Thermodynamics of Enzyme-Catalyzed Reactions: Part 1. Oxidoreductases

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Received August 27, 1992; revised manuscript received November 18, 1992

Equilibrium constants and enthalpy changes for reactions catalyzed by oxidoreductases 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. The thermodynamic conventions pertinent to the tabulation of equilibrium data are discussed. A distinction is made between those thermodynamic quantities which pertain to the overall biochemical reaction and those which pertain to a reference reaction that involves specific species. The data from 205 references have been examined and evaluated. Chemical Abstract Service Registry Numbers have been assigned to 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 participated.

Key words: chemical thermodynamics; enthalpies of reaction; enzyme-catalyzed reactions; equilibrium constants; evaluated data; oxidoreductases.

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1. Introduction

Thermodynamic data on enzyme-catalyzed reactions play an important role in the prediction of the extent of reaction and the position of equilibrium for any process in which these reactions occur. The importance of understanding the thermodynamics of these biochemical reactions was emphasized by Krebs and Kornberg in their monograph "A Survey of the Energy Transformations in Living Matter".[1] Their monograph also contains a useful appendix on Gibbs energy data of biological interest and a table on the thermodynamics of enzyme-catalyzed reactions. However, the amount of data available at that time was extremely limited. Reviews on various aspects of this subject have subsequently appeared.[2-10] Each of these reviews, however, has been limited in the extent of coverage given to this area and no comprehensive review exists. Thermodynamic information is also needed in biotechnology when one needs to optimize product yields and to calculate the energy requirements of a given reaction.

It is the aim of this review to provide a compilation of data on the thermodynamics of enzyme-catalyzed reactions, specifically those classified as oxidoreductases and corresponding to class 1 of the Nomenclature Committee of the International Union of Biochemistry.[11] The data presented herein is limited to direct equilibrium and calorimetric measurements performed on these reactions under *in vitro* conditions. This is the principal thermodynamic information that is needed to determine the position of equilibrium of a given reaction.

The following information is given for each entry in this review: 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. The absence of a piece of information indicates that it was not found in the paper cited.

2. Arrangement of Data

The primary ordering of the data is done in accord with the Enzyme Commission (EC) number assigned to the enzyme which has been used to catalyze the reaction studied. Here, we have followed the classification scheme recommended by the Nomenclature Committee of the International Union of Biochemistry as presented in "Enzyme Nomenclature".[11] If more than one enzyme was used to catalyze a reaction, the data is entered in the tables immediately following the enzyme used which occurs first in the numerical order established by the Enzyme Commission. A cross reference is also made in the tables under each of the individual enzymes which have been used in the study cited. When there is more than one reaction catalyzed by a given enzyme, the reactions listed under a given enzyme heading are ordered alphabetically according to the substrates involved in the reaction. Here, the substrates are ordered from left to right in the direction the reactions are written. If necessary, the ordering of the data for any given reaction is determined by the year in which the measurements were performed. If more than one set of measurements appeared in a given year, the entries are ordered by the last name(s) of the author(s).

While the above scheme is a useful way to order the thermodynamic data on enzyme-catalyzed reactions, one possible complication is that a given reaction can sometimes be catalyzed by more than one enzyme. Also, we have generally relied upon the author(s) of a given study for the identification of the enzyme. The user of these tables is therefore advised, when looking for data on a given reaction, to also look in these tables under those enzymes that catalyze reactions that are closely related to the one sought.

Section 8 contains a list of the substances in this review together with their Chemical Abstract Service (CAS) registry numbers. In some cases the CAS registry number refers to a salt of the substance. Cross references are also given to the Enzyme Commission numbers of the enzymes which have been used to catalyze the reactions in which the substances participate. Abbreviations are given in Sec. 9. Section 10 contains the references and the reference codes used in Sec. 7. The references are ordered chronologically.

3. Evaluation of Data

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. A similar rating system was used by Domalski, Evans, and Hearing in their review "Heat Capacities and Entropies of Organic Compounds in the Condensed Phase".[12]

The complete evaluation of the data contained in these tables would involve the adjustment of the results obtained for each reaction to a common standard state followed by thermochemical cycle calculations to determine how well the data for the various reactions fit together. The adjustment to a standard state generally requires thermodynamic data on hydrogen and metal ion binding to the substrates involved in the reaction as well as information on the activity coefficients of the species in the solution.[13] This is beyond the scope of this review. It is our belief that this complete evaluation would have great value in the organization and systematization of these data. However, such evaluations have been performed only for a limited set of biochemical substances and reactions (see Refs. 6, 9, and 10). These evaluations, which involved a solution of thermochemical networks, also included thermodynamic data on the condensed phases and, in some cases, electrochemical potentials. Thus, third law entropies and enthalpies of combustion, enthalpies of solution, solubilities, and activity coefficients were also included to make the necessary thermodynamic ties to the condensed phases.

It is highly desirable that equilibrium be approached from both directions in any equilibrium investigation. The failure of some investigators to do this is a serious oversight in the experimental work and is a primary source of systematic error in much of the "equilibrium" data reported in the literature. Another source of systematic error in many of these studies is sample impurity. As an example, Miller and Smith-Magowan[10] have pointed out that samples of nicotinamide-adenine dinucleotide (NAD) and nicotinamide-adenine dinucleotide phosphate (NADP) can also contain the respective α-isomers. Since, most enzymes are specific for the β-isomer, the presence of an unrecognized amount of the α-isomer can be a source of systematic error in equilibrium or calorimetric measurements. Occasionally, we have performed calculations on the data given in the papers or extracted values from figures in the papers. For example, we have sometimes been able to calculate an equilibrium constant where none has previously been calculated, e.g. if the investigator(s) have given results in terms of per cent conversion for a reaction of the type A = B.

4. Thermodynamic Conventions

There are two fundamentally different types of equilibrium constants given in these tables. This is illustrated by the following example for the hydrolysis of adenosine 5′-triphosphate (ATP) to adenosine 5′-diphosphate (ADP) and orthophosphate:

$$\mathrm{ATP(aq) + H_2O(l) = ADP(aq) + orthophosphate(aq).} \quad (1)$$

The apparent equilibrium constant for the overall biochemical reaction (1) is

$$K_c' = c(\mathrm{ADP})c(\mathrm{orthophosphate})/\{c(\mathrm{ATP})c^\circ\}. \quad (2)$$

The ATP, ADP, and orthophosphate each exist in several different ionized and metal bound forms: e.g. ATP^{4-}, $HATP^{3-}$, H_2ATP^{2-}, $MgATP^{2-}$, $MgHATP^{-}$, etc. Thus, ATP has often been denoted in the literature as ΣATP or as $(ATP)_{tot}$. When it is clear that one is dealing with total amounts of substances, it is not necessary to use either the Σ or "tot" and these designations can be dispensed with. This has been done throughout the tables of data in this review. In the above equation, c° is 1 mol dm^{-3}; it is included to make the apparent equilibrium constant dimensionless. The subscript c has been attached to the apparent equilibrium constant to indicate that it is based on the concentration (molarity) scale.

The apparent equilibrium constant can be used to calculate the standard transformed Gibbs energy of reaction $\Delta_r G'^\circ$ at specified conditions of temperature T, pressure p, ionic strength (I_m when the units are mol kg^{-1} and I_c when the units are mol dm^{-3}), pH, and pMg:

$$\Delta_r G'^\circ = -RT \ln K'. \quad (3)$$

The gas constant R is equal to 8.31451 J K^{-1} mol^{-1}. Either $\Delta_r G'^\circ$ or the apparent equilibrium constant K' can be used to determine the position of equilibrium of biochemical reactions.[14,15]

It is also possible to choose a reference reaction involving selected solute species:

$$ATP^{4-}(aq) + H_2O(l) = ADP^{3-}(aq) + HPO_4^{2-}(aq) + H^+(aq). \quad (4)$$

The equilibrium constant for this reference reaction is

$$K_c(\text{ref}) = c(ADP^{3-})c(HPO_4^{2-})c(H^+)/\{c(ATP^{4-})(c^\circ)^2\}. \quad (5)$$

Equations which relate these two different types of equilibrium constants have been derived.[16,17] To calculate the equilibrium constant K_c(ref) from the apparent equilibrium constant K_c', or *vice versa*, one needs the equilibrium constants for the binding of hydrogen and metal ions to ATP^{4-}, ADP^{3-}, and HPO_4^{2-}.

The standard or thermodynamic equilibrium constant for reaction (4) is written in terms of activities a:

$$K_c^\circ(\text{ref}) = a(ADP^{3-})a(HPO_4^{2-})a(H^+)/\{a(ATP^{4-})a(H_2O)\}. \quad (6)$$

The determination of K_c°(ref) requires either a knowledge of both K_c(ref) at a single ionic strength and of the appropriate ratio of activity coefficients or an extrapolation of values of K_c(ref), determined at several ionic strengths, to $I = 0$. The distinction between the equilibrium constant K_c(ref), as given in Eq. (5), and the apparent equilibrium constant K_c', as given in Eq. (2), will be maintained throughout this review. Where possible, we have also included calculated values of standard equilibrium constants which were given in the various papers examined.

To avoid confusion between these different types of equilibrium constants and to avoid ambiguity about whether specific species or sums of species are intended, ammonia, for example rather than NH_3 or NH_4^+, will be written when we mean total ammonia. The chemical formulas will be used when we mean one of these specific species. Other substances such as carbon dioxide (CO_2, HCO_3^-, and CO_3^{2-}), and orthophosphate ($H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}) will be treated in the same manner. Exceptions will be made for water which will always be written as H_2O and for gaseous hydrogen and oxygen which will be written as $H_2(g)$ and $O_2(g)$, respectively.

A similar situation exists for enthalpies of reaction. Thus, the standard transformed enthalpy change for a biochemical reaction (e.g. reaction (1) above) at specified conditions of temperature, pressure, pH, pMg, and ionic strength will be designated as $\Delta_r H'^\circ$ and the enthalpy change for a reference reaction (e.g. reaction (4) above) as $\Delta_r H^\circ$(ref). Enthalpy changes for a reference reaction which have been adjusted to a standard state will be designated as $\Delta_r H^\circ$(ref) at $I = 0$. The standard transformed enthalpy of reaction $\Delta_r H'^\circ$ can be calculated with the van't Hoff equation from apparent equilibrium constants which have been determined as a function of temperature. Unless indicated otherwise, we have assumed that $\Delta_r H'^\circ$ is independent of temperature (i.e. $\Delta_r C_p'^\circ = 0$) when performing this calculation. An enthalpy of reaction which has been determined calorimetrically will be designated as $\Delta_r H$(cal). To obtain either $\Delta_r H'^\circ$ or $\Delta_r H^\circ$(ref) from calorimetric data requires that corrections be made for heat effects due to possible changes in pH, pMg, ionic strength, and for the protonation of the buffer. In the case where the solutions are well buffered and the changes in pH, pMg, and ionic strength are small, the major correction is for the enthalpy of protonation of the buffer by any protons released (or absorbed) as a consequence of the reaction. Thus,

$$\Delta_r H'^\circ = \Delta_r H(\text{cal}) - \Delta_r N(H^+)\Delta_r H^\circ(\text{buff}) \quad (7)$$

where $\Delta_r N(H^+)$ is the change in the binding of H^+(aq) accompanying the biochemical reaction and $\Delta_r H^\circ$(buff) is the enthalpy of ionization of the buffer. Since this correction can be substantial, it will always be noted in these tables whether or not calorimetric results have been corrected for the enthalpy of protonation of the buffer. Unless indicated otherwise, we have relied upon the correction(s) made by the actual investigators. Enthalpies of reaction calculated from equilibrium constants measured at several temperatures require no such correction.

In this review, all units of energy are given in terms of the joule with conversions from results in calories based upon 1 cal = 4.184 J. The equilibrium and calorimetric results summarized in this review were all done at atmospheric pressure ($\approx$ 0.101325 MPa). The standard pressure for thermodynamic results is 0.1 MPa.

Occasionally, some investigators have calculated apparent equilibrium constants where the concentration of water was included. Thus, for the above example involving ATP hydrolysis, the apparent equilibrium constant might be written as

$$K' = c(\text{ADP})c(\text{orthophosphate})/\{c(\text{ATP})c(H_2O)\}. \quad (8)$$

Where this has been done, we have adjusted the reported values of K_c' to the usual convention represented by Eq. (2). At low solute concentrations, the concentration of water $c(H_2O)$ is 55.35 mol dm^{-3} at 298.15 K and 55.14 mol dm^{-3} at 310.15 K.

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. The conversion formulas relating these various measures of composition are summarized in Table 1. Thus, for the chemical reaction

$$A(aq) = B(aq) + C(aq), \quad (9)$$

TABLE 1. Conversion formulas involving the compositions of solutions

For the solutes ($i \geq 2$):		
$m_i = c_i(\rho - \sum_{i=2} c_i M_i)^{-1}$	$c_i = m_i\rho(1 + \sum_{i=2} m_i M_i)^{-1}$	
$m_i = x_i(M_1 x_1)^{-1}$	$x_i = m_i(M_1^{-1} + \sum_{i=2} m_i)^{-1}$	
$c_i = x_i\rho(\sum_{i=1} M_i x_i)^{-1}$	$x_i = c_i[(\rho - \sum_{i=2} c_i M_i)M_1^{-1} + \sum_{i=2} c_i]^{-1}$	
For the solvent:		
$m_1 = M_1^{-1}$	$c_1 = (\rho - \sum_{i=2} c_i M_i)M_1^{-1}$	$x_1 = 1 - \sum_{i=2} x_i$
As the amounts of the solute substances approach zero, the following limits apply for the measures of composition of the solutes:		
$m_i = c_i\rho^{-1} = x_i M_1^{-1}$	$c_i = m_i\rho^* = x_i\rho^* M_1^{-1}$	$x_i = m_i M_1 = c_i M_1/\rho^*$
The limits for the measures of composition of the solvent are:		
$m_1 = M_1^{-1}$	$c_1 = \rho^* M_1^{-1}$	$x_1 = 1$
symbol	*name*	*units*
c	concentration (molarity)	mol dm^{-3}
m	molality	mol (kg solvent)$^{-1}$
x	mole fraction	1
M	molar mass	kg mol^{-1}
ρ	mass density	mol dm^{-3}
subscript		
i	denotes any of several possible solutes	
1	denotes solvent	
2, 3,...	denote solutes	
superscript		
*	pure solvent	

$K_c = c(\mathrm{B})c(\mathrm{C})/\{c(\mathrm{A})c^\circ\}$, $K_m = m(\mathrm{B})m(\mathrm{C})/\{m(\mathrm{A})m^\circ\}$,

and $K_x = x(\mathrm{B})x(\mathrm{C})/x(\mathrm{A})$. Here, m and x are, respectively, molality and mole fraction and $m^\circ = 1$ mol kg^{-1}. The equilibrium constant expressed in terms of mole fractions is automatically dimensionless. The conversion formulas given in Table 1 can be used to adjust equilibrium constants given on any of the measures of composition in that table to any of the others. In this review, the various types of equilibrium constants for unsymmetrical reactions are denoted by their appropriate subscripts; no subscript is needed for a symmetrical reaction. When necessary, results have been adjusted to units of mol dm^{-3} to obtain the numerical value(s) of K_c given in these tables.

The density of the solution enters into the conversion of equilibrium constants which have been determined on a concentration basis, namely K_c to K_m, or K_c to K_x. This causes a slight complication in the calculation of the enthalpy of reaction from the derivative of K_c with respect to temperature since the derivative of the density of the solution with respect to temperature enters into this calculation. Fortunately, this is a small effect that can be neglected except for the most precise and accurate data. Also, this is not a problem for symmetrical reactions where the equilibrium constants are the same for any standard concentration. Enthalpies of reaction calculated from the temperature derivatives of equilibrium constants which are on a molality or mole fraction basis are identical to calorimetrically determined enthalpies of reaction which have been corrected for the enthalpy of buffer protonation.

Alcohol dehydrogenase (EC 1.1.1.1) catalyzes the NAD/NADH coupled conversion of ethanol to acetaldehyde:

$$\mathrm{NAD(aq)} + \mathrm{ethanol(aq)} = \mathrm{NADH(aq)} + \mathrm{acetaldehyde(aq)}. \quad (10)$$

The apparent equilibrium constant for the overall biochemical reaction (9) is

$$K' = c(\mathrm{NADH})c(\mathrm{acetaldehyde})/\{c(\mathrm{NAD})c(\mathrm{ethanol})\}. \quad (11)$$

The reference reaction corresponding to reaction (9) is:

$$\mathrm{NAD^-(aq) + ethanol(aq) = NADH^{2-}(aq) + acetaldehyde(aq) + H^+(aq).} \quad (12)$$

The equilibrium constant for this reference reaction is:

$$K_c(\mathrm{ref}) = c(\mathrm{NADH^{2-}})c(\mathrm{acetaldehyde})c(\mathrm{H^+})/\{c(\mathrm{NAD^-})c(\mathrm{ethanol})c^\circ\}. \quad (13)$$

In some cases, however, investigators have written:

$$\mathrm{NAD(aq) + ethanol(aq) = NADH(aq) + acetaldehyde(aq) + H^+(aq).} \quad (14)$$

This is neither a chemical reference reaction nor an (overall) biochemical reaction. It is an incorrect representation because it implies that exactly one hydrogen ion was produced in the reaction. This may not always be the situation. Secondly, the equation is not electrically balanced (it would only appear to be balanced if one were to write NAD^+ instead of NAD). In papers where this reaction has been written as in Eq. (14), the investigators have often given the quantity $[c(\mathrm{NADH})c(\mathrm{acetaldehyde})c(\mathrm{H^+})/\{c(\mathrm{NAD})c(\mathrm{ethanol})c^\circ\}]$ which is equal to $[K'c(\mathrm{H^+})/c^\circ]$. Since this quantity is not an apparent equilibrium constant, the standard transformed Gibbs energy of reaction should not be calculated from it. Thus, when investigators have given numerical values of the apparent equilibrium constant K_c' according to Eq. (11), we have included the results in these tables. However, when the only result reported is $K'c(\mathrm{H^+})/c^\circ$, it is also given in these tables along with the pH range over which the measurements were performed. However, we have rewritten the reaction and, when possible, calculated the apparent equilibrium constant in accord with Eq. (10). The oxidized form of nicotinamide-adenine dinucleotide, which is generally written as NAD^+ in the literature, does not have an electrical charge of +1 and, for this reason, a superscript + has not been attached to the NAD. The charges attached to the NAD and NADH in reaction (12) are those that would be expected for the predominant ionic forms at pH = 7. The assignment of these charges is based upon an examination of the structures of these substances and a knowledge of the acidity constants of the reactants and products (see below).

The quantity $K'c(\mathrm{H^+})/c^\circ$ has frequently been found to be independent of pH. The reason for this is that NAD has a pK of 3.88,[18,19] NADH a pK of 4.46,[19] and the ethanol and acetaldehyde are not ionized unless placed in extremely alkaline solutions. Thus, at neutral pH, the predominant species in aqueous solution are NAD^-, $NADH^{2-}$, ethanol^0, and acetaldehyde^0. These same species should also be predominant for $5 < \mathrm{pH} < 10$. Because of this, the quantity $[c(\mathrm{NADH})c(\mathrm{acetaldehyde})c(\mathrm{H^+})/\{c(\mathrm{NAD})c(\mathrm{ethanol})c^\circ\}] = [K'c(\mathrm{H^+})/c^\circ]$ is very nearly equal to $K_c(\mathrm{ref})$. The situation for NADP/NADPH coupled reactions is similar to that for NAD/NADH reactions. The only difference is that NADP also has a pK at 6.1[20] due to the ionization of the phosphate group attached at the 2′-hydroxyl position in the adenosine. On the basis of structure, one would expect the pK′s for the ionization of this phosphate group to be nearly equal for both NADP and NADPH. Thus, the statements made above regarding the thermodynamics of NAD/NADH coupled reactions should also be true for NADP/NADPH coupled reactions.

The review of Miller and Smith-Magowan[10] contains a discussion of some thermodynamic pathways to the standard Gibbs energy and enthalpy changes for the following reactions:

$$\mathrm{NAD^-(aq) + H_2(g) = NADH^{2-}(aq) + H^+(aq)} \quad (15)$$

$$\mathrm{NADP^{3-}(aq) + H_2(g) = NADPH^{4-}(aq) + H^+(aq).} \quad (16)$$

For reaction (15) at $T = 298.15$ K and $I_m = 0.1$ mol kg^{-1}, Miller and Smith-Magowan[10] give $\Delta_r G^\circ = 20.0$ kJ mol^{-1} and $\Delta_r H^\circ = -32.1$ kJ mol^{-1}. For reaction (16) at $T = 298.15$ K and $I_m = 0.1$ mol kg^{-1}, they[10] give $\Delta_r G^\circ = 21.1$ kJ mol^{-1} and $\Delta_r H^\circ = -26.7$ kJ mol^{-1}. Here, we have rewritten the corresponding equations in Miller and Smith-Magowan's Table 7 in accordance with the preceding discussion concerning the notation for NAD and NADP type species. For additional information related to the thermodynamics of these two important reactions, the reader is also referred to the study by Burton[21] and the review by Rekharsky *et al.*[22]

5. Acknowledgments

We acknowledge helpful discussions with Drs. Robert A. Alberty and Stanley L. Miller on the thermodynamics of biochemical reactions. We thank Amira Birnstein for her advice on the use of Chemical Abstracts.

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7. Table of Equilibrium Constants and Enthalpies of Reaction

7.1. Enzyme: alcohol dehydrogenase (EC 1.1.1.1)

benzyl alcohol(aq) + NAD(aq) = benzaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	9.8E−4
298.15	8.0	3.1E−3
298.15	8.5	9.8E−3
298.15	9.0	3.1E−2
298.15	9.5	9.8E−2

Reference: 80COO/BLA
Method: spectrophotometry
pH: 7.5 − 9.5
Evaluation: C

Cook *et al.* report $K'c(H^+)/c^\circ$ = 3.1E−11. The pH was probably in the range 7.5 to 9.5. The apparent equilibrium constants given above were calculated from this result. Also see 88MAC/FEW under EC 1.1.1.90.

1-butanol(aq) + NAD(aq) = butanal(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.3	1.8E−3

Reference: 68ERI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.01 mol dm^{-3})
pH: 8.2 − 8.4
Evaluation: B

Eriksson reports $K'c(H^+)/c^\circ$ = 9.1E−12. This is approximately equal to K° for the reference reaction: 1-butanol(aq) + NAD^-(aq) = butanal(aq) + $NADH^{2-}$(aq) + H^+(aq). The apparent equilibrium constant given above was calculated from this result.

1-butanol(aq) + NAD(aq) = butanal(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	8.8	59.4

Reference: 83BRA
Method: calorimetry
Buffer: Tris and glycylglycine
pH: 8.8
Evaluation: A

Brattlie carried out this reaction in two different buffers and with semicarbazide added to the reaction mixture. The result given above is the average of the results which have been corrected for the enthalpy of reaction of the acetaldehyde with the semicarbazide and for the enthalpies of protonation of the buffers.

cyclohexanol(aq) + NAD(aq) = cyclohexanone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.2	0.090
298.15	7.5	0.158
298.15	9.5	19.

Reference: 59MER/TOM
Method: spectrophotometry
Buffer: phosphate (0.001 mol dm^{-3})
pH: 7.2 − 9.5
Evaluation: C

Merritt and Tomkins report $K'c(H^+)$ as a function of pH. The apparent equilibrium constants given above were calculated from these results. The temperature is assumed to be 298.15 K.

cyclohexanol(aq) + NAD(aq) = cyclohexanone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	0.20

Reference: 80COO/BLA
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 8.0
Evaluation: B

Cook *et al.* report $K'c(H^+)/c^\circ$ = 2.0E−9 at pH = 8.0. The apparent equilibrium constant given above was calculated from this result.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.4	1.3E−5
298.15	7.0	5.3E−5
298.15	7.7	1.3E−4

Reference: 36EUL/ADL
Method: spectrophotometry
Buffer: phosphate
pH: 6.4 − 7.7
Evaluation: C

The temperature is assumed to be 298.15 K.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.05	6.0E−6
298.15	7.25	7.7E−5
298.15	8.0	1.2E−5

Reference: 37ADL/SRE
Method: spectrophotometry
pH: 6.05 − 8.0
Evaluation: D

The temperature was ambient and is assumed to be 298.15 K. Adler and Sreenivasaya did not state what the buffer was.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
293.15	7.9	7.41E−4

Reference: 37NEG/WUL
Method: spectrophotometry
Buffer: phosphate
pH: 7.9
Evaluation: C

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.30	2.6E−5
298.15	6.85	8.8E−5
298.15	7.15	1.9E−4
298.15	7.34	3.0E−4
298.15	7.61	5.1E−4
298.15	7.77	8.0E−4
298.15	8.17	2.2E−3

Reference: 38SCH/HEL
Method: spectrophotometry
pH: 6.30 − 8.17
Evaluation: C

The temperature is assumed to be 298.15 K.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	3.64E−4
298.15	8.0	1.15E−3
298.15	8.5	3.64E−3
298.15	9.0	1.15E−2
298.15	9.5	3.64E−2

Reference: 50RAC
Method: spectrophotometry
Buffer: pyrophosphate (0.01 mol dm^{-3})
pH: 7.4 − 9.5
Evaluation: B

Racker reports $K'c(H^+)/c^\circ$ = 1.15E−11 over the pH range 7.4 to 9.5. The apparent equilibrium constants given above were calculated from this result.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
293.15	7.0	1.1E−4
293.15	8.0	7.1E−4
293.15	9.0	1.05E−2
293.15	10.0	9.0E−2

Reference: 51THE/BON
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3}) and {glycine (0.10 mol dm^{-3}) + NaOH}
pH: 7.0 − 10.0
Evaluation: B

The apparent equilibrium constants given above were calculated from Theorell and Bonnichsen's results (given in their Tables 2, 3, 4, and 5) for $K'c(H^+)$ and the measured pH. We give above only those results obtained at low concentrations of alcohol dehydrogenase.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	7.00	1.6E−4
303.15	8.00	1.6E−3

Reference: 56KAP/CIO
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3})
pH: 6.51 − 8.07
Evaluation: C

Kaplan *et al.* report $K'c(H^+)/c^\circ$ = 1.6E−11 over the pH range 6.51 to 8.07. The apparent equilibrium constants given above were calculated from this result.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{c(NaCl)}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	K'
293.15	7.0	0.0	0.1	7.95E−5
293.15	8.0	0.0	0.1	8.40E−4
293.15	9.0	0.0	0.1	8.07E−3
293.15	10.0	0.0	0.1	7.95E−2
293.15	7.0	0.0	0.050	7.36E−5
293.15	7.0	0.0	0.096	8.07E−5
293.15	7.0	0.0	0.189	9.27E−5
293.15	7.0	0.0	0.259	9.25E−5
293.15	7.0	0.167	0.376	9.97E−5
293.15	7.0	0.333	0.423	1.047E−4
293.15	7.0	0.667	0.749	1.184E−4
288.15	7.0	0.0	0.1	6.46E−5
293.15	7.0	0.0	0.1	8.00E−5
298.15	7.0	0.0	0.1	9.77E−5
303.15	7.0	0.0	0.1	1.202E−4
308.15	7.0	0.0	0.1	1.445E−4
288.15	8.0	0.0	0.1	6.42E−4
293.15	8.0	0.0	0.1	7.95E−4
298.15	8.0	0.0	0.1	9.66E−4
303.15	8.0	0.0	0.1	1.175E−3
308.15	8.0	0.0	0.1	1.413E−3
288.15	9.0	0.0	0.1	6.35E−3
293.15	9.0	0.0	0.1	7.94E−3
298.15	9.0	0.0	0.1	9.72E−3
303.15	9.0	0.0	0.1	1.200E−2
308.15	9.0	0.0	0.1	1.454E−2

Reference: 58BAC
Method: spectrophotometry
Buffer: phosphate
pH: 7.0 – 10.0
Evaluation: A

The apparent equilibrium constants given above were calculated from the results for $K'c(H^+)$ reported by Backlin. The reference reaction is: ethanol(aq) + NAD^-(aq) = acetaldehyde(aq) + $NADH^{2-}$(aq) + H^+(aq). K(ref) is essentially equal to $K'c(H^+)$ over the pH range of the experiments in this study. From the results above, we calculate $\Delta_r G'^\circ$ = 22.9 kJ mol^{-1} at T = 298.15 K, pH = 7, and I = 0.1 mol dm^{-3}. Extrapolation of the results obtained at 293.15 K to I_c = 0, leads to K°(ref) = 5.96E−12. At 298.15 K, K°(ref) = 7.32E−12 and $\Delta_r G^\circ$(ref) = 63.6 kJ mol^{-1}. From the temperature dependence of the equilibrium constants we calculate $\Delta_r H'^\circ$ = 29.8 kJ mol^{-1} at pH = 7 and I_c = 0.1 mol dm^{-3}. We also have $\Delta_r H^\circ$(ref) = 29.8 kJ mol^{-1} at I_c = 0.1 mol dm^{-3}. Backlin gives a good comparison of his and earlier results from the literature.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
283.75	7.691	1.44E−4
283.75	7.680	1.28E−4
283.75	7.673	1.19E−4
290.50	7.658	1.87E−4
290.50	7.646	1.74E−4
293.40	7.635	2.13E−4
307.75	7.605	5.42E−4
307.75	7.584	4.87E−4
307.75	7.571	4.38E−4
315.95	7.568	7.34E−4
315.95	7.545	6.80E−4
315.95	7.528	6.63E−4

Reference: 74BUR
Method: spectrophotometry
Buffer: phosphate (0.005 mol dm^{-3})
pH: 7.52 – 7.69
Evaluation: A

The apparent equilibrium constants given above were calculated from Burton's Table 2. From these results we calculate $\Delta_r H'^\circ$ = 39.6 kJ mol^{-1} for the above reaction at pH = 7.6. Burton also reports the unpublished calorimetric results of M. Schott and J. M. Sturtevant for the reaction NAD(aq) + H_2(g) = NADH(aq).

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K'
311.15	7.0	0.25	1.94E−4

Reference: 79COR/CRO
Method: spectrophotometry
pH: 7.0
Evaluation: B

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.0	2.9E−3

Reference: 80COO/BLA
Method: spectrophotometry
Buffer: 2-(*N*-cycolohexylamino)ethanesulfonic acid (0.1 mol dm^{-3})
pH: 9.0
Evaluation: C

Cook *et al.* report $K'c(H^+)/c^\circ$ = 2.9E−12 at pH = 9.0. The apparent equilibrium constant given above was calculated from this result.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
310.15	7.3	3.7E−4

Reference: 83CRA/BOS
Method: spectrophotometry
Buffer: potassium phosphate (0.090 mol dm^{-3}) + KCl (0.040 mol dm^{-3})
pH: 7.3
Evaluation: C

From kinetic results, Crabb *et al.* found that $1.50E-11 < \{K'c(H^+)/c^\circ\} < 2.18E-11$. The result for K' was calculated from this result.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.4	2.4E−4

Reference: 87BED/TES
Method: spectrophotometry
Buffer: sodium phosphate (0.10 mol dm^{-3})
pH: 7.4
Evaluation: C

The result was obtained from the analysis of kinetic data.

ethanol(aq) + NAD(aq) = acetaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	8.9	49.8

Reference: 83BRA
Method: calorimetry
Buffer: Tris, TAPS, Bicine, and glycylglycine
pH: 8.8− 9.0
Evaluation: A

Brattlie carried out this reaction in four different buffers and with semicarbazide added to the reaction mixture. The result given above is the average of the results which have been corrected for the enthalpy of reaction of the acetaldehyde with the semicarbazide and for the enthalpies of protonation of the buffers.

ethanol(aq) + AP-NAD(aq) = acetaldehyde(aq) + AP-NADH(aq)

$\frac{T}{K}$	pH	K'
303.	15	7.00	0.03
303.	15	8.00	0.3

Reference: 56KAP/CIO
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3})
pH: 6.51− 8.07
Evaluation: C

AP-NAD and AP-NADH are, respectively, 3-acetylpyridine adenine dinucleotide and its reduced form. Kaplan *et al.* report $K'c(H^+)/c^\circ = 3.0E-9$ over the pH range 6.51 to 8.07. The apparent equilibrium constants given above were calculated from this result.

ethanol(aq) + desamino NAD(aq) = acetaldehyde(aq) + desamino NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.39	9.1E−6
298.15	6.60	3.0E−5
298.15	6.85	5.1E−5
298.15	7.18	1.5E−4
298.15	7.31	2.3E−4
298.15	7.69	5.6E−4
298.15	8.06	1.1E−3

Reference: 38SCH/HEL
Method: spectrophotometry
pH: 6.39− 8.06
Evaluation: C

The temperature is assumed to be 298.15 K. Also see 38SCH/EUL.

1-hexanol(aq) + NAD(aq) = hexanal(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.3	2.87E−3

Reference: 68ERI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.01 mol dm^{-3})
pH: 8.2−8.4
Evaluation: B

Eriksson reports $K'c(H^+)/c^\circ = 1.44E-11$. This is approximately equal to K for the reference reaction: 1-hexanol(aq) + NAD^-(aq) = hexanal(aq) + $NADH^{2-}$(aq) + H^+(aq). The apparent equilibrium constant given above was calculated from this result.

cis-3-hexen-1-ol(aq) + NAD(aq) = *cis*-3-hexenal(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.3	7.2E−4

Reference: 68ERI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.01 mol dm^{-3})
pH: 8.2−8.4
Evaluation: B

Eriksson reports $K'c(H^+)/c^\circ$ = 3.6E−12. This is approximately equal to K° for the reference reaction: *cis*-3-hexan-1-ol(aq) + NAD^-(aq) = *cis*-3-hexenal(aq) + $NADH^{2-}$(aq) + H^+(aq). The apparent equilibrium constant given above was calculated from this result. The position of equilibrium was approached from only one direction.

trans-2-hexen-1-ol(aq) + NAD(aq) = *trans*-2-hexenal(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.3	0.283

Reference: 68ERI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.01 mol dm^{-3})
pH: 8.2−8.4
Evaluation: B

Eriksson reports $K'c(H^+)/c^\circ$ = 1.42E−9. This is approximately equal to K° for the reference reaction: *trans*-2-hexen-1-ol(aq) + NAD^-(aq) = *trans*-2-hexanal(aq) + $NADH^{2-}$(aq) + H^+(aq). The apparent equilibrium constant given above was calculated from this result.

1-nonanol(aq) + NAD(aq) = nonanal(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.3	3.05E−2

Reference: 68ERI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.01 mol dm^{-3})
pH: 8.2−8.4
Evaluation: B

Eriksson reports $K'c(H^+)/c^\circ$ = 1.53E−10. This is approximately equal to K° for the reference reaction: 1-nonanol(aq) + NAD^-(aq) = nonanal(aq) + $NADH^{2-}$(aq) + H^+(aq). The apparent equilibrium constant given above was calculated from this result.

1-octanol(aq) + NAD(aq) = octanal(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.3	1.1E−3

Reference: 68ERI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.01 mol dm^{-3})
pH: 8.2−8.4
Evaluation: B

Eriksson reports $K'c(H^+)/c^\circ$ = 5.3E−12. This is approximately K° for the reference reaction: 1-octanol(aq) + NAD^-(aq) = octanal(aq) + $NADH^{2-}$(aq) + H^+(aq). The apparent equilibrium constant given above was calculated from this result.

1-propanol(aq) + NAD(aq) = propanal(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	8.8	47.7

Reference: 83BRA
Method: calorimetry
Buffer: Tris, TAPS, and glycylglycine
pH: 8.8
Evaluation: A

Brattlie carried out this reaction in three different buffers and with semicarbazide added to the reaction mixture. The result given above is the average of the results which have been corrected for the enthalpy of reaction of the acetaldehyde with the semicarbazide and for the enthalpies of protonation of the buffers.

2-propanol(aq) + NAD(aq) = acetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	7.3E−2

Reference: 52BUR
pH: 7.0
Evaluation: B

Burton reports $K'c(H^+)/c^\circ$ = 7.3E−9 at pH = 7.0 in this preliminary communication. The apparent equilibrium constant given above was calculated from this result. See 53BUR/WIL.

2-propanol(aq) + NAD(aq) = acetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.78	4.36
298.15	8.83	4.71
298.15	8.82	5.32
298.15	8.71	5.76
298.15	8.82	5.91
298.15	7.51	0.223
298.15	7.51	0.238
298.15	7.56	0.268
298.15	7.52	0.263
298.15	7.52	0.282
298.15	7.68	0.328
298.15	7.68	0.330
298.15	7.64	0.291
298.15	7.64	0.308
298.15	7.63	0.251
298.15	7.63	0.270
298.15	7.52	0.225
298.15	7.52	0.230
298.15	7.68	0.361
298.15	7.68	0.337
298.15	7.28	0.136
298.15	7.28	0.136
298.15	7.28	0.134
298.15	7.30	0.129
298.15	7.03	0.0758
298.15	7.18	0.109

Reference: 53BUR/WIL
Method: spectrophotometry
Buffer: pyrophosphate (0.0055 mol dm^{-3})
pH: 7.03 – 8.83
Evaluation: A

The apparent equilibrium constants given above were calculated from Burton and Wilson's Table 1. Burton and Wilson found a mean result of $K'c(H^+)/c^\circ$ = 7.19E – 9. Thus, for the reference reaction: 2-propanol(aq) + NAD^-(aq) = acetone(aq) + $NADH^{2-}$(aq) + H^+(aq), K(ref) = 7.19E – 9. A preliminary communication of this study was given in 52BUR.

2-propanol(aq) + NAD(aq) = acetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
282.45	7.650	0.131
282.55	7.621	0.128
282.65	7.621	0.131
285.55	7.653	0.157
285.65	7.653	0.162
285.85	7.653	0.158
286.10	7.663	0.171
298.75	7.581	0.318
309.95	7.548	0.498
310.15	7.552	0.549
310.35	7.547	0.516
311.35	7.546	0.556
313.75	7.516	0.591
314.85	7.565	0.713

Reference: 74BUR
Method: spectrophotometry
Buffer: phosphate (0.005 mol dm^{-3})
pH: 7.51 – 7.65
Evaluation: A

The apparent equilibrium constants given above were calculated from Burton's Table 1. Several of these results are averages of those given in this table (one result at T = 298.75 K was discarded). From these results we calculate $\Delta_r H'^\circ$ = 36.5 kJ mol^{-1} for the above reaction at pH = 7.6.

2-propanol(aq) + NAD(aq) = acetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	0.53

Reference: 80COO/BLA
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 8.0
Evaluation: B

Cook *et al.* report $K'c(H^+)/c^\circ$ = 5.3E – 9 at pH = 8.0. The apparent equilibrium constant given above was calculated from this result.

2-propanol(aq) + NAD(aq) = acetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	8.9	44.2

Reference: 83BRA
Method: calorimetry
Buffer: phosphate (0.255 mol dm^{-3})
pH: 8.9
Evaluation: A

The result given above has been corrected for the enthalpy of protonation of the phosphate buffer.

vitamin A alcohol(aq) + NAD(aq) = vitamin A aldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
310.15	7.0	0.033
310.15	8.0	0.33
310.15	9.0	3.3

Reference: 51BLI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.015 mol dm^{-3})
pH: 6.6–9.5
Evaluation: C

Bliss reports $K'c(H^+)/c^\circ$ = 3.3E−9 over the pH range 6.6 to 9.5. The apparent equilibrium constants given above were calculated from this result. It was also found that a plot of log K' versus pH was linear. Thus, for the reference reaction: vitamin A alcohol(aq) + NAD^-(aq) = vitamin A aldehyde(aq) + $NADH^{2-}$(aq) + H^+(aq), K(ref) ≈ 3.3E−9.

7.2. Enzyme: homoserine dehydrogenase (EC 1.1.1.3)

L-homoserine(aq) + NAD(aq) = L-aspartate 4-semialdehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.9	8.8E−3

Reference: 55BLA/WRI3
Method: spectrophotometry
Buffer: Tris + HCl
pH: 7.9
Evaluation: C

The apparent equilibrium constant given above was calculated from Black and Wright's Table IV. The temperature was assumed to be 298.15 K. The position of equilibrium was approached from only one direction.

L-homoserine(aq) + NADP(aq) = L-aspartate 4-semialdehyde(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.9	6.3E−4

Reference: 55BLA/WRI3
Method: spectrophotometry
Buffer: Tris + HCl
pH: 7.9
Evaluation: C

The apparent equilibrium constant given above was calculated from Black and Wright's Table IV. The temperature was assumed to be 298.15 K. The position of equilibrium was approached from only one direction.

7.3. Enzyme: (*R,R*)-butanediol dehydrogenase (EC 1.1.1.4)

(*R,R*)-2,3-butanediol(aq) + NAD(aq) = (*R*)-acetoin(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
300.15	7.4	7.23E−3
300.15	8.4	6.68E−2

Reference: 54STR/HAR
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3}) and Tris (0.05 mol dm^{-3})
pH: 7.4–8.4
Evaluation: B

Stecker and Harary report $K'c(H^+)$ at pH = 7.4 and pH = 8.4. The apparent equilibrium constants given above were calculated from these results.

7.4. Enzyme: glycerol dehydrogenase (EC 1.1.1.6)

glycerol(aq) + NAD(aq) = dihydroxyacetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.1	6.4E−5

Reference: 55BUR2
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.1 mol dm^{-3})
pH: 7.1
Evaluation: C

Burton reports $K'c(H^+)/c^\circ$ = 5.1E−12. This is an approximate result, with few details given about the equilibrium measurement. The temperature is assumed to be 298.15 K. The apparent equilibrium constant given above was calculated from this result.

glycerol(aq) + NAD(aq) = dihydroxyacetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.0	1.4E−2

Reference: 69BAR
Method: spectrophotometry
Buffer: sodium carbonate (0.5 mol dm^{-3})
pH: 9.0
Evaluation: C

Barrett reports $K'c(H^+)/c^\circ$ = 1.4E−11. The apparent equilibrium constant given above was calculated from this result.

glycerol(aq) + NAD(aq) = dihydroxyacetone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
300.15	5.30	4.75E−7
300.15	6.00	2.38E−6
300.15	6.50	7.53E−6
300.15	7.00	2.38E−5
300.15	7.50	7.53E−5
300.15	8.00	2.38E−4
300.15	8.25	4.23E−4

Reference: 74MCG/PHI
Method: spectrophotometry
Buffer: 2-(*N*-morpholino)ethane sulfonic acid (0.05 mol dm^{-3}); *N*-tris(hydroxymethyl)methyl-2-aminopropanesulfonic acid (0.05 mol dm^{-3}); tris(hydroxymethyl)methylaminopropanesulfonic acid (0.05 mol dm^{-3}).
pH: 5.30−8.25
Evaluation: C

McGregor *et al.* report $K'c(H^+)/c^\circ = (2.38 \pm 0.58)E-12$ for 5.30 < pH < 8.25. The apparent equilibrium constants were calculated from this result.

7.5. Enzyme: glycerol-3-phosphate dehydrogenase (NAD^+) (EC 1.1.1.8)

sn-glycerol 3-phosphate(aq) + NAD(aq) = dihydroxyacetone phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.9	1.6E−5
298.15	7.6	3.0E−4
298.15	8.1	5.9E−4

Reference: 37EUL/ADL2
Method: spectrophotometry
Buffer: phosphate
pH: 6.9−8.1
Evaluation: C

The temperature is assumed to be 298.15 K.

sn-glycerol 3-phosphate(aq) + NAD(aq) = dihydroxyacetone phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	7.0	7.1E−5

Reference: 49BAR
Method: spectrophotometry
Buffer: phosphate (0.067 mol dm^{-3})
pH: 7.0
Evaluation: C

This is an approximate result.

sn-glycerol 3-phosphate(aq) + NAD(aq) = dihydroxyacetone phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	1.74E−4
298.15	8.0	5.5E−4
298.15	8.5	1.74E−3
298.15	9.0	5.5E−3

Reference: 53BUR/WIL
Method: spectrophotometry
Buffer: veronal and pyrophosphate (0.003 mol dm^{-3})
pH: 7.5−9.2
Evaluation: B

Burton and Wilson report $K'c(H^+)/c^\circ = 5.5E-12$ at $I_c \approx 0.03$ mol dm^{-3}. The apparent equilibrium constants given above were calculated from this result. Burton and Wilson refer to *sn*-glycerol 3-phosphate as "L-glycerol 1-phosphate". However, it is clear from the contents of their paper that this substance is *sn*-glycerol 3-phosphate.

sn-glycerol 3-phosphate + NAD(aq) = dihydroxyacetone phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
282.95	7.0	9.62E−5
294.58	7.0	7.15E−5
295.26	7.0	6.64E−5
297.65	7.0	5.80E−5
298.28	7.0	5.59E−5
301.06	7.0	5.34E−5
309.70	7.0	3.07E−5

Reference: 58YOU/PAC
Method: spectrophotometry
Buffer: phosphate (0.2 mol dm^{-3})
pH: 6.85−7.24
Evaluation: B

The apparent equilibrium constants given above were calculated from the results given in Young and Pace's Fig. 9 with the exception of one result at T = 297.65 K. From the temperature dependency of K' we calculate $\Delta H'^\circ \approx -30$ kJ mol^{-1} at pH = 7.0.

7.6. Enzyme: D-xylulose reductase (EC 1.1.1.9)

allitol(aq) + NAD(aq) = D-psicose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	1.44E−4
298.15	8.00	1.44E−3

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 6.95 − 8.79
Cofactor(s): $MgCl_2$ (0.008 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 1.44E−11 over the pH range 6.95 to 8.79. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K.

D-glycero-D-glucoheptitol(aq) + NAD(aq) = D-sedoheptulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	5.54E−4
298.15	8.00	5.54E−3

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 6.95 − 8.79
Cofactor(s): $MgCl_2$ (0.008 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 5.54E−11 over the pH range 6.95 to 8.79. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K.

L-iditol(aq) + NAD(aq) = L-sorbose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	4.23E−3
298.15	8.00	4.23E−2

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 6.95 − 8.79
Cofactor(s): $MgCl_2$ (0.008 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 4.23E−10 over the pH range 6.95 to 8.79. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K.

ribitol(aq) + NAD(aq) = D-ribulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	1.75E−4
298.15	8.00	1.75E−3

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 6.95 − 8.79
Cofactor(s): $MgCl_2$ (0.008 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 1.75E−11 over the pH range 6.95 to 8.79. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K. Also see listings under EC 1.1.1.14 and EC 1.1.1.56.

D-sorbitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	4.19E−3
298.15	8.00	4.19E−2

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 6.95 − 8.79
Cofactor(s): $MgCl_2$ (0.008 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 4.19E−10 over the pH range 6.95 to 8.79. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K. Also see listings under EC 1.1.1.14.

L-threitol(aq) + NAD(aq) = L-erythrulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	6.91E−5
298.15	8.00	6.91E−4

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 6.95 − 8.79
Cofactor(s): $MgCl_2$ (0.008 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 6.91E−12 over the pH range 6.95 to 8.79. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K.

xylitol(aq) + NAD(aq) = D-xylulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	4.18E−4
298.15	8.0	4.18E−3

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 6.95−8.79
Cofactor(s): $MgCl_2$ (0.0080 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 4.18E−11 over the pH range 6.95 to 8.79. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K. Also see listings under EC 1.1.1.14.

xylitol(aq) + NAD(aq) = D-xylulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.5	6.0E−2

Reference: 81SUG/VEI
Method: spectrophotometry
Buffer: glycine (0.030 mol dm^{-3}) + NaOH
pH: 9.5
Evaluation: C

Sugai and Veiga report $K'c(H^+)/c^\circ$ = 1.9E−11 for pH = 9.5. The apparent equilibrium constant was calculated from this result.

xylitol(aq) + NAD(aq) = D-xylulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	4.3E−4

Reference: 84DIT/KUB2
Method: spectrophotometry
Buffer: Tris (0.025 mol dm^{-3}) + HCl
pH: 7.0
Cofactor(s): $MgCl_2$ (0.0005 mol dm^{-3})
Evaluation: C

Ditzelmüller *et al.* report 2.7E−11 < $\{K'c(H^+)/c^\circ\}$ < 5.8E−11 at pH = 7.0. The apparent equilibrium constant was calculated from this result. The temperature is assumed to be 298.15 K.

xylitol(aq) + NAD(aq) = D-xylulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	6.9E−4

Reference: 89RIZ/HAR
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3}) + HCl
pH: 7.0
Cofactor(s): $MgCl_2$ (0.05 mol dm^{-3})
Evaluation: C

Rizzi *et al.* also obtained K' = 6.9E−4 at pH = 7.0 from kinetic data. The temperature is assumed to be 298.15 K.

7.7. Enzyme: L-xylulose reductase (EC 1.1.1.10)

xylitol(aq) + NADP(aq) = L-xylulose(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	8.58E−4
298.15	8.00	8.58E−3

Reference: 57HOL/TOU
Method: spectrophotometry
Buffer: Tris (0.5 mol dm^{-3})
pH: 6.95−8.70
Cofactor(s): $MgCl_2$ (0.08 mol dm^{-3})
Evaluation: B

Hollmann and Touster report $K'c(H^+)/c^\circ$ = 8.58E−11 over the pH range 6.95 to 8.70. The apparent equilibrium constants given above were calculated from this result. The temperature is assumed to be 298.15 K. Also see entry under EC 1.1.1.21.

xylitol(aq) + NADP(aq) = L-xylulose(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	2.97E−4
298.15	8.00	2.97E−3
298.15	8.24	5.16E−3

Reference: 59HOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 7.0−8.24
Cofactor(s): $MgCl_2$ (0.008 mol dm^{-3})
Evaluation: B

Hollmann reports $K'c(H^+)/c^\circ$ = 2.97E−11 at pH = 7.0 and pH = 8.24. The apparent equilibrium constants given above were calculated from this. The temperature is assumed to be 298.15 K. Also see entry under EC 1.1.1.21.

7.8. Enzyme: L-iditol 2-dehydrogenase (EC 1.1.1.14)

galactitol(aq) + NAD(aq) = D-tagatose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.013

Reference: 91SCH/GIF
Method: spectrophotometry
Buffer: potassium phosphate (0.1 mol dm^{-3})
pH: 7.0
Evaluation: C

Schneider and Giffhorn report an "equilibrium constant of 1.3 nM". We assume that they are referring to $K'c(H^+)$ which they have determined to be 1.3E−9. The apparent equilibrium constant given above was calculated from this result.

D-glucitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.032

Reference: 91SCH/GIF
Method: spectrophotometry
Buffer: potassium phosphate (0.1 mol dm^{-3})
pH: 7.0
Evaluation: C

Schneider and Giffhorn report an "equilibrium constant of 3.2 nM". We assume that they are referring to $K'c(H^+)$ which they have determined to be 3.2E−9. The apparent equilibrium constant given above was calculated from this result.

D-mannitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
296.15	8.6	1.43

Reference: 62CHA/VEI
Method: spectrophotometry
Buffer: glycine + KOH
pH: 8.6
Evaluation: B

Chakravorty *et al.* report $K'c(H^+)/c^\circ$ = 3.59E−9 at pH = 8.6. The apparent equilibrium constant given above was calculated from this result. Also see listings under EC 1.1.1.67.

ribitol(aq) + NAD(aq) = D-ribulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
296.15	8.6	1.79E−2

Reference: 62CHA/VEI
Method: spectrophotometry
Buffer: glycine + KOH
pH: 8.6
Evaluation: B

Chakravorty *et al.* report $K'c(H^+)/c^\circ$ = 4.5E−11 at pH = 8.6. The apparent equilibrium constant given above was calculated from this result. Also see listings under EC 1.1.1.9 and EC 1.1.1.56.

D-sorbitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
293.15	8.0	0.240

Reference: 51BLA
Method: spectrophotometry and chemical analysis
Buffer: potassium phosphate (0.03 mol dm^{-3})
pH: 8.0
Evaluation: B

Also see listings under EC 1.1.1.9.

D-sorbitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	2.05E−2

Reference: 54WIL/BAN
Method: spectrophotometry
pH: 7.0
Evaluation: C

Williams-Ashman and Banks report $K'c(H^+)/c^\circ$ = 2.05E−9 at 298.15 K. The pH was not specified and is assumed to be 7.0. The apparent equilibrium constant given above was calculated from $K'c(H^+)$ and the assumed pH. Few details on the equilibrium determination were given. Also see listings under EC 1.1.1.9.

D-sorbitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
296.15	8.6	0.454

Reference: 62CHA/VEI
Method: spectrophotometry
Buffer: glycine + KOH
pH: 8.6
Evaluation: B

Chakravorty *et al.* report $K'c(H^+)/c^\circ$ = 1.14E−9 at pH = 8.6. The apparent equilibrium constant given above was calculated from this result. Also see listings under EC 1.1.1.9.

xylitol(aq) + NAD(aq) = D-xylulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
296.15	8.6	2.1E−2

Reference: 62CHA/VEI
Method: spectrophotometry
Buffer: glycine + KOH
pH: 8.6
Evaluation: B

Chakravorty *et al.* report $K'c(H^+)/c^\circ$ = 5.4E−11 at pH = 8.6. The apparent equilibrium constant given above was calculated from this result. Also see listings under EC 1.1.1.9.

7.9. Enzyme: mannitol-1-phosphate 5-dehydrogenase (EC 1.1.1.17)

D-mannitol 1-phosphate(aq) + NAD(aq) =
D-fructose 6-phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	5E−3

Reference: 55WOL/KAP
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3}) and bicarbonate (0.1 mol dm^{-3})
pH: 7.0
Evaluation: C

Wolff and Kaplan report $\{K'c(H^+)\}^{-1} \approx 200$ at pH = 7. Few details were given regrading this approximate result.

D-mannitol 1-phosphate(aq) + NAD(aq) =
D-fructose 6-phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
296.15	7.0	4.9E−3

Reference: 56WOL/KAP
Method: chemical analysis and spectrophotometry
pH: 6−10
Evaluation: C

Wolff and Kaplan report "an average K_e at pH 0 of $4.9 \pm 3.6 \times 10^{-10}$". We assume that this is a typographical error and that the pH should be 7.0. This would make the present result consistent with their earlier result [55WOL/KAP]. The apparent equilibrium constant given above was calculated from their result and the (assumed) pH. Few details of the equilibrium measurements were given.

7.10. Enzyme: *myo*-inositol 2-dehydrogenase (EC 1.1.1.18)

myo-inositol(aq) + NAD(aq) = 2-oxo-*myo*-inositol(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	8.92	2.7E−3
303.15	8.75	1.3E−3
303.15	8.67	1.3E−3
303.15	8.12	3.7E−4
303.15	8.11	6.7E−4

Reference: 56LAR/JAC
Method: spectrophotometry
Buffer: pyrophosphate (0.01 mol dm^{-3})
pH: 8.10−8.92
Evaluation: B

Larner *et al.* report $K'c(H^+)$ as a function of pH. The apparent equilibrium constants given above were calculated from these results.

myo-inositol(aq) + NAD(aq) = 2-oxo-*myo*-inositol(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.3	1.1E−3
298.15	8.5	1.7E−3
298.15	9.0	5.3E−3
298.15	9.5	1.7E−2
298.15	9.8	3.3E−2

Reference: 73VID/UDE
Method: spectrophotometry
Buffer: tetrapotassium tetraphosphate (0.0167 mol dm^{-3})
pH: 8.3−9.8
Evaluation: C

Vidal-Leiria and Van Uden report $K'c(H^+)/c^\circ = (5.3 \pm 2.5)$E−12 for 8.3 < pH < 9.8. The apparent equilibrium constant was calculated from this result.

7.11. Enzyme: aldehyde reductase (EC 1.1.1.21)

xylitol(aq) + NADP(aq) = D-xylose(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.8	2.1E−2

Reference: 66SCH/HOR
Method: spectrophotometry
Buffer: triethanolamine (0.1 mol dm^{-3}) + HCl
pH: 7.8
Evaluation: B

Scher and Horecker report $K'c(H^+)/c^\circ$ = 3.4E−10 at pH = 7.0. The apparent equilibrium constant given above was calculated from this result. Also see entries under EC 1.1.1.10.

xylitol(aq) + NADP(aq) = D-xylose(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	3.2E−3

Reference: 84DIT/KUB1
Method: spectrophotometry
Buffer: glycylglycine (0.025 mol dm^{-3})
pH: 7.5
Evaluation: C

Ditzelmüller *et al.* report $K'c(H^+)/c^\circ$ = 1E−10 at pH = 7.5. The apparent equilibrium constant was calculated from this result. The temperature is assumed to be 298.15 K.

7.12. Enzyme: quinate 5-dehydrogenase (EC 1.1.1.24)

quinate(aq) + NAD(aq) = 5-dehydroquinate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
305.15	7.2	4.61E−3

Reference: 55DAV/GIL
Method: spectrophotometry
Buffer: phosphate or (Tris + HCl)
pH: 7.2
Evaluation: D

Few experimental details about the equilibrium determination are given.

7.13. Enzyme: shikimate 5-dehydrogenase (EC 1.1.1.25)

shikimate(aq) + NADP(aq) = 5-dehydroshikimate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	7.0	0.036
303.15	7.8	0.18

Reference: 55DAV/GIL
Method: enzymatic assay and spectrophotometry
Buffer: Tris + HCl
pH: 7.0 and 7.8
Evaluation: C

shikimate(aq) + NADP(aq) = 5-dehydroshikimate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	7.0	0.0361
303.15	7.9	0.175

Reference: 55YAN/GIL
Method: spectrophotometry
Buffer: Tris (0.067 mol dm^{-3})
pH: 5.7−7.0
Evaluation: B

shikimate(aq) + NADP(aq) = 5-dehydroshikimate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.6	0.097

Reference: 70BAL/DEN
Method: spectrophotometry
pH: 7.6
Evaluation: C

This result is based upon unpublished data of D. Balinsky and W. W. Cleland. The temperature was not stated and is assumed to be 298.15 K.

7.14. Enzyme: glyoxylate reductase (EC 1.1.1.26)

(*R*)-glycerate(aq) + NAD(aq) = hydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	2.71E−6
298.15	7.50	1.31E−5
298.15	8.00	3.24E−5
298.15	8.10	5.60E−5
298.15	8.85	2.55E−4
298.15	9.20	4.81E−4

Reference: 55ZEL
Method: spectrophotometry
Buffer: pyrophosphate (0.033 mol dm^{-3})
pH: 7.0−9.2
Evaluation: B

The apparent equilibrium constants given above were calculated from Zelitch's Table IV. Also see entry under EC 1.1.1.27.

(*R*)-glycerate(aq) + NAD(aq) = hydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.03	7.2E−5
298.15	8.85	7.0E−4
298.15	9.08	1.2E−3

Reference: 68KOH/JAK2
Method: spectrophotometry
pH: 8.02−9.08
Evaluation: C

The apparent equilibrium constants given above were calculated from Kohn and Jakoby's Table III. Also see entry under EC 1.1.1.27.

(*R*)-glycerate(aq) + NAD(aq) = hydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	buffer	pH	K'
298.15	Tris + HCl	8.83	4.0E−4
298.15	Tris + HCl	8.50	2.3E−4
298.15	Tris + HCl	8.15	7.4E−5
298.15	phosphate	8.50	2.3E−4

Reference: 68KOH/WAR
Method: spectrophotometry
Buffer: (Tris + HCl) and potassium phosphate
pH: 8.15−8.83
Evaluation: B

The apparent equilibrium constants given above were calculated from Kohn and Warren's Table I. Also see entry under EC 1.1.1.27.

glycolate(aq) + NAD(aq) = glyoxylate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.82	1.03E−7
298.15	7.83	9.29E−8
298.15	7.85	1.20E−7
298.15	8.00	2.92E−7
298.15	8.10	2.33E−7
298.15	8.30	3.30E−7
298.15	8.40	3.05E−7

Reference: 55ZEL
Method: spectrophotometry
Buffer: pyrophosphate (0.033 mol dm^{-3})
pH: 7.82−8.40
Evaluation: B

The apparent equilibrium constants given above were calculated from Zelitch's Table III. Also see entry under EC 1.1.1.27.

glycolate(aq) + NAD(aq) = glyoxylate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.00	7.6E−10
298.15	8.05	6.4E−10
298.15	8.07	5.2E−10
298.15	8.09	5.2E−10
298.15	8.12	1.08E−9

Reference: 66CAR/HUL
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 8.00−8.12
Evaluation: C

Also see entry under EC 1.1.1.27.

glycolate(aq) + NAD(aq) = glyoxylate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	2.4E−7

Reference: 68KOH/JAK2
Method: spectrophotometry
pH: 8.00
Evaluation: C

The apparent equilibrium constant given above was calculated from Kohn and Jakoby's Table III. Also see entry under EC 1.1.1.27.

glycolate(aq) + NAD(aq) = glyoxylate(aq) + NADH(aq)

$\frac{T}{K}$	buffer	pH	K'
298.15	Tris + HCl	8.83	1.8E−6
298.15	Tris + HCl	8.50	7.3E−7
298.15	phosphate	8.50	9.3E−7

Reference: 70KOH/WAR
Method: spectrophotometry
Buffer: (Tris + HCl) and phosphate
pH: 8.50−8.83
Evaluation: C

The apparent equilibrium constant given above was calculated from Kohn and Warren's Table II. Also see entry under EC 1.1.1.27.

7.15. Enzyme: L-lactate dehydrogenase (EC 1.1.1.27)

glycolate(aq) + NAD(aq) = glyoxylate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.65	8.0	0.1
298.65	9.0	1.0

Reference: 69LAN/DEK
Method: spectrophotometry
Buffer: Tris (0.3 mol dm^{-3}) + HCl
pH: 7.4 – 9.2
Evaluation: D

Lane and Dekker report $K'c(H^+)/c^\circ$ = 1.0E – 9 for the pH range 7.4 to 9.2. The apparent equilibrium constants given above were calculated from this result. This result may be in error due to a side reaction involving the formation of oxalate. Also see entries under EC 1.1.1.26.

2-hydroxybutanoate(aq) + NAD(aq) = 2-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.65	8.0	3.0E – 3
298.65	8.0	3.0E – 2

Reference: 69LAN/DEK
Method: chromatography and spectrophotometry
Buffer: Tris (0.3 mol dm^{-3}) + HCl
pH: 7.4 – 9.2
Evaluation: C

Lane and Dekker report $K'c(H^+)/c^\circ$ = 3.0E – 11 for the pH range 7.4 to 9.2. The apparent equilibrium constants given above were calculated from this result.

2,4-dihydroxybutanoate(aq) + NAD(aq) = 2-oxo-4-hydroxybutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.65	8.0	1.2E – 2
298.65	9.0	1.2E – 1

Reference: 69LAN/DEK
Method: spectrophotometry
Buffer: Tris (0.3 mol dm^{-3}) + HCl
pH: 7.4 – 9.2
Evaluation: C

Lane and Dekker report $K'c(H^+)/c^\circ$ = 1.2E – 10 for the pH range 7.4 to 9.2. The apparent equilibrium constants given above were calculated from this result.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.58	7.7E – 5
298.15	7.61	8.3E – 5
298.15	8.38	1.1E – 3
298.15	8.51	1.4E – 3
298.15	8.82	2.0E – 3
298.15	8.83	2.5E – 3

Reference: 37EUL/ADL
Method: spectrophotometry
Buffer: phosphate
pH: 7.58 – 8.83
Evaluation: C

The temperature is assumed to be 298.15 K.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.4	9.6E – 6
298.15	7.4	7.1E – 6
298.15	7.9	3.1E – 5
298.15	8.1	5.0E – 5
298.15	8.2	2.0E – 4
298.15	8.3	2.9E – 4
298.15	8.35	2.9E – 4
298.15	8.7	1.5E – 4
298.15	8.9	3.3E – 4

Reference: 37EUL/ADL3
Method: spectrophotometry
Buffer: phosphate
pH: 7.58 – 8.83
Evaluation: C

The temperature is assumed to be 298.15 K. Von Euler *et al.* used two different sources of enzyme in this study.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	7.4	6.0E – 5

Reference: 43KUB/OTT
Method: spectrophotometry
Buffer: phosphate
pH: 7.4
Evaluation: C

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	1.39E−4
298.15	8.0	4.4E−4
298.15	8.5	1.39E−3
298.15	9.0	4.4E−3

Reference: 50RAC
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.01 mol dm^{-3})
pH: 7.4−9.3
Evaluation: B

Racker reports $K'c(H^+)/c^\circ$ = 4.4E−12 over the pH range 7.4 to 9.3. The apparent equilibrium constants given above were calculated from this result.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	2.3E−5
298.15	8.0	3.3E−4
298.15	9.0	3.0E−3
298.15	10.0	4.4E−2

Reference: 52NEI
Buffer: phosphate (0.1 mol dm^{-3}), pyrophosphate (0.1 mol dm^{-3}), and {glycine (0.1 mol dm^{-3}) + NaOH}
pH: 7.0−10.0
Evaluation: C

Neilands reports $K'c(H^+)$ at pH = 7.0, 8.0, 9.0, and 10.0. The apparent equilibrium constants given above were calculated from these results. Neilands also reports on the formation of a complex formed from the L-lactate dehydrogenase and the NADH.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
289.15	6.80	0.978E−5
298.15	6.80	1.74E−5
308.15	6.80	3.24E−5

Reference: 56HAK/GLA
Method: spectrophotometry
Buffer: sodium phosphate (0.05 mol dm^{-3})
pH: 6.80
Evaluation: A

D-lactate dehydrogenase (EC 1.1.1.28) may have also been present in the reaction mixtures. We calculate $\Delta_r H'^\circ$ = 46.7 kJ mol^{-1} at pH = 7.0 from the results given above.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	9.0	1.2E−3

Reference: 56KAP/CIO
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3})
pH: 9.0
Evaluation: C

Kaplan *et al.* report $K'c(H^+)/c^\circ$ = 1.2E−12 at pH = 9.0. The apparent equilibrium constant given above was calculated from this result.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.5	1.73E−2

Reference: 57HOH
Method: spectrophotometry
Buffer: glycol + NaOH
pH: 9.5
Evaluation: C

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.0	2.4E−3

Reference: 65DAW/DIC
Method: spectrophotometry
Buffer: Tris (0.17 mol dm^{-3}) and hydrazine (0.13 mol dm^{-3})
pH: 9.0
Evaluation: C

Dawkins and Dickens report $K'c(H^+)/c^\circ$ = 2.38E−12 at pH = 9.0. The apparent equilibrium constant given above was calculated from this result. The temperature is assumed to be 298.15 K.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K'
311.15	7.0	0.258	1.110E−4
311.15	7.0	0.138	1.023E−4
311.15	7.0	0.077	0.967E−4
311.15	7.0	0.045	0.936E−4

Reference: 67WIL/LUN
Method: spectrophotometry
Buffer: phosphate (0.012 mol dm^{-3} to 0.10 mol dm^{-3})
pH: 7.12−7.22
Evaluation: A

Williamson *et al.* report $K'c(H^+)$ in their Tables 2 and 4. The apparent equilibrium constants given above were calculated from their results.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.65	8.0	4.8E−4
298.65	9.0	4.8E−3

Reference: 69LAN/DEK
Method: spectrophotometry
Buffer: Tris (0.3 mol dm^{-3}) + HCl
pH: 7.4−9.2
Evaluation: C

Lane and Dekker report $K'c(H^+)/c^\circ$ = 4.8E−12 for the pH range 7.4 to 9.2. The apparent equilibrium constants given above were calculated from this result.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	7.5	61.9

Reference: 75DON/BAR
Method: calorimetry
Buffer: phosphate (0.5 mol dm^{-3})
pH: 7.5
Evaluation: B

The result given above has been corrected for the enthalpy of protonation of the buffer. Also see entry under EC 1.1.1.28.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
283.15	7.0	56.56
298.15	7.0	54.58
308.15	7.0	56.27

Reference: 79SCH/HIN
Method: calorimetry
Buffer: phosphate (0.2 mol dm^{-3})
pH: 7.0
Evaluation: A

The enthalpies of reaction given above have been corrected for the enthalpy of protonation of the buffer. Also see entry under EC 1.1.1.28.

(*S*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	4.5E−4

Reference: 80COO/BLA
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 8.0
Evaluation: B

Cook *et al.* report $K'c(H^+)/c^\circ$ = 4.5E−12 at pH = 8.0. The apparent equilibrium constant given above was calculated from this result.

(*S*)-lactate(aq) + AP-NAD(aq) = pyruvate(aq) + AP-NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	9.0	0.27

Reference: 56KAP/CIO
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3})
pH: 9.0
Evaluation: C

AP-NAD and AP-NADH are, respectively, 3-acetylpyridine adenine dinucleotide and its reduced form. Kaplan *et al.* report $K'c(H^+)/c^\circ$ = 2.7E−10 at pH = 9.0. The apparent equilibrium constant given above was calculated from this result.

7.16. Enzyme: D-lactate dehydrogenase (EC 1.1.1.28)

(*R*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	7.3	44.4

Reference: 55KAT
Method: calorimetry
Buffer: phosphate (0.15 mol dm^{-3})
pH: 7.3
Evaluation: B

A correction has been applied for the enthalpy of protonation of the buffer. Also see entries under EC 1.1.1.27.

(*R*)-lactate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.4E−5

Reference: 86MEI/GAD
Method: spectrophotometry
Buffer: potassium phosphate (0.20 mol dm^{-3})
pH: 7.0
Evaluation: C

7.17. Enzyme: glycerate dehydrogenase (EC 1.1.1.29)

(*R*)-glycerate(aq) + NAD(aq) = hydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
296.15	7.0	3.70E−6
296.15	7.4	8.57E−6
296.15	7.8	2.49E−5
296.15	8.0	2.73E−5
296.15	8.4	9.34E−5
296.15	8.8	1.63E−4
296.15	9.0	4.65E−4
296.15	9.4	7.10E−4

Reference: 57HOL/HOL
Method: spectrophotometry
Buffer: Tris and diethanolamine
pH: 7.0−9.4
Evaluation: C

Holzer and Holldorf report results in terms of $\{K'c(H^+)\}^{-1}$ as a function of pH. The apparent equilibrium constants given above were calculated from these results.

(*R*)-glycerate(aq) + NAD(aq) = hydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.0	6.1E−5

Reference: 65DAW/DIC
Method: spectrophotometry
Buffer: Tris (0.17 mol dm^{-3}) and hydrazine (0.13 mol dm^{-3})
pH: 9.0
Evaluation: C

Dawkins and Dickens report $K'c(H^+)/c^\circ$ = 6.1E−14 at pH = 9.0. The apparent equilibrium constant given above was calculated from this result. The temperature is assumed to be 298.15 K. Dawkins and Dickens also report a result of $K'c(H^+)/c^\circ$ = 2.E−12 at pH = 9.0 for the reaction of (*S*)-glycerate.

(*R*)-glycerate(aq) + NAD(aq) = hydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{c(MgCl_2)}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	K'
298.15	6.41	0.0	0.25	1.09E−6
298.15	6.99	0.0	0.25	3.79E−6
298.15	6.96	0.0	0.25	3.36E−6
298.15	7.22	0.0	0.25	6.91E−6
298.15	7.72	0.0	0.25	2.22E−5
298.15	7.72	0.0	0.25	2.17E−5
298.15	7.80	0.0	0.25	3.28E−5
298.15	6.41	0.0	0.25	1.15E−6
298.15	6.49	0.0	0.25	9.49E−7
298.15	7.03	0.0	0.25	4.54E−6
298.15	7.03	0.0	0.25	4.36E−6
298.15	6.98	0.0	0.25	5.44E−6
298.15	6.98	0.0	0.25	5.53E−6
298.15	8.05	0.0	0.25	6.10E−5
298.15	6.98	0.0	0.25	4.11E−6
298.15	6.98	0.0	0.25	3.82E−6
298.15	6.98	0.0	0.25	3.84E−6
298.15	6.96	0.0	0.25	3.72E−6
298.15	6.98	0.0	0.25	3.77E−6
298.15	6.98	0.0	0.25	4.19E−6
298.15	6.98	0.0	0.25	4.22E−6
298.15	6.97	0.0	0.25	4.13E−6
311.15	7.00	0.0	0.0595	3.80E−6
311.15	7.00	0.0	0.5	4.52E−6
311.15	7.00	0.0	1.0	5.40E−6
311.15	7.00	0.0030	0.25	4.19E−6
311.15	7.00	0.010	0.25	4.36E−6
303.15	7.00	0.0	0.25	2.64E−6
298.15	7.00	0.0	0.25	1.98E−6

Reference: 82GUY
Method: spectrophotometry
Buffer: potassium phosphate (0.025 mol dm^{-3})
pH: 6.41−7.72
Evaluation: A

The last seven apparent equilibrium constants given above were calculated from Guynn's results for $K'c(H^+)$. For the reference reaction which we have written here as: (*R*)-glycerate$^-$(aq) + NAD$^-$(aq) = hydroxypyruvate$^-$(aq) + NADH^{2-}(aq) + H$^+$(aq), Guynn calculated K_c(ref) = 4.36E−13. From Guynn's results obtained at 298.15 K, 303.15 K, and 311.15 K, we calculate $\Delta_r H'^\circ$(pH = 7.0, I_c = 0.25 mol dm^{-3}) = 47 kJ mol^{-1}.

7.18. Enzyme: 3-hydroxybutyrate dehydrogenase (EC 1.1.1.30)

(*R*)-3-hydroxybutanoate(aq) + NAD(aq) = 3-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.9E−3

Reference: 53LYN/OCH
pH: 7.0
Evaluation: D

This result is based upon the unpublished work of F. Lynen, G. Vogelmann, L. Wessely, O. Wieland, and W. Seubert. Few details were given. The temperature is assumed to be 298.15 K.

(*R*)-3-hydroxybutanoate(aq) + NAD(aq) = 3-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
305.15	8.0	0.13

Reference: 61DOU/MER
Buffer: Tris
pH: 8.0
Cofactor(s): Mg^{2+}
Evaluation: C

This is a preliminary report. Few details were given.

(*R*)-3-hydroxybutanoate(aq) + NAD(aq) = 3-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	buffer	pH	K'
298.15	Tris	8.70	0.609
298.15	Tris	8.55	0.417
298.15	Tris	8.10	0.193
298.15	Tris	7.70	0.0772
298.15	Tris	7.60	0.0520
298.15	Tris	7.40	0.0335
298.15	phosphate	7.05	0.0194
298.15	phosphate	7.00	0.0146

Reference: 62KRE/MEL
Method: spectrophotometry
Buffer: Tris (0.033 mol dm^{-3}) and phosphate
pH: 7.0 – 8.70
Evaluation: A

The apparent equilibrium constants given above were calculated from the results given in Table 1 of Krebs *et al.*

(*R*)-3-hydroxybutanoate(aq) + NAD(aq) = 3-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
305.15	8.0	0.13

Reference: 62SHU/DOU
Method: spectrophotometry
Buffer: Tris (0.033 mol dm^{-3}) + HCl
pH: 8.0
Cofactor(s): $MgCl_2$ (0.001 mol dm^{-3})
Evaluation: C

(*R*)-3-hydroxybutanoate(aq) + NAD(aq) = 3-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{\text{mol dm}^{-3}}$	K'
311.15	7.00	0.255	4.94E – 2
311.15	7.04	0.134	5.26E – 2
311.15	7.09	0.073	5.61E – 2
311.15	7.10	0.042	4.82E – 2

Reference: 67WIL/LUN
Method: spectrophotometry
Buffer: phosphate (0.0125 mol dm^{-3} to 0.10 mol dm^{-3})
pH: 6.84 – 7.24
Evaluation: A

Williamson *et al.* report $K'c(H^+)$ in their Tables 3 and 4. The apparent equilibrium constants given above were calculated from their results. The pH values given above are the averages of the ranges given in Williamson *et al.*'s Table 3.

(*R*)-3-hydroxybutanoate(aq) + NAD(aq) = 3-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.15	1.66

Reference: 86KON/POL
Method: spectrophotometry
Buffer: glycine
pH: 9.15
Evaluation: C

Konstanczak and Polster report $\{K'c(H^+)/c^\circ\}^{-1} = 10^{8.93}$ at pH = 9.15. The apparent equilibrium constant was calculated from this result.

7.19. Enzyme: 3-hydroxyisobutyrate dehydrogenase (EC 1.1.1.31)

3-hydroxy-2-methylpropanoate(aq) + NAD(aq) = 2-methyl-3-oxopropanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	3.1E – 3
298.15	9.0	3.6E – 2
298.15	10.0	1.2E – 1

Reference: 57ROB/COO
Method: spectrophotometry
Buffer: Tris (0.017 mol dm^{-3})
pH: 8.0 – 10.0
Evaluation: B

The temperature is assumed to be 298.15 K.

7.20. Enzyme: 3-hydroxyacyl-Coa dehydrogenase (EC 1.1.1.35)

(*S*)-3-hydroxybutanoyl-CoA(aq) + NAD(aq) = 3-oxobutanoyl-CoA(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	6.3E−4
298.15	8.0	6.3E−3
298.15	9.0	6.3E−2
298.15	10.0	6.3E−1

Reference: 54WAK/GRE
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3})
pH: 7.0−10.5
Evaluation: C

Wakil *et al.* report $K'c(H^+)/c^\circ$ = 6.3E−11 over the pH range 7.0 to 10.5. The apparent equilibrium constants given above were calculated from this result.

(*S*)-3-hydroxybutanoyl-CoA(aq) + NAD(aq) = 3-oxobutanoyl-CoA(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.8	0.012

Reference: 55LYN/WIE
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.025 mol dm^{-3}) + HCl
pH: 7.8
Evaluation: C

Lynen and Wieland report $\{K'c(H^+)\}^{-1}$ = 5.25E9 at pH = 7.8. The apparent equilibrium constant given above is based upon this result. Few details concerning the equilibrium investigation are reported.

(*S*)-3-hydroxybutanoyl-CoA(aq) + NAD(aq) = 3-oxobutanoyl-CoA(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.6	0.86

Reference: 57STE
Method: spectrophotometry
pH: 9.6
Evaluation: C

Stern reports $K'c(H^+)/c^\circ$ = 2.17E−10 at pH = 9.6. The apparent equilibrium constant given above was calculated from this result. Few details on the equilibrium investigation are reported.

(*S*)-3-hydroxyhexanoyl-CoA(aq) + NAD(aq) = 3-oxohexanoyl-CoA(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	2.5E−4
298.15	8.0	2.5E−3
298.15	9.0	2.5E−2
298.15	10.0	2.5E−1

Reference: 54WAK/GRE
Method: spectrophotometry
Buffer: Tris
pH: 7.0−10.5
Evaluation: C

Wakil *et al.* report $K'c(H^+)/c^\circ$ = 2.5E−11 over the pH range 7.0 to 10.5. The apparent equilibrium constants given above were calculated from this result.

7.21. Enzyme: malate dehydrogenase (EC 1.1.1.37)

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.46	2.3E−5
298.15	7.54	3.5E−5
298.15	7.71	5.0E−5
298.15	7.85	1.1E−4
298.15	8.33	2.0E−4
298.15	8.44	5.0E−4
298.15	8.49	6.3E−4

Reference: 37EUL/ADL
Method: spectrophotometry
Buffer: phosphate
pH: 7.46−8.49
Evaluation: C

The temperature is assumed to be 298.15 K.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	6.05	1.34E−6
295.15	6.55	5.55E−6
295.15	7.20	2.33E−5
295.15	7.75	6.94E−5
295.15	8.30	2.08E−4
295.15	9.95	6.76E−3

Reference: 52STE/OCH
Method: spectrophotometry
Buffer: potassium phosphate (0.025 mol dm^{-3})
pH: 6.05−9.95
Cofactor(s): $MgCl_2$ (0.003 mol dm^{-3})
Evaluation: B

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.83	5.31E−4
298.15	8.87	5.30E−4
298.15	8.95	6.92E−4
298.15	8.63	3.60E−4
298.15	8.85	6.37E−4
298.15	8.87	5.17E−4
298.15	8.89	5.23E−4
298.15	8.86	5.23E−4
298.15	8.81	4.66E−4
298.15	8.78	4.35E−4
298.15	8.75	4.46E−4
298.15	8.83	5.04E−4
298.15	8.19	1.06E−4
298.15	8.08	8.18E−5
298.15	7.55	2.75E−5

Reference: 53BUR/WIL
Method: spectrophotometry
Buffer: glycine (0.0027 mol dm^{-3})
pH: 7.55−8.95
Evaluation: A

The apparent equilibrium constants given above were calculated from Burton and Wilson's Table 2. Burton and Wilson obtained a mean result of $K'c(H^+)/c^\circ$ = 7.50E−13. Thus, for the reference reaction: (*S*)-malate(aq) + NAD^-(aq) = oxaloacetate(aq) + $NADH^{2-}$(aq) + H^+(aq), K(ref) = 7.50E−13. Results are also given for the ionic strength dependency of $K'c(H^+)$ in Burton and Wilson's Fig. 2.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	1.03E−4

Reference: 62RAV/WOL
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3}) + acetate
pH: 8.0
Evaluation: B

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	1.04E−4

Reference: 62RAV/WOL2
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3}) + acetate
pH: 8.0
Evaluation: B

Raval and Wolfe report $K'c(H^+)/c^\circ$ = 1.04E−12 at pH = 8.0. The apparent equilibrium constant given above was calculated from this result.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.06	9.76E−4
298.15	8.70	3.67E−3

Reference: 65YOS
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3}) + HCl
pH: 8.06−8.70
Evaluation: C

Yoshida reports $K'c(H^+)$ at pH = 8.06 and at pH = 8.70. The apparent equilibrium constants given above were calculated from these results.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.37	2.43E−5
298.15	7.54	3.49E−5
298.15	7.68	4.74E−5
298.15	7.76	6.19E−5
298.15	7.87	7.67E−5
298.15	7.99	1.01E−4
298.15	8.09	1.29E−4
298.15	8.19	1.62E−4

Reference: 66BER/MOE
Method: spectrophotometry
Buffer: triethanolamine (0.15 mol dm^{-3})
pH: 7.37−8.19
Evaluation: B

Bergmeyer and Moellering also report that $K'c(H^+)/c^\circ$ = 1.033E−12 over the pH range 7.37 to 8.19.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K'
311.15	7.0	0.25	2.78E−5

Reference: 67WIL/LUN
Method: spectrophotometry
Buffer: phosphate
pH: 7.0
Evaluation: B

This result was attributed by Williamson *et al.* to R. L. Veech.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.2	2.09E−4
298.15	9.2	2.04E−3
298.15	9.6	4.87E−3

Reference: 68KOH/JAK
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 8.2−9.6
Evaluation: C

The apparent equilibrium constants given above were calculated from the results given in Kohn and Jakoby's Table IV.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	buffer	pH	$\frac{I_c}{mol\ dm^{-3}}$	K'
311.15	phosphate	7.15	0.25	3.90E−5
311.15	phosphate	8.02	0.25	2.57E−4
311.15	Tris + acetate	8.15	0.25	2.0E−4

Reference: 68VEE
Method: spectrophotometry
Buffer: {Tris (0.5 mol dm^{-3}) + acetate (0.25 mol dm^{-3})} and potassium phosphate (0.10 mol dm^{-3})
pH: 7.15−8.15
Evaluation: B

Veech reports $K'c(H^+)/c^\circ$ = 2.76E−12 at pH = 7.15 and $K'c(H^+)/c^\circ$ = 2.45E−12 at pH = 8.02 with the potassium phosphate buffer and $K'c(H^+)/c^\circ$ = 1.4E−12 at pH = 8.15 with the (Tris + acetate) buffer. The apparent equilibrium constants given above were calculated from these results.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{c(Mg^{2+})}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	K'
298.15	7.06	0.0	0.25	1.13E−5
298.15	7.08	0.0	0.25	1.04E−5
298.15	7.06	0.0	0.25	1.20E−5
298.15	7.08	0.0	0.25	1.08E−5
298.15	7.11	0.0	0.25	1.23E−5
298.15	7.08	0.0	0.25	1.27E−5
311.15	7.07	0.0	0.25	3.41E−5
311.15	7.08	0.0	0.25	3.59E−5
311.15	7.14	0.0	0.25	3.96E−5
311.15	7.17	0.0	0.25	1.79E−5
311.15	7.11	0.0	0.25	8.98E−6
311.15	7.13	0.0	0.25	1.78E−5
311.15	7.07	1.11E−3	0.25	3.19E−5
311.15	7.06	1.11E−3	0.25	3.39E−5
311.15	7.09	1.11E−3	0.25	3.76E−5
311.15	7.11	1.11E−3	0.25	3.94E−5
311.15	7.09	1.11E−3	0.25	3.29E−5
311.15	7.05	1.11E−3	0.25	3.45E−5

Reference: 73GUY/GEL
Method: spectrophotometry
Buffer: potassium phosphate (0.050 mol dm^{-3})
pH: 7.06−7.17
Cofactor(s): Mg^{2+}
Evaluation: A

The apparent equilibrium constants given above were calculated from the results given in Guynn *et al.*'s Table II.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.3	1.17E−3

Reference: 75SCH/RIF
Method: spectrophotometry
pH: 9.3
Evaluation: A

For deuterated malate in the above reaction and under the same conditions given above, K' = 8.90E−4.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_t H'^\circ}{kJ\ mol^{-1}}$
298.15	7.4	89.5

Reference: 76JES
Method: calorimetry
Buffer: phosphate (0.5 mol dm^{-3})
pH: 7.40
Evaluation: B

The temperature is assumed to be 298.15 K. A correction has been applied for the enthalpy of protonation of the buffer.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.0	7.1E−4

Reference: 80COO/BLA
Method: spectrophotometry
Buffer: 3-[tris(hydroxylmethyl)methyl]aminopropanesulfonic acid (0.1 mol dm^{-3})
pH: 9.0
Evaluation: B

Cook *et al.* report $K'c(H^+)/c^\circ$ = 7.1E−13 at pH = 9.0. The apparent equilibrium constant given above was calculated from this result.

(*S*)-malate(aq) + NAD(aq) = oxaloacetate(aq) + NADH(aq)

$\frac{T}{K}$	pH	protein	K'
311.15	7.6		3.6E−5
311.15	7.6	BSA	6.4E−5
311.15	7.6	ovalbumin	2.4E−5

Reference: 85ANS/PRI
Method:
Buffer: sodium phosphate (0.1 mol dm^{-3})
pH: 7.6
Evaluation: D

Ansari *et al.* report $K'c(H^+)/c^\circ$ for the reaction occurring in buffer alone and in the presence of added proteins (bovine serum albumin (BSA) and ovalbumin) at a concentration of 500 g dm^{-3}. The apparent equilibrium constants were calculated from these results. Few experimental details were given and the results are stated to be preliminary.

meso-tartrate(aq) + NAD(aq) = (*E*)-dihydroxyfumarate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.54	5.3E−5
298.15	8.13	3.4E−4

Reference: 68KOH/JAK
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 7.54−8.13
Evaluation: C

The apparent equilibrium constants given above were calculated from the results given in Kohn and Jakoby's Table III. Also see 79KIM/PET.

meso-tartrate(aq) + NAD(aq) = 2-oxo-3-hydroxysuccinate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	1.25E−6

Reference: 79KIM/PET
Method: spectrophotometry
Buffer: Tris + acetate (0.05 mol dm^{-3})
pH: 8.0
Evaluation: B

Kimball *et al.* also determined $K'(T$ = 298.15 K, pH = 8.0) = 0.036 for the uncatalyzed reaction: (*E*)-dihydroxyfumarate(aq) = 2-oxo-3-hydroxysuccinate(aq). Thus, $K'(T$ = 298.15 K, pH = 8.0) = {(1.25E−6)/0.036)} = 3.5E−5 for the reaction: *meso*-tartrate(aq) + NAD(aq) = (*E*)-dihydroxyfumarate(aq) + NADH(aq). Also see 68KOH/JAK.

L-glutamate(aq) + (*S*)-malate(aq) + NAD(aq) = L-aspartate(aq) + 2-oxoglutarate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.4	4.1E−5

Reference: 80PET/AMI
Method: spectrophotometry
Buffer: Tris (0.090 mol dm^{-3}) + HCl
pH: 7.4
Evaluation: C

Aspartate aminotransferase (EC 2.6.1.1) was also present. This is an approximate result.

(*S*)-malate(aq) + acetyl-CoA(aq) + NAD(aq) + H_2O(l) = citrate(aq) + CoA(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	6.25	4.80E−1
295.15	7.20	1.08E1
295.15	7.60	1.01E2
295.15	8.20	5.99E2
295.15	8.70	5.61E3

Reference: 52STE/OCH
Method: spectrophotometry
Buffer: potassium phosphate (0.025 mol dm^{-3})
pH: 6.25−8.70
Cofactor(s): $MgCl_2$ (0.003 mol dm^{-3})
Evaluation: B

Citrate (*si*) synthase (EC 4.1.3.7) was also present. The results given by Stern *et al.* in their Table III and Fig. 3 included the concentration of water as 55.5 mol dm^{-3}. The apparent equilibrium constants given above have been adjusted so that the activity of water is unity.

7.22. Enzyme: malate dehydrogenase (decarboxylating) (EC 1.1.1.39)

(*S*)-malate(aq) + NAD(aq) = pyruvate(aq) + NADH(aq) + carbon dioxide(aq)

$\frac{T}{\mathrm{K}}$	pH	K_c'
298.15	6.5	1.1E−3

Reference: 83WED/BLA
Method: spectrophotometry
Buffer: *N*-(acetamido)-2-aminoethanesulfonic acid (0.050 mol dm^{-3})
pH: 6.5
Cofactor(s): Mn^{2+}
Evaluation: C

This result is based upon kinetic data.

7.23. Enzyme: malate dehydrogenase (oxaloacetate-decarboxylating) ($NADP^+$) (EC 1.1.1.40)

(*S*)-malate(aq) + NADP(aq) = pyruvate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{\mathrm{K}}$	pH	K_c'
297	7.4	0.051

Reference: 53HAR/KOR
Method: enzymatic assay; spectrophotometry
pH: 7.3−7.5
Cofactor(s): $MnCl_2$ (0.0010 mol dm^{-3})
Evaluation: B

(*S*)-malate(aq) + NADP(aq) = pyruvate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{\mathrm{K}}$	pH	$\frac{I_c}{\mathrm{mol\ dm^{-3}}}$	K_c'
311.15	7.0	0.03	0.0558
311.15	7.0	0.25	0.0344

Reference: 68VEE
Method: spectrophotometry
Buffer: $NaHCO_3$ (0.025 mol dm^{-3})
pH: 7.0
Cofactor(s): $MnCl_2$ (2×10^{-7} mol dm^{-3})
Evaluation: A

Also see 69VEE/EGG.

(*S*)-malate(aq) + NADP(aq) = pyruvate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{\mathrm{K}}$	pH	$\frac{I_c}{\mathrm{mol\ dm^{-3}}}$	K_c'
311.15	7.0	0.25	0.0344

Reference: 69VEE/EGG
Method: spectrophotometry
Buffer: $NaHCO_3$ (0.025 mol dm^{-3})
pH: 7.0
Cofactor(s): $MnCl_2$ (2×10^{-7} mol dm^{-3})
Evaluation: A

Veech *et al.* report an apparent equilibrium constant in their Table 2. This result was taken from the thesis of R. L. Veech [68VEE].

(*S*)-malate(aq) + NADP(aq) = pyruvate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{\mathrm{K}}$	pH	K_c'
298.15	7.1	0.030

Reference: 75SCH/RIF
Method: spectrophotometry
pH: 7.1
Evaluation: B

For deuterated (*S*)-malate in the above reaction and under the same conditions given above, $K_c' = 0.025$.

(*S*)-malate(aq) + NADP(aq) = pyruvate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{\mathrm{K}}$	pH	K_c'
298.15	7.1	0.029

Reference: 77SCH/CLE
Method: spectrophotometry
Buffer: acetic acid, glycine, cacodylic acid, and Hepes
pH: 7.1
Cofactor(s): $MgSO_4$ (0.020 mol dm^{-3})
Evaluation: C

This is an approximate result based upon kinetic data.

7.24. Enzyme: isocitrate dehydrogenase ($NADP^+$) (EC 1.1.1.42)

isocitrate(aq) + NADP(aq) = 2-oxoglutarate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{K}$	pH	K_c'
295.15	6.95	0.76

Reference: 48OCH
Method: spectrophotometry
Buffer: carbonate + bicarbonate
pH: 6.95
Cofactor(s): $MnCl_2$ (0.00060 mol dm^{-3})
Evaluation: C

The average pH at which the experiments were conducted is given above.

isocitrate(aq) + NADP(aq) = 2-oxoglutarate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
298.15	7.2	0.017	0.93
298.15	6.6	0.054	0.90
298.15	7.05	0.404	0.86
298.15	6.9	0.254	0.72
298.15	6.9	0.404	0.62

Reference: 68LON/DAL
Method: spectrophotometry
Buffer: carbonate + bicarbonate
pH: 6.6 – 7.2
Cofactor(s): $MgSO_4$ (0.000133 mol dm^{-3})
Evaluation: A

Londesborough and Dalziel measured the partial pressure of CO_2(g) over the solution and used auxiliary data to calculate the concentration of carbon dioxide(aq) in solution. The third result, given above for pH = 7.05, was obtained over the pH range 6.9 to 7.2. Londesborough and Dalziel also report results of equilibrium measurements which were performed at varying temperatures, ionic strengths, and concentrations of $MgSO_4$. These results are shown in their Figs. 1, 2, and 3 and are expressed in terms of the partial pressure of CO_2(g).

isocitrate(aq) + NADP(aq) = 2-oxoglutarate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
311.15	7.0	0.25	0.91

Reference: 68VEE
Method: spectrophotometry
Buffer: bicarbonate (0.25 mol dm^{-3})
pH: 7.0
Cofactor(s): $MnSO_4$ (0.00035 mol dm^{-3})
Evaluation: A

isocitrate(aq) + NADP(aq) = 2-oxoglutarate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	$c(MnCl_2)$	K_c'
293.15	7.4	0.404	3.3E – 3	0.076
293.15	7.4	0.404	2.0E – 4	0.81

Reference: 73SHE/GUL
Method: spectrophotometry
Buffer: carbonate + bicarbonate
pH: 7.4
Cofactor(s): $MnCl_2$
Evaluation: B

isocitrate(aq) + NADP(aq) = 2-oxoglutarate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.0	1.0

Reference: 80COO/BLA
Method: spectrophotometry
Buffer: potassium phosphate (0.1 mol dm^{-3})
pH: 8.0
Cofactor(s): $MgSO_4$ (0.002 mol dm^{-3})
Evaluation: C

7.25. Enzyme: phosphogluconate dehydrogenase (decarboxylating) (EC 1.1.1.44)

6-phospho-D-gluconate(aq) + NADP(aq) = D-ribulose 5-phosphate(aq) + NADPH(aq) + carbon dioxide(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
298.15	6.45	0.036	0.074
298.15	7.30	0.048	0.079
298.15	6.80	0.084	0.083
298.15	6.90	0.096	0.081
298.15	6.95	0.120	0.080
298.15	7.70	0.120	0.074
298.15	6.95	0.250	0.076
298.15	6.95	0.350	0.075
298.15	6.95	0.450	0.069

Reference: 69VIL/DAL
Method: spectrophotometry and pressure measurements
Buffer: $KHCO_3$
pH: 6.45 – 7.70
Evaluation: A

Villet and Dalziel measured the partial pressure of CO_2(g) over the solution and used auxiliary data to calculate the concentration of carbon dioxide(aq) in solution. They also report results of equilibrium measurements which were performed at varying temperatures in their Fig. 4.

7.26. Enzyme: glucose dehydrogenase (EC 1.1.1.47)

β-D-glucose(aq) + NAD(aq) = D-glucono-1,5-lactone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	6.7	15

Reference: 52STR/KOR
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 6.7
Evaluation: C

β-D-glucose(aq) + NAD(aq) = D-glucono-1,5-lactone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
294.15	7.0	3.1

Reference: 53BRI
Method: spectrophotometry
Buffer: phosphate (0.13 mol dm^{-3})
pH: 7.0
Evaluation: C

Brink reports $K'c(H^+)/c^\circ$ = 3.1E−7 at pH = 7.0. The apparent equilibrium constant given above was calculated from this result. The position of equilibrium was approached from only one direction.

7.27. Enzyme: galactose 1-dehydrogenase (EC 1.1.1.48)

D-galactose(aq) + NAD(aq) = D-galactono-1,4-lactone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	6.7	570.

Reference: 62DOU
Method: spectrophotometry
Buffer: phosphate
pH: 6.7
Evaluation: C

The same result is reported in [57DOU/CON].

D-galactose(aq) + NAD(aq) = D-galactono-1,4-lactone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.8	3.9E2
303.15	6.8	4.0E2
203.15	8.6	2.5E4

Reference: 74UEB/BLA
Method: gas-liquid chromatography
Buffer: potassium phosphate and sodium phosphate (0.1 mol dm^{-3})
pH: 6.8−8.6
Evaluation: C

7.28. Enzyme: glucose-6-phosphate 1-dehydrogenase (EC 1.1.1.49)

D-glucose 6-phosphate(aq) + NADP(aq) = D-glucono-1,5-lactone 6-phosphate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
301.15	6.40	1.50

Reference: 55GLA/BRO
Method: spectrophotometry
Buffer: maleate (0.063 mol dm^{-3})
pH: 6.40
Cofactor(s): $MgCl_2$ (0.010 mol dm^{-3})
Evaluation: B

D-glucose 6-phosphate(aq) + NADP(aq) = D-glucono-1,5-lactone 6-phosphate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.4	1.3
298.15	7.6	52

Reference: 70WUR/HES
Method: spectrophotometry
Buffer: imidazole (0.050 mol dm^{-3}) + HCl
pH: 6.4−7.6
Cofactor(s): $MgSO_4$ (0.008 mol dm^{-3})
Evaluation: D

Wurster and Hess (73WUR/HES) later corrected the result at pH = 7.6 to K' = 20.

D-glucose 6-phosphate(aq) + NADP(aq) = D-glucono-1,5-lactone 6-phosphate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.6	20

Reference: 73WUR/HES
Method: spectrophotometry
Buffer: imidazole (0.050 mol dm^{-3}) + HCl
pH: 6.4 – 7.6
Cofactor(s): $MgSO_4$ (0.008 mol dm^{-3})
Evaluation: C

D-glucose 6-phosphate(aq) + NADP(aq) + $H_2O(l)$ = 6-phospho-D-gluconate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
311.15	6.03	1.5E3
311.15	6.47	8.9E3
311.15	7.03	8.3E4

Reference: 86CAS/VEE
Method: enzymatic assay and spectrophotometry
pH: 6.03 – 7.03
Evaluation: B

6-phosphogluconolactonase (EC 3.1.1.31) was also present. The apparent equilibrium constants given above were calculated from the results given in Table VII in the miniprint section of Casazza and Veech's paper. The reaction mixture may not have reached equilibrium.

7.29. Enzyme: 3α-hydroxysteroid dehydrogenase (B-specific) (EC 1.1.1.50)

5α-androstane-3α-ol-17-one(aq) + NAD(aq) = 5α-androstane-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.0	5.8E – 3
298.15	7.0	5.8E – 2
298.15	8.0	5.8E – 1
298.15	9.0	5.8

Reference: 56TAL/MAR
Method: spectrophotometry
Buffer: orthophosphate (0.033 mol dm^{-3}) and pyrophosphate (0.033 mol dm^{-3})
pH: 6.1 – 9.2
Evaluation: B

Tallalay and Marcus report $K'c(H^+)/c^\circ$ = 5.8E – 9 over the pH range 6.1 to 9.0. The apparent equilibrium constants given above were calculated from this result. Results of individual measurements are shown in Tallalay and Marcus' Fig. 2 but are difficult to read accurately. Also see 63TAL.

5α-androstane-3α-ol-17-one(aq) + NAD(aq) = 5α-androstane-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	7.42E – 2

Reference: 57TAL
Method: spectrophotometry
pH: 7.0
Evaluation: C

Tallalay reports $K'c(H^+)/c^\circ$ = 7.42E – 9 at an unspecified pH which we assume to be ≈ 7.0. The apparent equilibrium constant given above is based on this result. Few details on the equilibrium measurements were given.

5α-androstane-3α-ol-17-one(aq) + NAD(aq) = 5α-androstane-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.092
298.15	8.0	0.92
298.15	9.0	9.2

Reference: 65BOY/BAR
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.1 mol dm^{-3})
pH: 6.3 – 9.85
Evaluation: B

Boyer *et al.* report $K'c(H^+)/c^\circ$ = 9.2E – 9 over the pH range 6.3 to 9.85. The apparent equilibrium constants given above were calculated from this result. They also report that a plot of log K' versus pH is linear over this pH range. Thus, for the reference reaction:
5α-androstane-3α-ol-17-one(aq) + NAD^-(aq) = 5α-androstane-3,17-dione(aq) + $NADH^{2-}$(aq) + H^+(aq),
K(ref) ≈ 9.2E – 9.

5α-androstane-3α,17β-diol(aq) + NAD(aq) = 5α-androstane-17β-ol-3-one(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	6.68E – 2

Reference: 57TAL
Method: spectrophotometry
pH: 7.0
Evaluation: C

Tallalay reports $K'c(H^+)/c^\circ$ = 6.68E – 9 at an unspecified pH which we assume to be ≈ 7.0. The apparent equilibrium constant given above is based on this result. Few details on the equilibrium measurements were given.

5α-androstane-3α-ol-17-one(aq) + TNAD(aq) =
5α-androstane-3,17-dione(aq) + TNADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.60
298.15	8.0	6.0
298.15	9.0	60.

Reference: 65BOY/BAR
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.1 mol dm^{-3})
pH: 6.3 – 9.85
Evaluation: B

TNAD and TNADH are, respectively, thionicotinamide-adenine dinucleotide and its reduced form. Boyer *et al.* report $K'c(H^+)/c^\circ$ = 6.0E – 8 over the pH range 6.3 to 9.85. The apparent equilibrium constants given above were calculated from this result. They also report that a plot of log K' versus pH is linear over this pH range. Thus, for the reference reaction: 5α-androstane-3α-ol-17-one(aq) + $TNAD^-$(aq) = 5α-androstane-3,17-dione(aq) + $TNADH^{2-}$(aq) + H^+(aq), K(ref) ≈ 6.0E – 8.

5β-androstane-3α-ol-17-one(aq) + NAD(aq) =
5β-androstane-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.57E – 2

Reference: 57TAL
Method: spectrophotometry
pH: 7.0
Evaluation: C

Tallalay reports $K'c(H^+)/c^\circ$ = 1.57E – 9 at an unspecified pH which we assume to be ≈ 7.0. The apparent equilibrium constant given above is based on this result. Few details on the equilibrium measurements were given.

5α-pregnane-3α,17α,21-triol-20-one(aq) + NAD(aq) =
5α-pregnane-17α,21-diol-3,20-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.13E – 2
298.15	8.0	1.13E – 1
298.15	9.0	1.13

Reference: 59TAL/LEV
Method: spectrophotometry
Buffer: phosphate (0.01 – 0.07 mol dm^{-3})
pH: 6.5 – 9.5
Evaluation: B

Tallalay and Levy report $K'c(H^+)/c^\circ$ = 1.13E – 9 over the pH range 6.5 to 9.5. The apparent equilibrium constants given above were calculated from this result.

5β-pregnane-3α,17α,21-triol-20-one(aq) + NAD(aq) =
5β-pregnane-17α,21-diol-3,20-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	2.13E – 2
298.15	8.0	2.13E – 1
298.15	9.0	2.13

Reference: 59TAL/LEV
Method: spectrophotometry
Buffer: phosphate (0.01 – 0.07 mol dm^{-3})
pH: 6.5 – 9.5
Evaluation: B

Tallalay and Levy report $K'c(H^+)/c^\circ$ = 2.13E – 9 over the pH range 6.5 to 9.5. The apparent equilibrium constants given above were calculated from this result.

5β-pregnane-3α,17α,21-triol-11,20-dione(aq) + NAD(aq) =
5β-pregnane-17α,21-diol-3,11,20-trione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.89
298.15	7.8	5.8

Reference: 56TOM
Method: spectrophotometry
Buffer: phosphate (0.020 mol dm^{-3})
pH: 7.0 – 7.8
Evaluation: C

The apparent equilibrium constants given above were calculated from results given in Tomkin's Table IV. The temperature is assumed to be 298.15 K.

5β-pregnane-3α,17α,21-triol-11,20-dione(aq) + NAD(aq) =
5β-pregnane-17α,21-diol-3,11,20-trione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.07E – 2

Reference: 57TAL
Method: spectrophotometry
pH: 7.0
Evaluation: C

Tallalay reports $K'c(H^+)/c^\circ$ = 1.07E – 9 at an unspecified pH which we assume to be ≈ 7.0. The apparent equilibrium constant given above is based on this result. Few details on the equilibrium measurements were given.

5β-pregnane-3α,17α,21-triol-11,20-dione(aq) + NAD(aq) =
5β-pregnane-17α,21-diol-3,11,20-trione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.07E−2
298.15	8.0	1.07E−1
298.15	9.0	1.07

Reference: 59TAL/LEV
Method: spectrophotometry
Buffer: phosphate (0.01 − 0.07 mol dm^{-3})
pH: 6.5 − 9.5
Evaluation: B

Tallalay and Levy report $K'c(H^+)/c^\circ$ = 1.07E−9 over the pH range 6.5 to 9.5. The apparent equilibrium constants given above were calculated from this result.

7.30. Enzyme: 3(or 17)β-hydroxysteroid dehydrogenase (EC 1.1.1.51)

5α-androstane-3β,17α-diol(aq) + NAD(aq) =
5α-androstane-17α-ol-3-one(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	2.11E−2

Reference: 57TAL
Method: spectrophotometry
pH: 7.0
Evaluation: C

Tallalay reports $K'c(H^+)/c^\circ$ = 2.11E−9 at an unspecified pH which we assume to be ≈ 7.0. The apparent equilibrium constant given above is based on this result. Few details on the equilibrium measurements were given.

4-androstene-17β-ol-3-one(aq) + NAD(aq) =
4-androstene-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.65	6.1	3.2E−2
298.65	7.6	1.4
298.65	8.1	4.0
298.65	9.2	8.9E1

Reference: 53TAL/DOB
Method: spectrophotometry
Buffer: orthophosphate (0.03 mol dm^{-3}) and pyrophosphate (0.03 mol dm^{-3})
pH: 6.1 − 9.2
Evaluation: B

The apparent equilibrium constants given above were obtained from Tallalay and Dobson's Fig. 2.

4-androstene-17β-ol-3-one(aq) + NAD(aq) =
4-androstene-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.0	0.026
298.15	7.0	0.26
298.15	8.0	2.6
298.15	9.0	26

Reference: 56TAL/MAR
Method: spectrophotometry
Buffer: orthophosphate (0.033 mol dm^{-3}) and pyrophosphate (0.033 mol dm^{-3})
pH: 6.1 − 9.0
Evaluation: B

Tallalay and Marcus report $K'c(H^+)/c^\circ$ = 2.6E−8 over the pH range 6.1 to 9.0. The apparent equilibrium constants given above were calculated from this result. Results of individual measurements are shown in Tallalay and Marcus' Fig. 2 but are difficult to read accurately. Tallalay and Marcus consider these results to be superior to the earlier results of Tallalay and Dobson [53TAL/DOB]. Also see 63TAL.

4-androstene-17β-ol-3-one(aq) + NAD(aq) =
4-androstene-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.37

Reference: 57TAL
Method: spectrophotometry
pH: 7.0
Evaluation: C

Tallalay reports $K'c(H^+)/c^\circ$ = 3.78E−8 at an unspecified pH which we assume to be ≈ 7.0. The apparent equilibrium constant given above is based on this result. Few details on the equilibrium measurements were given.

4-androstene-17β-ol-3-one(aq) + NAD(aq) =
4-androstene-3,17-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	3.78E−1
298.15	8.0	3.78
298.15	9.0	3.78E2

Reference: 59TAL/LEV
Method: spectrophotometry
Buffer: phosphate (0.01 − 0.07 mol dm^{-3})
pH: 6.5 − 9.5
Evaluation: B

Tallalay and Levy report $K'c(H^+)/c^\circ$ = 3.78E−8 over the pH range 6.5 to 9.5. The apparent equilibrium constants given above were calculated from this result.

5α-pregnane-3β,17α,21-triol-20-one(aq) + NAD(aq) = 5α-pregnane-17α,21-diol-3,20-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.88E−2
298.15	8.0	1.88E−1
298.15	9.0	1.88

Reference: 59TAL/LEV
Method: spectrophotometry
Buffer: phosphate (0.01 − 0.07 mol dm^{-3})
pH: 6.5 − 9.5
Evaluation: B

Tallalay and Levy report $K'c(H^+)/c^\circ$ = 1.88E−9 over the pH range 6.5 to 9.5. The apparent equilibrium constants given above were calculated from this result.

5β-pregnane-3β,17α,21-triol-20-one(aq) + NAD(aq) = 5β-pregnane-17α,21-diol-3,20-dione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	9.9E−3
298.15	8.0	9.9E−2
298.15	9.0	9.9E−1

Reference: 59TAL/LEV
Method: spectrophotometry
Buffer: phosphate (0.01 − 0.07 mol dm^{-3})
pH: 6.5 − 9.5
Evaluation: B

Tallalay and Levy report $K'c(H^+)/c^\circ$ = 9.9E−10 over the pH range 6.5 to 9.5. The apparent equilibrium constants given above were calculated from this result.

5α-pregnane-3β,17α,21-triol-11,20-dione(aq) + NAD(aq) = 5α-pregnane-17α,21-diol-3,11,20-trione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	9.2E−3

Reference: 57TAL
Method: spectrophotometry
pH: 7.0
Evaluation: C

Tallalay reports $K'c(H^+)/c^\circ$ = 9.2E−10 at an unspecified pH which we assume to be ≈ 7.0. The apparent equilibrium constant given above is based on this result. Few details on the equilibrium measurements were given.

5α-pregnane-3β,17α,21-triol-11,20-dione(aq) + NAD(aq) = 5α-pregnane-17α,21-diol-3,11,20-trione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	9.2E−3
298.15	8.0	9.2E−2
298.15	9.0	9.2E−1

Reference: 59TAL/LEV
Method: spectrophotometry
Buffer: phosphate (0.01 − 0.07 mol dm^{-3})
pH: 6.5 − 9.5
Evaluation: B

Tallalay and Levy report $K'c(H^+)/c^\circ$ = 9.2E−10 over the pH range 6.5 to 9.5. The apparent equilibrium constants given above were calculated from this result.

7.31. Enzyme: lactaldehyde reductase (NADPH) (EC 1.1.1.55)

1,2-propanediol(aq) + NADP(aq) = L-lactaldehyde(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.4	6.0E−5
298.15	9.0	2.4E−4
298.15	9.5	7.59E−4
298.15	10.0	2.4E−3

Reference: 60GUP/ROB
Method: spectrophotometry
Buffer: Tris
pH: 8.4 − 10.0
Evaluation: C

Gupta and Robinson report $K'c(H^+)/c^\circ$ = 2.4E−13 over the pH range 8.4 to 10.0. The apparent equilibrium constants given above were calculated from this result.

7.32. Enzyme: ribitol 2-dehydrogenase (EC 1.1.1.56)

ribitol(aq) + NAD(aq) = D-ribulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
310.15	7.4	3.1E−3
310.15	8.0	9.6E−3
310.15	8.5	7.0E−2

Reference: 58FRO
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 7.4 − 8.5
Evaluation: B

The apparent equilibrium constants given above are the averages of the forward and reverse direction results given in Fromm's Tables III and IV, respectively. Also see listings under EC 1.1.1.9 and EC 1.1.1.14.

ribitol(aq) + NAD(aq) = D-ribulose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
301.15	8.0	7.17E−3

Reference: 59NOR/FRO
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 8.0
Evaluation: B

Also see listings under EC 1.1.1.9 and EC 1.1.1.14.

7.33. Enzyme: 3-hydroxypropionate dehydrogenase (EC 1.1.1.59)

3-hydroxypropanoate(aq) + NAD(aq) = 3-oxopropanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.0	9E−3

Reference: 59DEN/ROB
Method: chromatography and spectrophotometry
Buffer: pyrophosphate (0.017 mol dm^{-3})
pH: 9.0
Evaluation: B

Den *et al.* report $K'c(H^+)/c^\circ$ = 9E−12 at pH = 9.0. We calculate K' = 9E−3 from this result. The temperature is assumed to be 298.15 K.

7.34. Enzyme: 2-hydroxy-3-oxopropionate reductase (EC 1.1.1.60)

(*R*)-glycerate(aq) + NAD(aq) = 2-hydroxy-3-oxopropanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
296.15	7.49	1.9E−6
296.15	8.49	1.60E−5

Reference: 61GOT/KOR
Method: spectrophotometry
Buffer: potassium phosphate (0.10 mol dm^{-3})
pH: 7.49−8.49
Evaluation: B

(*R*)-glycerate(aq) + NAD(aq) = 2-hydroxy-3-oxopropanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	5.3E−5

Reference: 68KOH
Method: spectrophotometry
Buffer: {Tris (0.2 mol dm^{-3}) + HCl} and phosphate (0.15 mol dm^{-3})
pH: 7.5
Evaluation: C

Kohn reports $K'c(H^+)/c^\circ$ = 1.7E−12 at pH = 7.5. The apparent equilibrium constant given above was calculated from this result. Equilibrium was not approached from both directions.

7.35. Enzyme: 4-hydroxybutyrate dehydrogenase (EC 1.1.1.61)

4-hydroxybutanoate(aq) + NAD(aq) = 4-oxobutanoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.14	3.9
298.15	8.00	25.

Reference: 60NIR/JAK
Method: spectrophotometry
Buffer: Tris + HCl
pH: 7.14−8.00
Evaluation: C

Nirenberg and Jakoby report $K'c(H^+)$ at pH = 7.14 and 8.00. The apparent equilibrium constants given above were calculated from these results. The temperature is assumed to be 298.15 K.

7.36. Enzyme: estradiol 17β-dehydrogenase (EC 1.1.1.62)

estradiol-17β(aq) + NAD(aq) = estrone(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.00	0.18
298.15	8.00	1.8
298.15	9.00	18
298.15	10.00	180

Reference: 58LAN/ENG
Method: spectrophotometry
Buffer: phosphate, Tris, and (carbonate + bicarbonate)
pH: 6.47−10.14
Evaluation: C

Langer and Engel report $K'c(H^+) \approx$ 1.8E−8 over the pH range 6.47 to 10.14. The apparent equilibrium constants given above were calculated from this result.

7.37. Enzyme: mannitol 2-dehydrogenase (EC 1.1.1.67)

D-mannitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
310.15	8.05	5.6E−2

Reference: 63EDM/WRI
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 8.05
Evaluation: B

Edmundowicz and Wriston report $K'c(H^+)/c^\circ$ = 5.0E−12 at pH = 8.05. The apparent equilibrium constant given above was calculated from this result. Also see listings under EC 1.1.1.14.

D-mannitol(aq) + NAD(aq) = D-fructose(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.2	0.084

Reference: 63MAR/BAR
Method: spectrophotometry
Buffer: Tris (0.16 mol dm^{-3})
pH: 7.2
Evaluation: C

Martinez *et al.* report $K'c(H^+) \approx$ 5.3E−9 at pH = 7.2. The apparent equilibrium constant given above was calculated from this result. Also see listings under EC 1.1.1.14.

7.38. Enzyme: gluconate 5-dehydrogenase (EC 1.1.1.69)

D-gluconate(aq) + NADP(aq) = 5-oxo-D-gluconate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	7.5	1.1E−4
303.15	8.0	3.5E−4
303.15	8.5	1.1E−3
303.15	9.0	3.5E−3

Reference: 63OKA
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})
pH: 7.3−9.1
Evaluation: C

Okamoto report $K'c(H^+)/c^\circ$ = 3.5E−12 over the pH range 7.3 to 9.1. The results given above were calculated from this result.

7.39. Enzyme: glycerol dehydrogenase (NADP+) (EC 1.1.1.72)

glycerol(aq) + NADP(aq) = (*R*)-glyceraldehyde(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
310.15	7.0	16.7

Reference: 72KOR/HUR
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 7.0
Evaluation: C

Kormann *et al.* report $K'c(H^+)/c^\circ$ = 1.67E−6 at pH = 7.0. The apparent equilibrium constant given above was calculated from this result.

7.40. Enzyme: glyoxylate reductase (NADP+) (EC 1.1.1.79)

glycolate(aq) + NADP(aq) = glyoxylate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.77	1.4E−10
298.15	7.83	1.4E−10
298.15	7.88	3.6E−10
298.15	7.90	3.5E−10
298.15	7.92	9.0E−11

Reference: 66CAR/HUL
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 7.77−7.92
Evaluation: B

7.41. Enzyme: aryl-alcohol dehydrogenase (EC 1.1.1.90)

benzyl alcohol(aq) + NAD(aq) = benzaldehyde(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
300.15	9.5	9.7E−2

Reference: 88MAC/FEW
Method: spectrophotometry
Buffer: Bicine (0.1 mol dm^{-3}) + NaOH
pH: 9.5
Evaluation: C

MacKintosh and Fewson report $K'c(H^+)/c^\circ$ = 3.08E−11 at pH = 9.5. The apparent equilibrium constant was calculated from this result. Also see 80COO/BLA under EC 1.1.1.1.

7.42. Enzyme: phosphoglycerate dehydrogenase (EC 1.1.1.95)

3-phospho-D-glycerate(aq) + NAD(aq) =
3-phosphohydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	1.0E−4

Reference: 65WAL/SAL
Method: spectrophotometry
Buffer: Tris (0.25 mol dm^{-3}) + HCl
pH: 8.0
Evaluation: C

Walsh and Sallach report $K'c(H^+)/c^\circ$ = 1E−12 at pH = 8.0. The apparent equilibrium constant given above was calculated from this result. This is an approximate result obtained from kinetic data.

3-phospho-D-glycerate(aq) + NAD(aq) =
3-phosphohydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	1.9E−3
310.15	7.5	2.2E−3

Reference: 68SUG/PIZ
Method: spectrophotometry and fluorometry
Buffer: phosphate (0.020 mol dm^{-3}) and Tris (0.020 mol dm^{-3})
pH: 7.5
Evaluation: B

Sugimoto and Pizer report $K'c(H^+)$ at pH = 7.5 at T = 298.15 K and at 310.15 K. The apparent equilibrium constants given above were calculated from these results.

3-phospho-D-glycerate(aq) + NAD(aq) =
3-phosphohydroxypyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	c($MgCl_2$)	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
311.15	6.76	0.0	0.25	1.53E−6
311.15	6.77	0.0	0.25	1.64E−6
311.15	7.00	0.0	0.25	3.14E−6
311.15	7.02	0.0	0.25	3.10E−6
311.15	7.03	0.0	0.25	3.14E−6
311.15	7.34	0.0	0.25	1.28E−5
311.15	7.53	0.0	0.25	1.12E−5
311.15	7.54	0.0	0.25	1.23E−5
311.15	7.56	0.0	0.25	1.09E−5
311.15	7.64	0.0	0.25	1.46E−5
311.15	7.92	0.0	0.25	2.86E−5
311.15	8.10	0.0	0.25	3.28E−5
311.15	7.12	0.0050	0.25	2.83E−6
311.15	7.12	0.020	0.25	2.61E−6
311.15	7.00	0.0	0.15	2.57E−6
311.15	7.00	0.0	0.75	3.77E−6
298.15	7.32	0.0	0.25	2.45E−6
298.15	7.30	0.0	0.25	2.28E−6

Reference: 81MER/MCA
Method: enzymatic assay and spectrophotometry
pH: 6.76−8.10
Cofactor(s): $MgCl_2$
Evaluation: A

Merrill *et al.* have performed equilibrium calculations to obtain equilibrium constants for the reference reaction which we have written as: 3-phospho-D-glycerate^{3-}(aq) + NAD^-(aq) = 3-phosphohydroxypyruvate^{3-}(aq) + $NADH^{2-}$(aq) + H^+(aq). For this reaction, $K_c(I_c$ = 0.25 mol dm^{-3}, T = 311.15 K) = 3.45E−13 and $K_c(I_c$ = 0.25 mol dm^{-3}, T = 298.15 K) = 1.30E−13.

7.43. Enzyme: diiodophenylpyruvate reductase (EC 1.1.1.96)

β-(3,5-diiodo-4-hydroxyphenyl)lactate(aq) + NAD(aq) =
β-(3,5-diiodo-4-hydroxyphenyl)pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.5	8.2E−7

Reference: 70NAK/TSU
Method: spectrophotometry
Buffer: phosphate (0.080 mol dm^{-3})
pH: 6.5
Evaluation: C

Nakano *et al.* report $K'c(H^+) \approx$ 2.6E−13 at pH = 6.5. The apparent equilibrium constant given above was calculated from this result.

7.44. Enzyme: 3-hydroxybenzyl-alcohol dehydrogenase (EC 1.1.1.97)

3-hydroxybenzyl alcohol(aq) + NADP(aq) =
3-hydroxybenzaldehyde(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	7.6	0.18

Reference: 72FOR/GAU
Method: spectrophotometry
Buffer: *N*-tris(hydroxymethyl)methyl-2-aminoethanesulfonic acid
pH: 7.6
Evaluation: C

7.45. Enzyme: 3-oxoacyl-[acyl-carrier protein] reductase (EC 1.1.1.100)

(3*R*)-3-hydroxybutanoyl-[acyl-carrier protein](aq) + NADP(aq) = 3-oxobutanoyl-[acyl-carrier protein](aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.25
298.15	9.0	16

Reference: 66TOO/WAK
Method: spectrophotometry
Buffer: potassium phosphate (0.125 mol dm^{-3})
pH: 7.0–9.0
Evaluation: B

Toomey and Wakil report $\{K'c(H^+)\}^{-1}$ = 3.93E7 at pH = 7.0 and $\{K'c(H^+)\}^{-1}$ = 6.20E7 at pH = 9.0. The apparent equilibrium constants given above were calculated from these results. The temperature is assumed to be 298.15 K.

7.46. Enzyme: carnitine 3-dehydrogenase (EC 1.1.1.108)

L-carnitine(aq) + NAD(aq) = 3-dehydrocarnitine(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	7.0	1.3E−4
303.15	8.0	1.3E−3
303.15	9.0	1.3E−2

Reference: 68AUR/KLE
Method: spectrophotometry
Buffer: Tris (0.05 mol dm^{-3}) + HCl
pH: 6.9–9.1
Cofactor(s):
Evaluation: B

Aurich *et al.* report $K'c(H^+)/c^\circ$ = 1.3E−11 over the pH range 6.9 to 9.1. The apparent equilibrium constants given above were calculated from this result.

7.47. Enzyme: indolelactate dehydrogenase (EC 1.1.1.110)

indole-3-lactate(aq) + NAD(aq) = indole-3-pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
310.15	7.0	6.3E2

Reference: 68JEA/DEM
Method: spectrophotometry
Buffer: potassium phosphate
pH: 7.0
Evaluation: C

Jean and DeMoss report $K'c(H^+)/c^\circ$ = 6.3E−6 at pH = 7.0. The apparent equilibrium constant given above was calculated from this result.

7.48. Enzyme: glucose 1-dehydrogenase ($NADP^+$) (EC 1.1.1.119)

D-glucose(aq) + NADP(aq) = D-glucono-1,5-lactone(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.4	3.4

Reference: 65LEE/DOB
Method: spectrophotometry
pH: 6.4
Evaluation: C

Lee and Dobrogosz report $K'c(H^+)/c^\circ$ = 1.34E−6 at pH = 6.4. The apparent equilibrium constant given above was calculated from this result. The temperature is assumed to be 298.15 K.

D-glucose(aq) + NADP(aq) = D-glucono-1,5-lactone(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	6.13	0.297
303.15	6.55	1.13
303.15	6.93	3.52

Reference: 68AVI/ALR
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3})
pH: 6.13–6.93
Evaluation: C

The reaction mixture described in Avigad *et al.*'s Table IV may not have reached equilibrium. The apparent equilibrium constants given above were calculated from Avigad *et al.*'s results for $K'c(H^+)$ over the pH range 6.13 to 6.93.

7.49. Enzyme: fructose 5-dehydrogenase ($NADP^+$) (EC 1.1.1.124)

D-fructose(aq) + NADP(aq) = 5-dehydro-D-fructose(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	6.20	8.56E−5
303.15	6.55	1.77E−4
303.15	6.80	3.03E−4
303.15	7.10	6.52E−4

Reference: 66AVI/ENG
Method: spectrophotometry
Buffer: Tris (0.017 mol dm^{-3}) and potassium phosphate (0.0017 mol dm^{-3})
pH: 6.20−7.10
Evaluation: C

The apparent equilibrium constants given above were calculated from the results of Avigad *et al.* for $K'c(H^+)$ over the pH range 6.20 to 7.10. The position of equilibrium was not approached from two different directions.

7.50. Enzyme: 2-deoxy-D-gluconate 3-dehydrogenase (EC 1.1.1.125)

2-deoxy-D-gluconate(aq) + NAD(aq) =
2-deoxy-3-dehydro-D-gluconate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
308.15	9.0	3.4E−3

Reference: 65EIC/CYN
Method: spectrophotometry
Buffer: sodium glycinate (0.12 mol dm^{-3})
pH: 9.0
Evaluation: C

This is an approximate result. Also, equilibrium was not approached from both directions. It is assumed that the result of 3.4E−12 which Eichorn and Cynkin report is $K'c(H^+)$ and that the pH = 9.0. The apparent equilibrium constant given above was calculated from this result.

7.51. Enzyme: L-threonate 3-dehydrogenase (EC 1.1.1.129)

L-threonate(aq) + NAD(aq) = 3-oxo-L-threonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.9	5.53E−3
298.15	7.0	3.42E−4
298.15	7.75	1.25E−3

Reference: 64ASP/JAK
Method: spectrophotometry
Buffer: phosphate (0.3 mol dm^{-3})
pH: 6.9−7.75
Evaluation: C

The temperature of reaction is assumed to be 298.15 K. The apparent equilibrium constants given above were calculated from Aspen and Jakoby's results for $K'c(H^+)$ over the pH range 6.9 to 7.75.

7.52. Enzyme: sorbitol-6-phosphate 2-dehydrogenase (EC 1.1.1.140)

D-sorbitol 6-phosphate(aq) + NAD(aq) =
D-fructose 6-phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.31	2.2

Reference: 59SHO/PRI
Buffer: Tris (0.035 mol dm^{-3})
pH: 9.31
Cofactor(s): $MgCl_2$ (0.0018 mol dm^{-3})
Evaluation: C

Shockley and Pride report $K'c(H^+)/c^\circ$ = 1.07E−9 at pH = 9.0. The apparent equilibrium constant given above was calculated from this result. The temperature is assumed to be 298.15 K.

7.53. Enzyme: 15-hydroxyprostaglandin dehydrogenase (NAD^+) (EC 1.1.1.141)

prostaglandin E_1(aq) + NAD(aq) = 15-oxo-prostaglandin E_1(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.0	0.065
298.15	7.0	0.65
298.15	8.0	6.5

Reference: 75BRA/JAR
Method: spectrophotometry
Buffer: potassium phosphate (0.093 mol dm^{-3})
pH: 6.0−8.0
Evaluation: B

These investigators report $K'c(H^+)/c^\circ$ = 6.5E−8 over the pH range 6.0 to 8.0. The apparent equilibrium constants given above were calculated from this result.

7.54. Enzyme: 21-hydroxysteroid dehydrogenase (NAD^+) (EC 1.1.1.150)

4-pregnene-11β,17α,21-triol-3,20-dione(aq) + NAD(aq) = 4-pregnene-11β,17α-diol-3,20,21-trione(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
303.15	6.9	7.8E−8
303.15	8.5	9.8E−4

Reference: 63MON/WHI
Method: radioactivity and spectrophotometry
Buffer: sodium phosphate (0.13 mol dm^{-3})
pH: 6.9−8.5
Evaluation: B

The apparent equilibrium constants given above were calculated from the results given in Monder and White's Table VIII.

7.55. Enzyme: sepiapterin reductase (EC 1.1.1.153)

7,8-dihydrobiopterin(aq) + NADP(aq) = sepiapterin(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.60	1.3E−1
298.15	7.65	4.3E−2
298.15	7.80	2.1E−2

Reference: 71KAT
Method: spectrophotometry
Buffer: potassium phosphate
pH: 7.60−7.80
Evaluation: B

7,8-dihydrobiopterin(aq) + NADP(aq) = sepiapterin(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.0	0.045

Reference: 82SUE/KAT
Method: spectrophotometry
Buffer: potassium phosphate (0.02 mol dm^{-3})
pH: 7.88−8.06
Evaluation: B

Sueoka and Katoh report $\{K'c(H^+)/c^\circ\}^{-1} = (2.20 \pm 0.46) \times 10^9$ for 7.88 < pH < 8.06. The apparent equilibrium constant was calculated from this result.

7,8-dihydrobiopterin(aq) + NADP(aq) = sepiapterin(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.88	0.045
298.15	7.93	0.037
298.15	7.95	0.039
298.15	8.02	0.046
298.15	8.06	0.038

Reference: 83KAT/SUE
Method: spectrophotometry
Buffer: potassium phosphate (0.020 mol dm^{-3})
pH: 7.88−8.06
Evaluation: B

7.56. Enzyme: coniferyl-alcohol dehydrogenase (EC 1.1.1.194)

coniferyl alcohol(aq) + NADP(aq) = coniferyl aldehyde(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	7.8	0.18
303.15	8.0	0.28
303.15	8.8	1.8

Reference: 75WYR/GRI
Method: spectrophotometry
Buffer: phosphate (0.20 mol dm^{-3})
pH: 7.8−8.8
Evaluation: C

Wyrambik and Grisebach report $K'c(H^+)/c^\circ = 2.8E-9$ over the pH range 7.8 to 8.8. The apparent equilibrium constants given above were calculated from this result.

7.57. Enzyme: (*R*)-2-hydroxyglutarate dehydrogenase (EC 1.1.1.a)

(*R*)-2-hydroxyglutarate(aq) + NAD(aq) = 2-oxoglutarate(aq) + NADH(aq)

$\frac{T}{K}$	buffer	pH	K'
298.15	phosphate	7.0	1.47E−5
298.15	Tris + HCl	7.0	1.83E−5

Reference: 87BUC/MIL
Method: spectrophotometry
Buffer: (Tris + HCl) and phosphate
pH: 6.91−7.44
Evaluation: A
Buckel and Miller report $K'c(H^+)/c^\circ = 1.47E-12$ for phosphate buffer and $K'c(H^+)/c^\circ = 1.83E-12$ for Tris buffer. They prefer the result determined with the phosphate buffer. The apparent equilibrium constants given above were calculated from these results. The ionic strength was adjusted to I_c = 0.1 mol dm^{-3} with NaCl.

7.58. Enzyme: sorbitol-6-phosphate dehydrogenase ($NADP^+$) (EC 1.1.1.b)

D-sorbitol 6-phosphate(aq) + NADP(aq) =
D-glucose 6-phosphate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
303.15	8.66	0.234

Reference: 81HIR
Method:
Buffer: Tris (0.05 mol dm^{-3}) + HCl
pH: 8.66
Evaluation: C

Hirai reports $K'c(H^+)/c^\circ$ = 5.12E−10 at pH = 8.66. The apparent equilibrium constant was calculated from this result. The position of equilibrium was approached from only one direction.

7.59. Enzyme: gluconate 2-dehydrogenase (EC 1.1.99.3)

D-gluconate(aq) + NADP(aq) = 2-oxo-D-gluconate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
293.15	7.12	8.20E−4
293.15	7.86	3.37E−3
293.15	8.31	1.13E−2
293.15	6.98	4.74E−4
293.15	7.24	6.37E−4
293.15	7.79	2.99E−3
293.15	8.25	1.28E−2
293.15	7.03	7.23E−4
293.15	7.39	9.22E−4
293.15	7.89	3.39E−3
293.15	8.36	1.16E−2

Reference: 59DEL/DEF
Method: spectrophotometry
Buffer: phosphate and (Tris + HCl)
pH: 6.98−8.36
Evaluation: B

The apparent equilibrium constants given above were calculated from the results in DeLey and Defloor's Table I.

7.60. Enzyme: lactate-malate transhydrogenase (EC 1.1.99.7)

(*S*)-lactate(aq) + oxaloacetate(aq) = (*S*)-malate(aq) + pyruvate(aq)

$\frac{T}{K}$	pH	K'
303.15	7.5	1.8

Reference: 66ALL
Method: enzymatic assay and spectrophotometry
Buffer: Tris + HCl
pH: 7.5
Evaluation: B

(*S*)-lactate(aq) + oxaloacetate(aq) = (*S*)-malate(aq) + pyruvate(aq)

$\frac{T}{K}$	pH	K'
297.15	7.8	4.3

Reference: 69DOL
Method: enzymatic assay and spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 7.8
Evaluation: B

7.61. Enzyme: glucoside 3-dehydrogenase (EC 1.1.99.13)

lactose(aq) + 2 cytochrome *c*(aq) = 3-oxolactose(aq) + 2 reduced cytochrome *c*(aq)

$\frac{T}{K}$	pH	K'
298.15	5.92	6.3

Reference: 68BEE/DEL
Method: spectrophotometry
Buffer: citrate + phosphate (0.1 mol dm^{-3})
pH: 5.92
Evaluation: C

Van Beeumen and De Ley report $K'\{c(H^+)\}^2$ = 1E−11. The apparent equilibrium constant given above was calculated from this result. The position of equilibrium was approached from only one direction.

7.62. Enzyme: formate dehydrogenase (EC 1.2.1.2)

formate(aq) + NAD(aq) = carbon dioxide(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.2	≈420

Reference: 76RUS/MUL
Method: spectrophotometry
Buffer: histidine hydrochloride (0.071 mol dm^{-3})
pH: 6.2
Evaluation: D

Ruschig *et al.* determined only the concentration of NADH. They then compared this result with the concentration of NADH calculated from an assumed apparent equilibrium constant of 420. They found that this calculated concentration was close to the measured concentration. Unfortunately, they did not report sufficient information to allow us to calculate an apparent equilibrium constant directly. The temperature is assumed to be 298.15 K.

formate(aq) + NAD(aq) = carbon dioxide(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	6.02	−15.19
298.15	6.44	−14.85
298.15	7.48	−14.02
298.15	8.01	−14.18

Reference: 79REK/EGO and 80REK/EGO
Method: calorimetry
Buffer: sodium phosphate (0.050 mol dm^{-3})
pH: 6.02 − 8.01
Evaluation: B

The results given above have not been corrected for the heat of protonation of the buffer.

7.63. Enzyme: acetaldehyde dehydrogenase (acetylating) (EC 1.2.1.10)

acetaldehyde(aq) + CoA(aq) + NAD(aq) = acetyl-CoA(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.89	7.2E3
298.15	7.80	8.2E3
298.15	7.30	2.0E3

Reference: 53BUR/STA
Method: spectrophotometry
Buffer: imidazole (0.033 mol dm^{-3}) + HCl
pH: 7.30 − 7.89
Evaluation: B

The apparent equilibrium constants given above were calculated from the results in Burton and Stadtman's Table VIII. They also report $K_c'c(H^+)/c^\circ$ = 1.2E−4. The temperature is assumed to be 298.15 K.

acetaldehyde(aq) + CoA(aq) + NAD(aq) = acetyl-CoA(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.0	1.2E3

Reference: 55STA/BUR
Buffer: Tris
pH: 7.0
Evaluation: C

Few details on the equilibrium measurements are given.

7.64. Enzyme: aspartate-semialdehyde dehydrogenase (EC 1.2.1.11)

L-aspartate 4-semialdehyde(aq) + NADP(aq) + orthophosphate(aq) = L-4-aspartyl phosphate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	5.70	2.0E2
298.15	4.40	7.4

Reference: 55BLA/WRI2
Method: enzymatic assay
Buffer: sodium borate (0.1 mol dm^{-3}) and imidazole chloride (0.1 mol dm^{-3})
pH: 4.40 − 5.70
Evaluation: B

The apparent equilibrium constant given above was calculated from Black and Wright's Table III. The temperature was assumed to be 298.15 K.

L-aspartate-4-semialdehyde(aq) + NADP(aq) + orthophosphate(aq) = L-4-aspartyl phosphate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.0	≈33

Reference: 62BLA
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 8.0 − 9.0
Evaluation: D

Black reports $\{K_c'c(H^+)\}^{-1} \approx$ 3.0E−6 at pH = 8.0. The apparent equilibrium constant given above was calculated from this result. Few details on the equilibrium investigation are reported.

7.65. Enzyme: glyceraldehyde-3-phosphate dehydrogenase (EC 1.2.1.12)

D-glyceraldehyde 3-phosphate(aq) + (aminomethyl)phosphonate(aq) + NAD(aq) = (3-phospho-D-glycerol-aminomethyl)phosphonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	3.8E−3

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2 − 8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + (chloroethyl)phosphonate(aq) + NAD(aq) = (3-phospho-D-glycerol-chloroethyl)phosphonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	9.3E−2

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2−8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + (chloromethyl)phosphonate(aq) + NAD(aq) = (3-phospho-D-glycerol-chloromethyl)phosphonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	2.4E−2

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2−8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + (ethyl)phosphonate(aq) + NAD(aq) = (3-phospho-D-glycerol-ethyl)phosphonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	0.60

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2−8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + (methoxy)phosphonate(aq) + NAD(aq) = (3-phospho-D-glycerol-methoxy)phosphonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	1.0E−2

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2−8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + (methyl)phosphonate(aq) + NAD(aq) = (3-phospho-D-glycerol-methyl)phosphonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	0.41

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2−8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + orthophosphate(aq) + NAD(aq) = 3-phospho-D-glyceroyl phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
296.15	7.2	0.36
296.15	8.0	1.3
296.15	8.3	0.92

Reference: 45DRA/MEY
Method: spectrophotometry
pH: 7.2−8.3
Evaluation: C

Drabkin and Meyerhoff state that these results are approximate.

D-glyceraldehyde 3-phosphate(aq) + orthophosphate(aq) + NAD(aq) = 3-phospho-D-glyceroyl phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	6.0	0.71
298.15	6.95	0.69
298.15	7.0	0.55
298.15	7.15	1.4
298.15	8.2	≈17.

Reference: 47MEY/OES
Method: spectrophotometry
Buffer: pyrophosphate, orthophosphate, and veronal-acetate
pH: 6.0−8.2
Evaluation: C

Meyerhof and Oesper state that this apparent equilibrium constant is independent of temperature over the range T = 295 K to 305 K. The apparent equilibrium constants given above are averages of the results given in Meyerhof and Oesper's Tables I and III.

D-glyceraldehyde 3-phosphate(aq) + orthophosphate(aq) + NAD(aq) = 3-phospho-D-glyceroyl phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.09	0.0984
298.15	7.08	0.156
298.15	7.85	0.193
298.15	8.10	0.187

Reference: 50COR/VEL
Method: enzymatic assay and spectrophotometry
pH: 7.09 – 8.10
Evaluation: C

The temperature is assumed to be 298.15 K. The results given above were calculated from the results given in Cori *et al.*'s Table V. In doing this calculation, we assumed that the equilibrium concentrations of NADH(aq) and of 3-phospho-D-glyceroylphosphate(aq) were equal to $\{c(\mathrm{NAD})_{\mathrm{initial}} - c(\mathrm{NAD})_{\mathrm{final}}\}$. The apparent equilibrium constants given above do not agree with those given in column 8 in Table V of Cori *et al.* Cori *et al.* have also recalculated the earlier results of Meyerhof and Oesper [47MEY/OES].

D-glyceraldehyde 3-phosphate(aq) + orthophosphate(aq) + NAD(aq) = 3-phospho-D-glyceroyl phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	4.2E – 2

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2 – 8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + orthophosphate(aq) + NAD(aq) = 3-phospho-D-glyceroyl phosphate(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{c(Mg^{2+})}{mol\ dm^{-3}}$	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
311.15	7.05	≤ 5E – 6	0.25	0.58
311.15	7.15	≤ 5E – 6	0.25	0.64
311.15	7.09	≤ 5E – 6	0.25	0.62
311.15	7.11	≤ 5E – 6	0.25	0.62
311.15	6.93	≤ 5E – 6	0.25	0.45
311.15	6.92	≤ 5E – 6	0.25	0.43
311.15	6.92	≤ 5E – 6	0.25	0.44
311.15	6.87	≤ 5E – 6	0.25	0.41
311.15	6.52	≤ 5E – 6	0.25	0.17
311.15	6.91	≤ 5E – 6	0.25	0.42
311.15	6.91	3.1E – 4	0.25	0.43
311.15	6.91	6.4E – 4	0.25	0.41
311.15	6.91	9.2E – 4	0.25	0.42
311.15	6.91	1.27E – 3	0.25	0.44
311.15	6.91	1.51E – 3	0.25	0.43
311.15	7.10	≤ 5E – 6	0.04	0.205
311.15	7.10	≤ 5E – 6	0.10	0.337
311.15	7.10	≤ 5E – 6	0.18	0.433
311.15	7.10	≤ 5E – 6	0.21	0.487
311.15	7.10	≤ 5E – 6	0.25	0.616
311.15	7.10	≤ 5E – 6	0.40	0.789
311.15	7.10	≤ 5E – 6	0.60	1.015

Reference: 79COR/LEA
Method: enzymatic assay and spectrophotometry
Buffer: potassium phosphate
pH: 6.52 – 7.15
Cofactor(s): $MgCl_2$
Evaluation: A

The apparent equilibrium constants given above were calculated from the results given in Cornell *et al.*'s Tables I, II, and III. In several cases, we obtained K_c' from $K_c' c(H^+)$ and the pH given by Cornell *et al.* The pH for the results given in Table II and III were taken to be 6.91 and 7.10, respectively.

D-glyceraldehyde 3-phosphate(aq) + phosphonate(aq) + NAD(aq) = (3-phospho-D-glyceroyl)phosphonate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.4	2.0E – 2

Reference: 79BYE/SHE
Method: spectrophotometry
pH: 8.2 – 8.6
Evaluation: C

The apparent equilibrium constant given above was obtained from Byers *et al.*'s Fig. 1.

D-glyceraldehyde 3-phosphate(aq) + ADP(aq) + NAD(aq) + orthophosphate(aq) = 3-phospho-D-glycerate(aq) + ATP(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
311.15	6.88	0.25	28
311.15	6.89	0.25	41
311.15	6.91	0.25	45
311.15	6.92	0.25	35
311.15	6.94	0.25	41
311.15	6.97	0.25	68
311.15	6.98	0.25	61
311.15	6.99	0.25	58
311.15	7.00	0.25	59
311.15	7.01	0.25	71
311.15	7.02	0.25	78

Reference: 68VEE
Method: spectrophotometry
Buffer: phosphate
pH: 6.88 – 7.02
Cofactor(s): $MgCl_2$ (0.0006 mol dm^{-3})
Evaluation: A

Phosphoglycerate kinase (EC 2.7.2.3) was also present. Veech reports $K_c'c(H^+)/c^\circ$ in his Table III.5. The apparent equilibrium constants given above were calculated from these results. Also see 70VEE/RAI.

D-glyceraldehyde 3-phosphate(aq) + ADP(aq) + NAD(aq) + orthophosphate(aq) = 3-phospho-D-glycerate(aq) + ATP(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
311.15	7.00	59

Reference: 70VEE/RAI
Method: spectrophotometry
Buffer: phosphate
pH: 6.88 – 7.02
Cofactor(s): $MgCl_2$ (0.0006 mol dm^{-3})
Evaluation: A

Phosphoglycerate kinase (EC 2.7.2.3) was also present. Veech *et al.* report $K_c'c(H^+)/c^\circ$ = 5.9E – 6 over the pH range 6.88 to 7.02. The apparent equilibrium constant given above was calculated from this result. The ionic strength was 0.25 mol dm^{-3}. Also see 68VEE.

D-glyceraldehyde 3-phosphate(aq) + ADP(aq) + NAD(aq) + orthophosphate(aq) = 3-phospho-D-glycerate(aq) + ATP(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{c(Mg^{2+})}{mol\ dm^{-3}}$	K_c'
310.15	7.0	2.34E – 3	1.93E3
310.15	7.0	2.19E – 3	1.54E3
310.15	7.0	8.91E – 4	1.31E3
310.15	7.0	7.41E – 4	1.13E3
310.15	7.0	3.80E – 4	9.75E2
310.15	7.0	3.31E – 4	8.17E2
310.15	7.0	2.09E – 4	6.22E2
310.15	7.0	1.66E – 4	6.70E2
310.15	7.0	1.48E – 4	5.86E2
310.15	7.0	8.32E – 5	4.90E2
310.15	7.0	6.17E – 5	4.12E2
310.15	7.0	2.34E – 5	3.53E2
310.15	7.0	1.78E – 5	2.88E2
310.15	7.0	3.02E – 6	3.06E2
310.15	7.0	2.00E – 6	2.88E2

Reference: 78MEE/AKE
Method: spectrophotometry
Buffer: phosphate (0.020 mol dm^{-3})
pH: 7.0
Cofactor(s): $MgCl_2$
Evaluation: B

Phosphoglycerate kinase (EC 2.7.2.3) was also present. The apparent equilibrium constants given above were taken from van der Meer *et al.*'s Fig. 2.

D-glyceraldehyde 3-phosphate(aq) + ADP(aq) + NAD(aq) + orthophosphate(aq) = 3-phospho-D-glycerate(aq) + ATP(aq) + NADH(aq)

$\frac{T}{K}$	pH	$\frac{c(Mg^{2+})}{mol\ dm^{-3}}$	K_c'
311.15	7.0	1.2E – 3	2.17E3

Reference: 79COR/LEA
Method: enzymatic assay and spectrophotometry
Buffer: potassium phosphate
pH: 6.90 – 7.08
Cofactor(s): $MgCl_2$
Evaluation: A

Phosphoglycerate kinase (EC 2.7.2.3) was also present. The apparent equilibrium constant given above was calculated from the results given in Cornell *et al.*'s Table V.

7.66. Enzyme: glyoxylate dehydrogenase (acylating) (EC 1.2.1.17)

glyoxylate(aq) + CoA(aq) + NADP(aq) = oxalyl-CoA(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'_c
298.15	6.60	24.3
298.15	6.70	38.5
298.15	6.80	44.7
298.15	6.85	51.8
298.15	6.98	73.4

Reference: 63QUA
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 6.70 – 6.98
Evaluation: B

The apparent equilibrium constants given above were calculated from Quayle's Table 1.

7.67. Enzyme: formate dehydrogenase ($NADP^+$) (EC 1.2.1.43)

formate(aq) + NADP(aq) = carbon dioxide(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
328.15	7.5	≈6.5E2

Reference: 83YAM/SAI
Method: spectrophotometry
Buffer: triethanolamine-maleate (0.1 mol dm^{-3})
pH: 7.5
Evaluation: C

The apparent equilibrium constant given above was calculated from the initial concentrations of bicarbonate and NADPH and the final concentration of NADP given by Yamamoto *et al.* Note that Yamamoto *et al.* state that "0.106 mM of NADPH is present at the completion of the reaction". However, it is clear from the context of their discussion and calculation that this is actually the concentration of the NADP at equilibrium. The position of equilibrium for this reaction was approached from only one direction.

7.68. Enzyme: succinate dehydrogenase (EC 1.3.99.1)

2 succinate(aq) + O_2(aq) = 2 fumarate(aq) + 2 H_2O(l)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	7.4	−72.4

Reference: 67POE/GUT
Method: calorimetry
Buffer: phosphate (0.10 mol dm^{-3}) and Tris (0.10 mol dm^{-3})
pH: 7.4
Evaluation: B

The result given above is the average of the results obtained in phosphate and Tris buffers. Since the results were the same in both buffers, there is no change in binding of H^+(aq) and the correction for the enthalpy of protonation of the buffer is zero.

7.69. Enzyme: butyryl-CoA dehydrogenase (EC 1.3.99.2)

butanoyl-CoA(aq) + indophenol(aq) = 2-butenoyl-CoA(aq) + reduced indophenol(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	10.

Reference: 54GRE/MII
Method: spectrophotometry
Buffer: histidine (0.01 mol dm^{-3})
pH: 7.0
Evaluation: B

butanoyl-CoA(aq) + pyocyanine(aq) = 2-butenoyl-CoA(aq) + reduced pyocyanine(aq)

$\frac{T}{K}$	pH	K'
303.15	7.2	0.23

Reference: 56HAU
Method: spectrophotometry
Buffer: phosphate (0.02 mol dm^{-3})
pH: 7.2
Evaluation: C

7.70. Enzyme: dihydroorotate dehydrogenase (EC 1.3.99.11)

(*S*)-dihydroorotate(aq) + NAD(aq) = orotate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
293.15	6.1	4.20E−4
293.15	6.4	1.06E−3
293.15	6.7	2.24E−3
293.15	7.2	6.19E−3

Reference: 61KRA/VEN
Method: spectrophotometry
Buffer: cysteine (0.0067 mol dm^{-3})
pH: 6.1 – 7.2
Evaluation: B

Krakow and Vennesland report $\{K'c(H^+)\}^{-1}$ as a function of the pH. The apparent equilibrium constants given above were calculated from these results.

(*S*)-dihydroorotate(aq) + AP-NAD(aq) = orotate(aq) + AP-NADH(aq)

$\frac{T}{K}$	pH	K'
293.15	6.1	0.035
293.15	6.4	0.093
293.15	6.7	0.189

Reference: 61KRA/VEN
Method: spectrophotometry
Buffer: cysteine (0.0067 mol dm^{-3})
pH: 6.1 – 6.7
Evaluation: B

AP-NAD and AP-NADH are, respectively, 3-acetylpyridine adenine dinucleotide and its reduced form. Krakow and Vennesland report $\{K'c(H^+)\}^{-1}$ as a function of the pH. The apparent equilibrium constants given above were calculated from these results.

7.71. Enzyme: alanine dehydrogenase (EC 1.4.1.1)

L-alanine(aq) + NAD(aq) + H_2O(l) = pyruvate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	10.0	1.36E – 4

Reference: 60OCO/HAL
Method: spectrophotometry
Buffer: carbonate + bicarbonate (0.075 mol dm^{-3})
pH: 10.0
Evaluation: C

O'Connor and Halvorson report $K_c'c(H^+)/c^\circ$ = 1.36E – 14 at pH = 10.0. The apparent equilibrium constant given above was calculated from this result.

L-alanine(aq) + NAD(aq) + H_2O(l) = pyruvate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.97	6.01E – 6
298.15	7.98	7.68E – 6
298.15	8.32	1.80E – 5
298.15	8.35	1.96E – 5
298.15	8.73	5.32E – 5
298.15	8.77	5.26E – 5
298.15	9.10	1.15E – 4
298.15	9.14	1.19E – 4
298.15	9.22	1.60E – 4
298.15	9.41	2.68E – 4

Reference: 60PIE/WIA
Method: spectrophotometry
Buffer: pyrophosphate (0.1 mol dm^{-3})
pH: 7.97 – 9.41
Evaluation: B

The apparent equilibrium constants given above were calculated from the results given in Pierard and Wiame's Table IV. There is a typographical error in the heading for column 7 in that table: "K × 10^4" should be "K × 10^{14}".

L-alanine(aq) + NAD(aq) + H_2O(l) = pyruvate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.21	1.13E – 5
298.15	8.98	7.65E – 5
298.15	10.05	8.25E – 4

Reference: 65YOS/FRE
Method: spectrophotometry
Buffer: Tris + HCl
pH: 8.21 – 10.05
Evaluation: B

The apparent equilibrium constants given above were calculated from the results given in Yoshida and Freese's Table II.

L-alanine(aq) + NAD(aq) + H_2O(l) = pyruvate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.9	4.3E – 6

Reference: 81GRI/CLE
Method: spectrophotometry
Buffer: *N*-tris(hydroxymethyl)methyl-2-amino-ethanesulfonic acid (0.050 mol dm^{-3})
pH: 7.9
Evaluation: C

Grimshaw and Cleland report $K_c'c(H^+)/c^\circ$ = 5.4E – 14 at pH = 7.9. The apparent equilibrium constant given above is calculated from this result.

7.72. Enzyme: glutamate dehydrogenase (EC 1.4.1.2)

L-glutamate(aq) + NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	6.05	3.9E – 11
298.15	6.63	1.3E – 9
298.15	7.01	1.3E – 9
298.15	7.26	7.6E – 9
298.15	7.36	6.5E – 9
298.15	7.39	9.4E – 9
298.15	7.40	7.9E – 9
298.15	7.43	1.5E – 8
298.15	7.45	1.7E – 8
298.15	7.57	7.7E – 9
298.15	7.60	2.0E – 8
298.15	7.66	1.1E – 8
298.15	7.82	2.4E – 8
298.15	8.01	3.6E – 8
298.15	8.05	7.0E – 8

Reference: 38EUL/ADL
Method: spectrophotometry
Buffer: phosphate
pH: 6.05 – 8.05
Evaluation: C

The temperature is assumed to be 298.15 K. We have recalculated the results of von Euler *et al.* on the assumption that the concentration of ammonia is equal to the concentration of NADH. Also see the discussion of Olson and Anfinsen [53OLS/ANF]. Also see entries under EC 1.4.1.3.

L-glutamate(aq) + NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	buffer	K_c'
303.65	6.37	Tris	3.47E−7
303.65	6.74	pyrophosphate	1.09E−6
303.65	7.02	Tris	1.47E−6
303.65	7.08	Tris	1.06E−6
303.65	7.38	pyrophosphate	4.17E−6
303.65	7.55	Tris	4.08E−6
303.65	7.69	Tris	2.30E−6
303.65	7.89	pyrophosphate	6.44E−6
303.65	8.17	pyrophosphate	7.20E−5
303.65	8.25	Tris	6.21E−5
303.65	8.27	Tris	1.88E−5
303.65	8.32	pyrophosphate	9.67E−5
303.65	7.6	pyrophosphate	9.95E−6

Reference: 53STR
Method: spectrophotometry
Buffer: Tris (0.045 mol dm^{-3}) and pyrophosphate (0.045 mol dm^{-3})
pH: 6.37−8.32
Evaluation: B

Strecker reports $K_c'c(H^+)$ as a function of pH. The apparent equilibrium constants given above were calculated from the results given in Strecker's Table II. Strecker considers the last result given above (at pH = 7.6) to be the most reliable. Also see entries under EC 1.4.1.3.

L-glutamate(aq) + NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
303.15	7.6	2.43E−6

Reference: 56KAP/CIO
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 7.6
Evaluation: C

Kaplan *et al.* report $K_c'c(H^+)/c^\circ$ = 6.1E−14 at pH = 7.6. The apparent equilibrium constant given above was calculated from this result. Also see entries under EC 1.4.1.3.

L-glutamate(aq) + NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
300.15	6.83	0.0245	4.22E−7
300.15	6.93	0.0245	4.14E−7
300.15	6.82	0.0445	5.81E−7
300.15	6.94	0.0445	5.73E−7
300.15	6.90	0.055	6.37E−7
300.15	6.90	0.055	5.62E−7
300.15	7.07	0.055	8.64E−7
300.15	6.92	0.067	7.04E−7
300.15	6.92	0.067	7.13E−7
300.15	6.94	0.067	6.79E−7
300.15	6.89	0.067	6.31E−7
300.15	6.98	0.089	8.66E−7
300.15	6.93	0.089	8.80E−7
300.15	6.95	0.089	7.79E−7
300.15	6.90	0.101	7.51E−7
300.15	7.06	0.101	1.16E−6
300.15	6.97	0.111	9.86E−7
300.15	6.98	0.111	1.01E−6
300.15	6.96	0.111	9.13E−7
300.15	6.98	0.135	1.08E−6
300.15	6.95	0.135	1.04E−6
300.15	6.97	0.135	1.05E−6
300.15	6.95	0.233	1.30E−6
300.15	6.90	0.233	1.24E−6
300.15	6.99	0.233	1.39E−6
300.15	6.90	0.471	1.52E−6
300.15	6.90	0.471	1.49E−6
300.15	7.17	0.471	2.78E−6
300.15	6.90	0.471	1.51E−6
300.15	6.79	0.471	1.12E−6
300.15	6.99	0.471	1.84E−6
300.15	6.99	0.471	1.83E−6
303.15	6.89	0.709	1.56E−6
303.15	7.02	0.709	2.18E−6
298.1	7.00	0.47	1.4E−6
300.1	7.00	0.47	1.8E−6
305.1	7.00	0.47	2.8E−6
309.8	7.00	0.47	4.3E−6
311.1	7.00	0.47	5.3E−6

Reference: 67ENG/DAL
Method: spectrophotometry
Buffer: phosphate
pH: 6.83−7.17
Evaluation: A

We calculated the apparent equilibrium constants given above from the results given in Engel and Dalziel's Table 1. Engel and Dalziel included both the concentration of the water and of the hydrogen ion in their calculations (see columns 7 and 8 in their Table 1). Engel and Dalziel extrapolated their results to I = 0 and obtained $K_c'c(H^+)/c(H_2O)$ = 6.4E−16 at pH = 7.0 and T = 300.15 K. This result corresponds to K_c' = 3.5E−7 at pH = 7.0. The last five apparent equilibrium constants given above (T = 298.1 K to T = 311.1 K) were obtained from Engel and Dalziel's Fig. 2. From these results we calculate $\Delta_r H'^\circ$(pH = 7.0 and I_c = 0.47 mol dm^{-3}) = 75 kJ mol^{-1}. Also see entries under EC 1.4.1.3.

L-glutamate(aq) + NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	protein	K'
311.15	7.6	BSA	4.8E−7
311.15	7.6	ovalbumin	8.0E−8

Reference: 85ANS/PRI
Method:
Buffer: sodium phosphate (0.1 mol dm^{-3})
pH: 7.6
Evaluation: D

Ansari *et al.* report $K_c'c(H^+)/c°$ for the reaction occurring in buffer alone and in the presence of added proteins (bovine serum albumin (BSA) and ovalbumin) at a concentration of 500 g dm^{-3}. The apparent equilibrium constants were calculated from these results. Few experimental details were given and the results are stated to be preliminary. Also see entries under EC 1.4.1.3.

L-glutamate(aq) + AP-NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + AP-NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
303.15	7.6	2.2E−3

Reference: 56KAP/CIO
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 7.6
Evaluation: C

AP-NAD and AP-NADH are, respectively, 3-acetylpyridine adenine dinucleotide and its reduced form. Kaplan *et al.* report $K_c'c(H^+)/c°$ = 5.6E−11 at pH = 7.6 The apparent equilibrium constant given above was calculated from this result.

7.73. Enzyme: glutamate dehydrogenase [NAD(P)$^+$] (EC 1.4.1.3)

L-glutamate(aq) + AP-NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + AP-NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'°}{kJ\ mol^{-1}}$
298.15	7.6	46.0
308.15	7.6	52.3

Reference: 78SUB
Method: calorimetry
Buffer: phosphate
pH: 7.6
Evaluation: A

AP-NAD and AP-NADH are, respectively, 3-acetylpyridine adenine dinucleotide and its reduced form. The results have been corrected for the enthalpy of protonation of the buffer.

L-glutamate(aq) + desamino NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + desamino NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
299.15	7.0	9.7E−7
299.15	7.5	3.1E−6
299.15	8.0	9.7E−6

Reference: 53OLS/ANF
Method: spectrophotometry
Buffer: phosphate (0.2 mol dm^{-3})
pH: 6.8−8.1
Evaluation: B

Olson and Anfinsen report $K_c'c(H^+)/(55.56c°)$ = 1.75E−15 over the pH range 6.8 to 8.1. We have calculated the apparent equilibrium constants given above from this result.

L-glutamate(aq) + NAD(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
300.15	6.5	4.6E−7
300.15	7.0	1.5E−6
300.15	7.5	4.6E−6

Reference: 53OLS/ANF
Method: spectrophotometry
Buffer: phosphate (0.2 mol dm^{-3})
pH: 6.4−7.5
Evaluation: B

Olson and Anfinsen report $K_c'c(H^+)/(55.56c°)$ = 2.61E−15 over the pH range 6.4 to 7.5. The apparent equilibrium constants given above were calculated from this result. Also see entries under EC 1.4.1.2.

L-glutamate(aq) + NADP(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADPH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
300.15	6.5	3.1E−7
300.15	7.0	9.9E−7
300.15	7.5	3.1E−6

Reference: 53OLS/ANF
Method: spectrophotometry
Buffer: phosphate (0.2 mol dm^{-3})
pH: 6.4−7.5
Evaluation: B

Olson and Anfinsen report $K_c'c(H^+)/(55.56c°)$ = 1.78E−15 over the pH range 6.4 to 7.5. We have calculated the apparent equilibrium constants given above from this result.

L-glutamate(aq) + NADP(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADPH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.0	4.5E−6

Reference: 59FRI
Method: spectrophotometry
Buffer: Tris (0.01 mol dm^{-3}) + acetate
pH: 8.0
Evaluation: D

Frieden's result, which is based upon kinetic data, is given as $K'c(H^+)/c^\circ$ = 4.5E−14. The apparent equilibrium constant given above is calculated from this result.

L-glutamate(aq) + NADP(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADPH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
300.15	6.93	0.026	2.09E−7
300.15	6.90	0.054	2.59E−7
300.15	6.94	0.054	2.91E−7
300.15	6.96	0.067	3.83E−7
300.15	6.93	0.067	3.67E−7
300.15	6.97	0.091	4.96E−7
300.15	6.96	0.112	5.22E−7
300.15	6.97	0.112	5.55E−7
300.15	6.92	0.134	5.92E−7
300.15	6.92	0.134	5.04E−7
300.15	6.95	0.134	6.34E−7
300.15	6.91	0.471	9.03E−7
300.15	6.79	0.471	8.08E−7
300.15	6.99	0.471	1.16E−6
298.1	7.00	0.47	1.1E−6
300.1	7.00	0.47	1.2E−6
305.1	7.00	0.47	2.0E−6
309.8	7.00	0.47	3.2E−6
311.1	7.00	0.47	3.6E−6

Reference: 67ENG/DAL
Method: spectrophotometry
Buffer: phosphate
pH: 6.79−6.97
Evaluation: A

We calculated the apparent equilibrium constants given above from the results given in Engel and Dalziel's Table 2. Engel and Dalziel included both the concentration of the water and of the hydrogen ion in their calculations (see columns 7 and 8 in their Table 2). Engel and Dalziel extrapolated their results to I = 0 and obtained $K_c'c(H^+)/c(H_2O)$ = 1.93E−16 at pH = 7.0 and T = 300.15 K. This result corresponds to K_c' = 1.1E−7 at pH = 7.0. The last five apparent equilibrium constants given above (T = 298.1 K to T = 311.1 K) were obtained from Engel and Dalziel's Fig. 2. From these results we calculate $\Delta_r H'^\circ$(pH = 7.0, I_c = 0.47 mol dm^{-3}) = 73 kJ mol^{-1}.

L-glutamate(aq) + NADP(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADPH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.6	2.91E−6
308.15	7.6	6.37E−6

Reference: 78SUB
Method: spectrophotometry
Buffer: phosphate
pH: 7.6
Evaluation: B

Subramanian reports $K_c'c(H^+)$ at pH = 7.6 at T = 298.15 K and at T = 308.15 K. The apparent equilibrium constants given above were calculated from the results given in Subramanian's Table 1.

L-glutamate(aq) + NADP(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADPH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	7.6	64.6
308.15	7.6	70.3

Reference: 78SUB
Method: calorimetry
Buffer: phosphate
pH: 7.6
Evaluation: A

The results given above have been corrected for the enthalpy of protonation of the buffer.

L-glutamate(aq) + NADP(aq) + H_2O(l) = 2-oxoglutarate(aq) + NADPH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	8.5	1.4E−5

Reference: 80COO/BLA
Method: spectrophotometry
Buffer: 3-[tris(hydroxylmethyl)methyl]aminopropanesulfonic acid (0.1 mol dm^{-3})
pH: 8.5
Evaluation: B

Cook *et al.* report $K_c'c(H^+)/c^\circ$ = 4.4E−14 at pH = 8.5. The apparent equilibrium constant given above was calculated from this result.

7.74. Enzyme: leucine dehydrogenase (EC 1.4.1.9)

(*S*)-leucine(aq) + NAD(aq) + H_2O(l) =
4-methyl-2-oxopentanoate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
298.15	11.1	1.11E−2

Reference: 61SAN/ZIN
Method: spectrophotometry
Buffer: glycine (0.1 mol dm^{-3}) + NaOH
pH: 11.1
Evaluation: B

Sanwal and Zink report $K_c'c(H^+)/c^\circ$ = 1.11E−13 at pH = 11.0. The apparent equilibrium constant given above was calculated from this result.

7.75. Enzyme: glycine dehydrogenase (EC 1.4.1.10)

glycine(aq) + NAD(aq) + H_2O(l) = glyoxylate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
303.15	6.4	5.7E−5

Reference: 62GOL/WAG
Method: spectrophotometry
Buffer: phosphate (0.08 mol dm^{-3})
pH: 6.4
Evaluation: C

Goldman and Wagner report $\{K_c'c(H^+)\}^{-1}$ = 4.4E10 at pH = 6.4. The apparent equilibrium constant given above was calculated from this result.

7.76. Enzyme: L-*erythro*-3,5-diaminohexanoate dehydrogenase (EC 1.4.1.11)

L-*erythro*-3,5-diaminohexanoate(a) + NAD(aq) + H_2O(l) =
(*S*)-5-amino-3-oxohexanoate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
299.15	7.00	4.0E−3
299.15	6.97	4.1E−3
299.15	6.93	3.8E−3
299.15	7.37	5.3E−3
299.15	7.37	5.0E−5
299.15	7.37	6.2E−3
299.15	7.37	8.3E−3

Reference: 72BAK/JEN
Method: radioactivity and spectrophotometry
Buffer: phosphate (0.088 mol dm^{-3})
pH: 7.0
Evaluation: A

The apparent equilibrium constants given above were calculated from Baker *et al.*'s Table VI. The fifth result given above may be an outlier.

7.77. Enzyme: 2,4-diaminopentanoate dehydrogenase (EC 1.4.1.12)

2,4-diaminopentanoate(aq) + NAD(aq) + H_2O(l) =
2-amino-4-oxopentanoate(aq) + NADH(aq) + ammonia(aq)

$\frac{T}{K}$	pH	K_c'
301.15	8.75	3.24E−4

Reference: 70TSU/FRI
Method: spectrophotometry
Buffer: sodium pyrophosphate (0.050 mol dm^{-3})
pH: 8.75
Evaluation: C

This is an approximate result.

7.78. Enzyme: pyrroline-2-carboxylate reductase (EC 1.5.1.1)

(*S*)-proline(aq) + NADP(aq) = Δ^1-pyrroline-2-carboxylate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.9	3.6E−3
298.15	8.5	3.6E−3
298.15	9.0	3.6E−3
298.15	9.2	3.6E−3

Reference: 85SRI/FIS
Method: spectrophotometry
Buffer: phosphate (0.01 mol dm^{-3}) and Tris (0.1 mol dm^{-3})
pH: 7.9−9.2
Evaluation: B

Srinivasan and Fisher state that K' for this reaction is constant over the pH range 7.9 to 9.2.

7.79. Enzyme: pyrroline-5-carboxylate reductase (EC 1.5.1.2)

(*S*)-proline(aq) + NADP(aq) = Δ^1-pyrroline-5-carboxylate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	9.23	4.3E−5

Reference: 81PAH/JAG
Method: spectrophotometry
Buffer: glycine + NaOH (0.15 mol dm^{-3})
pH: 9.23
Evaluation: C

The temperature is assumed to be 298.15 K.

7.80. Enzyme: dihydrofolate reductase (EC 1.5.1.3)

2 7,8-dihydrofolate(aq) = folate(aq) + 5,6,7,8-tetrahydrofolate(aq)

$\frac{T}{K}$	pH	K'
295.15	7.0	19.4

Reference: 84BLA/COC
Method: spectrophotometry and HPLC
Buffer: Tris (0.050 mol dm^{-3}) + HCl
pH: 7.3
Evaluation: C

5,6,7,8-tetrahydrofolate(aq) + NADP(aq) = 7,8-dihydrofolate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.78E−5

Reference: 63HUE
Method: spectrophotometry
pH: 7.0
Evaluation: C

The temperature is assumed to be 298.15 K.

5,6,7,8-tetrahydrofolate(aq) + NADP(aq) = 7,8-dihydrofolate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.5	6.1E−5
298.15	8.5	5.6E−4

Reference: 63MAT/HUE
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3})
pH: 8.5
Evaluation: B

The apparent equilibrium constants given above were calculated from Matthews and Huennekens' Table V.

5,6,7,8-tetrahydrofolate(aq) + NADP(aq) = 7,8-dihydrofolate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
310.15	6.7	≈2.4E−4
310.15	8.0	1.2E−3

Reference: 68NIX/BLA
Method: spectrophotometry
Buffer: {Tris (0.050 mol dm^{-3}) + HCl} and phosphate (0.050 mol dm^{-3})
pH: 6.7−8.0
Evaluation: C

Nixon and Blakley report $\{K'c(H^+)\}^{-1}$ at pH = 6.7 and 8.0. The apparent equilibrium constants given above were calculated from these results.

5,6,7,8-tetrahydrofolate(aq) + NADP(aq) = 7,8-dihydrofolate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	8.2	5.0E−4

Reference: 72NAG/JAE
Method: spectrophotometry
Buffer: Tris (0.4 mol dm^{-3}) + HCl
pH: 8.2
Evaluation: C

From kinetic data, Nagelschmidt and Jaenicke obtained $\{K'c(H^+)/c^\circ\}^{-1}$ = 3.2E11 at pH = 8.2. The apparent equilibrium constant was calculated from this result.

5,6,7,8-tetrahydrofolate(aq) + NADP(aq) = 7,8-dihydrofolate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	7.4	52.7

Reference: 73ROT/KIS
Method: calorimetry
Buffer: Tris (0.20 mol dm^{-3})
pH: 7.4
Evaluation: A

The result given above has been corrected for the enthalpy of protonation of the buffer.

7.81. Enzyme: methylenetetrahydrofolate dehydrogenase ($NADP^+$) (EC 1.5.1.5)

5,10-methylenetetrahydrofolate(aq) + NADP(aq) = 5,10-methenyltetrahydrofolate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.9	0.14

Reference: 67UYE/RAB
Method: spectrophotometry
Buffer: potassium maleate (0.05 mol dm^{-3})
pH: 6.9
Evaluation: B

7.82. Enzyme: D-octopine dehydrogenase (EC 1.5.1.11)

N^2-(D-1-carboxyethyl)-L-arginine(aq) + NAD(aq) + H_2O(l) = L-arginine(aq) + pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.0	3.0E−6

Reference: 86MEI/GAD
Method: spectrophotometry
Buffer: potassium phosphate (0.20 mol dm^{-3})
pH: 7.0
Evaluation: C

7.83. Enzyme: methylenetetrahydrofolate dehydrogenase (NAD^+) (EC 1.5.1.15)

5,10-methylenetetrahydrofolate(aq) + AP-NAD(aq) = 5,10-methenyltetrahydrofolate(aq) + AP-NADH(aq)

$\frac{T}{K}$	pH	K'
310.15	7.2	0.86
310.15	8.25	0.11

Reference: 91WOH/DIE
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 7.2−8.25
Evaluation: C

AP-NAD and AP-NADH are, respectively, 3-acetylpyridine adenine dinucleotide and its reduced form. The above results were calculated from Wohlfarth and Diekert's Tables 1 and 2.

5,10-methylenetetrahydrofolate(aq) + NAD(aq) = 5,10-methenyltetrahydrofolate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	6.7	2.0

Reference: 84RAG/LJU
Method: spectrophotometry
Buffer: Tris + maleate (0.5 mol dm^{-3})
pH: 6.7
Evaluation: D

This is an approximate result based upon kinetic data. The temperature is assumed to be 298.15 K.

5,10-methylenetetrahydrofolate(aq) + NAD(aq) = 5,10-methenyltetrahydrofolate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
310.15	7.8	0.012
310.15	7.9	0.0096

Reference: 91WOH/DIE
Method: spectrophotometry
Buffer: Tris (0.1 mol dm^{-3}) + HCl
pH: 7.8−7.9
Evaluation: C

The above results were calculated from Wohlfarth and Diekert's Tables 1 and 2.

7.84. Enzyme: alanopine dehydrogenase (EC 1.5.1.17)

2,2'-iminodipropanoate(aq) + NAD(aq) + H_2O(l) = L-alanine(aq) + pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	1.0E−6

Reference: 86MEI/GAD
Method: spectrophotometry
Buffer: potassium phosphate (0.20 mol dm^{-3})
pH: 7.0
Evaluation: C

2-methyliminodiacetate(aq) + NAD(aq) + H_2O(l) = glycine(aq) + pyruvate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K_c'
298.15	7.0	3.7E−7

Reference: 86MEI/GAD
Method: spectrophotometry
Buffer: potassium phosphate (0.20 mol dm^{-3})
pH: 7.0
Evaluation: C

7.85. Enzyme: Δ^1-piperidine-2-carboxylate reductase (EC 1.5.1.21)

L-pipecolate(aq) + NADP(aq) = Δ^1-piperidine-2-carboxylate(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
277.8	9.1	0.0111
281.2	9.1	0.0103
285.3	9.1	0.00719
291.1	9.1	0.00775
297.6	9.1	0.00585
305.0	9.1	0.00526

Reference: 91SRI/NAM
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3}) and Tris (0.1 mol dm^{-3})
pH: 9.0–9.2
Evaluation: B

We calculate $\Delta_r H'°(pH = 9.1) = -19.3$ kJ mol^{-1} from the above results. Srinivasan and Nambi report K(ref) = (0.00571 ± 0.00083) for the reference reaction which we have written as: L-pipecolate^{2-}(aq) + $NADP^{3-}$(aq) = Δ^1-piperidine 2-carboxylate$^-$(aq) + $NADPH^{4-}$(aq). The results given above were taken from their Fig. 2. Srinivasan and Nambi also report $\Delta_r H° = -20.9$ kJ mol^{-1} at I_c = 0.1 mol dm^{-3} for this reference reaction from the temperature dependency of the equilibrium constant.

7.86. Enzyme: NAD(P)$^+$ transhydrogenase (EC 1.6.1.1)

NAD(aq) + NADPH(aq) = NADH(aq) + NADP(aq)

$\frac{T}{K}$	pH	K'
310.15	6.0	1.48
310.15	6.5	1.43
310.15	7.5	1.41

Reference: 53KAP/COL
Method: spectrophotometry
Buffer: phosphate
pH: 6.0–7.5
Evaluation: B

NAD(aq) + NADPH(aq) = NADH(aq) + NADP(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'°}{kJ\ mol^{-1}}$
298.15	7.0	−4.1

Reference: 74SCH/STU
Method: calorimetry
pH: 7.0
Evaluation: C

This is unpublished data cited in 74BUR. Few details were given. The temperature is assumed to be 298.15 K and the pH ≈ 7.0. The change in binding of H^+(aq) should be zero for the above reaction at pH = 7 and the buffer protonation correction will also be zero.

7.87. Enzyme: glutathione reductase (NADPH) (EC 1.6.4.2)

2 reduced glutathione(aq) + NADP(aq) = oxidized glutathione(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'_c
293.15	7.4	1.5E−5
293.15	8.3	1.2E−4
293.15	9.3	3.2E−4

Reference: 63MAP/ISH
Method: radioactivity and fluorimetry
Buffer: phosphate (0.1 mol dm^{-3})
pH: 7.4–9.3
Evaluation: D

The apparent equilibrium constants given above were calculated from Mapson and Isherwood's Table 2. Veech [68VEE] states the above results are in error due to contamination of the glutathione.

2 reduced glutathione(aq) + NADP(aq) = oxidized glutathione(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'_c
283.15	6.8	6.44E−3
298.15	6.8	6.44E−3
313.15	6.8	5.95E−3

Reference: 63SCO/DUN
Method: spectrophotometry
Buffer: potassium phosphate (0.167 mol dm^{-3})
pH: 6.8
Evaluation: B

Scott *et al.* report $K'_c(H^+)$ at pH = 6.8. The apparent equilibrium constants given above were calculated from this result. We also calculated $\Delta_r H'°(pH = 6.8) \approx -2$ kJ mol^{-1} from the temperature dependency of the apparent equilibrium constant.

2 reduced glutathione(aq) + NADP(aq) = oxidized glutathione(aq) + NADPH(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K'_c
298.15	6.90	0.25	2.42E−2
311.15	6.90	0.25	1.56E−2

Reference: 68VEE
Method: fluorimetry
Buffer: potassium phosphate
pH: 6.90
Evaluation: A

Veech reports the quantity $K'c(H^+)/c°$ at pH = 6.90 at T = 298.15 K and at T = 311.15 K. The apparent equilibrium constants given above were calculated from these results.

2 reduced glutathione(aq) + NADP(aq) = oxidized glutathione(aq) + NADPH(aq)

$\frac{T}{K}$	pH	$\frac{I_c}{mol\ dm^{-3}}$	K_c'
311.15	6.90	0.25	1.56E−2

Reference: 69VEE/EGG
Method: fluorimetry
Buffer: potassium phosphate
pH: 6.90
Evaluation: A

Veech *et al.* report an apparent equilibrium constant in their Table 2 which was taken from the thesis of R. L. Veech (see 68VEE).

2 reduced glutathione(aq) + NADP(aq) = oxidized glutathione(aq) + NADPH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	6.8	3.6

Reference: 84PAU
Method: calorimetry
Buffer: imidazole (0.1 mol dm^{-3})
pH: 6.8
Evaluation: B

The result given above was corrected for the enthalpy of protonation of the buffer.

7.88. Enzyme: thioredoxin reductase (NADPH) (EC 1.6.4.5)

reduced thioredoxin(aq) + NADP(aq) = oxidized thioredoxin(aq) + NADPH(aq)

$\frac{T}{K}$	pH	K'
298.15	7.0	0.036
298.15	8.0	0.27
298.15	9.0	2.0

Reference: 64MOO/REI
Method: spectrophotometry
Buffer: Tris (0.098 mol dm^{-3})
pH: 7.0−9.0
Evaluation: C

Moore *et al.* report $\{K'c(H^+)\}^{-1}$ as a function of pH. The apparent equilibrium constants given above were calculated from these results. The temperature is assumed to be 298.15 K.

7.89. Enzyme: NADH dehydrogenase (EC 1.6.99.3)

2 NADH(aq) + O_2(aq) = 2 NAD(aq) + 2 H_2O(l)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
298.15	7.0	−516

Reference: 67POE/GUT
Method: calorimetry
Buffer: citrate, glycyl-glycine, phosphate, and (Tris + HCl)
pH: 6.4−8.4
Evaluation: B

The result given above is the average of the results obtained in several buffers. The results have been corrected for the enthalpies of protonation of the buffers. It is assumed that the "mole" referred to by Poe *et al.* is a mole of NADH.

7.90. Enzyme: 5,10-methylenetetrahydrofolate reductase ($FADH_2$) (EC 1.7.99.5)

5-methyltetrahydrofolate(aq) + flavin-adenine dinucleotide(aq) = 5,10-methylenetetrahydrofolate(aq) + reduced flavin-adenine dinucleotide(aq)

$\frac{T}{K}$	pH	K'
310.15	6.3	4.2E−4

Reference: 65KAT/BUC
Method: spectrophotometry
Buffer: phosphate (0.1 mol dm^{-3})
pH: 6.3
Evaluation: B

7.91. Enzyme: dihydrolipoamide dehydrogenase (EC 1.8.1.4)

dihydrolipoamide(aq) + NAD(aq) = lipoamide(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	6.23	0.081
295.15	6.86	0.18
295.15	7.19	0.28
295.15	7.53	0.36
295.15	7.74	0.65
295.15	7.90	1.0
295.15	8.23	1.5
295.15	8.42	2.6
295.15	8.59	3.6
295.15	9.08	4.8

Reference: 59SAN/LAN
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 6.23−9.08
Evaluation: B

The apparent equilibrium constants given above were obtained from Sanadi *et al.*'s Fig. 5. Sanadi *et al.* also report in their Table III a result of $K' \approx 0.15$ over the pH range 7.05 to 7.17.

dihydro-α-lipoate(aq) + NAD(aq) = α-lipoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	7.1	0.21

Reference: 57SAN/SEA
Method: spectrophotometry
Buffer: phosphate (0.026 mol dm^{-3})
pH: 7.1
Evaluation: C

Sanadi and Searls report $K'c(H^+)/c^\circ$ = 1.65E−8 at pH = 7.1. The apparent equilibrium constant given above was calculated from this result.

dihydro-α-lipoate(aq) + NAD(aq) = α-lipoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	6.0	5.5E−3

Reference: 59GOL
Method: spectrophotometry
Buffer: phosphate (0.06 mol dm^{-3})
pH: 6.0
Evaluation: B

The apparent equilibrium constant given above was calculated from the results given in Goldman's Table VI.

dihydro-α-lipoate(aq) + NAD(aq) = α-lipoate(aq) + NADH(aq)

$\frac{T}{K}$	pH	K'
295.15	7.1	0.13

Reference: 59SAN/LAN
Method: spectrophotometry
Buffer: phosphate (0.05 mol dm^{-3})
pH: 7.1
Evaluation: C

7.92. Enzyme: glutathione-CoA-glutathione transhydrogenase (EC 1.8.4.3)

CoA(aq) + oxidized glutathione(aq) = CoA-glutathione(aq) + reduced glutathione(aq)

$\frac{T}{K}$	pH	K'
298.15	6.9	1.25

Reference: 66CHA/WIL
Method: spectrophotometry and electrophoresis
Buffer: potassium phosphate (0.05 mol dm^{-3})
pH: 6.9
Evaluation: B

7.93. Enzyme: cytochrome-c oxidase (EC 1.9.3.1)

4 reduced cytochrome c(aq) + O_2(aq) = 4 cytochrome c(aq) + 2 H_2O(l)

$\frac{T}{K}$	pH	K_c'
298.15	7.4	≈0.75

Reference: 76GRE/BRI
Method: spectrophotometry
Buffer: potassium phosphate (0.1 mol dm^{-3})
pH: 7.4
Evaluation: C

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

4 reduced cytochrome c(aq) + O_2(aq) = 4 cytochrome c(aq) + 2 H_2O(l)

$\frac{T}{K}$	pH	$\frac{\Delta_r H'^\circ}{kJ\ mol^{-1}}$
299.4	7.4	−69.0

Reference: 91MOR/FRE
Method: calorimetry
Buffer: phosphate, MOPS, Tricine, and Tris
pH: 7.4
Evaluation: A

Morin and Freire found that one proton was consumed for each mole of cytochrome c which was oxidized. The result given above has been corrected for the enthalpies of protonation of the buffers.

7.94. Enzyme: hydrogen dehydrogenase (EC 1.12.1.2)

H_2(aq) + NAD(aq) = NADH(aq)

$\frac{T}{K}$	pH	$\frac{\Delta_r H(cal)}{kJ\ mol^{-1}}$
298.15	7.20	−27.4

Reference: 79REK/EGO and 80REK/EGO
Method: calorimetry
Buffer: potassium phosphate (0.050 mol dm^{-3})
pH: 7.20
Evaluation: B

The result given above has not been corrected for the enthalpy of protonation of the buffer.

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

Substance	CAS Registry Number[a]	Enzyme Commission Numbers
acetaldehyde	75-07-0	EC 1.1.1.1, EC 1.2.1.10
(*R*)-acetoin	53584-56-8	EC 1.1.1.4
acetone	67-64-1	EC 1.1.1.1
acetyl-CoA	102029-73-2	EC 1.2.1.10, EC 1.1.1.37 & EC 4.1.3.7
3-acetylpyridine adenine dinucleotide	86-08-8	EC 1.1.1.1, EC 1.1.1.27, EC 1.3.99.11, EC 1.4.1.2, EC 1.4.1.3, EC 1.5.1.15
3-acetylpyridine adenine dinucleotide (reduced)	153-59-3	EC 1.1.1.1, EC 1.1.1.27, EC 1.3.99.11, EC 1.4.1.2, EC 1.4.1.3, EC 1.5.1.15
adenosine 5′-diphosphate	58-64-0	EC 1.2.1.12 & EC 2.7.2.3
adenosine 5′-triphosphate	56-65-5	EC 1.2.1.12 & EC 2.7.2.3
L-alanine	56-41-7	EC 1.4.1.1, EC 1.5.1.17
allitol	488-44-8	EC 1.1.1.9
(aminomethyl)phosphonate	1066-51-9	EC 1.2.1.12
(*S*)-5-amino-3-oxohexanoate	40802-96-8	EC 1.4.1.11
2-amino-4-oxopentanoate	4439-83-2	EC 1.4.1.12
ammonia	1336-21-6	EC 1.4.1.1, EC 1.4.1.2, EC 1.4.1.3, EC 1.4.1.9, EC 1.4.1.10, EC 1.4.1.11, EC 1.4.1.12
5α-androstane-3α,17β-diol	1852-53-5	EC 1.1.1.50
5α-androstane-3β,17α-diol	5856-11-1	EC 1.1.1.51
5α-androstane-3,17-dione	846-46-8	EC 1.1.1.50
5β-androstane-3,17-dione	1229-12-5	EC 1.1.1.50
5α-androstane-3α-ol-17-one	53-41-8	EC 1.1.1.50
5β-androstane-3α-ol-17-one	53-42-9	EC 1.1.1.50
5α-androstane-17α-ol-3-one	571-24-4	EC 1.1.1.51
5α-androstane-17β-ol-3-one	521-18-6	EC 1.1.1.50
4-androstene-3,17-dione	63-05-8	EC 1.1.1.51
4-androstene-17β-ol-3-one	58-22-0	EC 1.1.1.51
L-arginine	74-79-3	EC 1.5.1.11
L-aspartate	56-84-8	EC 1.1.1.37 & EC 2.6.1.1
L-aspartate 4-semialdehyde	498-20-4	EC 1.1.1.3, EC 1.2.1.11
L-4-aspartyl phosphate	22138-53-0	EC 1.2.1.11
benzaldehyde	100-52-7	EC 1.1.1.1
benzyl alcohol	100-51-6	EC 1.1.1.1
butanal	123-72-8	EC 1.1.1.1
(*R*,*R*)-2,3-butanediol	24347-58-8	EC 1.1.1.4
1-butanol	71-36-3	EC 1.1.1.1
butanoyl-CoA	102282-28-0	EC 1.3.99.2
2-butenoyl-CoA	992-67-6	EC 1.3.99.2
carbon dioxide	124-38-9	EC 1.1.1.39, EC 1.1.1.40, EC 1.1.1.42, EC 1.1.1.44, EC 1.2.1.2, EC 1.2.1.43
N^2-(D-1-carboxyethyl)-L-arginine	34522-32-2	EC 1.5.1.11
L-carnitine	6645-46-1	EC 1.1.1.108
(chloroethyl)phosphonate	16672-87-0	EC 1.2.1.12
(chloromethyl)phosphonate	2565-58-4	EC 1.2.1.12
citrate	77-92-9	EC 1.1.1.37 & EC 4.1.3.7
CoA	85-61-0	EC 1.1.1.37 & EC 4.1.3.7, EC 1.2.1.10, EC 1.2.1.17
CoA-glutathione	6477-52-7	EC 1.8.4.3
coniferyl alcohol	458-35-5	EC 1.1.1.194
coniferyl aldehyde	458-36-6	EC 1.1.1.194
cyclohexanol	108-93-0	EC 1.1.1.1
cyclohexanone	108-94-1	EC 1.1.1.1
cytochrome *c*	9007-43-6[c]	EC 1.1.99.13, EC 1.9.3.1
cytochrome *c* (reduced)	9007-43-6[c]	EC 1.1.99.13, EC 1.9.3.1
3-dehydrocarnitine	10457-99-5	EC 1.1.1.108
5-dehydro-D-fructose	1684-29-3	EC 1.1.1.124
5-dehydroquinate	10534-44-8	EC 1.1.1.24
5-dehydroshikimate	32387-42-1	EC 1.1.1.25
2-deoxy-3-dehydro-D-gluconate	91446-99-0	EC 1.1.1.125
2-deoxy-D-gluconate	3442-69-1	EC 1.1.1.125
desamino β-nicotinamide-adenine dinucleotide	916-99-4	EC 1.1.1.1, EC 1.4.1.3
desamino β-nicotinamide-adenine dinucleotide (reduced)	20710-92-3	EC 1.1.1.1, EC 1.4.1.3
L-*erythro*-3,5-diaminohexanoate	34281-55-5	EC 1.4.1.11
2,4-diaminopentanoate	24317-81-5	EC 1.4.1.12

8. 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
7,8-dihydrobiopterin	6779-87-9	EC 1.1.1.153
7,8-dihydrofolate	4033-27-6	EC 1.5.1.3
dihydrolipoamide	3884-47-7	EC 1.8.1.4
dihydro-α-lipoate	462-20-4	EC 1.8.1.4
(*S*)-dihydroorotate	5988-19-2	EC 1.3.99.11
dihydroxyacetone	96-26-4	EC 1.1.1.6
dihydroxyacetone phosphate	102783-56-2	EC 1.1.1.8
2,4-dihydroxybutanoate	1518-62-3	EC 1.1.1.27
(*E*)-dihydroxyfumarate	133-38-0	EC 1.1.1.37
β-(3,5-diiodo-4-hydroxyphenyl)lactate	5388-57-8	EC 1.1.1.96
β-(3,5-diiodo-4-hydroxyphenyl)pyruvate	780-00-7	EC 1.1.1.96
L-erythrulose	533-50-6	EC 1.1.1.9
estradiol-17β	50-28-2	EC 1.1.1.62
estrone	53-16-7	EC 1.1.1.62
ethanol	64-17-5	EC 1.1.1.1
(ethyl)phosphonate	6779-09-5	EC 1.2.1.12
flavin-adenine nucleotide	146-14-5	EC 1.7.99.5
flavin-adenine nucleotide (reduced)	1910-41-4	EC 1.7.99.5
folate	75708-92-8	EC 1.5.1.3
formate	64-18-6	EC 1.2.1.2, EC 1.2.1.43
D-fructose	57-48-7	EC 1.1.1.9, EC 1.1.1.14, EC 1.1.1.67, EC 1.1.1.124
D-fructose 6-phosphate	26177-86-6	EC 1.1.1.17, EC 1.1.1.140
fumarate	110-17-8	EC 1.3.99.1
D-galactono-1,4-lactone	2782-07-2	EC 1.1.1.48
galactitol	608-66-2	EC 1.1.1.14
D-galactose	59-23-4	EC 1.1.1.48
D-glucitol	50-70-4	EC 1.1.1.14
D-gluconate	526-95-4	EC 1.1.1.69, EC 1.1.99.3
D-glucono-1,5-lactone	90-80-2	EC 1.1.1.47, EC 1.1.1.119
D-glucono-1,5-lactone 6-phosphate	2641-81-8	EC 1.1.1.49
D-glucose	50-99-7	EC 1.1.1.119
β-D-glucose	492-61-5	EC 1.1.1.47
D-glucose 6-phosphate	56-73-5	EC 1.1.1.49, EC 1.1.1.49 & EC 3.1.1.31, 1.1.1.b
L-glutamate	56-86-0	EC 1.1.1.37 & EC 2.6.1.1, EC 1.4.1.2, EC 1.4.1.3
glutathione (oxidized)	103239-24-3	EC 1.6.4.2, EC 1.8.4.3
glutathione (reduced)	70-18-8	EC 1.6.4.2, EC 1.8.4.3
(*R*)-glyceraldehyde	453-17-8	EC 1.1.1.72
D-glyceraldehyde 3-phosphate	142-10-9	EC 1.2.1.12, EC 1.2.1.12 & EC 2.7.2.3
(*R*)-glycerate	6000-40-4	EC 1.1.1.26, EC 1.1.1.29, EC 1.1.1.60
(*S*)-glycerate	28305-26-2	EC 1.1.1.29
D-glycero-D-glucoheptitol	608-61-7	EC 1.1.1.9
glycerol	56-81-5	EC 1.1.1.6, EC 1.1.1.72
sn-glycerol 3-phosphate	57-03-4	EC 1.1.1.8
glycine	56-40-6	EC 1.4.1.10, EC 1.5.1.17
glycolate	79-14-1	EC 1.1.1.26, EC 1.1.1.27, EC 1.1.1.79
glyoxylate	298-12-4	EC 1.1.1.26, EC 1.1.1.27, EC 1.1.1.79, EC 1.2.1.17, EC 1.4.1.10
H_2	1333-74-0	EC 1.12.1.2
H_2O	7732-18-5	EC 1.1.1.37 & EC 4.1.3.7, EC 1.1.1.49 & EC 3.1.1.31, EC 1.3.99.1, EC 1.4.1.1, EC 1.4.1.2, EC 1.4.1.3, EC 1.4.1.9, EC 1.4.1.10, EC 1.4.1.12, EC 1.5.1.7, EC 1.5.1.11, EC 1.5.1.17, EC 1.6.99.3, EC 1.9.3.1
hexanal	66-25-1	EC 1.1.1.1
1-hexanol	111-27-3	EC 1.1.1.1
cis-3-hexenal	6789-80-6	EC 1.1.1.1
trans-2-hexenal	6728-26-3	EC 1.1.1.1
cis-3-hexene-1-ol	928-96-1	EC 1.1.1.1
trans-2-hexene-1-ol	928-95-0	EC 1.1.1.1
L-homoserine	672-15-1	EC 1.1.1.3
3-hydroxybenzaldehyde	100-83-4	EC 1.1.1.97
3-hydroxybenzyl alcohol	620-24-6	EC 1.1.1.97
2-hydroxybutanoate	565-70-8	EC 1.1.1.27
(*R*)-3-hydroxybutanoate	625-72-9	EC 1.1.1.30

8. 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
4-hydroxybutanoate	591-81-1	EC 1.1.1.61
(*3R*)-3-hydroxybutanoyl-[acyl-carrier protein]	[b]	EC 1.1.1.100
(*S*)-3-hydroxybutanoyl-CoA	22138-45-0	EC 1.1.1.35
(*R*)-2-hydroxyglutarate	13095-47-1	EC 1.1.1.a
(*S*)-3-hydroxyhexanoyl-CoA	79171-47-4	EC 1.1.1.35
3-hydroxy-2-methylpropanoate	2068-83-9	EC 1.1.1.31
2-hydroxy-3-oxopropanoate	2480-77-5	EC 1.1.1.60
3-hydroxypropanoate	503-66-2	EC 1.1.1.59
hydroxypyruvate	113-60-6	EC 1.1.1.26, EC 1.1.1.29
L-iditol	488-45-9	EC 1.1.1.9
2,2'-iminodipropanoate	19149-54-3	EC 1.5.1.7
indole-3-lactate	1821-52-9	EC 1.1.1.110
indole-3-pyruvate	392-12-1	EC 1.1.1.110
indophenol	500-85-6	EC 1.3.99.2
indophenol (reduced)	1752-24-5	EC 1.3.99.2
myo-inositol	87-89-8	EC 1.1.1.18
isocitrate	320-77-4	EC 1.1.1.42
L-lactaldehyde	598-35-6	EC 1.1.1.55
(*R*)-lactate	10326-41-7	EC 1.1.1.28
(*S*)-lactate	79-33-4	EC 1.1.1.27, EC 1.1.99.7
lactose	63-42-3	EC 1.1.99.13
(*S*)-leucine	61-90-5	EC 1.4.1.9
lipoamide	940-69-2	EC 1.8.1.4
α-lipoate	1077-28-7	EC 1.8.1.4
(*S*)-malate	138-09-0	EC 1.1.1.37, EC 1.1.1.37 & EC 2.6.1.1, EC 1.1.1.37 & EC 4.1.3.7, EC 1.1.1.39, EC 1.1.1.40, EC 1.1.99.7
D-mannitol	69-65-8	EC 1.1.1.14, EC 1.1.1.67
D-mannitol 1-phosphate	104835-69-0	EC 1.1.1.17
5,10-methenyltetrahydrofolate	10360-12-0	EC 1.5.1.5, EC 1.5.1.15
(methoxy)phosphonate	812-00-0	EC 1.2.1.12
2-methyliminodiacetate	4408-64-4	EC 1.5.1.17
4-methyl-2-oxopentanoate	816-66-0	EC 1.4.1.9
2-methyl-3-oxopropanoate	6236-08-4	EC 1.1.1.31
5,10-methylenetetrahydrofolate	3432-99-3	EC 1.5.1.15, EC 1.7.99.5
(methyl)phosphonate	993-13-5	EC 1.2.1.12
5-methyltetrahydrofolate	134-35-0	EC 1.7.99.5
β-nicotinamide-adenine dinucleotide	53-84-9	EC 1.1.1.1, EC 1.1.1.3, EC 1.1.1.4, EC 1.1.1.6, EC 1.1.1.8, EC 1.1.1.9, EC 1.1.1.14, EC 1.1.1.17, EC 1.1.1.18, EC 1.1.1.24, EC 1.1.1.26, EC 1.1.1.27, EC 1.1.1.28, EC 1.1.1.29, EC 1.1.1.30, EC 1.1.1.31, EC 1.1.1.35, EC 1.1.1.37, EC 1.1.1.37 & EC 2.6.1.1, EC 1.1.1.37 & EC 4.1.3.7, EC 1.1.1.39, EC 1.1.1.47, EC 1.1.1.48, EC 1.1.1.50, EC 1.1.1.51, EC 1.1.1.56, EC 1.1.1.59, EC 1.1.1.60, EC 1.1.1.61, EC 1.1.1.62, EC 1.1.1.67, EC 1.1.1.95, EC 1.1.1.96, EC 1.1.1.108, EC 1.1.1.110, EC 1.1.1.125, EC 1.1.1.129, EC 1.1.1.140, EC 1.1.1.141, EC 1.1.1.150, EC 1.1.1.a, EC 1.2.1.2, EC 1.2.1.10, EC 1.2.1.12, EC 1.2.1.12 & EC 2.7.2.3, EC 1.3.99.11, EC 1.4.1.1, EC 1.4.1.2, EC 1.4.1.3, EC 1.4.1.9, EC 1.4.1.10, EC 1.4.1.11, EC 1.4.1.12, EC 1.5.1.11, EC 1.5.1.15, EC 1.5.1.17, EC 1.6.1.1, EC 1.6.99.3, EC 1.8.1.4, EC 1.12.1.2
β-nicotinamide-adenine dinucleotide (reduced)	606-68-8	EC 1.1.1.1, EC 1.1.1.3, EC 1.1.1.4, EC 1.1.1.6, EC 1.1.1.8, EC 1.1.1.9, EC 1.1.1.14, EC 1.1.1.17, EC 1.1.1.18, EC 1.1.1.24, EC 1.1.1.26, EC 1.1.1.27, EC 1.1.1.28, EC 1.1.1.29, EC 1.1.1.30, EC 1.1.1.31, EC 1.1.1.35, EC 1.1.1.37, EC 1.1.1.37 & EC 2.6.1.1, EC 1.1.1.37 & EC 4.1.3.7, EC 1.1.1.39, EC 1.1.1.47, EC 1.1.1.48,

8. 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
		EC 1.1.1.50, EC 1.1.1.51, EC 1.1.1.56, EC 1.1.1.59, EC 1.1.1.60, EC 1.1.1.61, EC 1.1.1.62, EC 1.1.1.67, EC 1.1.1.95, EC 1.1.1.96, EC 1.1.1.108, EC 1.1.1.110, EC 1.1.1.125, EC 1.1.1.129, EC 1.1.1.140, EC 1.1.1.141, EC 1.1.1.150, EC 1.1.1.a, EC 1.2.1.2, EC 1.2.1.10, EC 1.2.1.12, EC 1.2.1.12 & EC 2.7.2.3, EC 1.3.99.11, EC 1.4.1.1, EC 1.4.1.2, EC 1.4.1.3, EC 1.4.1.9, EC 1.4.1.10, EC 1.4.1.11, EC 1.4.1.12, EC 1.5.1.11, EC 1.5.1.15, EC 1.5.1.17, EC 1.6.1.1, EC 1.6.99.3, EC 1.8.1.4, EC 1.12.1.2
β-nicotinamide-adenine dinucleotide phosphate	53-59-8	EC 1.1.1.3, EC 1.1.1.10, EC 1.1.1.21, EC 1.1.1.25, EC 1.1.1.40, EC 1.1.1.42, EC 1.1.1.44, EC 1.1.1.49, EC 1.1.1.49 & EC 3.1.1.31, EC 1.1.1.55, EC 1.1.1.69, EC 1.1.1.72, EC 1.1.1.79, EC 1.1.1.97, EC 1.1.1.100, EC 1.1.1.119, EC 1.1.1.124, EC 1.1.1.153, EC 1.1.1.194, EC 1.1.1.b, EC 1.1.99.3, EC 1.2.1.11, EC 1.2.1.17, EC 1.2.1.43, EC 1.4.1.3, EC 1.5.1.1, EC 1.5.1.2, EC 1.5.1.3, EC 1.5.1.5, EC 1.5.1.21, EC 1.6.1.1, EC 1.6.4.2, EC 1.6.4.5
β-nicotinamide-adenine dinucleotide phosphate (reduced)	2646-71-1	EC 1.1.1.3, EC 1.1.1.10, EC 1.1.1.21, EC 1.1.1.25, EC 1.1.1.40, EC 1.1.1.42, EC 1.1.1.44, EC 1.1.1.49, EC 1.1.1.49 & EC 3.1.1.31, EC 1.1.1.55, EC 1.1.1.69, EC 1.1.1.72, EC 1.1.1.79, EC 1.1.1.97, EC 1.1.1.100, EC 1.1.1.119, EC 1.1.1.124, EC 1.1.1.153, EC 1.1.1.194, EC 1.1.1.b, EC 1.1.99.3, EC 1.2.1.11, EC 1.2.1.17, EC 1.2.1.43, EC 1.4.1.3, EC 1.5.1.1, EC 1.5.1.2, EC 1.5.1.3, EC 1.5.1.5, EC 1.5.1.21, EC 1.6.1.1, EC 1.6.4.2, EC 1.6.4.5
1-nonanol	143-08-8	EC 1.1.1.1
nonanal	124-19-6	EC 1.1.1.1
O_2	7782-44-7	EC 1.6.99.3, EC 1.3.99.1, EC 1.9.3.1
octanal	124-13-0	EC 1.1.1.1
1-octanol	111-87-5	EC 1.1.1.1
orotate	65-86-1	EC 1.3.99.11
orthophosphate	10049-21-5	EC 1.2.1.11, EC 1.2.1.12, EC 1.2.1.12 & EC 2.7.2.3
oxaloacetate	328-42-7	EC 1.1.1.37, EC 1.1.99.7
oxalyl-CoA	5060-54-8	EC 1.2.1.17
oxidized cytochrome c	9007-43-6[c]	EC 1.1.99.13, EC 1.9.3.1
oxidized flavin-adenine dinucleotide	146-14-5	EC 1.7.99.5
oxidized glutathione	103239-24-3	EC 1.6.4.2, EC 1.8.4.3
oxidized indophenol	500-12-1	EC 1.3.99.2
oxidized pyocyanine	85-66-5	EC 1.3.99.2
oxidized thioredoxin	[b]	EC 1.6.4.5
2-oxobutanoate	600-18-0	EC 1.1.1.27
3-oxobutanoate	541-50-4	EC 1.1.1.30
4-oxobutanoate	692-29-5	EC 1.1.1.61
3-oxobutanoyl-[acyl-carrier protein]	[b]	EC 1.1.1.100
3-oxobutanoyl-CoA	1420-36-6	EC 1.1.1.35
2-oxo-D-gluconate	669-90-9	EC 1.1.99.3
5-oxo-D-gluconate	5287-64-9	EC 1.1.1.69
2-oxoglutarate	328-50-7	EC 1.1.1.37 & EC 2.6.1.1, EC 1.1.1.42, EC 1.1.1.a, EC 1.4.1.2, EC 1.4.1.3
3-oxohexanoyl-CoA	19774-86-8	EC 1.1.1.35
2-oxo-4-hydroxybutanoate	22136-38-5	EC 1.1.1.27
2-oxo-3-hydroxysuccinate	1944-42-9	EC 1.1.1.37
3-oxolactose	15990-62-2	EC 1.1.99.13
2-oxo-*myo*-inositol	488-64-2	EC 1.1.1.18

8. 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
3-oxopropanoate	926-61-4	EC 1.1.1.59
15-oxo-prostaglandin E_1	22973-19-9	EC 1.1.1.141
3-oxo-L-threonate	89281-68-5	EC 1.1.1.129
6-phospho-D-gluconate	5341-70-4	EC 1.1.1.44, EC 1.1.1.49 & EC 3.1.1.31
3-phospho-D-glycerate	80731-10-8	EC 1.1.1.95, EC 1.2.1.12 & EC 2.7.2.3
3-phospho-D-glyceroyl phosphate	38168-82-0	EC 1.2.1.12
(3-phospho-D-glyceroyl)phosphonate	143669-87-8	EC 1.2.1.12
(3-phospho-D-glycerol-aminomethyl)phosphonate	143509-96-0	EC 1.2.1.12
(3-phospho-D-glycerol-chloroethyl)phosphonate	143509-97-1	EC 1.2.1.12
(3-phospho-D-glycerol-chloromethyl)phosphonate	143509-98-2	EC 1.2.1.12
(3-phospho-D-glycerol-ethyl)phosphonate	143509-99-3	EC 1.2.1.12
(3-phospho-D-glycerol-methoxy)phosphonate	143510-01-4	EC 1.2.1.12
(3-phospho-D-glycerol-methyl)phosphonate	143510-00-3	EC 1.2.1.12
3-phosphohydroxypyruvate	3913-50-6	EC 1.1.1.95
phosphonate	13598-36-2	EC 1.2.1.12
L-pipecolate	3105-95-1	EC 1.5.1.21
Δ^1-piperidine 2-carboxylate	2756-89-0	EC 1.5.1.21
5α-pregnane-17α,21-diol-3,20-dione	312-99-2	EC 1.1.1.50, EC 1.1.1.51
5β-pregnane-17α,21-diol-3,20-dione	566-42-7	EC 1.1.1.50, EC 1.1.1.51
5α-pregnane-17α,21-diol-3,11,20-trione	1482-51-5	EC 1.1.1.51
5β-pregnane-17α,21-diol-3,11,20-trione	68-54-2	EC 1.1.1.50
5α-pregnane-3β,17α,21-triol-11,20-dione	516-45-0	EC 1.1.1.51
5β-pregnane-3α,17α,21-triol-11,20-dione	53-05-4	EC 1.1.1.50
5α-pregnane-3α,17α,21-triol-20-one	601-01-4	EC 1.1.1.50
5α-pregnane-3β,17α,21-triol-20-one	516-47-2	EC 1.1.1.51
5β-pregnane-3α,17α,21-triol-20-one	68-60-0	EC 1.1.1.50
5β-pregnane-3β,17α,21-triol-20-one	601-03-06	EC 1.1.1.51
4-pregnene-11β,17α-diol-3,20,21-trione	14760-49-7	EC 1.1.1.150
4-pregnene-11β,17α,21-triol-3,20-dione	50-23-7	EC 1.1.1.150
(*S*)-proline	147-85-3	EC 1.5.1.1, EC 1.5.1.2
1,2-propanediol	57-55-6	EC 1.1.1.55
propanal	123-38-6	EC 1.1.1.1
1-propanol	71-23-8	EC 1.1.1.1
2-propanol	67-63-0	EC 1.1.1.1
prostaglandin E_1	745-65-3	EC 1.1.1.141
D-psicose	551-68-8	EC 1.1.1.9
pyocyanine	85-66-5	EC 1.3.99.2
pyocyanine (reduced)	107518-21-8	EC 1.3.99.2
Δ^1-pyrroline-2-carboxylate	2139-03-9	EC 1.5.1.1
Δ^1-pyrroline-5-carboxylate	108321-37-5	EC 1.5.1.2
pyruvate	127-17-3	EC 1.1.1.27, EC 1.1.1.28, EC 1.1.1.39, EC 1.1.1.40, EC 1.1.99.7, EC 1.4.1.1, EC 1.5.1.11, EC 1.5.1.17
quinate	77-95-2	EC 1.1.1.24
reduced cytochrome c	9007-43-6[c]	EC 1.1.99.13, EC 1.9.3.1
reduced flavin-adenine dinucleotide	1910-41-4	EC 1.7.99.5
reduced glutathione	70-18-8	EC 1.6.4.2, EC 1.8.4.3
reduced indophenol	1752-24-5	EC 1.3.99.2
reduced pyocyanine	107518-21-8	EC 1.3.99.2
reduced thioredoxin	52500-60-4[c]	EC 1.6.4.5
ribitol	488-81-3	EC 1.1.1.9, EC 1.1.1.14, EC 1.1.1.56
D-ribulose	488-84-6	EC 1.1.1.9, EC 1.1.1.14, EC 1.1.1.56
D-ribulose 5-phosphate	108321-99-9	EC 1.1.1.44
D-sedoheptulose	3019-74-7	EC 1.1.1.9
sepiapterin	17094-01-8	EC 1.1.1.153
shikimate	138-59-0	EC 1.1.1.25
D-sorbitol	50-70-4	EC 1.1.1.9, EC 1.1.1.14
D-sorbitol 6-phosphate	108392-12-7	EC 1.1.1.140, EC 1.1.1.b
L-sorbose	87-79-6	EC 1.1.1.9
succinate	110-15-6	EC 1.3.99.1
D-tagatose	87-81-0	EC 1.1.1.14
meso-tartrate	147-73-9	EC 1.1.1.37
5,6,7,8-tetrahydrofolate	135-16-0	EC 1.5.1.3
thionicotinamide-adenine dinucleotide	4090-29-3	EC 1.1.1.50
thionicotinamide-adenine dinucleotide (reduced)	38850-22-5	EC 1.1.1.50

8. 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
thioredoxin (oxidized)	52500-60-4[c]	EC 1.6.4.5
thioredoxin (reduced)	52500-60-4[c]	EC 1.6.4.5
L-threitol	2319-57-5	EC 1.1.1.9
L-threonate	70753-61-6	EC 1.1.1.129
vitamin A alcohol	68-26-8	EC 1.1.1.1
vitamin A aldehyde	116-31-4	EC 1.1.1.1
xylitol	87-99-0	EC 1.1.1.9, EC 1.1.1.10, EC 1.1.1.14, EC 1.1.1.21
D-xylose	58-86-6	EC 1.1.1.21
D-xylulose	551-84-8	EC 1.1.1.9, EC 1.1.1.14, EC 1.1.1.21
L-xylulose	527-50-4	EC 1.1.1.10

[a]In some cases the CAS registry number refers to a salt of the substance.
[b]In the absence of an amino acid sequence, no CAS registry number is assigned to this substance.
[c]In the absence of an amino acid sequence, the CAS registry numbers are the same for the oxidized and reduced forms.

9. Abbreviations

ADP	adenosine 5'-diphosphate
AP-NAD	3-acetylpyridine adenine dinucleotide
AP-NADH	3-acetylpyridine adenine dinucleotide (reduced)
ATP	adenosine 5'-triphosphate
Bicine	*N,N*-Bis(2-hydroxyethyl)glycine
CoA	coenzyme-A
desamino NAD	desamino β-nicotinamide-adenine dinucleotide
desamino NADH	desamino β-nicotinamide-adenine dinucleotide (reduced)
HEPES	*N*-2-Hydroxyethylpiperazine-N'-ethanesulfonic acid
MOPS	3-(N-morpholino)propanesulfonic acid
NAD	β-nicotinamide-adenine dinucleotide
NADH	β-nicotinamide-adenine dinucleotide (reduced)
NADP	β-nicotinamide-adenine dinucleotide phosphate
NADPH	β-nicotinamide-adenine dinucleotide phosphate (reduced)
TAPS	*N*-Tris(hydroxymethyl)methyl-3-aminopropanesulfonic acid
TNAD	thionicotinamide-adenine dinucleotide
TNADH	thionicotinamide-adenine dinucleotide (reduced)
Tricine	*N*-Tris(hydroxymethyl)methylglycine
Tris	tris(hydroxymethyl)aminomethane

10. Reference Codes and References in the Table

36EUL/ADL von Euler, H.; Adler, E.; Hellström, H.; Hoppe-Seyler's Z. Physiol. Chem.; **241**, 239 (1936).

37ADL/SRE Adler, E.; Sreenivasaya, M.; Hoppe-Seyler's Z. Physiol. Chem.; **249**, 24 (1937).

37EUL/ADL von Euler, H.; Adler, E.; Günther, G.; Hoppe-Seyler's Z. Physiol. Chem.; **247**, 65 (1937).

37EUL/ADL2 von Euler, H.; Adler, E.; Günther, G.; Hoppe-Seyler's Z. Physiol. Chem.; **249**, 1 (1937).

37EUL/ADL3 von Euler, H.; Adler, E.; Günther, G.; Hellström, H.; Hoppe-Seyler's Z. Physiol. Chem.; **245**, 217 (1937).

37NEG/WUL Negelein, E.; Wulff, H.-J.; Biochem. Z.; **293**, 351 (1937).

38EUL/ADL von Euler, H.; Adler, E.; Günther, G.; Das, N.B.; Hoppe-Seyler's Z. Physiol. Chem.; **254**, 61 (1938).

38SCH/EUL Schlenk, F.; von Euler, H.; Günther, G.; Arkiv. Kemi Mineral. Geol.; **12B**, 1 (1938).

38SCH/HEL Schlenk, F.; Hellström, H.; von Euler, H.; Ber. Dtsch. Chem. Ges.; **71**, 1471 (1938).

43KUB/OTT Kubowitz, F.; Ott, P.; Biochem. Z.; **314**, 94 (1943).

45DRA/MEY Drabkin, D.L.; Meyerhof, O.; J. Biol. Chem.; **157**, 571 (1945).

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

48OCH Ochoa, S.; J. Biol. Chem.; **174**, 133 (1948).

49BAR Baranowski, T.; J. Biol. Chem.; **180**, 535 (1949).

50COR/VEL Cori, C.F.; Velick, S.F.; Cori, G.T.; Biochim. Biophys. Acta; **4**, 160 (1950).

50RAC Racker, E.; J. Biol. Chem.; **184**, 313 (1950).

51BLA Blakley, R.L.; Biochem. J.; **49**, 257 (1951).

51BLI Bliss, A.F.; Arch. Biochem. Biophys.; **31**, 197 (1951).

51THE/BON Theorell, H.; Bonnichsen, R.; Acta Chem. Scand.; **5**, 1105 (1951).

52BUR Burton, K.; Biochim. Biophys. Acta; **8**, 114 (1952).

52NEI Neilands, J.B.; J. Biol. Chem.; **199**, 373 (1952).

52STE/OCH Stern, J.R.; Ochoa, S.; Lynen, F.; J. Biol Chem.; **198**, 313 (1952).

52STR/KOR Strecker, H.J.; Korkes, S.; J. Biol. Chem.; **196**, 769 (1952).

53BRI Brink, N.G.; Acta Chem. Scand.; **7**, 1081 (1953).

53BUR/STA Burton, R.M.; Stadtman, E.R.; J. Biol. Chem.; **202**, 873 (1953).

53BUR/WIL Burton, K.; Wilson, T.H.; Biochem. J.; **54**, 86 (1953).

53HAR/KOR Harary, I.; Korey, S.R.; Ochoa, S.; J. Biol. Chem.; **203**, 595 (1953).

53KAP/COL Kaplan, N.O.; Colowick, S.P.; Neufeld, E.F.; J. Biol. Chem.; **205**, 1 (1953).

53LYN/OCH Lynen, F.; Ochoa, S.; Biochim. Biophys. Acta; **12**, 299 (1953).

53OLS/ANF Olson, J.A,; Anfinsen, C.B.; J. Biol. Chem.; **202**, 841 (1953).

53STR Strecker, H.J.; Arch. Biochem. Biophys.; **46**, 128 (1953).

53TAL/DOB Talalay, P.; Dobson, M.M.; J. Biol. Chem.; **205**, 823 (1953).

54GRE/MII Green, D.E.; Mii, S.; Mahler, H.R.; Bock, R.M.; J. Biol. Chem.; **206**, 1 (1954).

54STR/HAR Strecker, H.J.; Harary, I.; J. Biol. Chem.; **211**, 263 (1954).

54WAK/GRE Wakil, S.J.; Green, D.E.; Mii, S.; Mahler, H.R.; J. Biol. Chem.; **207**, 631 (1954).

54WIL/BAN Williams-Ashman, H.G.; Banks, J.; Arch. Biochem. Biophys.; **50**, 513 (1954).

55BLA/WRI2 Black, S.; Wright, N.G.; J. Biol. Chem.; **213**, 39 (1955).

55BLA/WRI3 Black, S.; Wright, N.G.; J. Biol. Chem.; **213**, 51 (1955).

55BUR2 Burton, R.M.; Methods Enzymol.; **1**, 397 (1955).

55DAV/GIL Davis, B.D.; Gilvarg, C.; Mitsuhashi, S.; Methods Enzymol.; **2**, 300 (1955).

55GLA/BRO Glaser, L.; Brown, D.H.; J. Biol. Chem.; **216**, 67 (1955).

55KAT Katz, S.; Biochim. Biophys. Acta; **17**, 226 (1955).

55LYN/WIE Lynen, F.; Wieland, O.; Methods Enzymol.; **1**, 566 (1955).

55STA/BUR Stadtman, E.R.; Burton, R.M.; Methods Enzymol.; **1**, 518 (1955).

55WOL/KAP Wolff, J.B.; Kaplan, N.O.; Methods Enzymol.; **1**, 346 (1955).

55YAN/GIL Yaniv, H.; Gilvarg, C.; J. Biol. Chem.; **213**, 787 (1955).

55ZEL Zelitch, I.; J. Biol. Chem.; **216**, 553 (1955).

56HAK/GLA Hakala, M.T.; Glaid, A.J.; Schwert, G.W.; J. Biol. Chem.; **221**, 191 (1956).

56HAU Hauge, J.G.; J. Am. Chem. Soc.; **78**, 5266 (1956).

56KAP/CIO Kaplan, N.O.; Ciotti, M.M.; Stolzenbach, F.E.; J. Biol. Chem.; **221**, 833 (1956).

56LAR/JAC Larner, J.; Jackson, W.T.; Graves, D.J.; Stamer, J.R.; Arch. Biochem. Biophys.; **60**, 352 (1956).

56TAL/MAR Talalay, P.; Marcus, P.I.; J. Biol. Chem.; **218**, 675 (1956).

56TOM Tomkins, G.M.; J. Biol. Chem.; **218**, 437 (1956).

56WOL/KAP Wolff, J.B.; Kaplan, N.O.; J. Biol. Chem.; **218**, 849 (1956).

57DOU/CON Doudoroff, M.; Contopoulou, C.R.; Burns, S.; Proc. Internat. Sympos. Enzyme Chem. (Tokyo and Kyoto) (1957).

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