>)

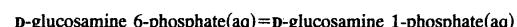
pH: 6.48–6.86

Cofactor(s): MgCl<sub>2</sub>

Evaluation: A

Guynn also calculated  $K=11.0$  at  $T=311.15$  K and  $I_c=0.25$  mol dm<sup>-3</sup> for the chemical reference reaction: 2-phospho- $\alpha$ -D-glycerate<sup>3-</sup>(aq)  $\rightleftharpoons$  3-phospho- $\alpha$ -D-glycerate<sup>3-</sup>(aq). Although the experimental data are not given in his paper, Guynn also obtained  $K=11.1$  at  $T=298.15$  K and  $I_c=0.25$  mol dm<sup>-3</sup>. Guynn stated that there was no significant effect on the apparent equilibrium constant due either to variation of  $c(\text{Mg}^{2+})$  over the range 0.0059 to 0.0142 mol dm<sup>-3</sup> and/or to variation of the ionic strength over the range 0.06 to 1.0 mol dm<sup>-3</sup>. These results confirmed those of Clark *et al.* [74CLA/BIR] and showed that much of the earlier literature was in error.

#### 4.42. Enzyme: phosphoglucomutase (EC 5.4.2.2)



$\frac{T}{K}$	pH	$K'$
303.15	7.11	0.28
303.15	7.53	0.24
303.15	7.80	0.28

Reference: 53BRO

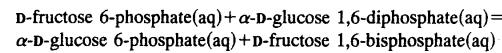
Method: enzymatic assay

pH: 7.11–7.80

Cofactor(s): MgSO<sub>4</sub> (0.0015 mol dm<sup>-3</sup>)

Evaluation: C

The approximate values of the apparent equilibrium constant given here were calculated from percent conversion data.



$\frac{T}{K}$	pH	$K'$
311.15	7.0	≈12

Reference: 69PAS/LOW

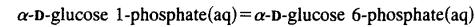
Method: fluorimetry

Buffer: imidazole (0.05 mol dm<sup>-3</sup>)+HCl

pH: 7.0

Cofactor(s): MgCl<sub>2</sub> (0.001 mol dm<sup>-3</sup>)

Evaluation: B



$\frac{T}{K}$	pH	$K'$
293.15	≈7.5	19.8
303.15	≈7.5	17.2
313.15	≈7.5	16.2

Reference: 42COL/SUT

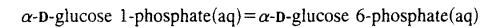
Buffer: barbital (0.025 mol dm<sup>-3</sup>)

pH: 6.19–7.46

Cofactor(s): Mn<sup>2+</sup>

Evaluation: C

The apparent equilibrium constants given here were calculated from the percent conversion data given by Colowick and Sutherland. They also stated that the position of equilibrium was independent of the pH for  $6.19 \leq \text{pH} \leq 7.46$ . From the temperature dependence of the apparent equilibrium constant we calculate  $\Delta_H^\circ$  ( $T=303$  K, pH=7.5) ≈ -8 kJ mol<sup>-1</sup>.



$\frac{T}{K}$	pH	$K'$
298.15	7.0	17

Reference: 59ATK/JOH

Method: enzymatic assay and spectrophotometry

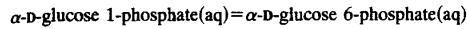
Buffer: NaOH+HCl

pH: 7.0

Cofactor(s): MgCl<sub>2</sub> (0.025 mol dm<sup>-3</sup>)

Evaluation: B

This result was also given in [61ATK/JOH].



$\frac{T}{K}$	pH	$K'$
303.15	7.5	17.2

Reference: 59MCC/NAJ

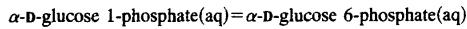
Method: enzymatic assay

Buffer: histidine ( $0.04 \text{ mol dm}^{-3}$ )

pH: 7.5

Cofactor(s):  $\text{Mg}^{2+}$ 

Evaluation: C



$\frac{T}{K}$	pH	$\frac{c(\text{Mg}^{2+})}{\text{mol dm}^{-3}}$	$\frac{I_c}{\text{mol dm}^{-3}}$	$K'$
311.15	7.04	0.0008	0.25	17.4

Reference: 74GUY/VEL

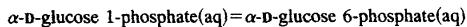
Method: enzymatic assay and spectrophotometry

Buffer: Tris + HCl

pH: 7.04

Cofactor(s):  $\text{MgCl}_2$ 

Evaluation: A



$\frac{T}{K}$	pH	$K'$
298.15	8.48	17.1

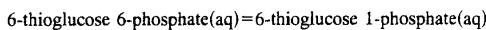
Reference: 89GOL/TEW

Method: HPLC

Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ ) + HCl

pH: 8.48

Evaluation: A



$\frac{T}{K}$	pH	$K'$
295.15	8.4	46

Reference: 91KNI/SEM

Method: NMR

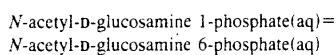
Buffer: Taps ( $0.072 \text{ mol dm}^{-3}$ )

pH: 8.4

Cofactor(s):  $\text{MgCl}_2$  ( $0.0072 \text{ mol dm}^{-3}$ )

Evaluation: C

#### 4.43. Enzyme: phosphoacetylglucosamine mutase (EC 5.4.2.3)



$\frac{T}{K}$	pH	$K'$
310.15	7.7	6

Reference: 56REI

Method: spectrophotometry

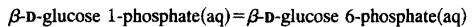
Buffer: Tris ( $0.033 \text{ mol dm}^{-3}$ ) + acetate

pH: 7.7

Cofactor(s):  $\text{MgSO}_4$  ( $0.0017 \text{ mol dm}^{-3}$ )

Evaluation: C

#### 4.44. Enzyme: $\beta$ -phosphoglucomutase (EC 5.4.2.6)



$\frac{T}{K}$	pH	$K'$
310.15	6.5	24

Reference: 61BEN/SCH

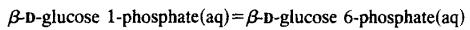
Method: enzymatic assay

Buffer: histidine ( $0.001 \text{ mol dm}^{-3}$ )

pH: 6.5

Cofactor(s):  $\text{MnCl}_2$  ( $0.0008 \text{ mol dm}^{-3}$ )

Evaluation: B



$\frac{T}{K}$	pH	$K'$
310.15	7.0	28.6

Reference: 74BEL/MAR

Method: spectrophotometry

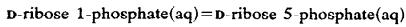
Buffer: Hepes ( $0.050 \text{ mol dm}^{-3}$ )

pH: 7.0

Cofactor(s): magnesium acetate ( $0.005 \text{ mol dm}^{-3}$ )

Evaluation: B

#### 4.45. Enzyme: phosphopentomutase (EC 5.4.2.7)



$\frac{T}{K}$	pH	$\frac{c(\text{Mg}^{2+})}{\text{mol dm}^{-3}}$	$\frac{I_c}{\text{mol dm}^{-3}}$	$K'$
311.15	7.0	0.001	0.25	26.0

Reference: 92KIM/KIN

Method: enzymatic assay

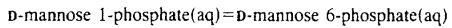
Buffer: Mops

pH: 7.0

Cofactor(s):  $\text{Mg}^{2+}$ 

Evaluation: A

#### 4.46. Enzyme: phosphomannomutase (EC 5.4.2.8)



$\frac{T}{K}$	pH	$K'$
303.15	7.0	8.5

Reference: 76MI/R

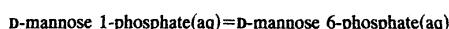
Method: enzymatic assay and spectrophotometry

Buffer: Tris acetate ( $0.02 \text{ mol dm}^{-3}$ )

pH: 7.0

Cofactors(s):  $\text{MgCl}_2$  ( $0.001 \text{ mol dm}^{-3}$ )

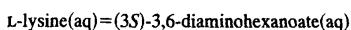
Evaluation: B



$\frac{T}{K}$	pH	$K'$
303.15	7.5	16.2

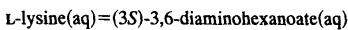
Reference: 92XIA/XUE  
 Method: spectrophotometry  
 Buffer: Tris (0.1 mol dm<sup>-3</sup>)  
 pH: 7.5  
 Cofactor(s): magnesium acetate (0.005 mol dm<sup>-3</sup>)  
 Evaluation: C

#### 4.47. Enzyme: lysine 2,3-aminomutase (EC 5.4.3.2)



$\frac{T}{K}$	pH	$K'$
310.15	7.8	6.7

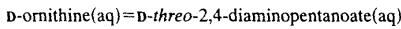
Reference: 70CHI/ZAP  
 Method: radioactivity  
 Buffer: Tris (0.025 mol dm<sup>-3</sup>) + HCl  
 pH: 7.8  
 Evaluation: B



$\frac{T}{K}$	pH	$K'$
303.15	7.7	5.3

Reference: 87MOS/FRE  
 Method: chromatography and radioactivity  
 Buffer: potassium phosphate (0.04 mol dm<sup>-3</sup>)  
 pH: 7.7  
 Evaluation: C

#### 4.48. Enzyme: D-ornithine 4,5-aminomutase (EC 5.4.3.5)



$\frac{T}{K}$	pH	$K'$
310.15	9.0	0.90

Reference: 73SOM/COS  
 Method: chromatography and radioactivity  
 Buffer: Tris (0.1 mol dm<sup>-3</sup>)  
 pH: 9.0  
 Evaluation: C

The value of the apparent equilibrium constant given here was calculated from percent conversion data.

#### 4.49. Enzyme: methylaspartate mutase (EC 5.4.99.1)

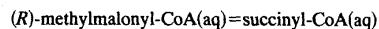


$\frac{T}{K}$	pH	$K'$
303.15	8.2	10.7

Reference: 64BAR/ROO  
 Method: spectrophotometry  
 Buffer: Tris (0.050 mol dm<sup>-3</sup>) + HCl  
 pH: 8.2  
 Cofactor(s): CaCl<sub>2</sub> (0.0005 mol dm<sup>-3</sup>)  
 Evaluation: C

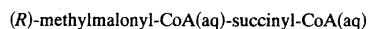
Equilibrium was approached from only one direction.

#### 4.50. Enzyme: methylmalonyl-CoA mutase (EC 5.4.99.2)



$\frac{T}{K}$	pH	$K'$
303.15	7.5	18.6

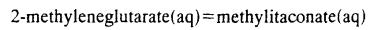
Reference: 65CAN/FOC  
 Method: enzymatic assay and spectrophotometry  
 Buffer: Tris (0.05 mol dm<sup>-3</sup>) + HCl  
 pH: 7.5  
 Evaluation: B



$\frac{T}{K}$	pH	$K'$
298.15	7.4	23.1

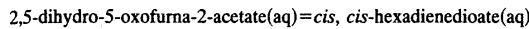
Reference: 64KEL/ALL  
 Method: enzymatic assay  
 Buffer: Tris (0.049 mol dm<sup>-3</sup>) + HCl  
 pH: 7.4  
 Evaluation: B

#### 4.51. Enzyme: 2-methyleneglutarate mutase (EC 5.4.99.4)



$\frac{T}{K}$	pH	$K'$
307.15	7.9	0.23

Reference: 71KUN/STA  
 Method: spectrophotometry  
 Buffer: potassium phosphate  
 pH: 7.9  
 Evaluation: B

**4.52. Enzyme: muconate cycloisomerase (EC 5.5.1.1)**


$\frac{T}{K}$	pH	Buffer	$K'$
303.15	6.0	succinate	0.010
303.15	6.5	histidine	0.011
303.15	7.5	Tris	0.041
303.15	8.0	Tris	0.078
303.15	9.0	glycine	0.29

Reference: 54SIS/STA

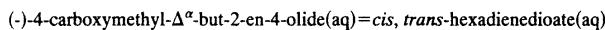
Method: spectrophotometry

Buffer: glycine, Tris, histidine, succinate

pH: 6.0–9.0

Cofactor(s):  $Mn^{2+}$ 

Evaluation: B



$\frac{T}{K}$	pH	$K'$
303.15	8.0	4.0

Reference: 54SIS/STA

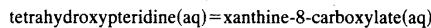
Method: spectrophotometry

Buffer: Tris (0.00015 mol dm<sup>-3</sup>)

pH: 8.0

Cofactor(s):  $MnCl_2$  (0.001 mol dm<sup>-3</sup>)

Evaluation: B

**4.53. Enzyme: tetrahydroxypteridine cycloisomerase (EC 5.5.1.3)**


$\frac{T}{K}$	pH	$K'$
296.15	7.5	≈620

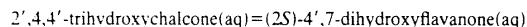
Reference: 64MCN/DAM

Method: radioactivity

Buffer: Tris (0.07 mol dm<sup>-3</sup>) + HCl

pH: 7.5

Evaluation: C

**4.54. Enzyme: chalcone isomerase (EC 5.5.1.6)**


$\frac{T}{K}$	pH	$K'$
298.15	7.6	7.6

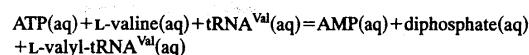
Reference: 88BED/HAD

Method: spectrophotometry

Buffer: Tris (0.050 mol dm<sup>-3</sup>) + HCl

pH: 7.6

Evaluation: B

**4.55. Enzyme: valine-tRNA ligase (EC 6.1.1.9)**


$\frac{T}{K}$	pH	$K'$
310.15	7.0	0.32

Reference: 61BER/BER

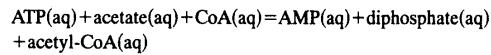
Method: radioactivity and spectrophotometry

Buffer: sodium cacodylate (0.1 mol dm<sup>-3</sup>)

pH: 7.0

Cofactor(s):  $MgCl_2$  (0.002 mol dm<sup>-3</sup>)

Evaluation: A

**4.56. Enzyme: acetate-CoA ligase (EC 6.2.1.1)**


$\frac{T}{K}$	pH	$K'$
310.15	7.5	2.7

Reference: 53JON

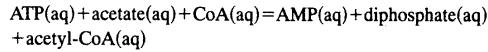
Method: spectrophotometry and chemical analysis

Buffer: Tris (0.16 mol dm<sup>-3</sup>)

pH: 7.5

Cofactor(s):  $MgCl_2$ 

Evaluation: B



$\frac{T}{K}$	pH	$K'$
311.15	7.5	0.86
311.15	8.0	0.86
311.15	8.5	0.86

Reference: 54HEL

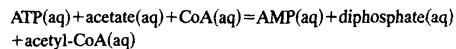
Method: enzymatic assay

Buffer: Tris (0.1 mol dm<sup>-3</sup>)

pH: 7.5–8.5

Cofactor(s):  $MgCl_2$  (0.005 mol dm<sup>-3</sup>)

Evaluation: C



$T$ K	pH	$c(\text{Mg}^{2+})$ mol dm <sup>-3</sup>	$I_c$ mol dm <sup>-3</sup>	$K'$
311.15	7.00	0.00083	0.25	8.45
311.15	7.00	0.00080	0.25	8.29
311.15	7.00	0.00082	0.25	8.46
298.15	7.00	0.00095	0.25	11.6
298.15	7.00	0.00077	0.25	10.7
298.15	7.00	0.00077	0.25	11.1
298.15	7.00	0.00077	0.25	11.4
298.15	6.99	0.00077	0.25	13.7
298.15	7.07	0.00073	0.25	9.81
311.15	7.03	0.00064	0.25	8.66
311.15	7.03	0.00064	0.25	8.15
311.15	7.03	0.00064	0.25	9.85
311.15	7.03	0.00064	0.25	9.82
311.15	7.03	0.00064	0.25	9.54
311.15	7.03	0.00074	0.25	8.34
311.15	7.03	0.00074	0.25	9.74
311.15	7.03	0.00074	0.25	9.68
311.15	7.03	0.00074	0.25	8.70
311.15	7.03	0.00074	0.25	8.68
311.15	7.03	0.00075	0.25	9.88
311.15	7.06	0.000025	0.25	10.4
311.15	7.07	0.000036	0.25	9.70
311.15	7.05	0.000036	0.25	8.99
311.15	7.10	0.000036	0.25	8.90
311.15	7.04	0.00026	0.25	9.66
311.15	6.97	0.0025	0.25	11.5
311.15	7.06	0.0028	0.25	9.82
311.15	6.89	0.0063	0.25	15.5
311.15	6.89	0.0063	0.25	15.2
311.15	7.39	0.0052	0.25	15.7
311.15	7.40	0.0052	0.25	14.4
311.15	7.41	0.0052	0.25	14.9
311.15	7.53	0.0050	0.25	18.8
311.15	7.53	0.0050	0.25	19.4

Reference: 74GUY/WEB

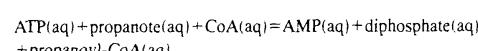
Method: spectrophotometry and enzymatic assay

pH: 7.0

Cofactor(s): MgCl<sub>2</sub>

Evaluation: A

Guynn *et al.* also calculated  $K(T=298.15 \text{ K}, I_c=0.25 \text{ mol dm}^{-3})=2.12\text{E}-8$  and  $K(T=311.15 \text{ K}, I_c=0.25 \text{ mol dm}^{-3})=1.59\text{E}-8$  for the chemical reference reaction:  $\text{ATP}^{4-}(\text{aq}) + \text{acetate}^-(\text{aq}) + \text{CoA}(\text{aq}) \rightleftharpoons \text{AMP}^{2-}(\text{aq}) + \text{diphosphate}^{4-}(\text{aq}) + \text{acetyl-CoA}(\text{aq}) + \text{H}^+(\text{aq})$ .



$T$ K	pH	$K'$
311.15	8.0	1.15

Reference: 54HEL

Method: enzymatic assay

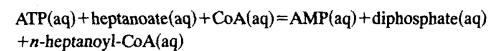
Buffer: Tris (0.1 mol dm<sup>-3</sup>)

pH: 8.0

Cofactor(s): MgCl<sub>2</sub> (0.005 mol dm<sup>-3</sup>)

Evaluation: C

#### 4.57. Enzyme: butyrate-CoA ligase (EC 6.2.1.2)



$T$ K	pH	$K'$
311.15	8.0	1.11

Reference: 53MAH/WAK

Method: spectrophotometry

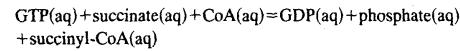
Buffer: glycylglycine (0.002 mol dm<sup>-3</sup>)

pH: 8.0

Cofactor(s): MgCl<sub>2</sub>

Evaluation: B

#### 4.58. Enzyme: succinate-CoA ligase (GDP forming) (EC 6.2.1.4)



$T$ K	pH	$c(\text{Mg}^{2+})$ mol dm <sup>-3</sup>	$I_c$ mol dm <sup>-3</sup>	$K'$
298.15	7.15	0.00124	0.25	1.68
298.15	7.19	0.00126	0.25	1.72
298.15	7.15	0.00126	0.25	1.58
298.15	7.15	0.00127	0.25	1.82
298.15	7.14	0.00129	0.25	1.66
298.15	6.83	0.00143	0.25	1.25
298.15	6.85	0.00144	0.25	1.54
298.15	6.82	0.00145	0.25	1.70
311.15	7.12	0.00011	0.25	1.00
311.15	7.17	0.00116	0.25	0.63
311.15	7.17	0.00115	0.25	0.52
311.15	7.12	0.00125	0.25	0.79
311.15	7.09	0.00128	0.25	0.74
311.15	7.08	0.00130	0.25	0.72
311.15	7.03	0.00131	0.25	0.82
311.15	7.27	0.00128	0.25	0.54
311.15	7.30	0.00127	0.25	0.50
311.15	7.27	0.00128	0.25	0.56
311.15	6.75	0.00133	0.25	1.03
311.15	6.75	0.00133	0.25	1.04
311.15	6.75	0.00133	0.25	1.03
311.15	7.11	0.00130	0.25	0.65
311.15	7.11	0.00130	0.25	0.53
311.15	7.12	0.00131	0.25	0.54
311.15	6.93	0.00133	0.25	0.82
311.15	7.10	0.00132	0.25	0.61
311.15	7.10	0.00133	0.25	0.77
311.15	7.08	0.00134	0.25	0.72
311.15	6.82	0.00138	0.25	0.53
311.15	6.75	0.00140	0.25	0.72
311.15	6.83	0.00142	0.25	0.87
311.15	6.80	0.00145	0.25	0.79
311.15	7.05	0.00666	0.25	0.79
311.15	7.04	0.00666	0.25	0.75
311.15	7.02	0.0139	0.25	0.68
311.15	7.01	0.0139	0.25	0.73
311.15	6.94	0.0189	0.25	0.60
311.15	6.96	0.0189	0.25	0.63

Reference: 78LYN.GUY

Method: fluorimetry and spectrophotometry

Buffer: Tris (0.1 mol dm<sup>-3</sup>) + acetic acid

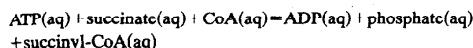
pH: 6.75–7.30

Cofactor(s): MgCl<sub>2</sub>

Evaluation: A

Lynn and Guynn calculated  $K(T=298.15 \text{ K}, I_c=0.25 \text{ mol dm}^{-3})=3.02$  and  $K(T=311.15 \text{ K}, I_c=0.25 \text{ mol dm}^{-3})=1.29$  for the chemical reference reaction:  $\text{GTP}^{4-}(\text{aq}) + \text{succinate}^{2-}(\text{aq}) + \text{CoA}(\text{aq}) \rightleftharpoons \text{GDP}^{3-}(\text{aq}) + \text{HPO}_4^{2-}(\text{aq}) - \text{succinyl-CoA}(\text{aq})$ .

**4.59. Enzyme: succinate-CoA ligase (ADP forming)  
(EC 6.2.1.5)**



$\frac{T}{K}$	pH	$K'$
293.15	7.4	0.27

Reference: 55KAU/ALI

Method: spectrophotometry

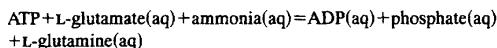
Buffer: Tris ( $0.10 \text{ mol dm}^{-3}$ ) + HCl

pH: 7.4

Cofactor(s):  $\text{MgCl}_2$  ( $0.010 \text{ mol dm}^{-3}$ )

Evaluation: B

**4.60 Enzyme: glutamate-ammonia ligase  
(EC 6.3.1.2)**



$\frac{T}{K}$	pH	$K'$
295.15	7.0	1800
310.15	6.0	400
310.15	7.0	1233
310.15	7.9	3000

Reference: 54LEV/MEI

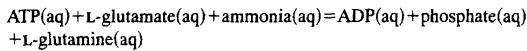
Method: chemical analysis and enzymatic assay

Buffer: imidazole ( $0.1 \text{ mol dm}^{-3}$ ) or Tris ( $0.1 \text{ mol dm}^{-3}$ )

pH: 6.0–7.9

Cofactor(s):  $\text{MgCl}_2$  or  $\text{MnCl}_2$

Evaluation: A



$\frac{T}{K}$	pH	$K'$
308.15	7.4	1700

Reference: 55VAR/WEB

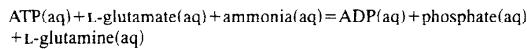
Method: chromatography and radioactivity

Buffer: Tris ( $0.045 \text{ mol dm}^{-3}$ )

pH: 7.4

Cofactor(s):  $\text{MgSO}_4$  ( $0.030 \text{ mol dm}^{-3}$ )

Evaluation: C



$\frac{T}{K}$	pH	$c(\text{MgCl}_2)$ $\text{mol dm}^{-3}$	$I_c$ $\text{mol dm}^{-3}$	$K'$
310.15	6.6	0.0504	0.20	162
310.15	7.0	0.0504	0.30	270
310.15	7.1	0.0107	0.22	280
310.15	7.5	0.0495	0.21	668
310.15	7.58	0.0098	0.17	831

Reference: 72ROS/SLA

Method: Enzymatic assay and chemical analysis

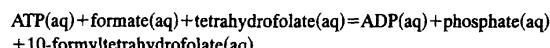
Buffer: Tris ( $0.10 \text{ mol dm}^{-3}$ )

pH: 6.6–7.58

Cofactor(s):  $\text{MgCl}_2$

Evaluation: A

**4.61. Enzyme: formate-tetrahydrofolate ligase  
(EC 6.3.4.3)**



$\frac{T}{K}$	pH	$K'$
310.15	7.7	41

Reference: 62HIM/RAB

Method: spectrophotometry

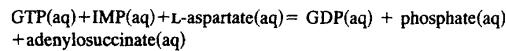
Buffer: triethanolamine ( $0.1 \text{ mol dm}^{-3}$ )

pH: 7.7

Cofactor(s):  $\text{MgCl}_2$  ( $0.010 \text{ mol dm}^{-3}$ )

Evaluation: B

**4.62 Enzyme: adenylosuccinate synthase  
(EC 6.3.4.4)**



$\frac{T}{K}$	pH	$K'$
310.15	8.0	2.9

Reference: 58FRO

Method: spectrophotometry

Buffer: glycine ( $0.071 \text{ mol dm}^{-3}$ )

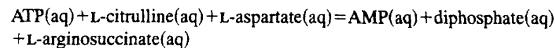
pH: 8.0

Cofactor(s):  $\text{MgSO}_4$  ( $0.018 \text{ mol dm}^{-3}$ )

Evaluation: C

The position of equilibrium was approached from only one direction.

**4.63. Enzyme: arginosuccinate synthase  
(EC 6.3.4.5)**



$\frac{T}{K}$	pH	$c(\text{MgCl}_2)$ $\text{mol dm}^{-3}$	$K'$
311.15	5.90	0.0066	0.14
311.15	6.91	0.0066	2.14
311.15	7.70	0.0066	38.3
311.15	7.79	0.0066	69.5

Reference: 60SCH/RAT

Method: spectrophotometry

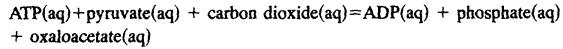
Buffer: Tris ( $0.1 \text{ mol dm}^{-3}$ )

pH: 5.90–7.79

Cofactor(s):  $\text{MgCl}_2$  ( $0.0066 \text{ mol dm}^{-3}$ )

Evaluation: A

**4.64. Enzyme: pyruvate carboxylase  
(EC 6.4.1.1)**



T K	pH	Buffer	c(MgCl <sub>2</sub> ) mol dm <sup>-3</sup>	c(MnCl <sub>2</sub> ) mol dm <sup>-3</sup>	K'
298.15	7.4	phosphate	0.0045	0	6.55
298.15	8.0	phosphate	0.0045	0	10.2
298.15	7.4	phosphate	0.0090	0	6.80
298.15	7.03	Tris	0	0.0025	1.40
298.15	7.06	Tris	0	0.0025	2.0
298.15	7.8	Tris	0	0.0025	0.59

Reference: 66WOO/DAV

Method: spectrophotometry and enzymatic assay

Buffer: potassium phosphate (0.010 mol dm<sup>-3</sup>) and {Tris (0.010 mol dm<sup>-3</sup>)+HCl}

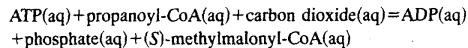
pH: 7.03–8.0

Cofactor(s): MgCl<sub>2</sub> and MnCl<sub>2</sub>

Evaluation: A

The convention used for carbon dioxide in the overall biochemical reaction is that one mole of that substance contains one mole of water. Wood *et al.* also calculated  $K(T=298.15 \text{ K}, I_c=0.1 \text{ mol dm}^{-3})=1.4E-6$  for the chemical reference reaction:  $\text{ATP}^{4-}(\text{aq}) + \text{pyruvate}^-(\text{aq}) + \text{HCO}_3^-(\text{aq}) = \text{ADP}^{3-}(\text{aq}) + \text{HPO}_4^{2-}(\text{aq}) + \text{oxaloacetate}^{2-}(\text{aq}) + \text{H}^+(\text{aq})$ .

**4.65. Enzyme: propanoyl-CoA carboxylase  
(EC 6.4.1.3)**



T K	pH	K'
310.15	8.15	0.0081

Reference: 62HAL/FEN

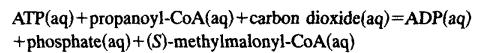
Method: spectrophotometry

Buffer: Tris (0.067 mol dm<sup>-3</sup>)

pH: 8.15

Cofactor(s): MgCl<sub>2</sub> (0.0025 mol dm<sup>-3</sup>)

Evaluation: B



T K	pH	K'
301.15	8.1	5.7

Reference: 65KAZ/GRO

Method: spectrophotometry and enzymatic assay

Buffer: Tris (0.1 mol dm<sup>-3</sup>)+HCl

pH: 8.1

Cofactor(s): MgCl<sub>2</sub> (0.06 mol dm<sup>-3</sup>)

Evaluation: C

Kaziro *et al.* used a calculated concentration of  $\text{HCO}_3^-(\text{aq}) \approx 0.029 \text{ mol dm}^{-3}$  to obtain the apparent equilibrium constant given here. We have assumed that this calculated concentration is equal to the sum of the concentrations of the species  $\text{CO}_2(\text{aq})$ ,  $\text{HCO}_5^-(\text{aq})$ , and  $\text{CO}_2^-(\text{aq})$ . The term carbon dioxide (aq) in the overall biochemical reaction represents the total amounts of these three species in solution; the convention used is that one mole of carbon dioxide contains one mole of water.

## 5. List of Substances with Chemical Abstract Service (CAS) Registry Numbers with Cross References to Enzyme Commission Numbers

Substance	CAS Registry Number*	Enzyme Commission Numbers
acetate	64-19-7	6.2.1.1
acetyl-coenzyme A	102029-73-2	6.2.1.1
<i>N</i> -acetyl-D-glucosamine	7512-17-6	5.1.3.8
<i>N</i> -acetyl-D-glucosamine 1-phosphate	6866-69-9	5.4.2.3
<i>N</i> -acetyl-D-glucosamine 6-phosphate	102029-88-9	5.1.3.9, 5.4.2.3
<i>N</i> -acetyl-D-mannosamine	3615-17-6	5.1.3.8
<i>N</i> -acetyl-D-mannosamine 6-phosphate	7433-20-7	5.1.3.9
adenosine 5'-diphosphate	58-64-0	6.2.1.5, 6.3.1.2, 6.3.4.3, 6.4.1.1, 6.4.1.3
adenosine 5'-monophosphate	18422-05-4	6.1.1.9, 6.2.1.1, 6.2.1.2, 6.3.4.5
adenosine 5'-triphosphate	56-65-5	6.1.1.9, 6.2.1.1, 6.2.1.2, 6.2.1.5, 6.3.1.2, 6.3.4.3, 6.3.4.5, 6.4.1.1, 6.4.1.3
adenylosuccinate	19046-78-7	6.3.4.4
D-alanine	338-69-2	5.1.1.1
L-alanine	56-41-7	5.1.1.1
$\beta$ -D-allose	7283-09-2	5.3.1.5
D-altrose	1990-29-0	5.3.1.5
D- $\alpha$ -amino-n-butyrate	2623-91-8	5.1.1.10
L- $\alpha$ -amino-n-butyrate	1492-24-6	5.1.1.10
6-amino-D-fructose 6-phosphate	133473-44-6	5.3.1.9
6-amino-D-glucose 6-phosphate	133473-41-3	5.3.1.9
ammonia	1336-21-6	5.3.1.10, 6.3.1.2
D-arabino-3-hexulose 6-phosphate	53010-97-2	5.3.1.b
D-arabinose	28697-53-2	5.3.1.3
L-arabinose	87-72-9	5.3.1.4
D-arabinose 5-phosphate	89927-09-3	5.3.1.13
L-arginosuccinate	2387-71-5	6.3.4.5
L-aspartate	56-84-8	6.3.4.4, 6.3.4.5
carbon dioxide	124-38-9	6.4.1.1, 6.4.1.3
(-)-4-carboxymethyl- $\Delta^{\alpha}$ -but-2-en-4-olide	32486-24-1	5.5.1.1
L-citrulline	372-75-8	6.3.4.5
coenzyme A	85-61-0	6.2.1.1, 6.2.1.2, 6.2.1.4, 6.2.1.5
cytidine-5'-diphospho-3,6-dideoxy-D-glucose	25417-33-8	5.1.3.10
cytidine-5'-diphospho-3,6-dideoxy-D-mannose	25417-34-9	5.1.3.10
L,L-2,6-diaminohexanedioate	14289-34-0	5.1.1.7
meso-diaminohexanedioate	922-54-3	5.1.1.7
(3S)-3,6-diaminohexanoate	504-21-2	5.4.3.2
D-threo-2,4-diaminopentanoate	126253-36-9	5.4.3.5
2,5-dihydro-3-oxofuran-2-acetate	6666-46-2	5.5.1.1
(2S)-4',7-dihydroxyflavanone	578-86-4	5.5.1.6
dimethylallyl diphosphate	358-72-5	5.3.3.2
dimethylmaleate	624-48-6	5.3.3.6
diphosphate	2406-09-3	6.1.1.9, 6.2.1.1, 6.2.1.2, 6.3.4.5
D-erythrose	583-50-6	5.3.1.2
D-erythrulose	533-49-3	5.3.1.2
formate	64-18-6	6.3.4.3
10-formyltetrahydrofolate	2800-34-2	6.3.4.3
D-fructose	57-48-7	5.3.1.5, 5.3.1.7
L-fructose	7776-48-9	5.3.1.a
D-fructose 1,6-bisphosphate	488-69-7	5.3.1.1, 5.4.2.2
D-fructose 6-phosphate	26177-86-6	5.3.1.8, 5.3.1.9, 5.3.1.10, 5.3.1.b, 5.4.2.2
D-fructuronate	669-90-9	5.3.1.12
L-fucose	6696-41-9	5.3.1.3
L-fuculose	13074-08-3	5.3.1.3
$\alpha$ -D-galactose 1-phosphate	2255-14-3	5.1.3.2
D-galacturonate	685-73-4	5.3.1.12
D-glucosamine 1-phosphate	19889-76-0	5.4.2.2
D-glucosamine 6-phosphate	3616-42-0	5.3.1.10, 5.4.2.2
D-glucose	50-99-7	5.3.1.5
$\alpha$ -D-glucose 1,6-diphosphate	91183-87-8	5.4.2.2
$\alpha$ -D-glucose 1-phosphate	59-56-3	5.1.3.2, 5.4.2.2

6. List of Substances with Chemical Abstract Service (CAS) Registry Numbers  
With Cross References to Enzyme Commission Numbers—Continued

Substance	CAS Registry Number <sup>a</sup>	Enzyme Commission Numbers
$\beta$ -D-glucose 1-phosphate	32972-46-6	5.4.2.6
D-glucose 6-phosphate	56-73-5	5.3.1.9
$\alpha$ -D-glucose 6-phosphate	15209-11-7	5.4.2.2
$\beta$ -D-glucose 6-phosphate	54010-71-8	5.4.2.6
D-glucuronate	6556-12-3	5.3.1.12
D-glutamate	6893-26-1	5.1.1.3
L-glutamate	56-86-0	5.1.1.3, 5.4.99.1, 6.3.1.
L-glutamine	56-85-9	6.3.1.2
D-glyceraldehyde 3-phosphate	142-10-9	5.3.1.1
glycerone phosphate	102783-56-2	5.3.1.1
guanosine 5'-diphosphate	146-91-8	6.2.1.4, 6.3.4.4
guanosine-5'-diphospho-L-galactose	6815-91-4	5.1.3.18
guanosine-5'-diphosphomannose	3123-67-9	5.1.3.18
guanosine 5'-triphosphate	36051-31-7	6.2.1.4, 6.3.4.4
H <sub>2</sub> O	7732-18-5	5.3.1.10
heptanoate	111-14-8	6.2.1.2
n-heptanoyl-coenzyme A	17331-97-4	6.2.1.2
cis,cis-hexadienedioate	1119-72-8	5.5.1.1
cis,trans-hexadienedioate	1119-73-9	5.5.1.1
cis-4-hydroxy-D-proline	2584-71-6	5.1.1.8
trans-4-hydroxy-L-proline	51-35-4	5.1.1.8
inosine 5'-monophosphate	131-99-7	6.3.4.4
isopentenyl diphosphate	358-71-4	5.3.3.2
D-leucine	328-38-1	5.1.1.10
L-leucine	61-90-5	5.1.1.10
D-lysine	923-27-3	5.1.1.5
L-lysine	56-87-1	5.1.1.5, 5.4.3.2
D-lyxose	1114-34-7	5.3.1.7, 5.3.1.15
D-mannose	3458-28-4	5.3.1.7
L-mannose	10030-80-5	5.3.1.a
D-mannose 1-phosphate	51306-17-3	5.4.2.8
D-mannose 6-phosphate	70442-25-0	5.3.1.8, 5.4.2.8
L-threo-3-methylaspartate	31571-69-4	5.4.99.1
2-methyleneglutарате	3621-79-2	5.4.99.4
methylitaconate	27697-13-8	5.3.3.6, 5.4.99.4
(R)-methylmalonyl-coenzyme A	73173-92-9	5.1.99.1, 5.4.99.2
(S)-methylmalonyl-coenzyme A	73173-91-8	5.1.99.1, 6.4.1.3
9-cis,12-cis-octadecadienoate	60-33-3	5.2.1.5
9-cis,11-trans-octadecadienoate	872-23-1	5.2.1.5
D-ornithine	16682-12-5	5.4.3.5
oxaloacetate	328-42-7	6.4.1.1
enol-oxaloacetate	7619-04-7	5.3.2.2
keto-oxaloacetate	328-42-7	5.3.2.2
enol-phenylpyruvate	5801-57-0	5.3.2.1
keto-phenylpyruvate	156-06-9	5.3.2.1
phosphate	10049-21-5	6.2.1.4, 6.2.1.5, 6.3.1.2, 6.3.4.3, 6.3.4.4, 6.4.1.1, 6.4.1.3
2-phospho-D-glycerate	70195-25-4	5.4.2.1
3-phospho-D-glycerate	80731-10-8	5.4.2.1
propanoyl-coenzyme A	317-66-8	6.4.1.3
propanoate	79-09-4	6.2.1.1
propanoyl-coenzyme A	108321-21-7	6.2.1.1
D-psicose	551-68-8	5.3.1.5
pyruvate	127-17-3	6.4.1.1
all-trans-retinal	116-31-4	5.2.1.3
all-cis-retinal	564-87-4	5.2.1.3
D-rhamnose	634-74-2	5.3.1.7
L-rhamnose	10030-85-0	5.3.1.14
D-rhamnulose	4429-06-5	5.3.1.7
L-rhamnulose	14807-05-7	5.3.1.14
D-ribose	50-69-1	5.3.1.20
D-ribose 1-phosphate	14075-00-4	5.4.2.7
D-ribose 5-phosphate	4300-28-1	5.3.1.6, 5.4.2.7
D-ribulose	488-84-6	5.3.1.3, 5.3.1.20
L-ribulose	2042-27-5	5.3.1.4

6. List of Substances With Chemical Abstract Service (CAS) Registry Numbers  
With Cross References to Enzyme Commission Numbers—Continued

Substance	CAS Registry Number <sup>a</sup>	Enzyme Commission Numbers
D-ribulose 5-phosphate	108321-99-9	5.1.3.1, 5.3.1.6, 5.3.1.13
L-ribulose 5-phosphate	2922-69-2	5.1.3.4
succinate	110-15-6	6.2.1.4, 6.2.1.5
succinyl-coenzyme A	108347-97-3	5.4.99.2, 6.2.1.4, 6.2.1.5
D-tagaturonate	6812-01-7	5.3.1.12
tetrahydrofolate	135-16-0	6.3.4.3
tetrahydroxypteridine	2817-14-3	5.5.1.3
6-thioglucose 1-phosphate	160705-76-0	5.4.2.2
6-thioglucose 6-phosphate	133832-95-8	5.4.2.2
2',4,4'-trihydroxymalcone	961-29-5	5.5.1.6
tRNA <sup>Val</sup>	b	6.1.1.9
uridine-5'-diphospho-L-arabinose	15839-78-8	5.1.3.5
uridine-5'-diphospho-D-fucose	16375-63-6	5.1.3.2
uridine-5'-diphosphogalactose	89705-69-1	5.1.3.2
uridine-5'-diphospho-D-galacturonate	148407-07-2	5.1.3.6
uridine-5'-diphosphoglucose	133-89-1	5.1.3.2
uridine-5'-diphospho-D-glucuronate	63700-19-6	5.1.3.6
uridine-5'-diphospho-D-quinovose	19083-14-8	5.1.3.2
uridine-5'-diphospho-D-xylose	108320-89-4	5.1.3.5
L-valine	72-18-4	6.1.1.9
L-valyl-tRNA <sup>Val</sup>	b	6.1.1.9
xanthine-8-carboxylate	2577-18-6	5.5.1.3
D-xylose	58-86-6	5.3.1.5
D-xylulose	551-84-8	5.3.1.5, 5.3.1.7, 5.3.1.15
D-xylulose 5-phosphate	105931-44-0	5.1.3.1, 5.1.3.4

<sup>a</sup>In some cases the CAS registry number refers to a salt of the substance.<sup>b</sup>In the absence of a nucleic acid sequence, no CAS registry number is assigned to this substance.

## 6. Abbreviations

ADP	adenosine 5'-diphosphate	GTP	guanosine 5'-triphosphate
AMP	adenosine 5'-monophosphate	Hepes	<i>N</i> -(2-hydroxyethyl) piperazine- <i>N'</i> -ethanesulfonic acid
ATP	adenosine 5'-triphosphate	IMP	inosine 5'-monophosphate
CDP	cytidine 5'-diphosphate	Mops	3-morpholinopropanesulfonic acid
Ches	2-(cyclohexylamino) ethanesulfonic acid	RNA	ribonucleic acid
CoA	coenzyme A	Taps	3-[tris(hydroxymethyl) methyl-3-amino] propanesulfonic acid
GDP	guanosine 5'-diphosphate	Tris	tris (hydroxymethyl) aminomethane
		UDP	uridine 5'-diphosphate

## 7. Glossary of Symbols

Symbol	Name	Unit
$c$	concentration	$\text{mol dm}^{-3}$
$c^\circ$	standard concentration ( $c^\circ = 1 \text{ mol dm}^{-3}$ )	$\text{mol dm}^{-3}$
$\Delta_f C_p^\circ$	standard heat capacity of reaction at constant pressure	$\text{J K}^{-1} \text{ mol}^{-1}$
$\Delta_f G^\circ$	standard Gibbs energy of reaction	$\text{kJ mol}^{-1}$
$\Delta_f G'^\circ$	standard transformed Gibbs energy of reaction	$\text{kJ mol}^{-1}$
$\Delta_f H^\circ$	standard enthalpy of reaction	$\text{kJ mol}^{-1}$
$\Delta_f H'^\circ$	standard transformed enthalpy of reaction	$\text{kJ mol}^{-1}$
$\Delta_f H(\text{cal})$	calorimetrically determined enthalpy of reaction	$\text{kJ mol}^{-1}$
$I_c$	ionic strength, concentration basis	$\text{mol dm}^{-3}$
$I_m$	ionic strength, molality basis	$\text{mol kg}^{-1}$
$K$	equilibrium constant <sup>a</sup>	dimensionless
$K'$	apparent equilibrium constant <sup>a</sup>	dimensionless
$m$	molality	$\text{mol kg}^{-1}$
$m^\circ$	standard molality ( $m^\circ = 1 \text{ mol kg}^{-1}$ )	$\text{mol kg}^{-1}$
$\Delta_f N(\text{H}^+)$	change in binding of hydrogen ion in a biochemical reaction	dimensionless
pH	$-\log_{10}\{c(\text{H}^+)/c^\circ\}^b$	dimensionless
pX	$-\log_{10}\{c(X)/c^\circ\}$	dimensionless
$\Delta_f S^\circ$	standard entropy of reaction	$\text{J K}^{-1} \text{ mol}^{-1}$
$T$	thermodynamic temperature	K
$x$	mole fraction	dimensionless

<sup>a</sup>When needed, a subscript  $c$ ,  $m$ , or  $x$  is added to these quantities to designate a concentration, molality, or mole fraction basis.

<sup>b</sup>This is an approximate definition. The IUPAC Green Book (I. Mills, T. Cvitaš, K. Homann, N. Kallay, and K. Kuchitsu, "Quantities, Units and Symbols in Physical Chemistry," Blackwell Scientific Publications, Oxford, 1993) contains a discussion of the operational definition of pH.

## 8. Reference Codes and References in the Table

34MEY/LOH	Meyerhof, O.; Lohmann, K.; Biochem. Z.; <b>271</b> , 89 (1934).	56ENG	Englesberg, E.; Fed. Proc., Fed. Am. Soc. Exp. Biol.; <b>15</b> , 586 (1956).
35MEY/KIE	Meyerhof, O.; Kiessling, W.; Biochem. Z.; <b>276</b> , 239 (1935).	56GRE/COH	Green, M.; Cohen, S. S.; J. Biol. Chem.; <b>219</b> , 557 (1956).
35MEY/KIE2	Meyerhof, O.; Kiessling, W.; Biochem. Z.; <b>280</b> , 99 (1935).	56HUB	Hubbard, R.; J. Gen. Physiol.; <b>39</b> , 935 (1956).
35MEY	Meyerhof, O.; Biochem. Z.; <b>277</b> , 77 (1935).	56HUR/HOR	Hurwitz, J.; Horecker, B. L.; J. Biol. Chem.; <b>223</b> , 993 (1956).
35MEY/LOH	Meyerhof, O.; Lohmann, K.; Biochem. Z.; <b>275</b> , 430 (1935).	56LEL/CAR	Leloir, L. F.; Cardini, C. E.; Biochim. Biophys. Acta; <b>20</b> , 33 (1956).
38MEY/SCH	Meyerhof, O.; Schulz, W.; Biochem. Z.; <b>297</b> , 60 (1938).	56PAL/DOU	Palleroni, N. J.; Doudoroff, M.; J. Biol. Chem.; <b>218</b> , 535 (1956).
41UTT/WER	Utter, M. F.; Werkman, C. H.; J. Bacteriol.; <b>42</b> , 665 (1941).	56RAM/GIR	Ramasarma, T.; Giri, K. V.; Arch. Biochem. Biophys.; <b>62</b> , 91 (1956).
42COL/SUT	Colowick, S. P.; Sutherland, E. W.; J. Biol. Chem.; <b>144</b> , 423 (1942).	56REI	Reissig, J. L.; J. Biol. Chem.; <b>219</b> , 753 (1956).
43MEY/JUN	Meyerhof, O.; Junowicz-Kocholaty, R.; J. Biol. Chem.; <b>149</b> , 71 (1943).	56STU/HOR	Stumpf, P. K.; Horecker, B. L.; J. Biol. Chem.; <b>218</b> , 753 (1956).
47MEY/OES	Meyerhof, O.; Oesper, P.; J. Biol. Chem.; <b>170</b> , 1 (1947).	57ASH/HIC	Ashwell, G.; Hickman, J.; J. Biol. Chem.; <b>226</b> , 65 (1957).
49MEY/OES	Meyerhof, O.; Oesper, P.; J. Biol. Chem.; <b>179</b> , 1371 (1949).	57BUR/HOR	Burma, D. P.; Horecker, B. L.; Biochim. Biophys. Acta; <b>24</b> , 660 (1957).
50OES/MEY	Oesper, P.; Meyerhof, O.; Arch. Biochem. Biophys.; <b>27</b> , 223 (1950).	57MAX	Maxwell, E. S.; J. Biol. Chem.; <b>229</b> , 139 (1957).
50SLE	Slein, M. W.; J. Biol. Chem.; <b>186</b> , 753 (1950).	57ROD/TOW	Rodwell, V. M.; Towne, J. C.; Grisolia, S.; J. Biol. Chem.; <b>228</b> , 875 (1957).
51WOO/GUN	Wood, W. A.; Gunslaus, I. C.; J. Biol. Chem.; <b>190</b> , 403 (1951).	58BRU/NOL	Brunn, F. H.; Noltmann, E.; Vahlhaus, E.; Biochem. Z.; <b>330</b> , 483 (1958).
52LEL/CAR	Leloir, L. F.; Cardini, C. E.; Cabib, E.; Ann. Asoc. Quim. Argent.; <b>40</b> , 228 (1952).	58DUR/HOR	Burma, D. P.; Horecker, B. L.; J. Biol. Chem.; <b>231</b> , 1053 (1958).
52NAR/WOO	Narrod, S. A.; Wood, W. A.; Arch. Biochem. Biophys.; <b>35</b> , 462 (1952).	58FRO	Fromm, H. J.; Biochim. Biophys. Acta; <b>29</b> , 255 (1958).
53BOD	Bodansky, O.; J. Biol. Chem.; <b>202</b> , 829 (1953).	58HEA/HOR	Heath, E. C.; Horecker, B. L.; Smyriiotis, P. Z.; Takagi, Y. J. Biol. Chem.; <b>231</b> , 1031 (1958).
53BRO	Brown, D. H.; J. Biol. Chem.; <b>204</b> , 877 (1953).	58NOL/BRU	Noltman, E.; Bruns, F. H.; Biochem. Z.; <b>330</b> , 514 (1958).
53COH	Cohen, S. S.; J. Biol. Chem.; <b>201</b> , 71 (1953).	58TAB/SRE	Tabachnick, M.; Strene, P. A.; Cooper, J.; Racker, E.; Arch. Biochem. Biophys.; <b>74</b> , 315 (1958).
53HOC/WAT	Hochster, R. M.; Watson, R. W.; J. Am. Chem. Soc.; <b>75</b> , 3284 (1953).	58WOL/SIM	Wolin, M. J.; Simpson, F. J.; Wood, W. A.; J. Biol. Chem.; <b>232</b> , 559 (1958).
53JON	Jones, M. E.; Fed. Proc., Fed. Am. Soc. Exp. Biol.; <b>12</b> , 708 (1953).	59ATK/JOH	Atkinson, M. R.; Johnson, E.; Morton, R. K.; Nature; <b>184</b> , 1925 (1959).
53MAH/WAK	Mahler, H. R.; Wakil, S. J.; Bock, R. M.; J. Biol. Chem.; <b>204</b> , 453 (1953).	59CHI/SUG	Chiba, H.; Sugimoto, E.; Bull. Agric. Chem. Soc. Jpn.; <b>23</b> , 207 (1959).
53MIT/LAM	Mitsuhashi, S.; Lampen, J. O.; J. Biol. Chem.; <b>204</b> , 1011 (1953).	59ITO/GRI	Ito, N.; Grisolia, S.; J. Biol. Chem.; <b>234</b> , 242 (1959).
54AXE/JAN	Axelrod, B.; Jang, R.; J. Biol. Chem.; <b>209</b> , 847 (1954).	59MCC/NAJ	McCoy, E. E.; Najjar, V. A.; J. Biol. Chem.; <b>234</b> , 3017 (1959).
54HAN/CRA	Hansen, R. G.; Craine, E. M.; J. Biol. Chem.; <b>208</b> , 293 (1954).	60AGO/ARA	Agosin, M.; Aravena, L.; Enzymologia; <b>22</b> , 281 (1960).
54HEL	Hele, P.; J. Biol. Chem.; <b>206</b> , 671 (1954).	60ASH/WAH	Ashwell, G.; Wahba, A. J.; Hickman, J.; J. Biol. Chem.; <b>235</b> , 1559 (1960).
54HOC/WAT	Hochster, R. M.; Watson, R. W.; Arch. Biochem. Biophys.; <b>48</b> , 120 (1954).	60FEI/NEU	Feingold, D. S.; Neufeld, E. F.; Hassid, W. Z.; J. Biol. Chem.; <b>235</b> , 910 (1960).
54LEV/MEI	Levintow, L.; Meister, A.; J. Biol. Chem.; <b>209</b> , 265 (1954).	60ICH/FUR	Ichihara, A.; Furiya, S.; Suda, M.; J. Biochem. (Tokyo); <b>48</b> , 277 (1960).
54MAR/WIL	Marr, A. G.; Wilson, P. W.; Arch. Biochem. Biophys.; <b>49</b> , 474 (1954).	60KAH/LOW	Kahana, S. E.; Lowry, O. H.; Schulz, D. W.; Passoneau, J. V.; Crawford, E. J.; J. Biol. Chem.; <b>235</b> , 2178 (1960).
54SIS/STA	Sistrom, W. R.; Stanier, R. Y.; J. Biol. Chem.; <b>210</b> , 821 (1954).	60SCII/RAT	Schuegraf, A.; Ratner, S.; Warner, R. C.; J. Biol. Chem.; <b>235</b> , 3597 (1960).
55DIC/WIL	Dickens, F.; Williamson, D. H.; Nature; <b>176</b> , 400 (1955).	60VOL	Volk, W. A.; J. Biol. Chem.; <b>235</b> , 1550 (1960).
55KAU/ALI	Kaufman, S.; Alivisatos, S. G. A.; J. Biol. Chem.; <b>216</b> , 141 (1955).	61ATK/JOH	Atkinson, M. R.; Johnson, E.; Morton, R. K.; Biochem. J.; <b>79</b> , 12 (1961).
55SLE	Slein, M. W.; J. Am. Chem. Soc.; <b>77</b> , 1663 (1955).	61BEN/SCH	Ben-Zvi, R.; Schramm, M.; J. Biol. Chem.; <b>236</b> , 2186 (1961).
55THO/GOM	Thorne, C. B.; Gomez, C. G.; Housewright, R. D.; J. Bacteriol.; <b>69</b> , 357 (1955).	61BER/BER	Berg, P.; Bergmann, F. H.; Ofengand, E. J.; Dieckmann, M.; J. Biol. Chem.; <b>236</b> , 1726 (1961).
55VAR/WEB	Varner, J. E.; Webster, G. C.; Plant Physiol.; <b>30</b> , 393 (1955).	61MAH	Mahler, H. R.; in "Biochemist's Handbook;" C. Long, ed.; D. Van Nostrand Co., Princeton, New Jersey (1961), pp. 418-419.
56COW/PIZ	Cowgill, R. W.; Pizer, L. I.; J. Biol. Chem.; <b>223</b> , 885 (1956).	62DOU	Doudoroff, M.; Methods Enzymol.; <b>5</b> , 335 (1962).
56DIC/WIL	Dickens, F.; Williamson, D. H.; Biochem. J.; <b>64</b> , 567 (1956).	62GRI	Grisolia, S.; Methods Enzymol.; <b>5</b> , 236 (1962).
		62HAL/FEN	Halenz, D. R.; Feng, J.-Y.; Hegre, C. S.; Lane, M. D.; J. Biol. Chem.; <b>237</b> , 2140 (1962).

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| 62HIM/RAB  | Himes, R. H.; Rabinowitz, J. C.; <i>J. Biol. Chem.</i> ; <b>237</b> , 2903 (1962).  | 68SAL/NOR | Salo, W. L.; Nordin, J. H.; Peterson, D. R.; Bevill, J. D.; Kirkwood, S.; <i>Biochim. Biophys. Acta</i> ; <b>151</b> , 48 (1968).              |
| 62HOR      | Horecker, B. L.; <i>Methods Enzymol.</i> ; <b>5</b> , 253 (1962).   | 69BLA/FRA | Blasi, F.; Fragomele, F.; Covelli, I.; <i>J. Biol. Chem.</i> <b>244</b> , 4864 (1969).   |
| 62UEH      | Uehara, K.; <i>Methods Enzymol.</i> ; <b>5</b> , 350 (1962).  | 69FAN/FEI | Fan, D.-F.; Feingold, D. S.; <i>Plant Physiol.</i> ; <b>44</b> , 59 (1969).  |
| 63ALL/KEL  | Allen, S. H. G.; Kellermeyer, R.; Stjernholm, R.; Wood, H. G.; <i>J. Biol. Chem.</i> ; <b>238</b> , 1637 (1963).              | 69PAS/LOW | Passonneau, J. V.; Lowry, O. H.; Schulz, D. W.; Brown, J. G.; <i>J. Biol. Chem.</i> ; <b>244</b> , 902 (1969).                                 |
| 63DOB/DEM  | Dobrogosz, W. J.; Demoss, R. D.; <i>Biochim. Biophys. Acta</i> ; <b>77</b> , 629 (1963).                                      | 69VEE/RAI | Veech, R. L.; Rajzman, L.; Dalziel, K.; Krebs, H. A. <i>Biochem. J.</i> ; <b>115</b> , 837 (1969).   |
| 63DOM/ZEC  | Domagk, G. F.; Zech, R.; <i>Biochem. Z.</i> ; <b>339</b> , 145 (1963).  | 69WHI/LEJ | White, P. J.; Lejeune, B.; Work, E.; <i>Biochem. J.</i> ; <b>113</b> , 589 (1969).   |
| 63HIN/WOL  | Hines, M. C.; Wolfe, R. G.; <i>Biochemistry</i> ; <b>2</b> , 770 (1963).  | 70BEN/FRI | Benson, R. L.; Friedman, S.; <i>J. Biol. Chem.</i> ; <b>245</b> , 2219 (1970).   |
| 64ADA/NOR  | Adams, E.; Norton, I. L.; <i>J. Biol. Chem.</i> ; <b>239</b> , 1525 (1964).   | 70CHI/ZAP | Chirpich, T. P.; Zappia, V.; Costilow, R. N.; Barker, H. A.; <i>J. Biol. Chem.</i> ; <b>245</b> , 1778 (1970).                                 |
| 64BAR/ROO  | Barker, H. A.; Roozc, V.; Suzuki, F.; Iodice, A. A.; <i>J. Biol. Chem.</i> ; <b>239</b> , 3260 (1964).                        | 70FAN/FEI | Fan, D.-F.; Feingold, D. S.; <i>Plant Physiol.</i> ; <b>44</b> , 592 (1970).   |
| 64IMA/MOR  | Imae, Y.; Morikawa, N.; Kurahashi, K.; <i>J. Biochem. (Tokyo)</i> ; <b>56</b> , 138 (1964).                                   | 70HEY/ELB | Hey-Ferguson, A.; Elbein, A. D.; <i>J. Bacteriol.</i> ; <b>101</b> , 777 (1970).   |
| 64KEL/ALL  | Kellermeyer, R. W.; Allen, S. H. G.; Stjernholm, R.; Wood, H. G.; <i>J. Biol. Chem.</i> ; <b>239</b> , 2562 (1964).           | 70WUR/SCH | Wurster, B.; Schneider, F.; <i>Hoppe-Seyler's Z. Physiol. Chem.</i> ; <b>351</b> , 961 (1970).   |
| 64LOW/PAS  | Lowry, O. H.; Passonneau, J. V.; <i>J. Biol. Chem.</i> ; <b>239</b> , 31 (1964).  | 71KUN/STA | Kung, H.-F.; Stadtman, T. C.; <i>J. Biol. Chem.</i> ; <b>246</b> , 3378 (1971).  |
| 64MCN/DAM  | McNutt, W. S.; Damle, S. P.; <i>J. Biol. Chem.</i> ; <b>239</b> , 4272 (1964).  | 72ROS/SLA | Rosing, J.; Slater, E. C.; <i>Biochim. Biophys. Acta</i> ; <b>267</b> , 275 (1972).  |
| 64SAT/TSU  | Sato, T.; Tsumura, N.; <i>J. Chem. Soc. Jpn.</i> ; <b>67</b> , 683 (1964).  | 72WUR/HES | Wurster, B.; Hess, B.; <i>FEBS Lett.</i> ; <b>23</b> , 341 (1972).   |
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| 64WIL/HOG  | Wilson, D. B.; Hogness, D. S.; <i>J. Biol. Chem.</i> ; <b>239</b> , 2469 (1964).  | 73LAN     | Lantero, O. J., Jr.; in "Enzyme Engineering," Vol. 4; E. K. Pye and L. B. Wingard, eds.; Plenum Press, New York (1973) pp. 349-351.            |
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