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.

Contents

1. Introduction

This paper completes a series of reviews[1-4] 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.[5] 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 $\Delta_r H$(cal). Apparent equilibrium constants calculated from kinetic data are also tabulated. If the change in binding of the hydrogen ion $\Delta_r N(H^+)$ in a biochemical reaction is known, the standard transformed enthalpy of reaction $\Delta_r H'^\circ$ can be calculated from the calorimetrically determined enthalpy of reaction.[6] Equilibrium constants K and standard molar enthalpies of reaction $\Delta_r H^\circ$ for chemical reference reactions are also given if they have been reported in the literature. The standard transformed enthalpy of reaction $\Delta_r H'^\circ$ can be used to calculate the temperature dependence of apparent equilibrium constants K' in the same way that the standard enthalpy of reaction $\Delta_r H^\circ$ 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.[1-4] 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.[1] 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

$$A(aq)=B(aq)+C(aq), \quad (1)$$

$K_c=c(B)c(C)/\{c(A)c^\circ\}$, $K_m=m(B)m(C)/\{m(A)m^\circ\}$, and $K_x=x(B)x(C)/x(A)$. Here, c, m, and x are, respectively, concentration, molality, and mole fraction, $c^\circ=1$ mol dm^{-3}, and $m^\circ=1$ 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.[7-18] 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."[19] 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

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3. References for the Introductory Discussion

[1] R. N. Goldberg, Y. B. Tewari, D. Bell, K. Fazio, and E. Anderson, J. Phys. Chem. Ref. Data **22**, 515 (1993).
[2] R. N. Goldberg and Y. B. Tewari, J. Phys. Chem. Ref. Data **23**, 547 (1994).
[3] R. N. Goldberg and Y. B. Tewari, J. Phys. Chem. Ref. Data **23**, 1035 (1994).
[4] R. N. Goldberg and Y. B. Tewari, J. Phys. Chem. Ref. Data **24**, 1669 (1995).
[5] E. C. Webb, "Enzyme Nomenclature 1992" (Academic Press, San Diego, 1992).
[6] R. A. Alberty and R. N. Goldberg, Biophys. Chem. **47**, 213 (1993).
[7] H. A. Krebs and H. L. Kornberg, with an appendix by K. Burton, "A Survey of the Energy Transformations in Living Matter" (Springer-Verlag, Berlin, 1957).
[8] M. R. Atkinson and R. K. Morton, in "Comparative Biochemistry," edited by M. Florkin and H. S. Mason (Academic Press, New York, 1960), Vol. 2; pp. 1–95.
[9] J. M. Sturtevant, in "Experimental Thermochemistry—Volume II," edited by H. A. Skinner (Interscience, New York, 1962).
[10] T. E. Barman, "Enzyme Handbook" (Springer-Verlag, New York, 1969), Vols. I and II.
[11] T. E. Barman, "Enzyme Handbook" (Springer-Verlag, New York, 1974), Supplement I.
[12] H. D. Brown, in "Biochemical Microcalorimetry," edited by H. D. Brown (Academic Press, New York, 1969), pp. 149–164.
[13] R. C. Wilhoit, in "Biochemical Microcalorimetry," edited by H. D. Brown (Academic Press, New York, 1969); pp. 33–81, 305–317.
[14] R. K. Thauer, K. Jungermann, and K. Decker, Bacteriol. Rev. **41**, 100 (1977).
[15] M. V. Rekharsky, A. M. Egorov, G. L. Gal'chenko, and I. V. Berezin, Thermochim. Acta **46**, 89 (1981).
[16] M. V. Rekharsky, G. L. Gal'chenko, A. M. Egorov, and I. V. Berezin, in "Thermodynamic Data for Biochemistry and Biotechnology," edited by H. J. Hinz (Springer-Verlag, Berlin, 1986), pp. 431–444.
[17] R. N. Goldberg and Y. B. Tewari, J. Phys. Chem. Ref. Data **18**, 809 (1989).
[18] S. L. Miller and D. Smith-Magowan, J. Phys. Chem. Ref. Data **19**, 1049 (1990).
[19] R. A. Alberty, "Recommendations for Nomenclature and Tables in Biochemical Thermodynamics," Pure Appl. Chem. **66**, 1641 (1994).

4. Table of Equilibrium Constants and Enthalpies of Reaction

4.1. Enzyme: alanine racemase (EC 5.1.1.1)

L-alanine(aq)=D-alanine(aq)

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

Reference: 51WOO/GUN
Method: enzymatic assay and manometry
Buffer: phosphate (0.011 mol dm^{-3})
pH: 8.1
Evaluation: B

This equilibrium constant must equal 1.0.

L-alanine(aq)=D-alanine(aq)

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

Reference: 54MAR/WIL
Method: enzymatic assay
Buffer: Tris (0.067 mol dm^{-3})
pH: 8.0
Evaluation: B

The equilibrium constant must equal 1.0.

L-alanine(aq)=D-alanine(aq)

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

Reference: 55THO/GOM
Method: manometry and enzymatic assay
Buffer: phosphate (0.01 mol dm^{-3})
pH: 7.4
Evaluation: B

This equilibrium constant must equal 1.0.

L-alanine(aq)=D-alanine(aq)

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

Reference: 84WAS/DAU
Method: enzymatic assay and spectrophotometry
Buffer: Ches (0.1 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)

L-glutamate(aq)=D-glutamate(aq)

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

Reference: 52NAR/WOO
Method: enzymatic assay
Buffer: phosphate (0.1 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)

L-lysine(aq)=D-lysine(aq)

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

Reference: 60ICH/FUR
Buffer: phosphate (0.04 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)

L,L-2,6-diaminoheptanedioate(aq)=meso-diaminoheptanedioate(aq)

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

Reference: 69WHI/LEJ
Method: manometry and spectrophotometry
Buffer: phosphate (0.1 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)

trans-4-hydroxy-L-proline(aq)=*cis*-4-hydroxy-D-proline(aq)

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

Reference: 64ADA/NOR
Method: ion exchange chromatography
Buffer: Tris (0.05 mol dm^{-3})
ph: 8.1
Evaluation: B

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

L-leucine(aq)=D-leucine(aq)

$\frac{T}{K}$	pH	K′
310.15	8.3	1.0

Reference: 67SOD/OSU
Method: manometry and enzymatic assay
Buffer: diphosphate (0.03 mol dm^{-3})
Evaluation: B

This equilibrium constant must equal 1.0

L-α-amino-*n*-butyrate(aq)=D-α-amino-*n*-butyrate(aq)

$\frac{T}{K}$	pH	K′
310.15	8.3	1.0

Reference: 67SOD/OSU
Method: manometry and enzymatic assay
Buffer: diphosphate (0.03 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)

D-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

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

Reference: 56HUR/HOR
Method: Enzymatic assay and spectrophotometry
Buffer: Tris (0.078 mol dm^{-3})
pH: 7.5
Cofactor(s): $MgCl_2$
Evaluation: B

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

D-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

$\frac{T}{K}$	pH	K′
310.15	7.5	0.83

Reference: 56STU/HOR
Method: spectrophotometry
Buffer: Tris (0.025 mol dm^{-3})
pH: 7.5
Evaluation: C

D-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

$\frac{T}{K}$	pH	K′
310.15	7.5	1.4

Reference: 57ASH/HIC
Method: spectrophotometry
Buffer: imidazole (0.01 mol dm^{-3})
pH: 7.5
Evaluation: C

D-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

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

Reference: 58TAB/SRE
Method: enzymatic assay and spectrophotometry
Buffer: glycylglycine (0.056 mol dm^{-3})
pH: 7.5
Evaluation: B

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

D-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

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

Reference: 86CAS/VEE
Method: enzymatic assay and spectrophotometry
Buffer: phosphate (0.020 mol dm^{-3})
pH: 7.0
Cofactor(s): $MgCl_2$
Evaluation: A

Also see data given under EC 5.1.3.4.

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

UDPglucose(aq)=UDPgalactose(aq)

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

Reference: 57MAX
Method: spectrophotometry
Buffer: glycine (0.1 mol dm^{-3})
pH: 8.7
Evaluation: C

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

UDPglucose(aq)=UDPgalactose(aq)

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

Reference: 64IMA/MOR
Method: spectrophotometry
Buffer: glycine (0.1 mol dm^{-3}) + NaOH
pH: 8.7
Evaluation: A

UDPglucose(aq)=UDPgalactose(aq)

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

Reference: 64WIL/HOG
Method: spectrophotometry
Buffer: potassium phosphate (0.05 mol dm^{-3}) and glycine (0.05 mol dm^{-3})
pH: 7.1 and 8.7
Evaluation: B

UDPglucose(aq)=UDPgalactose(aq)

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

Reference: 68SAL/NOR
Method: chromatography and spectrophotometry
Buffer: glycine (0.24 mol dm^{-3})+NaOH
pH: 8.7
Evaluation: C

UDPglucose(aq)=UDPgalactose(aq)

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

Reference: 69FAN/FEI
Method: radioactivity and spectrophotometry
Buffer: glycine (0.12 mol dm^{-3})+NaOH
pH: 9.0
Evaluation: B

UDPglucose(aq)=UDPgalactose(aq)

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

Reference: 84DEY
Method: spectrophotometry
Buffer: glycine (0.1 mol dm^{-3})
pH: 9.5
Evaluation: C

α-D-galactose 1-phosphate(aq)=α-D-glucose 1-phosphate(aq)

$\frac{T}{K}$	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.

α-D-galactose 1-phosphate(aq)=α-D-glucose 1-phosphate(aq)

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

Reference: 54HAN/CRA
Method: paper chromatography
Buffer: acetate (0.005 mol dm^{-3})+cacodylate (0.005 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 Craine. The temperature of reaction was not stated and was assumed to be 298.15 K.

UDP-D-quinovose(aq)=UDP-D-fucose(aq)

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

Reference: 68SAL/NOR
Method: chromatography and spectrophotometry
Buffer: glycine (0.24 mol dm^{-3})+NaOH
pH: 8.7
Evaluation: C

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

L-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

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

Reference: 56DIC/WIL
Method: chromatography and spectrophotometry
Buffer: glycylglycine (0.06 mol dm^{-3})
pH: 7.6
Cofactor(s): $MgCl_2$ (0.01 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.

L-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

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

Reference: 57BUR/HOR
Method: enzymatic assay
Buffer: Tris (0.2 mol dm^{-3})
pH: 7.0
Evaluation: C

L-ribulose 5-phosphate(aq)=D-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 mol dm^{-3})
pH: 7.0
Evaluation: B

L-ribulose 5-phosphate(aq)=D-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 mol dm^{-3})
pH: 8.4
Evaluation: B

L-ribulose 5-phosphate(aq)=D-xylulose 5-phosphate(aq)

$\frac{T}{K}$	pH	K'
310.15	6.0	≈1.0

Reference: 62HOR
Method: radioactivity
Buffer: succinate (0.092 mol dm^{-3})+NaOH
pH: 6.0
Cofactor(s): $MgCl_2$ (0.013 mol dm^{-3})
Evaluation: C

4.10. Enzyme: UDParabinose 4-epimerase (EC 5.1.3.5)

UDP-L-arabinose(aq)=UDP-D-xylose(aq)

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

Reference: 60FEI/NEU
Method: electrophoresis and radioactivity
Buffer: Tris (0.08 mol dm^{-3})+HCl
pH: 7.5
Evaluation: B

UDP-L-arabinose(aq)=UDP-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 mol dm^{-3}) + NaOH
pH: 8.7
Evaluation: C

UDP-L-arabinose(aq)=UDP-D-xylose(aq)

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

Reference: 70FAN/FEI
Method: gas–liquid chromaography
Buffer: phosphate (0.075 mol dm^{-3})
pH: 8.0
Evaluation: B

4.11. Enzyme: UDPglucuronate 4-epimerase (EC 5.1.3.6)

UDP-D-glucuronate(aq)=DUP-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 mol dm^{-3}) + HCl
pH: 7.5
Evaluation: B

UDP-D-glucuronate(aq)=UDP-D-galacturonate(aq)

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

Reference: 74GAU/MAI
Method: radioactivity
Buffer: Tris (0.1 mol dm^{-3})+HCl
pH: 7.5
Evaluation: B

4.12. Enzyme: *N*-acylglucosamine 2-epimerase (EC 5.1.3.8)

N-acetyl-D-glucosamine(aq)=*N*-acetyl-D-mannosamine(aq)

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

Reference: 65GHO/ROS2
Method: radioactivity
Buffer: Tris (0.063 mol dm^{-3}) + HCl
pH: 7.6
Cofactor (s): ATP (0.025 mol dm^{-3}) and $MgCl_2$ (0.0125 mol dm^{-3})
Evaluation: C

4.13. Enzyme: *N*-acylglucosamine-6-phosphate 2-epimerase (EC 5.1.3.9)

N-acetyl-D-glucosamine 6-phosphate(aq)=
N-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 mol dm^{-3})
pH: 7.6
Evaluation: C

4.14. Enzyme: CDPabequose epimerase (EC 5.1.3.10)

CDP-3,6-dideoxy-D-glucose(aq)=CDP-3,6-dideoxy-D-mannose(aq)

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

Reference: 66MAT
Method: chromatography and radioactivity
Buffer: Tris (0.1 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)

α-D-glucose 6-phosphate(aq)=β-D-glucose 6-phosphate(aq)

$\frac{T}{K}$	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): $MgSO_4$ (0.008 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)

GDPmannose(aq)=GDP-L-galactose(aq)

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

Reference 82BAR/HEB
Buffer: Tris (0.04 mol dm^{-3}) + HCl
pH: 8.0
Evaluation: C

The apparent equilibrium consteant 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)

(*R*)-methylmalonyl-CoA(aq)=(*S*)-methylmalonyl-CoA(aq)

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

Reference 63ALL/KEL
Method: spectrophotometry
Buffer: Tris (0.05 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)

all-*trans*-retinal(aq)=11-*cis*-retinal(aq)

$\frac{T}{K}$	pH	K'
309.15	7.0	≈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)

9-*cis*, 12-*cis*-octadecadienoate(aq)=9-*cis*, 11-*trans*-octadecadienoate(aq)

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

Reference: 67KEP/TOV
Method: radioactivity
Buffer: phosphate (0.1 mol dm^{-3})
pH: 7.0
Evaluation: B

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

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

$\frac{T}{K}$	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 $\Delta_r H'^\circ$ (T=318 K, pH≈7)≈2 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 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 mol dm^{-3})+HCl
pH: 7.5
Evaluation: C

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

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

Reference: 69VEE/RAI
Method: spectrophotometry
Buffer: sodium phosphate (0.010 mol dm^{-3})
pH: 7.0
Evaluation: A

Veech *et al.* stated that the addition of Mg^{2+} (0.005 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 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 $\Delta_r H'^\circ$ ($\bar{T}$=255 K, pH=7) =47 kJ mol^{-1}.

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

T/K	pH	Salt	c(salt)/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_2SO_4	0.2	0.00055
293.15	7	$MgCl_2$	0.06	0.00035
293.15	7	$MgCl_2$	0.12	0.00035
293.15	7	$MgCl_2$	0.24	0.00035
273.15	7	$MgCl_2$	0.12	0.000071
293.15	7	$MgCl_2$	0.12	0.00029
333.15	7	$MgCl_2$	0.12	0.0012
273.15	7	$MgCl_2$	0.006	0.00014
293.15	7	$MgCl_2$	0.06	0.00037
293.15	7	$MgCl_2$	0.031	0.00031
293.15	7	$MgCl_2$	0.012	0.00051
293.15	7	$MgCl_2$	0.006	0.00064
293.15	7	$MgCl_2$	0.0025	0.0011
293.15	7	$MgCl_2$	0.0012	0.0014
313.15	7	$MgCl_2$	0.031	0.0014
313.15	7	$MgCl_2$	0.012	0.0020
313.15	7	$MgCl_2$	0.006	0.0025
313.15	7	$MgCl_2$	0.0012	0.0056
333.15	7	$MgCl_2$	0.031	0.0046
333.15	7	$MgCl_2$	0.012	0.0056
333.15	7	$MgCl_2$	0.006	0.0082
333.15	7	$MgCl_2$	0.0012	0.015

Reference: 35MEY
Method: spectrophotometry
pH: ≈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 $\Delta_r H'^\circ$ ($\bar{T}$=303 K, pH=7)=52 kJ mol^{-1}.

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

T/K	$\Delta_r H$(cal)/kJ mol^{-1}
293.15	58
313.15	64

Reference: 35MEY/LOH
Method: calorimetry
Buffer: phosphate
Evaluation: C

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

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

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): $MgCl_2$
Evaluation: B

Fructose-bisphosphate aldolase (EC 4.1.2.13) was also present. From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ (T=296 K, pH=9.0)≈55 kJ mol^{-1}.

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

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 $\Delta_r H'^\circ$ ($\bar{T}$=318 K, pH≈7)=50 kJ mol^{-1}.

4.21. Enzyme: erythrose isomerase (EC 5.3.1.2)

D-erythrose(aq)=D-erythrulose(aq)

T/K	pH	K'
308.15	5.8	2.3

Reference: 62UEH
Method: chemical analysis
Buffer: phosphate (0.04 mol dm^{-3})
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)

T/K	K'
310.15	≈0.18

Reference: 53COH
Method: spectrophotometry
Buffer: glyclglycine (0.1 mol dm^{-3})
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.

D-arabinose(aq)=D-ribulose(aq)

$\frac{T}{K}$	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 mol dm^{-3})
pH: 7.4
Cofactor (s): $Mg(NO_3)_2$ (≈0.013 mol dm^{-3})
Evaluation: A

From the temperature dependence of the apparent equilibrium constant Tewari and Goldberg calculated $\Delta_r H'°(T=332\ K, pH=7.4)=-20.9$ kJ mol^{-1}.

L-fucose(aq)=L-fuculose(aq)

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

Reference: 56GRE/COH
Method: chemical analysis
Buffer: phosphate (0.050 mol dm^{-3})
pH: 8.0
Evaluation: B

4.23. Enzyme: L-arabinose isomerase (EC 5.3.1.4)

L-arabinose(aq)=L-ribulose(aq)

$\frac{T}{K}$	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 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)

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

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

Reference: 64SAT/TSU
Method: polarimetry
Buffer: phosphate and barbital
pH: 7.6–7.7
Cofactor(s): $MgSO_4$
Evaluation: C

This is an approximate result.

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

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

Reference: 65ICH/HIR
Method: spectrophotometry
Buffer: phosphate
pH: 8.0
Cofactor(s): $CoSO_4$
Evaluation: B

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

D-glucose(aq)=D-glucose(aq)

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

Reference: 65TSU/SAT
Method: spectrophotometry
Buffer: ammonium (0.05 mol dm^{-3})
pH: 9.0
Cofactor(s): Mg^{2+}(0.001 mol dm^{-3}) and Co^{2+}(0.001 mol dm^{-3})
Evaluation: C

This is an approximate result calculated from percent conversion data.

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

$\frac{T}{K}$	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)

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 mol dm^{-3})
pH: 6.5
Cofactor(s): $CoCl_2$ (0.001 mol dm^{-3})
Evaluation: B

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

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 mol dm^{-3})
pH: 7.0
Cofactor(s): $MgSO_4$ (0.009 mol dm^{-3})
Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ (T=321 K, pH=7.0)=10.5 kJ mol^{-1}.

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

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 mol dm^{-3})
pH: 6.85
Cofactor(s): $MgSO_4$ (0.02 mol dm^{-3})+$CoCl_2$ (0.001 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)

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): Co^{2+} and Mg^{2+}
Evaluation: C

Few details were given in this study. From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ (T=302 K, pH=7.8)=8.7 kJ mol^{-1}.

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

T/K	pH	K'
323.15	7.0	1.03

Reference: 74FRA/LEE
Buffer: β-glycerophosphate (0.05 mol dm^{-3})
pH: 7.0
Cofactor(s): Mg^{2+} and Co^{2+}
Evaluation: C

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

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

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): Mg^{2+}
Evaluation: B

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

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

T/K	pH	K'
340.15	7.1	1.04
350.15	7.1	1.09
360.15	7.1	1.16

Reference: 74SCA/SHI
Buffer: phosphate (0.03 mol dm^{-3})
pH: 7.0–7.2
Cofactor(s): Mg^{2+} and 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)

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): $MgSO_4$ (0.005 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 $\Delta_r H'^\circ$ (T=323 K, pH=7.3)=4.9 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): Co^{2+} and Mg^{2+}
Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ ($\tilde{T}$=328 K, pH=7.0)=9.4 kJ mol^{-1}.

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): 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): $MgSO_4$ (0.003 mol dm^{-3})
Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ ($\tilde{T}$=331 K, pH=7.5)=7.1 kJ mol^{-1}.

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): Mg^{2+} and Co^{2+}
Evaluation: A

From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ ($\tilde{T}$=346 K, pH=7.0)=6.3 kJ mol^{-3}.

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^{-3}) and {Tris (0.050 mol dm^{-3})+HCl}
pH: 7.5
Cofactor(s): $MgSO_4$
Evaluation: A

Tewari and Goldberg used their combined equilibrium and calorimetric data to calculate K=0.869, $\Delta_r G^\circ$=0.35 kJ mol^{-1}, and $\Delta_r H^\circ$=2.78 kJ mol^{-1}, and $\Delta_r C_p^\circ$ =76 J K^{-1} 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	$\frac{\Delta_r H(\text{cal})}{\text{kJ mol}^{-1}}$
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): $MgSO_4$ and $CoCl_2$
Evaluation: A

D-glucose(aq)=D-fructose

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)

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^{-3}) and $CoCl_2$ (0.001 mol dm^{-3})
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. Oliver and du Toit also calculated $\Delta_r H'^\circ$ ($\bar{T}$=328 K, pH=7.0)=6.0 kJ mol^{-1} for the above reaction.

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

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 $\Delta_r H'^\circ$ ($\bar{T}$=318 K, pH=7.0)=2.4 kJ mol^{-1}.

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

T/K	pH	K'
333.15	7.5	1.08

Reference: 92DEM/ATT
Buffer: Tris (0.05 mol dm^{-3})+HCl
pH: 7.5
Cofactor(s): Co^{2+} (0.001 mol dm^{-3}) and Mg^{2+} (0.070 mol dm^{-3})
Evaluation: C

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

D-psicose(aq)=β-D-allose(aq)

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^{-3})
pH: 7.4
Evaluation: A

Tewari and Goldberg also calculated $\Delta_r H^\circ$ (T=298.15 K)=7.4 kJ mol^{-1} and $\Delta_r C_p^\circ$ ≈67 J K^{-1} mol^{-1} for the chemical reference reaction: D-psicose(aq)=β-D-allose(aq).

D-psicose(aq)=D-altrose(aq)

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)

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 mol dm^{-3})
pH: 7.0
Evaluation: C

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 mol dm^{-3})
pH: 7.5
Cofactor(s): $MgCl_2$ (0.0004 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 mol dm^{-3})
pH: 6.0
Cofactor(s): $MgCl_2$ (0.001 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: 82HSI/CHI
Method: liquid chromatography
Buffer: β-glycerophosphate (0.1 mol dm^{-3})
pH: 7.5
Cofactor(s): $MgSO_4$ (0.001 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 $\Delta_r H'^\circ$ (T=329 K, pH=7.5)=24 kJ mol^{-1}.

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 mol dm^{-3})
pH: 8.7
Cofactor(s): $MgSO_4$ (≈0.013 mol dm^{-3})
Evaluation: A

Tewari *et al.* used their combined equilibrium and calorimetric data to calculate K=0.170, $\Delta_r G^\circ$=4.39 kJ mol^{-1}, and $\Delta_r H^\circ$=16.1 kJ mol^{-1}, and $\Delta_r C_p^\circ$ ≈40 J K^{-1} mol^{-1} at T=298.15 K for the chemical reference reaction: D-xylose(aq)=D-xylulose(aq). This is the predominant reaction at neutral pHs.

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

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
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 (≈0.025 mol dm^{-3})
pH: 7.4
Cofactor(s): $MgSO_4$
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): $MgSO_4$ (0.01 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 $\Delta_r H'^\circ$ (T =330 K, pH=7.0)=20.2 kJ mol^{-1} for the above reaction.

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

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

$\frac{T}{K}$	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^{-3})
pH: 7.0
Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ ($\bar{T}$=292 K, pH=7.0)≈13 kJ mol^{-1}

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

$\frac{T}{K}$	pH	K'
310.15	7.0	≈0.59

Reference: 55DIC/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.

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

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

Reference: 56DIC/WIL
Method: chromatography and spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})
pH: 7.4
Evaluation: C

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

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

$\frac{T}{K}$	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

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

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

Reference: 58TAB/SRE
Method: enzymatic assay and spectrophotometry
Buffer: glycylglycine (0.056 mol dm^{-3})
pH: 7.5
Evaluation: B

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

D-ribose 5-phosphate(aq)=D=ribulose 5-phosphate

$\frac{T}{K}$	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^{-3})+HCl
pH: 7.5
Evaluation: B

From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ ($\bar{T}$=305 K, pH=7.5)≈33 kJ mol^{-1}

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

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

Reference: 63DOB/DEM
Method: spectrophotometry
Buffer: Tris (0.020 mol dm^{-3})+HCl
pH: 7.6
Evaluation: C

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

$\frac{T}{K}$	pH	$\frac{c(Mg^{2+})}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	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^{-3})
pH: 7.0
Cofactor(s): $MgCl_2$
Evaluation: A

D-ribose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

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

Reference: 88TEW/STE
Method: calorimetry
Buffer: Tris (0.1 mol dm^{-3})
pH: 8.52
Cofactor(s): $MgCl_2$ (0.00010 mol dm^{-3})
Evaluation: B

This is an approximate result.

4.26. Enzyme: mannose isomerase (EC 5.3.1.7)

D-lyxose(aq)=D-xylulose(aq)

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

Reference: 56PAL/DOU
Method: chemical analysis and spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})+HCl
Cofactor(s): $MgCl_2$ (0.01 mol dm^{-3})
Evaluation: C

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

D-mannose(aq)=D-fructose(aq)

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

Reference: 56PAL/DOU
Method: chemical analysis and spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})+HCl
Cofactor(s): $MgCl_2$ (0.01 mol dm^{-3})
Evaluation: C

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

D-mannose(aq)=D-fructose(aq)

$\frac{T}{K}$	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 mol dm^{-3})
pH: 7.0
Evaluation B

From the temperature dependence of the apparent equilibrium constant $\Delta_r H'^\circ$ ($\bar{T}$=321 K, pH=7.0) is approximately zero.

D-mannose(aq)=D-fructose(aq)

$\frac{T}{K}$	pH	K'
310.15	7.5	≈1.9

Reference: 70HEY/ELB
Method: spectrophotometry and chemical analysis
Buffer: Tris+maleate
pH: 7.5
Evaluation C

D-rhamnose(aq)=D-rhamnulose(aq)

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

Reference: 56PAL/DOU
Method: chemical analysis and spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})+HCl
pH: 7.4
Cofactor(s): $MgCl_2$ (0.01 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)

D mannose 6 phosphate(aq)=D fructose 6 phosphate(aq)

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

Reference 50SLE
Method: spectrophotometry
Buffer: barbital (0.05 mol dm^{-3})
pH: 7.4
Cofactor(s): $MgCl_2$ (0.07 mol dm^{-3})
Evaluation: B

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

D-mannose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

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

Reference: 58NOL/BRU
Method: spectrophotometry
Buffer: acetate
pH: 5.9
Evaluation: C

D-mannose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

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

Reference: 88TEW/STE
Method: calorimetry
Buffer: Tris (0.1 mol dm^{-3})
pH: 8.50
Cofactor(s): $MgCl_2$ (0.00010 mol dm^{-3})
Evaluation: A

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

D-mannose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

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

Reference: 88TEW/STE
Method: calorimetry
Buffer: Tris (0.1 mol dm^{-3})
pH: 8.50
Cofactor(s): $MgCl_2$ (0.00010 mol dm^{-3})
Evaluation: A

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

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

6-amino-D-glucose 6-phosphate(aq)=6-amino-D-fructose 6-phosphate(aq)

T/K	pH	K'
278.85	8.7	0.202

Reference: 91SEM/CLE
Method: NMR and spectrophotometry
Buffer: Ches (0.10 mol dm^{-3})
pH: 8.7
Evaluation: B

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	K'
303.15	7.4	0.45

Reference: 50SLE
Method: spectrophotometry
Buffer: barbital (0.05 mol dm^{-3})
pH: 7.4
Cofactor(s): $MgCl_2$ (0.07 mol dm^{-3})
Evaluation: B

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

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	K'
310.15	7.4	0.67

Reference: 53BOD
Method: spectrophotometry
Buffer: sodium acetate + diethyl barbiturate
pH: 7.4
Evaluation: B

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	K'
310.15	≈7.65	0.67

Reference: 56RAM/GIR
Method: chemical analysis
Buffer: barbital (0.02 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.

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	K'
310.15	7.5	0.67

Reference: 58NOL/BRU
Method: spectrophotometry
Buffer: barbital
pH: 7.5
Evaluation: C

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/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 mol dm^{-3})
pH: 8.0
Evaluation: A

From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'°(T=302$ K, pH=8.0)=9.7 kJ mol^{-1}.

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	I_c/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

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	K'
303.15	8.0	0.32

Reference: 66REI
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})+ acetate
pH: 8.0
Evaluation: C

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	K'
310.15	7.5	0.54

Reference: 67TAK/HIZ
Method: spectrophotometry
Buffer: Tris (0.040 mol dm^{-3})+HCl
pH: 7.5
Evaluation: C

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	I_c/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: spectrophotmetry
Buffer: Tris (0.050 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 $\Delta_t H'^\circ(T=298$ K, pH=8.5, $I_c=0.12$ mol $dm^{-3})=11.8$ kJ mol^{-1} and $\Delta_t C_p'^\circ \approx 59$ J K^{-1} mol^{-1}. Dysan and Noltmann also reported that the apparent equilibrium constant at $T=303.15$ K was independent of pH for $6.0 \leq pH \leq 10.0$.

D-glucose 6-phosphate(aq)=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 mol dm^{-3})+HCl
pH: 6.4
Cofactor(s): $MgSO_4$
Evaluation: B

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

T/K	pH	$c(MgCl_2)$/mol dm^{-3}	c(Tris)/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): $MgCl_2$
Evaluation: A

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

D-glucose 6-phosphate(aq) = D-fructose 6-phosphate(aq)

T/K	pH	$c(MgCl_2)$/mol dm^{-3}	c(Tris)/mol dm^{-3}	$\Delta_t H$(cal)/kJ mol^{-1}
298.15	8.7	0.0010	0.10	11.77
298.15	8.7	0.0010	0.30	11.69
298.15	8.7	0.0010	0.64	11.67
298.15	8.7	0.00010	0.10	11.65
298.15	8.7	0.0025	0.10	11.63
304.95	8.7	0.00010	0.10	11.82
310.15	8.7	0.00010	0.10	12.17
316.15	8.7	0.00010	0.10	12.42

Reference: 88TEW/STE
Method: calorimetry
Buffer: Tris
pH: 8.7
Cofactor(s): $MgCl_2$ (0.00010 mol dm^{-3})
Evaluation: A

Tewari *et al.* also calculated $\Delta_t H^\circ=11.7$ kJ mol^{-1} and $\Delta_t C_p^\circ=44$ J K^{-1} mol^{-1} at $T=298.15$ K and $I=0$ for the chemical reference reaction: D-glucose 6-phosphate^{2-}(aq) =D-fructose 6-phosphate^{2-}(aq).

D-glucose 6-phosphate(aq)=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 mol dm^{-3})+HCl
pH: 8.1
Evaluation: C

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

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

Reference: 90SAN/SIN
Method: enzymatic assay + spectrophotometry
Buffer: Tris (0.05 mol dm^{-3}) + HCl
pH: 8.6
Evaluation: C

D-glucose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

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

Reference: 91SEM/CLE
Method: NMR and spectrophotometry
Buffer: Ches (0.10 mol dm^{-3})
pH: 8.7
Evaluation: B

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

D-glucosamine 6-phosphate(aq) + $H_2O(1)$=D-fructose 6-phosphate(aq) +ammonia(aq)

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

Reference: 56LEL/CAR
Buffer: Tris (0.4 mol dm^{-3})
pH: 8.4
Evaluation: B

D-glucosamine 6-phosphate(aq) + $H_2O(1)$=D-fructose 6-phosphate(aq) +ammonia(aq)

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

Reference: 70BEN/FRI
Method: spectrophotometry
Buffer: Tris (0.050 mol dm^{-3})+HCl
pH: 8.5
Evaluation: B

4.30. Enzyme: glucuronate isomerase (EC 5.3.1.12)

D-galacturonate(aq)=D-tagaturonate(aq)

$\frac{T}{K}$	pH	Buffer	K'
310.15	8.0	phosphate	0.25
310.15	8.0	borate	≈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.*

D-glucuronate(aq)=D-fructuronate(aq)

$\frac{T}{K}$	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 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)

D-arabinose 5-phosphate(aq)=D-ribulose 5-phosphate(aq)

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

Reference: 60VOL
Method: spectrophotometry
Buffer: glycylglycine (0.0033 mol dm^{-3})
pH: 8.0
Evaluation: B

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

L-rhamnose(aq)=L-rhamnulose(aq)

$\frac{T}{K}$	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 K. Also see data given under EC 5.3.1.7.

L-rhamnose(aq)=L-rhamnulose(aq)

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

Reference: 63DOM/ZEC
Method: spectrophotometry
Buffer: Tris (0.0.063 mol dm^{-3})+HCl
pH: 8.5
Cofactor(s): $MnCl_2$ (0.0013 mol dm^{-3})
Evaluation: C

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

L-rhamnose(aq)=L-rhamnulose(aq)

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

Reference: 64TAK/SAW
Method: spectrophotometry
Buffer: Tris (0.01 mol dm^{-3})
pH: 7.6
Cofactor(s): $MnCl_2$ (0.01 mol dm^{-3})
Evaluation: B

L-rhamnose(aq)=L-rhamnulose(aq)

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

Reference: 66DOM/ZEC
Method: spectrophotometry
Buffer: Tris (0.1 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-lyxose ketol-isomerase (EC 5.3.1.15)

D-lyxose(aq)=D-xylulose(aq)

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

Reference: 65AND/ALL
Method: spectrophotometry
Buffer: sodium cacodylate (0.06 mol dm^{-3})
pH: 7.0
Cofactor(s): $MnCl_2$ (0.01 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-ribose(aq)=D-ribulose(aq)

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

Reference: 75IZU/REE
Buffer: Tris (0.025 mol dm^{-3})
pH: 7.5
Cofactor(s): $MnCl_2$ (0.0025 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-ribose(aq)=D-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 mol dm^{-3})
pH: 7.4
Cofactor(s): $Mg(NO_3)_2$ (≈0.013 mol dm^{-3})
Evaluation: A

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

D-ribose(aq)=D-ribulose(aq)

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

Reference: 85TEW/GOL2
Method: calorimetry
Buffer: phosphate
pH: 6.8–7.4
Cofactor(s): $MgSO_4$
Evaluation: A

4.35. Enzyme: L-mannose ketol-isomerase (EC 5.3.1.a)

L-mannose(aq)=L-fructose(aq)

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

Reference: 68MAY/AND
Method: spectrophotometry and polarimetry
Buffer: Tris (0.0217 mol dm^{-3}) + HCl
pH: 7.6
Cofactor(s): $CoCl_2$ (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)

D-arabino-3-hexulose 6-phosphate(aq)=D-fructose 6-phosphate(aq)

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

Reference: 74FER/STR
Method: enzymatic assay and spectrophotometry
Buffer: phosphate (0.050 mol dm^{-3})
pH: 7.0
Cofactor(s): $MgCl_2$ (0.001 mol dm^{-3})
Evaluation: B

This result was obtained from kinetic data.

4.37. Enzyme: phenylpyruvate tautomerase (EC 5.3.2.1)

keto-phenylpyruvate(aq)=*enol*-phenylpyruvate(aq)

$\frac{T}{K}$	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. Enxyme: oxaloacetate tautomerase (EC 5.3.2.2)

keto-oxaloacetate(aq)=*enol*-oxaloacetate(aq)

$\frac{T}{K}$	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)

isopentenyl diphosphate(aq)=dimethylallyl diphosphate(aq)

$\frac{T}{K}$	pH	K'
310.15	8.0	≈6.7

Reference: 65SHA/CLE
Method: radioactivity
Buffer: Tris (0.048 mol dm^{-3})+HCl
pH: 8.0
Cofactor(s): $MgCl_2$ (0.0048 mol dm^{-3})
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)

methylitaconate(aq)=dimethylmaleate(aq)

$\frac{T}{K}$	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)

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

$\frac{T}{K}$	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.

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

$\frac{T}{K}$	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.

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

$\frac{T}{K}$	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 mol dm^{-3})
pH: 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 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	≈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 mol dm^{-3})+HCl
pH: 7.0
Cofactor(s): $MgSO_4$ (0.0033 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 mol dm^{-3})
pH: 7.0
Evaluation: A

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

$\frac{T}{K}$	pH	Buffer	$\frac{c(MgCl_2)}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	K'
303.15	5.42	maleate (0.0333 mol dm^{-3})	0.0	0.065	8.65
303.15	6.20	imidazole (0.0333 mol dm^{-3})	0.0	0.065	10.02
303.15	6.45	imidazole (0.0333 mol dm^{-3})	0.0	0.065	10.50
303.15	6.66	Tris (0.0333 mol dm^{-3})	0.0	0.065	10.72
303.15	7.10	Tris (0.0333 mol dm^{-3})	0.0	0.065	11.40
303.15	7.50	Tris (0.0333 mol dm^{-3})	0.0	0.065	11.59
303.15	7.89	Tris (0.0333 mol dm^{-3})	0.0	0.065	11.65
303.15	6.97	Tris (0.0333 mol dm^{-3})	0.0	0.30	10.06
303.15	7.45	Tris (0.0333 mol dm^{-3})	0.0	0.30	10.45
303.15	7.89	Tris (0.0333 mol d^{-3})	0.0	0.30	11.10
303.15	7.01	Tris (0.0333 mol dm^{-3})	0.0	0.30	10.43
303.15	7.55	Tris (0.0333 mol dm^{-3})	0.0	0.30	10.84
303.15	7.80	Tris (0.0333 mol dm^{-3})	0.0	0.30	11.14
303.15	8.12	Tris (0.0333 mol dm^{-3})	0.0	0.30	11.47
293.15	6.22	imidazole (0.0333 mol dm^{-3})	0.0	0.065	9.81
293.15	7.24	Tris (0.0333 mol dm^{-3})	0.0	0.065	11.28
293.15	8.06	Tris (0.0333 mol dm^{-3})	0.0	0.065	11.74
303.15	7.40	Tris (0.0167 mol dm^{-3})	0.0453	0.085	11.11
303.15	7.40	Tris (0.0167 mol dm^{-3})	0.0453	0.059	11.64
303.15	7.40	Tris (0.0167 mol dm^{-3})	0.0453	0.046	11.30
303.15	7.40	Tris (0.0167 mol dm^{-3})	0.0333	0.038	11.36
303.15	7.40	Tris (0.0167 mol dm^{-3})	0.0333	0.032	11.31

Reference: 75CLA/BIR
Method: spectrophotometry
Buffer: sodium maleate; imidazole+HNO_3; and Tris+HCl
pH: 5.42–8.06
Cofactor(s): $MgCl_2$
Evaluation: A

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

$\frac{T}{K}$	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^{-3}+HCl)
pH: 4.6–7.2
Cofactor(s): $MgSO_4$ (0.0033 mol dm^{-3})
Evaluation: C

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

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

Reference: 76 HIL/ATT
Method: enzymatic assay and spectrophotometry
Buffer: imidazole (0.05 mol dm^{-3})+HCl
pH: 7.3
Cofactor(s): $MgCl_2$ (0.0018 mol dm^{-3})
Evaluation: B

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

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

$\frac{T}{K}$	pH	$\frac{c(Mg^{2+})}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	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^{-3})
pH: 6.48–6.86
Cofactor(s): $MgCl_2$
Evaluation: A

Guynn also calcualted $K=11.0$ at $T=311.15$ K and $I_c=0.25$ mol dm^{-3} for the chemical reference reaction: 2-phospho-D-glycerate^{3-}(aq) =3-phospho-D-glycerate^{3-}(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^{-3}. Guynn stated that there was no significant effect on the apparent equilibrium constant due either to variation of $c(Mg^{2+})$ over the range 0.0059 to 0.0142 mol dm^{-3} and/or to variation of the ionic strength over the range 0.06 to 1.0 mol dm^{-3}. 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)

D-glucosamine 6-phosphate(aq)=D-glucosamine 1-phosphate(aq)

$\frac{T}{K}$	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): $MgSO_4$ (0.0015 mol dm^{-3})
Evaluation: C

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

D-fructose 6-phosphate(aq)+α-D-glucose 1,6-diphosphate(aq)= α-D-glucose 6-phosphate(aq)+D-fructose 1,6-bisphosphate(aq)

$\frac{T}{K}$	pH	K'
311.15	7.0	≈12

Reference: 69PAS/LOW
Method: fluorimetry
Buffer: imidazole (0.05 mol dm^{-3})+HCl
pH: 7.0
Cofactor(s): $MgCl_2$ (0.001 mol dm^{-3})
Evaluation: B

α-D-glucose 1-phosphate(aq)=α-D-glucose 6-phosphate(aq)

$\frac{T}{K}$	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^{-3})
pH: 6.19–7.46
Cofactor(s): Mn^{2+}
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 $6.19 \leq pH \leq 7.46$. From the temperature dependence of the apparent equilibrium constant we calculate $\Delta_r H'^\circ$ ($T=303$ K, pH=7.5)≈−8 kJ mol^{-1}.

α-D-glucose 1-phosphate(aq)=α-D-glucose 6-phosphate(aq)

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

Reference: 59ATK/JOH
Method: enzymatic assay and spectrophotometry
Buffer: NaOH+HCl
pH: 7.0
Cofactor(s): $MgCl_2$ (0.025 mol dm^{-3})
Evaluation: B

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

α-D-glucose 1-phosphate(aq)=α-D-glucose 6-phosphate(aq)

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

Reference: 59MCC/NAJ
Method: enzymatic assay
Buffer: histidine (0.04 mol dm^{-3})
pH: 7.5
Cofactor(s): Mg^{2+}
Evaluation: C

α-D-glucose 1-phosphate(aq)=α-D-glucose 6-phosphate(aq)

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

Reference: 74GUY/VEL
Method: enzymatic assay and spectrophotmetry
Buffer: Tris+HCl
pH: 7.04
Cofactor(s): $MgCl_2$
Evaluation: A

α-D-glucose 1-phosphate(aq)=α-D-glucose 6-phosphate(aq)

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

Reference: 89GOL/TEW
Method: HPLC
Buffer: Tris (0.1 mol dm^{-3})+HCl
pH: 8.48
Evaluation: A

6-thioglucose 6-phosphate(aq)=6-thioglucose 1-phosphate(aq)

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

Reference: 91KNI/SEM
Method: NMR
Buffer: Taps (0.072 mol dm^{-3})
pH: 8.4
Cofactor(s): $MgCl_2$ (0.0072 mol dm^{-3})
Evaluation: C

4.43. Enzyme: phosphoacetylglucosamine mutase (EC 5.4.2.3)

N-acetyl-D-glucosamine 1-phosphate(aq)=
N-acetyl-D-glucosamine 6-phosphate(aq)

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

Reference: 56REI
Method: spectrophotometry
Buffer: Tris (0.033 mol dm^{-3})+acetate
pH: 7.7
Cofactor(s): $MgSO_4$ (0.0017 mol dm^{-3})
Evaluation: C

4.44. Enzyme: β-phosphoglucomutase (EC 5.4.2.6)

β-D-glucose 1-phosphate(aq)=β-D-glucose 6-phosphate(aq)

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

Reference: 61BEN/SCH
Method: enzymatic assay
Buffer: histidine (0.001 mol dm^{-3})
pH: 6.5
Cofactor(s): $MnCl_2$ (0.0008 mol dm^{-3})
Evaluation: B

β-D-glucose 1-phosphate(aq)=β-D-glucose 6-phosphate(aq)

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

Reference: 74BEL/MAR
Method: spectrophotometry
Buffer: Hepes (0.050 mol dm^{-3})
pH: 7.0
Cofactor(s): magnesium acetate (0.005 mol dm^{-3})
Evaluation: B

4.45. Enzyme: phosphopentomutase (EC 5.4.2.7)

D-ribose 1-phosphate(aq)=D-ribose 5-phosphate(aq)

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

Reference: 92KIM/KIN
Method: enzymatic assay
Buffer: Mops
pH: 7.0
Cofactor(s): Mg^{2+}
Evaluation A

4.46. Enzyme: phosphomannomutase (EC 5.4.2.8)

D-mannose 1-phosphate(aq)=D-mannose 6-phosphate(aq)

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

Reference: 76 MUR
Method: enzymatic assay and spectrophotometry
Buffer: Tris acetate (0.02 mol dm^{-3})
pH: 7.0
Cofactor(s): $MgCl_2$ (0.001 mol dm^{-3})
Evaluation: B

D-mannose 1-phosphate(aq)=D-mannose 6-phosphate(aq)

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

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

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

L-lysine(aq)=(3*S*)-3,6-diaminohexanoate(aq)

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

Reference: 70CHI/ZAP
Method: radioactivity
Buffer: Tris (0.025 mol dm^{-3})+HCl
pH: 7.8
Evaluation: B

L-lysine(aq)=(3*S*)-3,6-diaminohexanoate(aq)

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

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

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

D-ornithine(aq)=D-*threo*-2,4-diaminopentanoate(aq)

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

Reference: 73SOM/COS
Method: chromatography and radioactivity
Buffer: Tris (0.1 mol dm^{-3})
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)

L-*threo*-3-methylaspartate(aq)=L-glutamate(aq)

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

Reference: 64BAR/ROO
Method: spectrophotometry
Buffer: Tris (0.050 mol dm^{-3})+HCl
pH: 8.2
Cofactor(s): $CaCl_2$ (0.0005 mol dm^{-3})
Evaluation: C

Equilibrium was approached from only one direction.

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

(*R*)-methylmalonyl-CoA(aq)=succinyl-CoA(aq)

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

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

(*R*)-methylmalonyl-CoA(aq)-succinyl-CoA(aq)

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

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

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

2-methyleneglutarate(aq)=methylitaconate(aq)

$\frac{T}{K}$	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)

2,5-dihydro-5-oxofurna-2-acetate(aq)=*cis, cis*-hexadienedioate(aq)

$\frac{T}{K}$	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

(-)-4-carboxymethyl-Δ^{α}-but-2-en-4-olide(aq)=*cis, trans*-hexadienedioate(aq)

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

Reference: 54SIS/STA
Method: spectrophotometry
Buffer: Tris (0.00015 mol dm^{-3})
pH: 8.0
Cofactor(s): $MnCl_2$ (0.001 mol dm^{-3})
Evaluation: B

4.53. Enzyme: tetrahydroxypteridine cycloisomerase (EC 5.5.1.3)

tetrahydroxypteridine(aq)=xanthine-8-carboxylate(aq)

$\frac{T}{K}$	pH	K'
296.15	7.5	≈620

Reference: 64MCN/DAM
Method: radioactivity
Buffer: Tris (0.07 mol dm^{-3})+HCl
pH: 7.5
Evaluation: C

4.54. Enzyme: chalcone isomerase (EC 5.5.1.6)

2′,4,4′-trihydroxychalcone(aq)=(2*S*)-4′,7-dihydroxyflavanone(aq)

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

Reference: 88BED/HAD
Method: spectrophotometry
Buffer: Tris (0.050 mol dm^{-3})+HCl
pH: 7.6
Evaluation: B

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

ATP(aq)+L-valine(aq)+$tRNA^{Val}$(aq)=AMP(aq)+diphosphate(aq)
+L-valyl-$tRNA^{Val}$(aq)

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

Reference: 61BER/BER
Method: radioactivity and spectrophotometry
Buffer: sodium cacodylate (0.1 mol dm^{-3})
pH: 7.0
Cofactor(s): $MgCl_2$ (0.002 mol dm^{-3})
Evaluation: A

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

ATP(aq)+acetate(aq)+CoA(aq)=AMP(aq)+diphosphate(aq)
+acetyl-CoA(aq)

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

Reference: 53JON
Method: spectrophotometry and chemical analysis
Buffer: Tris (0.16 mol dm^{-3})
pH: 7.5
Cofactor(s): $MgCl_2$
Evaluation: B

ATP(aq)+acetate(aq)+CoA(aq)=AMP(aq)+diphosphate(aq)
+acetyl-CoA(aq)

$\frac{T}{K}$	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^{-3})
pH: 7.5–8.5
Cofactor(s): $MgCl_2$ (0.005 mol dm^{-3})
Evaluation: C

ATP(aq)+acetate(aq)+CoA(aq)=AMP(aq)+diphosphate(aq)+acetyl-CoA(aq)

T/K	pH	$c(Mg_{2+})$/mol dm^{-3}	I_c/mol dm^{-3}	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): $MgCl_2$
Evaluation: A

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

ATP(aq)+propanote(aq)+CoA(aq)=AMP(aq)+diphosphate(aq)+propanoyl-CoA(aq)

T/K	pH	K'
311.15	8.0	1.15

Reference: 54HEL
Method: enzymatic assay
Buffer: Tris (0.1 mol dm^{-3})
pH: 8.0
Cofactor(s): $MgCl_2$ (0.005 mol dm^{-3})
Evaluation: C

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

ATP(aq)+heptanoate(aq)+CoA(aq)=AMP(aq)+diphosphate(aq)+*n*-heptanoyl-CoA(aq)

T/K	pH	K'
311.15	8.0	1.11

Reference: 53MAH/WAK
Method: spectrophotometry
Buffer: glyclyglycine (0.002 mol dm^{-3})
pH: 8.0
Cofactor(s): $MgCl_2$
Evaluation: B

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

GTP(aq)+succinate(aq)+CoA(aq)=GDP(aq)+phosphate(aq)+succinyl-CoA(aq)

T/K	pH	$c(Mg^{2+})$/mol dm^{-3}	I_c/mol dm^{-3}	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^{-3})+acetic acid
pH: 6.75–7.30
Cofactor(s): $MgCl_2$
Evaluation: A

Lynn and Guynn calculated $K(T=298.15\ K, I_c=0.25\ mol\ dm^{-3})=3.02$ and $K(T=311.15\ K, I_c=0.25\ mol\ dm^{-3})=1.29$ for the chemical reference reaction: $GTP^{4-}(aq)+succinate^{2-}(aq)+CoA(aq)=GDP^{3-}(aq)+HPO_4^{2-}(aq)+succinyl\text{-}CoA^-(aq)$.

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

ATP(aq) + succinate(aq) + CoA(aq) = ADP(aq) + phosphate(aq) + succinyl-CoA(aq)

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

Reference: 55KAU/ALI
Method: spectrophotometry
Buffer: Tris (0.10 mol dm^{-3})+HCl
pH: 7.4
Cofactor(s): $MgCl_2$ (0.010 mol dm^{-3})
Evaluation: B

4.60 Enzyme: glutamate-ammonia ligase (EC 6.3.1.2)

ATP+L-glutamate(aq)+ammonia(aq)=ADP(aq)+phosphate(aq) +L-glutamine(aq)

$\frac{T}{K}$	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 mol dm^{-3}) or Tris (0.1 mol dm^{-3})
pH: 6.0–7.9
Cofactor(s): $MgCl_2$ or $MnCl_2$
Evaluation: A

ATP(aq)+L-glutamate(aq)+ammonia(aq)=ADP(aq)+phosphate(aq) +L-glutamine(aq)

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

Reference: 55VAR/WEB
Method: chromatography and radioactivity
Buffer: Tris (0.045 mol dm^{-3})
pH: 7.4
Cofactor(s): $MgSO_4$ (0.030 mol dm^{-3})
Evaluation: C

ATP(aq)+L-glutamate(aq)+ammonia(aq)=ADP(aq)+phosphate(aq) +L-glutamine(aq)

$\frac{T}{K}$	pH	$\frac{c(MgCl_2)}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	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 mol dm^{-3})
pH: 6.6–7.58
Cofactor(s): $MgCl_2$
Evaluation: A

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

ATP(aq)+formate(aq)+tetrahydrofolate(aq)=ADP(aq)+phosphate(aq) +10-formyltetrahydrofolate(aq)

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

Reference: 62HIM/RAB
Method: spectrophotometry
Buffer: triethanolamine (0.1 mol dm^{-3})
pH: 7.7
Cofactor(s): $MgCl_2$ (0.010 mol dm^{-3})
Evaluation: B

4.62 Enzyme: adenyloscuccinate synthase (EC 6.3.4.4)

GTP(aq)+IMP(aq)+L-aspartate(aq)= GDP(aq) + phosphate(aq) +adenylosuccinate(aq)

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

Reference: 58FRO
Method: spectrophotometry
Buffer: glycine (0.071 mol dm^{-3})
pH: 8.0
Cofactor (s): $MgSO_4$(0.018 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)

ATP(aq)+L-citrulline(aq)+L-aspartate(aq)=AMP(aq)+diphosphate(aq) +L-arginosuccinate(aq)

$\frac{T}{K}$	pH	$\frac{c(MgCl_2)}{mol\ dm^{-3}}$	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
3.11.15	7.79	0.0066	69.5

Reference: 60SCH/RAT
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})
pH: 5.90–7.79
Cofactor(s): $MgCl_2$ (0.0066 mol dm^{-3})
Evaluation: A

4.64. Enzyme: pyruvate carboxylase (EC 6.4.1.1)

ATP(aq)+pyruvate(aq) + carbon dioxide(aq)=ADP(aq) + phosphate(aq) + oxaloacetate(aq)

$\frac{T}{K}$	pH	Buffer	$c(MgCl_2)$ / mol dm^{-3}	$c(MnCl_2)$ / mol dm^{-3}	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^{-3}) and {Tris (0.010 mol dm^{-3})+HCl}
pH: 7.03–8.0
Cofactor(s): $MgCl_2$ and $MnCl_2$
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 $K(T=298.15\ K, I_c=0.1\ mol\ dm^{-3})=1.4E-6$ for the chemical reference reaction: $ATP^{4-}(aq)+pyruvate^{-}(aq)+HCO_3^{-}(aq)=ADP^{3-}(aq)+HPO_4^{2-}(aq)+oxaloacetate^{2-}(aq)+H^{+}(aq)$.

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

ATP(aq)+propanoyl-CoA(aq)+carbon dioxide(aq)=ADP(aq)+phosphate(aq)+(*S*)-methylmalonyl-CoA(aq)

$\frac{T}{K}$	pH	K'
310.15	8.15	0.0081

Reference: 62HAL/FEN
Method: spectrophotometry
Buffer: Tris (0.067 mol dm^{-3})
pH: 8.15
Cofactor(s): $MgCl_2$ (0.0025 mol dm^{-3})
Evaluation: B

ATP(aq)+propanoyl-CoA(aq)+carbon dioxide(aq)=ADP(aq)+phosphate(aq)+(*S*)-methylmalonyl-CoA(aq)

$\frac{T}{K}$	pH	K'
301.15	8.1	5.7

Reference: 65KAZ/GRO
Method: spectrophotometry and enzymatic assay
Buffer: Tris (0.1 mol dm^{-3})+HCl
pH: 8.1
Cofactor(s): $MgCl_2$ (0.06 mol dm^{-3})
Evaluation: C

Kaziro *et al.* used a calculated concentration of $HCO_3^{-}(aq)\approx0.029$ 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 $CO_2(aq)$, $HCO_3^{-}(aq)$, and $CO_3^{2-}(aq)$. 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 Commision Numbers

Substance	CAS Registry Number[a]	Enzyme Commission Numbers
acetate	64-19-7	6.2.1.1
acetyl-coenzyme A	102029-73-2	6.2.1.1
N-acetyl-D-glucosamine	7512-17-6	5.1.3.8
N-acetyl-D-glucosamine 1-phosphate	6866-69-9	5.4.2.3
N-acetyl-D-glucosamine 6-phosphate	102029-88-9	5.1.3.9, 5.4.2.3
N-acetyl-D-mannosamine	3615-17-6	5.1.3.8
N-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
β-D-allose	7283-09-2	5.3.1.5
D-altrose	1990-29-0	5.3.1.5
D-α-amino-*n*-butyrate	2623-91-8	5.1.1.10
L-α-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-Δ^{α}-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-diaminoheptanedioate	14289-34-0	5.1.1.7
meso-diaminoheptanedioate	922-54-3	5.1.1.7
(3*S*)-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-5-oxofuran-2-acetate	6666-46-2	5.5.1.1
(2*S*)-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	2466-09-3	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
α-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
α-D-glucose 1,6-diphosphate	91183-87-8	5.4.2.2
α-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[a]	Enzyme Commission Numbers
β-D-glucose 1-phosphate	32972-46-6	5.4.2.6
D-glucose 6-phosphate	56-73-5	5.3.1.9
α-D-glucose 6-phosphate	15209-11-7	5.4.2.2
β-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_2O	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-methyleneglutarate	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[a]	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′-trihydroxychalcone	961-29-5	5.5.1.6
$tRNA^{Val}$	[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-$tRNA^{Val}$	[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

[a]In some cases the CAS registry number refers to a salt of the substance.

[b]In the absence of a nucleic acid sequence, no CAS registry number is assigned to this substance.

6. Abbreviations

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

7. Glossary of Symbols

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

[a]When needed, a subscript c, m, or x is added to these quantities to designate a concentration, molality, or mole fraction basis.

[b]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.; **271**, 89 (1934).

35MEY/KIE Meyerhof, O.; Kiessling, W.; Biochem. Z.; **276**, 239 (1935).

35MEY/KIE2 Meyerhof, O.; Kiessling, W.; Biochem. Z.; **280**, 99 (1935).

35MEY Meyerhof, O.; Biochem. Z.; **277**, 77 (1935).

35MEY/LOH Meyerhof, O.; Lohmann, K.; Biochem. Z.; **275**, 430 (1935).

38MEY/SCH Meyerhof, O.; Schulz, W.; Biochem. Z.; **297**, 60 (1938).

41UTT/WER Utter, M. F.; Werkman, C. H.; J. Bacteriol.; **42**, 665 (1941).

42COL/SUT Colowick, S. P.; Sutherland, E. W.; J. Biol. Chem.; **144**, 423 (1942).

43MEY/JUN Meyerhof, O.; Junowicz-Kocholaty, R.; J. Biol. Chem.; **149**, 71 (1943).

47MEY/OES Meyerhof, O.; Oesper, P.; J. Biol. Chem.; **170**, 1 (1947).

49MEY/OES Meyerhof, O.; Oesper, P.; J. Biol. Chem.; **179**, 1371 (1949).

50OES/MEY Oesper, P.; Meyerhof, O.; Arch. Biochem. Biophys.; **27**, 223 (1950).

50SLE Slein, M. W.; J. Biol. Chem.; **186**, 753 (1950).

51WOO/GUN Wood, W. A.; Gunslaus, I. C.; J. Biol. Chem.; **190**, 403 (1951).

52LEL/CAR Leloir, L. F.; Cardini, C. E.; Cabib, E.; Ann. Asoc. Quim. Argent.; **40**, 228 (1952).

52NAR/WOO Narrod, S. A.; Wood, W. A.; Arch. Biochem. Biophys.; **35**, 462 (1952).

53BOD Bodansky, O.; J. Biol. Chem.; **202**, 829 (1953).

53BRO Brown, D. H.; J. Biol. Chem.; **204**, 877 (1953).

53COH Cohen, S. S.; J. Biol. Chem.; **201**, 71 (1953).

53HOC/WAT Hochster, R. M.; Watson, R. W.; J. Am. Chem. Soc.; **75**, 3284 (1953).

53JON Jones, M. E.; Fed. Proc., Fed. Am. Soc. Exp. Biol.; **12**, 708 (1953).

53MAH/WAK Mahler, H. R.; Wakil, S. J.; Bock, R. M.; J. Biol. Chem.; **204**, 453 (1953).

53MIT/LAM Mitsuhashi, S.; Lampen, J. O.; J. Biol. Chem.; **204**, 1011 (1953).

54AXE/JAN Axelrod, B.; Jang, R.; J. Biol. Chem.; **209**, 847 (1954).

54HAN/CRA Hansen, R. G.; Craine, E. M.; J. Biol. Chem.; **208**, 293 (1954).

54HEL Hele, P.; J. Biol. Chem.; **206**, 671 (1954).

54HOC/WAT Hochster, R. M.; Watson, R. W.; Arch. Biochem. Biophys.; **48**, 120 (1954).

54LEV/MEI Levintow, L; Meister, A.; J. Biol. Chem.; **209**, 265 (1954).

54MAR/WIL Marr, A. G.; Wilson, P. W.; Arch. Biochem. Biophys.; **49**, 474 (1954).

54SIS/STA Sistrom, W. R.; Stanier, R. Y.; J. Biol. Chem.; **210**, 821 (1954).

55DIC/WIL Dickens, F.; Williamson, D. H., Nature; **176**, 400 (1955).

55KAU/ALI Kaufman, S.; Alivisatos, S. G. A.; J. Biol. Chem.; **216**, 141 (1955).

55SLE Slein, M. W.; J. Am. Chem. Soc.; **77**, 1663 (1955).

55THO/GOM Thorne, C. B.; Gomez, C. G.; Housewright, R. D.; J. Bacteriol.; **69**, 357 (1955).

55VAR/WEB Varner, J. E.; Webster, G. C.; Plant Physiol.; **30**, 393 (1955).

56COW/PIZ Cowgill, R. W.; Pizer, L. I.; J. Biol. Chem.; **223**, 885 (1956).

56DIC/WIL Dickens, F.; Williamson, D. H.; Biochem. J.; **64**, 567 (1956).

56ENG Englesberg, E.; Fed. Proc., Fed. Am. Soc. Exp. Biol.; **15**, 586 (1956).

56GRE/COH Green, M.; Cohen, S. S.; J. Biol. Chem.; **219**, 557 (1956).

56HUB Hubbard, R.; J. Gen. Physiol.; **39**, 935 (1956).

56HUR/HOR Hurwitz, J.; Horecker, B. L.; J. Biol. Chem.; **223**, 993 (1956).

56LEL/CAR Leloir, L. F.; Cardini, C. E.; Biochim. Biophys. Acta; **20**, 33 (1956).

56PAL/DOU Palleroni, N. J.; Doudoroff, M.; J. Biol. Chem.; **218**, 535 (1956).

56RAM/GIR Ramasarma, T.; Giri, K. V.; Arch. Biochem. Biophys.; **62**, 91 (1956).

56REI Reissig, J. L.; J. Biol. Chem.; **219**, 753 (1956).

56STU/HOR Stumpf, P. K.; Horecker, B. L.; J. Biol. Chem.; **218**, 753 (1956).

57ASH/HIC Ashwell, G; Hickman, J.; J. Biol. Chem.; **226**, 65 (1957).

57BUR/HOR Burma, D. P.; Horecker, B. L.; Biochim. Biophys. Acta; **24**, 660 (1957).

57MAX Maxwell, E. S.; J. Biol. Chem.; **229**, 139 (1957).

57ROD/TOW Rodwell, V. M.; Towne, J. C.; Grisolia, S.; J. Biol. Chem.; **228**, 875 (1957).

58BRU/NOL Bruns, F. H.; Noltmann, E.; Vahlhaus, E.; Biochem. Z.; **330**, 483 (1958).

58BUR/HOR Burma, D. P.; Horecker, B. L.; J. Biol. Chem.; **231**, 1053 (1958).

58FRO Fromm, H. J.; Biochim. Biophys. Acta; **29**, 255 (1958).

58HEA/HOR Heath, E. C.; Horecker, B. L.; Smyrniotis, P. Z.; Takagi, Y. J. Biol. Chem.; **231**, 1031 (1958).

58NOL/BRU Noltman, E.; Bruns, F. H.; Biochem. Z.; **330**, 514 (1958).

58TAB/SRE Tabachnick, M.; Srere, P. A.; Cooper, J.; Racker, E.; Arch. Biochem. Biophys.; **74**, 315 (1958).

58WOL/SIM Wolin, M. J.; Simpson, F. J.; Wood, W. A.; J. Biol. Chem.; **232**, 559 (1958).

59ATK/JOH Atkinson, M. R.; Johnson, E.; Morton, R. K.; Nature; **184**, 1925 (1959).

59CHI/SUG Chiba, H; Sugimoto, E.; Bull. Agric. Chem. Soc. Jpn.; **23**, 207 (1959).

59ITO/GRI Ito, N.; Grisolia, S.; J. Biol. Chem.; **234**, 242 (1959).

59MCC/NAJ McCoy, E. E.; Najjar, V. A.; J. Biol. Chem.; **234**, 3017 (1959).

60AGO/ARA Agosin, M.; Aravena, L.; Enzymologia; **22**, 281 (1960).

60ASH/WAH Ashwell, G.; Wahba, A. J.; Hickman, J.; J. Biol. Chem.; **235**, 1559 (1960).

60FEI/NEU Feingold, D. S.; Neufeld, E. F.; Hassid, W. Z.; J. Biol. Chem.; **235**, 910 (1960).

60ICH/FUR Ichihara, A.; Furiya, S.; Suda, M.; J. Biochem. (Tokyo); **48**, 277 (1960).

60KAH/LOW Kahana, S. E.; Lowry, O. H.; Schulz, D. W.; Passoneau, J. V.; Crawford, E. J.; J. Biol. Chem.; **235**, 2178 (1960).

60SCH/RAT Schuegraf, A.; Ratner, S.; Warner, R. C.; J. Biol. Chem.; **235**, 3597 (1960).

60VOL Volk, W. A.; J. Biol. Chem.; **235**, 1550 (1960).

61ATK/JOH Atkinson, M. R.; Johnson, E.; Morton, R. K.; Biochem. J.; **79**, 12 (1961).

61BEN/SCH Ben-Zvi, R.; Schramm, M.; J. Biol. Chem.; **236**, 2186 (1961).

61BER/BER Berg, P.; Bergmann, F. H.; Ofengand, E. J.; Dieckmann, M.; J. Biol. Chem.; **236**, 1726 (1961).

61MAH Mahler, H. R.; in "Biochemist's Handbook;" C. Long, ed.; D. Van Nostrand Co., Princeton, New Jersey (1961), pp. 418–419.

62DOU Doudoroff, M.; Methods Enzymol.; **5**, 335 (1962).

62GRI Grisolia, S.; Methods Enzymol.; **5**, 236 (1962).

62HAL/FEN Halenz, D. R.; Feng, J.-Y.; Hegre, C. S.; Lane, M. D.; J. Biol. Chem.; **237**, 2140 (1962).

62HIM/RAB Himes, R. H.; Rabinowitz, J. C.; J. Biol. Chem.; **237**, 2903 (1962).

62HOR Horecker, B. L.; Methods Enzymol.; **5**, 253 (1962).

62UEH Uehara, K.; Methods Enzymol.; **5**, 350 (1962).

63ALL/KEL Allen, S. H. G.; Kellermeyer, R.; Stjernholm, R.; Wood, H. G.; J. Biol. Chem.; **238**, 1637 (1963).

63DOB/DEM Dobrogosz, W. J.; Demoss, R. D.; Biochim. Biophys. Acta; **77**, 629 (1963).

63DOM/ZEC Domagk, G. F.; Zech, R.; Biochem. Z.; **339**, 145 (1963).

63HIN/WOL Hines, M. C.; Wolfe, R. G.; Biochemistry; **2**, 770 (1963).

64ADA/NOR Adams, E.; Norton, I. L.; J. Biol. Chem.; **239**, 1525 (1964).

64BAR/ROO Barker, H. A.; Rooze, V.; Suzuki, F.; Iodice, A. A.; J. Biol. Chem.; **239**, 3260 (1964).

64IMA/MOR Imae, Y.; Morikawa, N.; Kurahashi, K.; J. Biochem. (Tokyo); **56**, 138 (1964).

64KEL/ALL Kellermeyer, R. W.; Allen, S. H. G.; Stjernholm, R.; Wood, H. G.; J. Biol. Chem.; **239**, 2562 (1964).

64LOW/PAS Lowry, O. H.; Passonneau, J. V.; J. Biol. Chem.; **239**, 31 (1964).

64MCN/DAM McNutt, W. S.; Damle, S. P.; J. Biol. Chem.; **239**, 4272 (1964).

64SAT/TSU Sato, T.; Tsumura, N.; J. Chem. Soc. Jpn.; **67**, 683 (1964).

64TAK/SAW Takagi, Y.; Sawada, H.; Biochim. Biophys. Acta; **92**, 10 (1964).

64WIL/HOG Wilson, D. B.; Hogness, D. S.; J. Biol. Chem.; **239**, 2469 (1964).

65AND/ALL Anderson, R. L.; Allison, D. P.; J. Biol. Chem.; **240**, 2367 (1965).

65ANN/KOS Annett, R. G.; Kosicki, G. W.; Can. J. Biochem.; **43**, 1887 (1965).

65CAN/FOC Cannata, J. J. B.; Focesi, A., Jr.; Mazumder, R.; Warner, R. C.; Ochoa, S.; J. Biol. Chem.; **240**, 3249 (1965).

65GHO/ROS Ghosh, S.; Roseman, S.; J. Biol. Chem.; **240**, 1525 (1965).

65GHO/ROS2 Ghosh, S.; Roseman, S.; J. Biol. Chem.; **240**, 1531 (1965).

65ICH/HIR Ichimura, M.; Hirose, Y.; Katsuya, N.; Yamada, K.; J. Agric. Chem. Soc. (Jpn.); **39**, 291 (1965).

65KAZ/GRO Kaziro, Y.; Grossman, A.; Ochoa, S.; J. Biol. Chem.; **240**, 64 (1965).

65SHA/CLE Shah, D. H.; Cleland, W. W.; Porter, J. W.; J. Biol. Chem.; **240**, 1946 (1965).

65TSU/SAT Tsumura, N.; Sato, T.; Agric. Biol. Chem.; **29**, 1129 (1965).

66MAT Matsuhashi, S.; J. Biol. Chem.; **241**, 4275 (1966).

66NAT Natake, M.; Agric. Biol. Chem.; **30**, 887 (1966).

66REI Reithel, F. J.; Methods Enzymol.; **9**, 565 (1966).

66WOO/DAV Wood, H. G.; Davis, J. J.; Lochmüller, H.; J. Biol. Chem.; **241**, 5692 (1966).

67DAN/YOS Danno, G.; Yoshimura, S.; Natake, M.; Agric. Biol. Chem.; **31**, 284 (1967).

67KEP/TOV Kepler, C.; Tove, S. B.; J. Biol. Chem.; **242**, 5686 (1967).

67SOD/OSU Soda, K.; Osumi, T.; Agric. Biol. Chem.; **31**, 1097 (1967).

67TAK Takasaki, Y.; Agric. Biol. Chem.; **31**, 309 (1967).

67TAK2 Takasaki, Y.; Agric. Biol. Chem.; **31**, 435 (1967).

67TAK/HIZ Takeda, Y.; Hizukuri, S.; Nikuni, Z.; Biochim. Biophys. Acta; **146**, 568 (1967).

68BUR/WAL Burton, P. M.; Waley, S. G.; Biochim. Biophys. Acta; **151**, 714 (1968).

68DYS/NOL Dyson, J. E. D.; Noltmann, E. A.; J. Biol. Chem.; **243**, 1401 (1968).

68MAY/AND Mayo, J. W.; Anderson, R. L.; J. Biol. Chem.; **243**, 6330 (1968).

68SAL/NOR Salo, W. L.; Nordin, J. H.; Peterson, D. R.; Bevill, J D.; Kirkwood, S.; Biochim. Biophys. Acta; **151**, 48 (1968).

69BLA/FRA Blasi, F.; Fragomele, F.; Covelli, I.; J. Biol. Chem **244**, 4864 (1969).

69FAN/FEI Fan, D.-F.; Feingold, D. S.; Plant Physiol.; **44**, 59 (1969).

69PAS/LOW Passonneau, J. V.; Lowry, O. H.; Schulz, D. W.; Brown J. G.; J. Biol. Chem.; **244**, 902 (1969).

69VEE/RAI Veech, R. L.; Raijman, L.; Dalziel, K.; Krebs, H. A. Biochem. J.; **115**, 837 (1969).

69WHI/LEJ White, P. J.; Lejeune, B.; Work, E.; Biochem. J.; **113**, 589 (1969).

70BEN/FRI Benson, R. L.; Friedman, S.; J. Biol. Chem.; **245**, 2219 (1970).

70CHI/ZAP Chirpich, T. P.; Zappia, V.; Costilow, R. N.; Barker, H. A.; J. Biol. Chem.; **245**, 1778 (1970).

70FAN/FEI Fan, D.-F.; Feingold, D. S.; Plant Physiol.; **44**, 592 (1970).

70HEY/ELB Hey-Ferguson, A.; Elbein, A. D.; J. Bacteriol.; **101**, 777 (1970).

70WUR/SCH Wurster, B.; Schneider, F.; Hoppe-Seyler's Z. Physiol. Chem.; **351**, 961 (1970).

71KUN/STA Kung, H.-F.; Stadtman, T. C.; J. Biol. Chem.; **246**, 3378 (1971).

72ROS/SLA Rosing, J.; Slater, E. C.; Biochim. Biophys. Acta; **267**, 275 (1972).

72WUR/HES Wurster, B.; Hess, B.; FEBS Lett.; **23**, 341 (1972).

73HAV/PIT Havewala, N. B.; Pitcher, W. H.; in "Enzyme Engineering," Vol. 4; E. K. Pye and L. B. Wingard, eds.; Plenum Press, New York (1973) pp. 315–328

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.

73SOM/COS Somack, R.; Costilow, R. N.; Biochemistry; **12**, 2597 (1973).

74BEL/MAR Belocopitow, E.; Marechal, L. R.; Eur. J. Biochem.; **46**, 631 (1974).

74CLA/BIR Clarke, J. B.; Birch, M.; Britton, H. G.; Biochem. J.; **139**, 491 (1974).

74FER/STR Ferenci, T.; Ström, T.; Quayle, J. R.; Biochem. J.; **144**, 477 (1974).

74FRA/LEE Fratzke, A. R.; Lee, Y. Y.; Tsao, G. T.; Ges Verfahrenstechnik und Chem./AICLE, Jt. Meeting; Vol. 4; Munich, Germany (1974).

74GAU/MAI Gaunt, M. A.; Maitra, E. S.; Ankel, H.; J. Biol. Chem.; **249**, 2366 (1974).

74GUY/VEL Guynn, R. W.; Veloso, D.; Lawson, J. W. R.; Veech, R. L.; Biochem. J.; **140**, 369 (1974).

74GUY/WEB Guynn, R. W.; Webster, L. T., Jr.; Veech, R. L.; J. Biol. Chem.; **249**, 3248 (1974).

74MCK McKay, G. A.; "Kinetics of the Isomerization of D-Glucose to D-Fructose;" Thesis, Illinois Institute of Technology (1974).

74SCA/SHI Scallet, B. L.; Shieh, K.; Ehrenthal, I.; Slapshak, L.; Die Stärke; **26**, 405 (1974).

75GRI/CAR Grisolia, S.; Carreras, J.; Methods Enzymol.; **42**, 435 (1975).

75IZU/REE Izumori, K.; Rees, A. W.; Elbein, A. D.; J. Biol. Chem.; **250**, 8085 (1975).

75KRI Krietsch, W. K. G.; Methods Enzymol.; **41**, 434 (1975).

76HIL/ATT Hill, B.; Attwood, M. M.; J. Gen. Microbiol.; **96**, 185 (1976).

76LLO/KHA Lloyd, N. E.; Khaleeluddin, K.; Cereal Chem.; **53**, 27 (1976).

76MUR Murata, T.; Plant Cell Physiol.; **17**, 1099 (1976).

76SPR/LIM Sproull, R. D.; Lim, H. C.; Schneider, D. R.; Biotechnol. Bioeng.; **18**, 633 (1976).

78LYN/GUY Lynn, R.; Guynn, R. W.; J. Biol. Chem.; **253**, 2546 (1978).

79MCK/TAV McKay, G. A.; Tavlarides, L. L.; J. Mol. Catal.; **6**, 57 (1979).

81GON/CHE Gong, C.-S.; Chen, L.-F.; Flickinger, M. C.; Chiang, L.-C.; Tsao, G. T.; Appl. Environ. Microbiol.; **41**, 430 (1981).

82BAR/HEB Barber, G. A.; Hebda, P. A.; Methods Enzymol.; **83**, 522 (1982).

82GUY Guynn, R. W.; Arch. Biochem. Biophys.; **218**, 14 (1982).

82HSI/CHI Hsiao, H.-Y.; Chiang, L.-C.; Chen, L.-F.; Tsao, G. T.; Enzyme Microb. Technol. **4**, 25 (1982).

83TIL van Tilburg, R.; "Engineering Aspects of Biocatalysts in Industrial Starch Conversion Technology;" Thesis, Delft University (1983).

84DEY Dey, P. M.; Phytochemistry; **23**, 729 (1984).

84LLO/CHA Lloyd, N. E.; Chan, Y. C.; personal communication (1984) cited in [84TEW/GOL].

84TEW/GOL Tewari, Y. B.; Goldberg, R. N.; J. Solution Chem.; **13**, 523 (1984).

84WAS/DAU Wasserman, S. A.; Daub, E.; Grisafi, P.; Botstein, D.; Walsh, C. T.; Biochemistry; **23**, 5182 (1984).

85MAK/KIE Makkee, M.; Kieboom, A. P. G.; van Bekkum, H.; Starch/Stärke; **37**, 232 (1985).

85TEW/GOL Tewari, Y. B.; Goldberg, R. N.; Appl. Biochem. Biotechnol.; **11**, 17 (1985).

85TEW/GOL2 Tewari, Y. B.; Goldberg, R. N.; Biophys. Chem.; **22**, 197 (1985).

85TEW/STE Tewari, Y. B.; Steckler, D. K.; Goldberg, R. N.; Biophys. Chem.; **22**, 181 (1985).

86CAS/VEE Casazza, J. P.; Veech, R. L.; J. Biol. Chem.; **261**, 690 (1986).

86OLI/TOI Oliver, S. P.; du Toit, P. J.; Biotechnol. Bioeng.; **28**, 684 (1986).

86POL/MEN Polishchuk, E. G.; Menyailova, I. I.; Nachapetyan, L. A.; Bioteknologiya; No. 5, pp. 79–82 (1986).

86TEW/GOL Tewari, Y. B.; Goldberg, R. N.; Biophys. Chem.; **24**, 291 (1986).

87MOS/FRE Moss, M.; Frey, P. A.; J. Biol. Chem.; **262**, 14859 (1987).

88BED/HAD Bednar, R. A.; Hadcock, J. R.; J. Biol. Chem.; **263**, 9582 (1988).

88LIM/RAI Lim, W. A.; Raines, R. T., Knowles, J. R.; Biochemistry; **27**, 1158 (1988).

88TEW/STE Tewari, Y. B.; Steckler, D. K.; Goldberg, R. N.; J. Biol. Chem.; **263**, 3664 (1988).

89GOL/TEW Goldberg, R. N.; Tewari, Y. B.; Ahluwalia, J. C.; J. Biol. Chem.; **264**, 9901 (1989).

89SAN/SIN Sangwan, R. S.; Singh, R.; J. Biosci.; 14, 47 (1989).

90SAN/SIN Sangwan, R. S.; Singh, R.; Indian J. Biochem. Biophys.; **27**, 23 (1990).

91KNI/SEM Knight, W. B.; Sem, D. S.; Smith, K.; Miziorko, H. M.; Rendina, A. R.; Cleland, W. W.; Biochemistry; **30**, 4970 (1991).

91SEM/CLE Sem, D. S.; Cleland, W. W.; Biochemistry; **30**, 4978 (1991).

92DEM/ATT Demerdash, M.; Attia, R. M.; Zentralbl. Mikobiol.; **147**, 297 (1992).

92KIM/KIN Kim, Y.-A.; King, M. T.; Teague, W. E., Jr.; Rufo, G. A., Jr.; Veech, R. L.; Passoneau, J. V.; Am. J. Physiol.; **262**, E344 (1992).

92XIA/XUE Xiang-ju, Gu; Xue-qin, S.; Yu-xiang, J.; Acta Botanica Sinica; **34**, 278 (1992).