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# ISOELECTRIC POINTS AND MOLECULAR WEIGHTS OF PROTEINS

## A TABLE

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## 1. INTRODUCTION

The aim of this article is to provide a list of proteins having known macromolecular parameters, with particular emphasis on isoelectric points (pI) and molecular weights (M.W.). The new updated revision of the classical tables of Darnall and Klotz[1] now has more than 500 entries, each complete with the native molecular weight of the macromolecule, as well as its subunit number and M.W. For each entry, these workers also list the source and, when applicable, the organ of origin. This is very important, since lack of this information in previous tables has generated confusion.

The main aim of Darnall and Klotz[1] was to tabulate proteins having a known quaternary structure. Similar tables have been published by Kleine[2]. However, there is no literature compilation of information on the charge (pI) as well as on the size (M.W.) of proteins. Yet, the pI of a protein is a very important parameter, and its knowledge is very important for the proper use of several techniques, such as disc electrophoresis, isotachophoresis, isoelectric focusing, ion-exchange chromatography and even ammonium sulphate fractionation. Until recently, the literature data on pI values of proteins were scanty and even contradictory. With the advent of isoelectric focusing[3–6], pI data for proteins have been rapidly expanding, to an extent which justifies their collection in a table. Thus, the main emphasis here is on the availability and collection of protein pI values. When available, we also report their M.W. values and quaternary structure. The combined knowledge of these two parameters makes possible the macromolecular mapping of proteins[7]. Most proteins, in fact, are unequivocally determined by values of their pI and M.W. (except, perhaps,

for very close genetic variants of a protein, such as human haemoglobin). Many of the entries in our tables, which lack data on M.W. and subunit structure, can be found in the tables of Darnall and Klotz[1]. However, for the same protein the source and/or the organ may be different; therefore we decided not to report such data.

Since most of the proteins reported display microheterogeneity, we have marked the main components with an asterisk when this information was available or could be deduced from graphs or tables. In addition, we also report not only the source and the organ, but also the intracellular location, in the case of isozymes displaying different properties in different subcellular compartments. Unfortunately, there is quite a degree of uncertainty as to the temperature of pH measurement. This is quite an important parameter when defining the pI of a protein, since acid–base equilibria are temperature dependent and a pI of a protein, if quoted without the temperature of measurement, is *per se* ambiguous and lacks an exact physicochemical significance. Some workers never report the temperature of pH measurement. Most workers simply refer to measurements performed at room temperature, which, unfortunately, is not unequivocally determined. Only a few workers have made pH measurements at a precise temperature, in a thermostatted vessel. Since the way in which a pH measurement is made is of utmost importance in defining pI, we summarize here the different techniques used, either in liquid or in gel media.

*(A) Measurement of pH in isoelectric focusing*

The pI of a protein determined by isoelectric focusing (IEF) also represents its isoionic point in the absence of complex-forming ions[8]. By definition, the isoionic point is a measure of the intrinsic acidity of a pure protein, as it is defined as that pH which does not change on addition of a small amount of pure protein[9]. This definition is also applicable to a protein analyzed by IEF, as the pH of the isoelectric zone does not alter on addition of more protein. It should be remembered that pI values estimated by IEF are temperature dependent and usually decrease with increasing temperature[6]. The difference in pI for the same protein, measured at 25 and at 4°, could be as high as 0.5 pH units, the higher value being obtained at the lower temperature. This difference is usually more pronounced in alkaline regions, and when a protein has a pI value close to the p$K$ of some of its functional groups.

Unfortunately, when given a pI value for a protein at a certain temperature it is difficult to extrapolate this value to another temperature, since the temperature coefficient, dpI/d$T$, can vary from protein to protein. Thus Bours[10], by measuring the pI values of $\beta$-lactoglobulin A and B at 4 and 25°, found a value of dpI/d$T$ of $-(0.9 \pm 0.2) \cdot 10^{-2}$ pH unit per degree. On the other hand, measurements of pI at 4 and 25° for carbonic anhydrase have given a dpI/d$T$ value of $-(1.3 \pm 0.2) \cdot 10^{-2}$ pH unit per degree. In the case of myoglobin[10], the temperature coefficient is as high as $-1.7 \cdot 10^{-2}$ pH unit per degree.

Ideally, pH measurements should be made at the same temperature used during the IEF separation, since in IEF the temperature coefficient, dpI/d$T$, refers to the corresponding carrier ampholytes rather than to the protein contained in a given fraction. In fact, at the usual concentration of Ampholine (1%), the buffering capacity of the carrier ampholytes in the isoelectric state will normally be sufficient to permit them to dictate the pH even in the presence of as much as 1% of protein[11,12]. This

means that the pH value assigned to the concentration maximum of a focused protein at a temperature different from the IEF temperature will refer to the corresponding ampholyte fraction rather than to the protein[13]. Furthermore, different protolytic groups are known to display widely different degrees of temperature dependence in their dissociation constants (as a consequence of large differences in their standard heats of ionization)[14]. Thus, once a protein has been focused at 4°, a pI measurement made at 20 or at 25° may not represent the true pI of the protein or the pI of the Ampholine molecules surrounding it.

In addition, pH measurements can also be affected by the presence of solutes such as glycerol and sucrose, which are commonly used in IEF. As sucrose lowers the dielectric constant of the solvent and this, in turn, causes the p$K$ values of amino acids to increase[15], it can be expected that the pI value of a given protein is increased on increasing the concentration of sucrose. When IEF is performed in the presence of urea, it should be noted that urea appreciably decreases the activity coefficient of hydrogen ions, resulting in apparently higher p$K$ and pI values of the carrier ampholytes. Correction factors should therefore be used for pI determinations of proteins in urea[16].

*(B) pH measurements after IEF in density gradients*

In preparative IEF in liquid support media, combined UV and pH readings of all of the collected fractions can be a lengthy and cumbersome procedure. To overcome this, Jonsson *et al.*[17] automated the analysis of column contents by pumping them at a constant rate through series-coupled flow cells, one cell for the recording of pH and the other cell for the determination of UV absorbance. This set-up, however, presented some difficulties in pH determination, which are discussed in detail by these workers[17]. More recently, Secchi[18] described a modification of this technique, which appears to overcome many of the problems. A combined glass electrode (Ingold Type 401-M7, provided with a flow vessel and water cooling jacket) is coupled in series with the UV flow cell of an LKB Uvicord II. In this case, the UV signal and pH readings are fed, via a control unit, to the same galvanometric recorder used for the UV readings (LKB 6500). Since the volume lag between the pH and UV cells is only 0.35 ml, accurate and simultaneous pH and UV readings are obtained on the same recorder chart. Moreover, since the pH cell is thermostatted, pH readings are made at the temperature of the focusing column. Another advantage of flow systems is that absorption of carbon dioxide from the air, which might affect pI readings by lowering the pH of the solution, especially in alkaline regions, is avoided.

A similar set-up was reported by Strongin *et al.*[19], who built a pH flow cell in Perspex with Type K-401 and Type GK 2320c pH electrodes from Radiometer A/S. When using flow cells, the peristaltic pump should be attached after the cells, in order to prevent leakage of potassium chloride from the electrodes and to keep the flow-rate as low as possible (to avoid pressure on the glass membrane of the electrode, which could alter the pH readings). Alternatively, for measurement of the pH course in a micro-column, where fractions of only 60 $\mu$l are collected, Fredriksson[20] described the use of a Radiometer micro glass electrode, in which the pH-sensitive membrane is shaped as a horizontal capillary. The capillary can be filled, via a vertical polyethylene tube, simply by suction. A volume as small as 20 $\mu$l is sufficient for pH reading. Values correct to within 0.01 pH unit have been reported.

*(C) pH measurements after IEF in gel media*

When performing IEF in solid support media, it is convenient to be able to measure directly the pH gradient along the gel length. For flat gels, a surface electrode may be used with a coplanar glass reference electrode having either a flat face or a spear tip. In either case, it is advisable to have the probes of both electrodes as close as possible to minimize errors due to differences in conductivity throughout the gel.

One of the first electrodes developed for pH measurements on gel surfaces is the antimony micro-electrode, in conjunction with a calomel reference electrode, reported by Beeley *et al.*[21]. This electrode, which was originally developed by Kleinberg[22] to measure the pH of dental plaques, has a spear tip of 1 mm in diameter. Measurements are made by placing the gel over a sheet of graph paper, pressing the reference electrode at any position along the gel length and scanning at regular intervals with the antimony micro-electrode. Where the pH reading has been made, the gel is marked by serration with a scalpel blade. This allows a much greater accuracy in the determination of pI by interpolation on a graph of pH *versus* protein position in the gel. With the antimony electrode, readings of electromotive force are obtained on the millivolt scale and are converted into units of pH by means of an appropriate calibration graph. This type of electrode might be better standardized against Ampholine solutions, which in turn are calibrated against standard buffers[23]. One important property of the antimony micro-electrode, in contrast to very small glass electrodes, is its rapid equilibration time (less than 10 sec), even at low temperatures, which makes it very attractive for use at 4°. However, one disadvantage of this electrode is its low reproducibility, given by Beeley *et al.*[21] as $< 0.25$ pH units, in comparison with the resolution of 0.02 pH units, and even less, afforded by IEF.

Alternatively, on gel slabs, the pH can be measured directly on the gel surface with a flat membrane electrode, such as LOT Type 403-30-M8 from Ingold. However, since this electrode has a high surface area (membrane diameter, 8 mm), Drysdale[24] (in collaboration with Ingold Inc., Lexington, Mass., U.S.A.) has developed a flat membrane micro-electrode. This h-shaped electrode contains the reference unit in one arm, and the measuring membrane in a parallel arm. The two electrodes are coplanar, and are only 3 mm apart in order to offset variations in conductivity along the gel. The pH membrane has a diameter of 2.5 mm. This allows accurate pH measurements over a small surface; however, due to the high impedance of the small glass membrane, this electrode is practically of no use at low temperatures, since the response times are extremely long.

In order to overcome the problems connected with the use of surface electrodes, we have devised a simple method for accurate pH measurements in gel slabs, using a standard combination micro-electrode. The gel slab is focused over plastic graph paper placed on the cooling block of an LKB Multiphor 2117 apparatus, thermostatted at 4°. At the end of the experiment, 22 or 23 gel segments are cut from the side of the gel, at 0.5-cm intervals. Simultaneously, a 1–2-mm diameter hole is bored in the gel (with the help of a gel puncher for immunodiffusion and of a suction pump) in a zone corresponding to the middle of the 0.5-cm gel segment removed for pH measurement. Since this operation is made on the cooling block, and requires only a few minutes, no appreciable diffusion of the protein zones takes place. The rectangular gel segments removed are eluted in small test-tubes with 0.3 ml of 10 m*M*

KCl. Since the combination micro-electrode, with a saturated solution of KCl and buffers, is kept in the cold room (connected to the electronic control unit outside by a cable passing through the wall), accurate and reproducible pH measurements are obtained from the gel eluates at the focusing temperature. The pH profile can be easily superimposed on the stained gel slab with the aid of the 22 or 23 holes punched in it.

### *(D) Use of pH markers*

An alternative to pH measurements along the gel length, especially when working with thin-layer equipment, is the use of a calibrated mixture of pH markers,

TABLE 1

pH MARKERS FOR ISOELECTRIC FOCUSING

| *pH marker* | *pI at 25°* | *pI at 4°* [§] |
|---|---|---|
| *Proteins* | | |
| Cytochrome *c* | 9.28 ± 0.02* | |
| Ribonuclease | 8.88 ± 0.03* | |
| Myoglobin (sperm whale): | | |
| major component | 8.18 ± 0.02*; 8.18 ± 0.04** | |
| minor component | 7.68 ± 0.02* | |
| Myoglobin (horse): | | |
| major component | 7.33 ± 0.01*; 7.45 ± 0.04** | 7.58 ± 0.02 |
| minor component | 6.88 ± 0.02*; 7.15 ± 0.04** | 7.22 ± 0.05 |
| Bovine haemoglobin A | 6.80*** | |
| Carbonic anhydrase (bovine) | | 6.18 ± 0.02 |
| Conalbumin | 5.88 ± 0.02* | |
| β-Lactoglobulin B | 5.31* | 5.45 ± 0.02 |
| β-Lactoglobulin A | 5.14 ± 0.01* | 5.35 |
| Bovine insulin | 5.32 ± 0.02*** | |
| Albumin (bovine) Cohn: | | |
| fraction 5 | 4.90*** | 4.95 ± 0.02 |
| Ovalbumin | 4.70*** | |
| Horse spleen ferritin I | 4.50 ± 0.02* | |
| Horse spleen ferritin II | 4.38 ± 0.02* | |
| Horse spleen ferritin III | 4.23 ± 0.03* | |
| *Dyes* | | |
| Tris(5-hydroxy-1,10-phenanthroline)iron(II) | 7.15** | |
| Tris(5-hydroxy-1,10-phenanthroline)iron(II) –tris(4-hydroxy-1,10-phenanthroline)-iron(II) | 6.82** | |
| Tris(4-hydroxy-1,10-phenanthroline)iron(II) –tris(5-hydroxy-1,10-phenanthroline)-iron(II) | 6.24** | |
| Congo Red | 5.80*** | |
| Tris(4-hydroxy-1,10-phenanthroline)iron(II) | 5.45** | |
| Evans blue | 5.35*** | |
| Methyl Blue | 3.60*** | |
| Fast green FCF (major component) | 3.05*** | |
| Patent blue V | 3.00*** | |

* Ref. 27.
** Ref. 26.
*** Ref. 25.
§ Ref. 10.

TABLE 2

pI AND M.W. VALUES OF PROTEINS

accl. = Acclimated, chloro. = chloroplast, cyto. = cytoplasm, lyso. = lysosome, micro. = microsome, mitoch. = mitochondria, n.g. = not given, nucl. = nucleus, perox. = peroxisome, r.t. = room temperature, s.p.c. = single polypeptide chain and str. = strain.

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temperature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No.* | *M.W.* | | | |
| Acetoacetyl-CoA thiolase[28,29] | yeast | cytosol | $1.4 \cdot 10^5$ | | | 5.3 | 1 | n.g. |
| | | mitoch. | $0.65 \cdot 10^5$ | | | 7.8 | 1 | n.g. |
| Acetoacetyl-CoA thiolase[30] | rat | liver cyto. | | | | 4.8 | 1 | n.g. |
| | | liver mitoch. | | | | 8.4 | 1 | n.g. |
| Acetoacetyl-CoA thiolase[30] | ox | liver cyto. | | | | 5.2 | 1 | n.g. |
| | | liver mitoch. | | | | 7.8 | 1 | n.g. |
| Acetoacetyl-CoA thiolase[31] | rat | brain cyto. | | | | 5.1 | 1 | n.g. |
| | | brain mitoch. | | | | 8.3 | 1 | n.g. |
| β-N-Acetyl glucosaminidase[32] | *Sclerotinia fructigena* | | 141000 | | | 3.76 | 1 | n.g. |
| β-N-Acetyl glucosaminidase[33,34] | jack bean meal | | 100000 | | | 4.8 | 1 | r.t. |
| β-N-Acetyl glucosaminidase[35] | sheep | testis | | | | 6.0, 6.3 | 2 | 5 |
| N-Acetyl hexosaminidase[36] | ram | testis | 140000 | | | 6.45, 5.85*, 5.95* | 3 | 5 |
| | ram | epididymis | 140000 | | | 7.15, 7.05*, 6.7, 6.1 | 4 | 5 |
| N-Acetyl muramyl-L-alanine amidase[37] | *Staphylococcus aureus* | | 30000 | | | 9.7 | 1 | 4 |
| Acetyl transferase A[38] | rat | thymus (nucl.) | 99000 | | | 5.90 | 1 | n.g. |
| Acetyl transferase $B_1$[38] | rat | thymus (nucl.) | 110000 | | | 4.75 | 1 | n.g. |
| Acetyl transferase $B_2$[38] | rat | thymus (nucl.) | 92000 | | | 4.75 | 1 | n.g. |
| Acid β-galactosidase[39,40] | rat | intestine | 95000 | | | 4.2*, 4.6, 5.4*, 6.1, 8.0 | 5 | 1.5 |
| Acid phosphatase[41] | rat | liver | 100000 | | | 7.7, 4.5 | 2 | 4 |
| Acid phosphatase[42] | *S. aureus* | str. 408 | | | | 9.58*, 8.40 | 2 | n.g. |
| | *S. aureus* | str. 8325 | | | | 9.47*, 8.42 | 2 | n.g. |
| Acid protease[43] | *Rhizopus chinensis* | | 35000 | | | 5.2*, 5.9 | 2 | n.g. |
| Acid ribonuclease[44] | Lymphosarcoma P1798 | | 19000 | | | 5.3 | 1 | n.g. |
| Aconitase[45] | pig | heart | 66000 | | | 8.5*, 8.1, 7.9 | 3 | n.g. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Aconitate hydratase[46] | pig | heart cyto. | | | | 5.4 | 1 | 0 |
| | pig | heart mitoch. | | | | 7.4 | 1 | 0 |
| Adenine phosphoribosyl transferase[47,48] | mouse | fibroblast | | | | 5.5 | 1 | r.t. |
| | human | fibroblast | 34000 | 3 | 11000 | 4.48 | 1 | r.t. |
| Adenosine deaminase[49] | human | erythrocyte | 32000 | | | 4.70, 4.83*, 4.94, 5.06 | 4 | n.g. |
| Adenylate kinase[50,51] | rat | liver | 46000 | 2 | 23000 | 7.5, 8.0 | 2 | n.g. |
| Adenylate kinase[52] | *Escherichia coli* | | 27000 | | s.p.c. | 4.95 | 1 | n.g. |
| Albumin[53,54] | ox | plasma | 69000 | | s.p.c. | 5.18, 5.07, 4.98 | 3 | 25 |
| Albumin[54,55] | human | serum | 69000 | | s.p.c. | 5.85* | 3 | n.g. |
| Alcohol dehydrogenase[56,57] | horse | liver | 80000 | 2 | 41000 | 8.08, 8.28, 8.51, 8.7*, 9.29* | 12 | n.g. |
| Alcohol dehydrogenase[58] | rat | liver | 68000 | 2 | 39000 | 9.7 | 1 | 0 |
| Aldehyde dehydrogenase[59] | horse | liver | 245000 | 4 | 57000 | 5.05*, 4.80 | 2 | n.g. |
| Aldolase[60,61] | yeast | | 80000 | 2 | 40000 | 5.1, 5.2*, 5.3 | 3 | n.g. |
| Aldolase[62] | human | muscle | 160000 | 4 | 40000 | 9.13, 9.30*, 9.4*, 9.59*, 9.73 | 5 | 4 |
| Aldolase[62] | hen | muscle | 160000 | 4 | 40000 | 9.87, 9.96*, 10.0*, 10.06*, 10.11 | 5 | 4 |
| Aldolase[62] | pigeon | muscle | 160000 | 4 | 40000 | 9.9, 9.97*, 10.0*, 10.09*, 10.15 | 5 | 4 |
| Aldolase[62] | rabbit | muscle | 160000 | 4 | 40000 | 9.1, 9.27, 9.42*, 9.57*, 9.71 | 5 | 4 |
| Aldolase[62] | rat | muscle | 160000 | 4 | 40000 | 9.1, 9.25, 9.39*, 9.53*, 9.70* | 5 | 4 |
| Aldose reductase[63,64] | yeast | | 61000 | 1 | 23000 | 5.05 | 1 | n.g. |
| | | | | 1 | 36600 | | | |
| Alkaline phosphatase[65] | human | placenta | 116000 | 2 | 58000 | 4.6 | 1 | n.g. |
| Alkaline phosphatase[66] | human | kidney | | | | 4.3, 4.8, 5.9 | 3 | n.g. |
| Alkaline phosphatase[66,67] | calf | intestine | 140000 | 2 | 69000 | 4.4 | 1 | n.g. |
| Alkaline phosphatase[68] | human | liver | | | | 3.9 | 1 | n.g. |
| Alkaline phosphatase[69,70] | *E. coli* | | 80000 | 2 | 40000 | 5.06, 5.17, 5.20, 5.26*, 5.38 | 5 | 25 |
| L-Amino acid oxidase[71,72] | *Crotalus adamanteus* | venom | 135000 | 2 | 70000 | (5.2–8.4) 5.60*, 5.71*, 5.87* | 18 | 4 |

*(Continued on p. 8)*

TABLE 2 *(continued)*

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temperature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No.* | *M.W.* | | | |
| α-Amylase[73,74] | human | parotid | 55000 | | | 5.95 | 1 | 4 |
| α-Amylase[74,75] | human | saliva | 55000 | | | 6.4, 6.1, 5.6, 5.3 | 4 | 22 |
| α-Amylase[76] | rat | pancreas | 56000 | | s.p.c. | 8.77*, 8.95* | 2 | n.g. |
| α-Amylase[77] | guinea pig | pancreas | | | 52000 | 8.4 | 1 | 5–10 |
| Anthranilate synthetase[78,79] | *Serratia marcescens* | | 150000 | 2 | 21000 | 4.6 | 1 | n.g. |
| | | | | 2 | 60000 | | | |
| Arginine esterase[80] | *Contortrix laticinctus* | venom | 30000 | | | 9.1 | 1 | n.g. |
| Aryl β-glucosidase[81,82] | *Aspergillus niger* | | 50000 | | | 4.21, 4.43* | 2 | 4 |
| Aryl β-glucosidase[82] | *Stereum sanguinolentum* | | 50000 | | | 4.00, 4.08 | 2 | 4 |
| Aryl β-glucosidase[82] | *Fomes annosus* | | 50000 | | | 4.08, 4.17 | 2 | 4 |
| Aryl β-glucosidase[82] | *Chrysosporium lignorum* | | 50000 | | | 4.22, 4.38, 4.44 | 3 | 4 |
| Arylesterase[83] | guinea pig | cerebral cortex | 180000, 78000 | | | 5.1*, 5.8* | 2 | n.g. |
| Arylsulphatase[84] | *Pseudomonas aeruginosa* | | | | 60000 | 4.85*, 4.9* | 2 | n.g. |
| Arylsulphatase[85] | rat | kidney | | | | 4.4, 6.2 | 2 | n.g. |
| Arylsulphatase A[86] | red kangaroo | liver | 100000 | | | 5.1, 5.4 | 2 | n.g. |
| Arylsulphatase B[86] | red kangaroo | liver | 45000 | | | 7.0 | 1 | n.g. |
| L-Asparaginase[87,88] | *Erwinia carotovora* | | 135000 | 4 | 32500 | 8.00 | 1 | r.t. |
| L-Asparaginase[89,90] | *E. coli* | | 133000 | 4 | 33000 | 5.35 | 1 | 5 |
| Asparagine synthetase[91] | *E. coli* | | 80000 | | | 5.5 | 1 | n.g. |
| Aspartate aminotransferase[92,93] | pig | heart | 92500 | | | 5.35, 5.41, 5.43, 5.53, 5.69* | 5 | 25 |
| Aspartate aminotransferase[94] | sheep | liver | 89000 | | | 5.35, 5.56, 5.75 | 3 | n.g. |
| Aspartic β-semialdehyde dehydrogenase[95] | yeast | | 156000 | 4 | 41000 | 6.17 | 1 | n.g. |
| Aspartokinase L-homoserine dehydrogenase[96] | *E. coli* | str. $K_{12}$ | 360000 | 4 | 86000 | 6.1 | 1 | n.g. |
| Biotin carboxyl-carrier protein[97] | *E. coli* | | 45000 | 2 | 22500 | 4.5 | 1 | n.g. |
| Bromelin[98] | *Ananas comosus* | stem | 22000 | | | 9.7 | 1 | 25 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Butyrylcholinesterase[99] | human | brain | 300000–400000 | | | (5.6–7.0) | 4–5 | 22 |
| | | | 500000–1500000 | | | (5.6–8.0) | 6 | 22 |
| Carbonic anhydrase[100] | bull shark | erythrocyte | 38000 | | | 4.5 | 1 | n.g. |
| Carbonic anhydrase[101] (A ,B, C, F, D, G, H, M, N, O, P, T, U, X) | human | erythrocyte | 25400–29700 | | | (4.85–8.12) | 14 | n.g. |
| Carbonic anhydrase[102] | guinea pig | colonic mucosa | 30000 | | | 5.2, 7.4 | 2 | n.g. |
| Carbonic anhydrase[103] | pig | erythrocyte | 30375 | | | 7.3 | 1 | 1 |
| Carbonic anhydrase B[103,104] | ox | | 30000 | | | 5.89 | 1 | 22 |
| Carboxylesterase $E_1$[105] | rat | liver micro. | 150000 | | | 5.7 | 1 | n.g. |
| Carboxylesterase $E_2$[105] | rat | liver micro. | 70000 | | | 6.6 | 1 | n.g. |
| Carboxylesterase $E_1$[106] | rat | liver micro. | 177000 | 3 | 61500 | 5.65 | 1 | n.g. |
| Carboxylesterase[107] | beef | liver | 55000 | | s.p.c. | 5.5 | 1 | n.g. |
| Carboxypeptidase $G_1$[108] | *Pseudomonas stutzeri* | | 92000 | 2 | 46000 | 7.1* | 4 | n.g. |
| Carnitine acetyltransferase[109] | rabbit | heart, brain, muscle | | | | 6.1, 6.7, 7.9* | 3 | n.g. |
| Carnitine acetyltransferase[109] | human | adrenal | | | | 6.0, 6.8, 7.4* | 3 | n.g. |
| Carnitine acetyltransferase[109] | human | heart | | | | 6.1, 6.7, 7.6* | 3 | n.g. |
| Carnitine acetyltransferase[109] | human | brain | | | | 6.1, 6.6, 7.5* | 3 | n.g. |
| Carnitine acetyltransferase[109] | pigeon | muscle | | | | 7.0, 5.85*, 7.8* | 3 | n.g. |
| Catalase[110] | mouse | liver perox. | | | | 6.7 | 1 | 6 |
| | | liver cyto. | | | | 8.0, 8.2*, 8.5 | 3 | 6 |
| Catechol oxidase[111] (tyrosinase) | *Vitis vinifera* | | | | | 4.7*, 4.9*, 5.1 | 3 | n.g. |
| Cathepsin $B_1$[112] | human | liver | 25500 | | s.p.c. | (4.5–5.5) 5.0* | 6 | n.g. |
| Cellulase[113] | *Chrysosporium lignorum* | | | | | 4.27, 4.43*, 4.7* 5.05*, 5.53 | 5 | 4 |
| Cellulase[82] | *Aspergillus niger* | | | | | 3.9, 4.2, 4.52* | 3 | 4 |
| Cellulase[82] | *St. sanguinolentum* | | | | | 3.58 | 1 | 4 |
| Cellulase[82] | *Fomes annosus* | | | | | 3.9, 4.2* | 2 | 4 |
| Cellulase ($C_1$ component)[114] | *Trichoderma koningii* | | | | | 3.8, 3.95* | 2 | 5 |
| Ceramide trihexosidase[115] | human | plasma | 95000 | 4 | 22000 | 3.0 | 1 | n.g. |
| Cerebrocuprein[116] | human | brain | 35700 | | | 4.74 | 1 | n.g. |

*(Continued on p. 10)*

TABLE 2 *(continued)*

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temper-ature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No.* | *M.W.* | | | |
| Cereolysin[117] | *Bacillus cereus* | | | | | 6.5 | 1 | n.g. |
| Choline acetyltransferase[118] | pigeon | brain | | | | 6.6 | 1 | 4–6 |
| Choline acetyltransferase[118] | guinea pig | brain | | | | 6.8 | 1 | 4–6 |
| Choline acetyltransferase[118] | rat | brain | | | | 7.5, 7.8, 8.3* | 3 | 4–6 |
| Choline acetyltransferase[118] | cat | brain | | | | 7.0, 7.6, 8.4* | 3 | 4–6 |
| Cholinesterase[119] | *Pleuronectes platessa* | muscle | | | | 5.3, 6.9, 7.5 | 3 | n.g. |
| α-Chymotrypsin[120,121] | ox | pancreas | 21600 | | | 8.38, 8.76* | 2 | n.g. |
| δ-Chymotrypsin[122] | *Pseudomonas aeruginosa* | | | | | 8.5 | 1 | 4 |
| Chymotrypsinogen A[123] | beef | pancreas | 25000 | | | 8.8, 9.2, 9.6* | 3 | n.g. |
| Chymotrypsinogen A[73,124] | ox | pancreas | 23600 | | s.p.c. | 8.97 | 1 | 4 |
| Chymotrypsinogen[77] | guinea pig | pancreas | 25850 | | s.p.c. | 4.8, 8.7* | 2 | 5–10 |
| Citrate synthase[125] | trout | liver (cold accl.) | | | | 5.76 | 1 | 20 |
| | | liver (warm accl.) | | | | 5.05 | 1 | 20 |
| Clostridio peptidase B[126] | *Clostridium perfringens* | | | | | 4.85 | 1 | 18 |
| Coagulation factor VII[127] | human | serum | 44700 | | | 5.6 | 1 | n.g. |
| Cobalophilin (Vitamin $B_{12}$-binding protein)[128] | human | saliva | 69000 | | s.p.c. | (4.5–5) | 6 | r.t. |
| Cobalophilin (Vitamin $B_{12}$-binding protein)[129] | human | amniotic fluid | 59300 | | s.p.c. | 3.0, 3.3, 3.7*, 3.9 | 4 | r.t. |
| Colicin $E_2$[130] | *E. coli* | | 62000 | | | 7.41, 7.63* | 2 | 22 |
| Colicin $E_3$[130] | *E. coli* | | 62000 | | | 6.64 | 1 | 22 |
| Co-lipase[131] | pig | pancreas | 9650 | | s.p.c. | 5.0 | 1 | n.g. |
| Concanavalin A[132,133] | jack bean | | 71000 | 4 | 17500 | 4.5, 4.7, 5.05*, 5.5 | 4 | n.g. |
| Creatine phosphokinase[67,134] | rabbit | | 81000 | 2 | 40000 | 6.6, 6.7, 6.9 | 3 | r.t. |
| Crotoxin[135] | rattle | venom | 9000 | | s.p.c. | 3.7 | 1 | n.g. |
| | snake | | 12000 | | s.p.c. | 8.6 | 1 | n.g. |
| α-Crystallin[136–138] | cow | lens | $2.7 \cdot 10^6$ ($\alpha_1$)<br>620000 ($\alpha_2$) | | 21500 | 4.5, 4.85* | 2 | 4 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| β-Crystallin[136–138] | cow | lens | 220000 ($\beta_H$)<br>80000 ($\beta_L$) | | 27500 | (5.95–7.0) 6.55*<br>6.80*, 7.0* | 10 | 4 |
| γ-Crystallin[137,138] | cow | lens | | | 20500 | 7.25, 7.35, 7.6*, 7.80 | 4 | 4 |
| Cyclic AMP dependent protein kinase[139] | rat | liver | | | | 7.6, 8.2*, 8.5* | 3 | n.g. |
| Cyclic nucleotide phosphodiesterase[140] | pea | seedlings | 350000 | | | 4.3, 4.6, 4.8 | 3 | n.g. |
| Cystathione synthase[141,142] | rat | liver | 250000 | 2 | 51000 | 5.5 | 1 | n.g. |
| | | | | 2 | 73000 | | | |
| | chicken | liver | 125000 | | | 6.0 | 1 | n.g. |
| Cytochrome *b*-555[143] | house fly | larvae | 11300 | | s.p.c. | 4.24*, 4.28*, 4.32 | 3 | 0–2 |
| Cytochrome $b_5$ reductase[144] | calf | liver | 43000 | | s.p.c. | 6.8 | 1 | n.g. |
| Cytochrome *c*[145] | horse | heart | | | | 9.0, 9.4* | 2 | n.g. |
| Cytochrome *c*[146] | beef | heart | 12200 | | s.p.c. | 10.37, 10.57, 10.80* | 4 | 4 |
| Cytochrome *c*[147] | *Ustilago sphaerogena* | | 12500 | | s.p.c. | 9.4 | 1 | n.g. |
| Cytochrome $c_{550}$[148] | *Spirillum itersonii* | | 10800 | | s.p.c. | 9.86 | 1 | 4 |
| Cytochrome $c_{551}$[149] | *Azotobacter vinelandii* | | 12000 | | s.p.c. | 4.63 (reduced) | 1 | 15 |
| | | | | | | 5.17 (oxidized) | 1 | 15 |
| Cytochrome $c_{553}$[149] | *Azotobacter vinelandii* | | 12000 | | s.p.c. | 4.07 (reduced) | 1 | 15 |
| | | | | | | 4.26 (oxidized) | 1 | 15 |
| Cytochrome $p_{450CAM}$[150] | *Pseudomonas putida* | | 45000 | | s.p.c. | 4.55 | 1 | 20 |
| Cytochrome *c* peroxidase[151] | *Pseudomonas fluorescens* | | | | | 6.5, 6.7* | 2 | 9 |
| DDT dehydrochlorinase[152,153] | house fly | | 120000 | 4 | 30000 | 6.3, 6.9, 7.4* | 3 | n.g. |
| Deoxyribonuclease[154] | *S. aureus* | | | | | 2.5*, 5.0, 6.2, 8.5, 10.1* | 5 | 4 |
| Dextranase[155] | *Aspergillus carneus* | | 71000 | | | 4.12*, 4.35 | 2 | n.g. |
| Dextranase[156] | *Cytophaga johnsonii* | | 60000 | | | 5.1, 5.35*, 5.76* | 3 | 4 |

*(Continued on p. 12)*

TABLE 2 *(continued)*

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temperature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No.* | *M.W.* | | | |
| N,O-Diacetyl muraminidase[157] | *Chalaropsis* | | 19000 | | s.p.c. | 7.53 | 1 | 20 |
| Diacetyl reductase[158] | *Aerobacter aerogenes* | | 100000 | 4 | 25000 | 5.75, 5.9, 6.55*, 6.8* | 4 | 0 |
| DNA polymerase[159] | *Drosophila melanogaster* | embryos | | | | 5.3*, 5.8*, 6.3*, 7.5 | 4 | n.g. |
| DNA polymerase I[159] | *E. coli* | | | | | 5.2 | 1 | n.g. |
| Endonuclease[160] | ox | plasma | 38000 | | | 7.3 | 1 | 0 |
| Endonuclease[161] | *E. coli* | | | | | 4.3*, 6.1*, 8.5 | 3 | 15 |
| Endonuclease[162] | *Micrococcus lysodeikticus* | | 13500 | | | 4.8*, 9.0* | 2 | 25 |
| Enolase[60,163] | yeast | | 88000 | 2 | 44000 | 5.4, 5.6*, 6.0, 6.6, 6.7*, 6.8, 7.1 | 7 | n.g. |
| Enterotoxin A[164] | *S. aureus* | | 27800 | | s.p.c. | 6.64, 7.26*, 7.68*, 8.14 | 4 | 4 |
| Enterotoxin B[165] | *S. aureus* | | 24500 | | | 7.85, 7.93, 8.25*, 8.55* | 4 | 24 |
| Enterotoxin B[166] | *S. aureus* | | 24500 | | | 8.5, 9.05*, 9.4*, 9.56 | 4 | 4 |
| Epidermolytic toxin[167] | *S. aureus* | | 25000 | | s.p.c. | 6.2, 7.05* | 2 | n.g. |
| Erabutoxin C[168] | *Laticauda semifasciata* | venom | 7000 | | s.p.c. | 9.24 | 1 | n.g. |
| Erythroagglutinin[169] | red kidney bean | | 150000 | 4 | 37000 | 6.5 | 1 | n.g. |
| Erythrocruorin[170] | *Lumbricus* | blood | 3450000 | 148 | 23230 | 5.05 | 1 | 20 |
| Erythrocuprein[116,171] | human | erythrocyte | 33600 | | | 4.75 | 1 | n.g. |
| Esterase[140] | beef | liver | 55000 | | | 5.5 | 1 | n.g. |
| Ferritin[172,173] | horse | spleen | 440000 | 24 | 18500 | (4.27–4.57) 4.27*, 4.35*, 4.40* | 9 | 20 |
| Ferritin[174] | human | liver | | | | 5.29, 5.35, 5.45*, 5.50, 5.55 | 5 | n.g. |
| Ferritin[175] | rabbit | liver | | | | 4.98, 5.00*, 5.15, 5.18 | 4 | n.g. |
| Ferritin[176] | rat | liver | | | | 5.16, 5.24*, 5.3 | 5 | 20 |
| α-Fetoprotein[177] | human | foetus | 72000 | | | 4.78*, 5.2 | 2 | 25 |
| Fibrinogen[178] | rabbit | plasma | | | | 5.45, 5.50, 5.55 | 3 | n.g. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Follicle stimulating hormone (FSH)[179] | rat | hypophysis | | | | 2.8 | 1 | n.g. |
| Fructose-1,6-diphosphatase[180] | chicken | breast | | | | 8.6 | 1 | n.g. |
| | chicken | liver | | | | 8.1 | 1 | n.g. |
| Fructose-1,6-diphosphatase I and II[181] | *Paralithodes camtchatica* | gill | | | | 7.5, 5.3* | 2 | n.g. |
| | | hypodermis | | | | 7.2*, 5.4 | 2 | n.g. |
| Fructose diphosphate aldolase[182] | *Euglena gracilis* | chloro. | | | | 4.6 | 1 | n.g. |
| | | cyto. | | | | 5.7 | 1 | n.g. |
| Fumarase[183] | pig | heart | 194000 | 4 | 48500 | (5.9–8.2) 7.58*, 7.73*, 7.90* | 11 | n.g. |
| α-D-Galactosidase[184] | *Aspergillus niger* | | | | | 4.1, 4.5* | 2 | n.g. |
| β-D-Galactosidase[184] | *Aspergillus niger* | | | | | 4.3 | 1 | n.g. |
| β-D-Galactosidase[185] | *Neurospora crassa* | | 96000 | | | 4.78*, 5.82 | 2 | n.g. |
| β-1,3-Glucan hydrolase[186] | *Nicotiana glutinosa* | | 45000 | | | 4.87 | 1 | n.g. |
| Glucose-6-phosphate dehydrogenase[187] | *Candida utilis* | | 110000 | 2 | 55000 | 5.50, 5.87, 6.54* | 3 | n.g. |
| Glucose-6-phosphate dehydrogenase[188] | human | erythrocyte | | | | 5.79, 5.94, 6.11, 6.6*, 7.04* | 6 | r.t. |
| β-D-Glucosidase[189] | pig | kidney | 50000 | | | 4.9*, 5.1 | 2 | n.g. |
| β-Glucosidase[82] | *Aspergillus niger* | | | | | 4.46 | 1 | 4 |
| β-Glucosidase[82] | *Chrisosporium lignorum* | | | | | 4.38 | 1 | 4 |
| β-Glucosidase $A_3$[190] | *Aspergillus wentii* | | 170000 | | s.p.c. | 3.8 | 1 | n.g. |
| Glucosinolase[191] | *Sinapis alba* | | | | | 5.0, 5.55 | 2 | 20 |
| Glucosyl transferase[192] | parsley | cell culture | 50000 | | | 5.0 | 1 | n.g. |
| β-Glucuronidase[85] | rat | kidney | | | | 4.6, 6.7 | 2 | n.g. |
| β-Glucuronidase[193] | rat | preputials | 280000 | 4 | 75000 | 6.15 | 1 | 20 |
| L-Glutamate-phenylpyruvate aminotransferase[194] | beef | kidney (mitoch.) | | | | 9.8 | 1 | n.g. |
| L-Glutaminase[195] | *E. coli* | | | | | 4.2 | 1 | n.g. |
| Glutaminase-asparaginase[196] | Achromobacteraceae | | 138000 | 4 | 35000 | 8.3 | 1 | n.g. |
| L-Glutamylcyclotransferase[197] | sheep | brain | | | | 4.65, 5.25, 5.45* 5.75*, 6.20 | 5 | n.g. |

*(Continued on p. 14)*

TABLE 2 *(continued)*

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temper-ature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No* | *M.W.* | | | |
| L-Glutamylcyclotransferase[197] | human | brain | | | | 4.06*, 4.25 | 2 | n.g. |
| Glutathione epoxide transferase[198] | rat | liver | 40000 | 2 | 24000 | 7.14 | 1 | 4 |
| Glutathione-S-transferase[199] | rat | liver | 40000 | | | 6.9*, 8.1* | 2 | n.g. |
| Glyceraldehyde-3-phosphate dehydrogenase[95,200] | yeast | | 144700 | 4 | 35000 | 6.25 | 1 | n.g. |
| Glyceraldehyde-3-phosphate dehydrogenase[201] | rabbit | liver, muscle | 140000 | 4 | 36000 | 8.32, 8.52* | 2 | n.g. |
| L-Glycerol-3-phosphate dehydrogenase[60] | rabbit | adipose tissue | 66000 | | | 6.35 | 1 | n.g. |
| | | skeletal muscle | 78000 | 2 | 37500 | 6.45 | 1 | n.g. |
| $\alpha_1$-Glycoprotein[202] | bull frog | serum | 200000 | | s.p.c. | 4.5 | 1 | 9 |
| GSH transferase[203] | sheep | liver | | | | 7.1, 9.5 | 2 | n.g. |
| | rat | liver | | | | 7.6, 8.0*, 8.6*, 9.4 | 4 | n.g. |
| | mouse | liver | | | | 8.2*, 9.8 | 2 | n.g. |
| | house fly | | | | | 5.15*, 5.9, 6.8 | 3 | n.g. |
| | cockroach | | | | | 4.5, 6.6*, 8.5 | 3 | n.g. |
| | grass grub | | | | | 4.5, 5.2*, 8.8 | 3 | n.g. |
| Guanine phosphorybosyl transferase[204] | *E. coli* | | | | | 5.5 | 1 | 4 |
| Gulonolactonase[205] | rat | kidney | 42000 | | s.p.c. | 5.20 | 1 | 4 |
| Haemoglobin A[206,207] | human | erythrocytes | 64500 | 4 | 16000 | 6.95 | 1 | r.t. |
| Haemoglobin C[206,207] | human | erythrocytes | 64500 | 4 | 16000 | 7.40 | 1 | r.t. |
| Haemoglobin S[206,207] | human | erythrocytes | 64500 | 4 | 16000 | 7.25 | 1 | r.t. |
| Haemoglobin $F_I$[206,207] | human | foetus | 64500 | 4 | 16000 | 6.90 | 1 | r.t. |
| Haemoglobin $F_{II}$[206,207] | human | foetus | 64500 | 4 | 16000 | 7.15 | 1 | r.t. |
| Haemoglobin A ($\alpha$-chain)[208] | human | erythrocytes | | | 16000 | 8.12 | 1 | 4 |
| Haemoglobin S ($\beta$-chain)[208] | human | erythrocytes | | | 16000 | 7.08 | 1 | 4 |
| Haemoglobin[209] | harp seal | blood | | | | 7.06*, 8.04 | 2 | n.g. |
| $\alpha$-Haemolysin ($\alpha$-toxin)[210] | *S. aureus* | str. V8 | 44000 | | | 5.0, 7.0, 8.5* | 3–4 | 4 |
| $\beta$-Haemolysin[211] | *S. aureus* | str. R1 | | | | 3.5, 9.5* | 2 | 4 |
| $\delta$-Haemolysin( $\delta$-lysin)[211,212] | *S. aureus* | str. R1 | 74000 | | | 9.6 | 1 | 4 |
| Hemerytrin[213] | *Dendrostomum pyroides* | | 107000 | 8 | 13000 | 6.71 | 1 | n.g. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hepatocuprein[116] | human | liver | 35600 | | | 4.76 | 1 | n.g. |
| Hexokinase[214,215] | yeast | | 102000 | 2 | 51000 | 4.7 | 1 | n.g. |
| Hyaluronate lyase[216] | *S. aureus* | str. M18 | | | | 7.4, 7.9* | 2 | 4 |
| Hyaluronate lyase[217] | *S. aureus* | str. V8 | | | | 6.4*, 8.2* | 4 | 4 |
| L-3-Hydroxyacyl coenzyme A dehydrogenase[218,219] | pig | heart | 65000 | 2 | 31000 | 8.95 | 1 | 4 |
| Hypoxanthine-guanine phosphoribosyltransferase[220] | human | erythrocytes | 68000 | 2 | 34000 | 5.66, 5.82, 6.00 | 3 | 5 |
| Insulin[73,221] | beef | | 11466 | 2 | 5730 | 5.72 | 1 | 4 |
| Insulin[67] | pig | | | | | 6.0 | 1 | r.t. |
| Invertase[222] | yeast | | | | | (3.4–4 4) 4.02*, 4.24* | 10 | 4 |
| Invertase[223] | *Neurospora crassa* | | 210000 | 4 | 51500 | 4.78 | 1 | n.g. |
| Isocitrate dehydrogenase[224] | baker's yeast | | 375000 | 10 | 40000 | 5.5 | 1 | n.g. |
| Isocitrate lyase[225] | *Neurospora crassa* | | | | | 5.5 | 1 | n.g. |
| 2-Keto-3-deoxy-6-phosphogluconate aldolase[226] | *Pseudomonas putida* | | 73300 | 3 | 24000 | 4.7 | 1 | n.g. |
| α-Ketoglutarate-glyoxylate carboligase[227] | *Mycobacterium phlei* | | | | | 5.6 | 1 | n.g. |
| Laccase A[228,229] | *Polyporus versicolor* | | 62000 | | | 3.07, 3.27 | 2 | 4 |
| Laccase B[228] | *Polyporus versicolor* | | | | | 5.70*, 5.9, 6.13*, 6.26, 6.36, 6.56 | 6 | 4 |
| β-Lactamase (pennicillinase)[230,231] | *S. aureus* | str. 408 | 56000 | | | 8.38, 9.25* | 2 | n.g. |
| | | str. 8325 | | | | 8.48, 9.55* | 2 | n.g. |
| Lactase[232] | rat | intestine | | | | 4.4 | 1 | n.g. |
| Lactate dehydrogenase[225] | chinese hamster | skeletal muscle | | | | 5.7 | 1 | n.g. |
| Lactate dehydrogenase[60] | rabbit | muscle | | | | 8.3, 8.4, 8.55* | 3 | n.g. |
| Lactate dehydrogenase[233] | *Bacillus stearothermophilus* | | 135000 | 4 | 34000 | 5.5 | 1 | n.g. |
| β-Lactoglobulin[67,234] | cow | milk | 35000 | 2 | 17500 | 5.1, 5.26*, 5.34* | 3 | r.t. |
| β-Lactoglobulin A[235] | cow | milk | | | | 5.13 | 1 | 25 |
| β-Lactoglobulin B[235] | cow | milk | | | | 5.23 | 1 | 25 |

*(Continued on p. 16)*

TABLE 2 *(continued)*

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temperature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No.* | *M.W.* | | | |
| Lactoperoxidase[236] | cow | milk | 85000 | | | 9.16, 9.32, 9.49, 9.68*, 9.7*, 9.80* | 6 | n.g. |
| Leghaemoglobin[237] | *Lupin* | root nodules | 20000 | | s.p.c. | 5.08, 5.13 | 2 | n.g. |
| | *serradella* | root nodules | 18000 | | s.p.c. | 5.00, 5.05 | 2 | n.g. |
| Leucoagglutinin[238] | kidney bean | | 126000 | 4 | 31000 | 5.1 | 1 | n.g. |
| Leucoagglutinin[169] | kidney bean | | 140000 | 4 | 35000 | 5.0 | 1 | n.g. |
| Leucyl-t-RNA synthetase[239] | yeast | | 120000 | 2 | 60000 | 4.9 | 1 | n.g. |
| Lipase[240] | *Corynebacterium acnes* | | | | 80000 | 3.8 | 1 | n.g. |
| Lipase 1[77] | guinea pig | pancreas | | | 66000 | 5.1 | 1 | 5–10 |
| Lipase 2[77] | guinea pig | pancreas | | | 49700 | 8.1 | 1 | 5–10 |
| Lipoamide dehydrogenase[241] | pig | heart | 100000 | | | 5.6, 6.0, 6.5*, 6.8* | 4 | n.g. |
| Lipoxydase (lipoxygenase)[242,243] | soybean | | 108000 | 2 | 54000 | 5.65 | 1 | 25 |
| Lipoxygenase[243,244] | soybean | | 108000 | 2 | 54000 | 5.68, 6.15, 6.26 | 3 | n.g. |
| Lipoxygenase[245] | pea | | 70000 | | | 5.80*, 5.82* | 2 | n.g. |
| Lipoxygenase[246] | pea | | 70000 | | | 5.85, 5.92, 5.97, 6.01, 6.06, 6.17 | 6 | 25 |
| Lipoyldehydrogenase[247] | pig | heart | | | | 5.9, 6.1, 6.3, 6.6, 6.8*, 7.0, 7.2 | 7 | n.g. |
| Luciferase[248] | firefly | | 100000 | 2 | 50000 | 5.7, 6.4* | 2 | n.g. |
| Luteinizing hormone (LH)[249,250] | rat | hypophysis | 31000 | 2 | 15500 | 9.0* | 4 | n.g. |
| Lysin[251] | *Tegula pfeifferi* | egg membrane | 8800 | | | 7.9 | 1 | n.g. |
| Lysozyme[252] | human | serum | | | | 10.0*, 11.0 | 2 | 4 |
| Malic enzyme[253] | *Ascaris suum* | muscle | 248000 | 4 | 66400 | 6.63 | 1 | 5 |
| Malonyl CoA-ACP transacylase[254] | *E. coli* | | 36600 | | s.p.c. | 4.65 | 1 | n.g. |
| Mannanase[82] | *Aspergillus niger* | | | | | 3.95 | 1 | 4 |
| | *St. sanguinolentum* | | | | | 3.58 | 1 | 4 |
| | *Fomes annosus* | | | | | 3.9*, 4.2 | 2 | 4 |
| | *Chrysosporium lignorum* | | | | | 4.11 | 1 | 4 |
| Mannosidase[62] | *Aspergillus niger* | | | | | 4.68 | 1 | 4 |
| α-Mannosidase[255] | soybean | | 175000 | | | 4.5, 4.75* | 2 | n.g. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Methionyl t-RNA synthetase[256] | *Bacillus brevis* | | 100000 | | | 4.4 | 1 | n.g. |
| | | | 200000 | | | 5.0* | 1 | n.g. |
| Methylesterase[257] | tomato | pectin | 26300 | | | 8.4 | 1 | 20 |
| Mevalonic kinase[258] | hog | liver | 98000 | | | 4.7 | 1 | n.g. |
| Myoglobin[259] | horse | muscle | 17500 | | s.p.c. | 6.47, 6.53, 6.60, 6.79, 6.83, 6.92, 7.17* | 7 | 20 |
| Myoglobin[73] | horse | muscle | 17500 | | s.p.c. | 6.76, 7.16 | 2 | 4 |
| Myoglobin[6] | horse | muscle | 17500 | | s.p.c. | 6.8, 6.86, 7.27, 7.76 | 4 | 4 |
| Myoglobin[87] | horse | muscle | 17500 | | s.p.c. | 6.8, 7.0, 7.1*, 7.5* | 4 | r.t. |
| Myoglobin[259] | ox | muscle | 17500 | | s.p.c. | 6.56, 6.74, 7.01* | 3 | 20 |
| Myoglobin[73] | whale | sperm | | | | 7.52, 7.79 | 2 | 4 |
| Myoglobin[87] | whale | sperm | | | | 7.1, 7.4, 7.6, 7.68*, 8.01* | 5 | r.t. |
| Myosin[260] | Acanthamoeba | | 180000 | 1 | 140000 | 8.0* | 3 | n.g. |
| | | | | 1 | 16000 | | | |
| | | | | 1 | 14000 | | | |
| Myrosinase C[261] | rapeseed | | 135000 | 2 | 65000 | 4.96, 4.99, 5.06* | 3 | n.g. |
| | white mustard | | 151000 | 2 | 62000 | 5.08 | 1 | n.g. |
| NADH dehydrogenase[262] | *Rhodospirillum rubrum* | | 33000 | | | 4.80*, 4.94 | 2 | 20 |
| | | | 26000 | | | 4.50 | 1 | 20 |
| NADP isocitrate dehydrogenase[263] | rainbow trout | liver (2°) | | | | 5.75 | 1 | n.g. |
| | | liver (17°) | | | | 5.72*, 6.9 | 2 | n.g. |
| Nerve growth factor[264,265] | mouse | salivary gland | 26500 | 2 | 13200 | 4.50, 9.30* | 2 | n.g. |
| Neuraminidase[266] | *Vibrio cholerae* | | | | | 4.80 | 1 | n.g. |
| Neuraminidase[266] | *Cl. perfringens* | | | | | 4.95 | 1 | n.g. |
| Neuraminidase[267] | Influenza virus | $A_2$/1957 | 200000 | 4 | 50000 | 5.2, 5.35, 5.5*, 5.8*, 6.2, 6.5 | 6 | 20 |
| Neuraminidase[268] | Pneumococcus | | 69800 | | s.p.c. | 4.9 | 1 | r.t. |
| Neutral protease[269] | rabbit | polymorphonuclear leucocytes (lyso.) | | | | 4.2*, 4.8, 5.2*, 6.3, 7.0, 8.2, 9.1 | 7 | n.g. |
| Nitrate reductase[270] | spinach | | 240000 | | | 3.5, 4.9* | 2 | n.g. |
| Nitrogenase[271] | *Klebsiella pneumoniae* | | 218000 | 2 | 50000 | 5.0 | 1 | n.g. |
| | | | | 2 | 60000 | | | |
| | | | 66800 | 2 | 34600 | 4.0*, 5.9 | 3 | n.g. |

*(Continued on p. 18)*

TABLE 2 *(continued)*

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temperature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No.* | *M.W.* | | | |
| Nucleoside diphosphokinase[272] | human | erythrocyte | 85000 | | | 5.4, 5.8*, 6.3 6.8, 7.3, 8.3 | 6 | n.g. |
| Nucleotide phosphotransferase[273] | *E. coli* | | 29000 | | | 6.8, 7.1* | 2 | n.g. |
| Ornithine aminotransferase[274] | rat | liver | 132000 | 4 | 33000 | 5.38 | 1 | 6 |
| Ornithine transcarbamylase[275] | human | liver | | | | 3.2*, 4.4 | 2 | 0 |
| Ornithine transcarbamylase[276] | ox | liver | 108000 | 3 | 37800 | 6.19, 6.36, 6.44, 6.49, 6.59, 6.77, 6.95* | 7 | 22 |
| Ovotransferrin[277] | hen | egg | 80000 | | | 5.62, 5.78*, 6.05, 6.25*, 6.50, 6.05, 6.25*, 6.50, 6.73* | 6 | 20 |
| Oxoacyl CoA thiolase[278] | ox | liver (mitoch.) | | | | 5.7*, 6.3, 6.7* | 3 | n.g. |
| | rat | liver (mitoch.) | | | | 6.95, 8.15* | 2 | n.g. |
| Palmitoyl CoA synthetase[279] | rat | liver | 168000 | 6 | 27000 | 5.5 | 1 | n.g. |
| Parvalbumins[280] | *Raja clavata* | muscle | 11900 | | | 4.45 | 1 | r.t. |
| | *Raja montagui* | muscle | 12300 | | | 4.65 | 1 | r.t. |
| Pepsin[281,282] | hog | gastric juice | 33000 | | | 2.86*, 2.94 | 2 | 4 |
| Peroxidase[283] | horseradish | root | 45900 | | | 4.0, 8.8, >11 | 4 | n.g. |
| Peroxidase[284,285] | horseradish | | 40000 | | | (3.9–9) 6.1*, 6.6*, 7.2* | 20 | 20 |
| Phosphoacetyl glucosamine mutase[286] | pig | submaxillary gland | | | | 4.8 | 1 | r.t. |
| Phosphodiesterase[287] | sugar beet | leaves | 110000 | | | 3.85 | 1 | n.g. |
| Phosphoenolpyruvate carboxylase[288,289] | *E. coli* | | 402000 | 4 | 99600 | 4.92 | 1 | 21 |
| Phosphoglucomutase[290] | rabbit | muscle | 64900 | | s.p.c. | 6.8* | 4 | n.g. |
| 6-Phosphogluconate dehydrogenase[291] | *Neurospora crassa* | | 115000 | 2 | 57000 | 4.93, 5.50* | 2 | 10 |
| Phosphoglucose isomerase[292] | human | erythrocyte | 125000 | 2 | 62000 | 9.0, 9.1, 9.2* | 3 | n.g. |
| Phospholypase A[293] | honey bee | venom | 40000 | 2 | 19500 | 10.5 | 1 | n.g. |
| Phospholypase A[294] | *Naja naja* | venom | 8500–20200 | | | (4.60–5.66) 4.95* | 11 | n.g. |
| Phospholypase A[294] | *Vipera russellii* | venom | 15000–23800 | | | (4.62–9.90) 9.52*, 9.90* | 7 | n.g. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Phospholypase A[295] | *Laticauda semi-fasciata* | venom | 11000 | | | 6.6 | 1 | n.g. |
| Phospholypase A[296] | *Agkistrodon halys blomhoffii* | | 13800 | | | 4.0*, 10.0* | 2 | 20 |
| Phospholypase C[117] | *Cl. perfringens* | | | | | 5.2*, 5.5* | 2 | n.g. |
| Phosphomannanase[297] | *Bacillus circulans* | | 47000 | | | 5.9, 6.8* | 2 | n.g. |
| Phosphorylase a[298] | pig | heart | | | | 5.45, 5.9, 6.3 | 3 | n.g. |
| Phosphorylase b[298] | pig | heart | | | | 5.5, 5.9, 6.25, 6.35* | 4 | n.g. |
| C-Phycocyanin[299] | *Oscillatoria agardhii* | | 26300 | 1 | 12200 | 4.65 | 1 | 3 |
| | | | | 1 | 14100 | | | |
| Plasminogen[300] | human | plasma | 81000 | | s.p.c. | (6.4–8.5) 7.5*, 7.8*, 8.1* | 8 | r.t. |
| Procarboxypeptidase A[301] | human | pancreatic juice | | | | 6.22, 6.37, 6.56, 6.72 | 4 | r.t. |
| Procarboxypeptidase A[77] | guinea pig | pancreas | | | 45000 | 4.6, 4.8* | 2 | 5–10 |
| Procarboxypeptidase B[77] | guinea pig | pancreas | | | 47700 | 6.6 | 1 | 5–10 |
| Progesterone binding globulin[302] | guinea pig | serum | 82800 | | | 3.5, 4.4 | 2 | 4 |
| Progesterone binding plasma protein[303] | guinea pig | plasma | 77500 | | s.p.c. | 3.6* | 3 | n.g. |
| Proelastase[77] | guinea pig | pancreas | | | 28000 | 6.9, 7.5 | 2 | 5–10 |
| Prolactin[304] | human | plasma, amniotic fluid, pituitary | 27500 | | | 6.53 | 1 | n.g. |
| Protamine kinase[305] | rat | brain | | | | 5.3, 5.8, 7.4, 8.2 | 4 | n.g. |
| Protease[306] | *Bacteroides amylophilus* | | 60000 | 2 | 30000 | 4.25* | 2 | n.g. |
| Protease[307] | *Aspergillus niger* | | | | 49000, 56000 | 4.1, 4.5 | 2 | n.g. |
| | | | | | 68000 | 6.2 | 1 | n.g. |
| Prothrombin[308] | ox | blood | | | | 4.6* | 3 | 0 |
| Protocollagen proline hydroxylase[309] | chick | embryo | 248000 | 2 | 113000 | 4.4 | 1 | n.g. |
| Purine nucleoside phosphorylase[310] | human | erythrocyte | 84000 | 3 | 28000 | 6.0*, 6.5, 7.0, 7.5, 7.8 | 5 | n.g. |
| Pyridine nucleotide dehydrogenase[311] | human | erythrocyte | 28000 | | | 6.2*, 7.45 | 2 | n.g. |

*(Continued on p. 20)*

TABLE 2 *(continued)*

| *Protein* | *Source* | *Organ and/or subcellular location* | *M.W.* | *Subunit* | | *pI* | *No. of iso-enzymes* | *Temperature (°C)* |
|---|---|---|---|---|---|---|---|---|
| | | | | *No.* | *M.W.* | | | |
| IMP: Pyrophosphate phosphoribosyl transferase[310] | human | erythrocyte | 68000 | | | (5.5–7.5) 6.0*, 6.5* | 9 | n.g. |
| Pyruvate kinase[312] | rat | liver | | | | 5.50*, 5.75*, 6.0, 6.75 | 4 | n.g. |
| | rat | muscle | | | | 6.75 | 1 | n.g. |
| Pyruvate kinase[313] | oyster | mantle | | | | 6.35* | 3 | n.g. |
| | oyster | adductor muscle | | | | 5.6, 6.5* | 3 | n.g. |
| Ribonuclease[77] | guinea pig | pancreas | 13500 | | s.p.c. | 8.7, 8.8 | 2 | 5–10 |
| Ribose 5-phosphate isomerase[314] | pea | leaf (chloro.) | | | | 4.95* | 3 | 0 |
| | | leaf (cyto.) | | | | 4.75* | 2 | 0 |
| RNA polymerase II[315] | human | HeLa cells | 500000 | | 2200000, 1400000, 35000, (25000), (170000) | 4.75 | 1 | n.g. |
| Serine sulphhydrase[141] | chicken | liver | 125000 | | | 6.0 | 1 | n.g. |
| Seryl t-RNA synthetase[316] | *E. coli* | str. B | 103000 | 2 | 53000 | 6.15 | 1 | n.g. |
| Seryl t-RNA synthetase[317] | *E. coli* | str. K12 | 100000 | 2 | 50000 | 3.9 | 1 | n.g. |
| Staphylokinase[217] | *S. aureus* | | | | | 6.5 | 1 | 4 |
| Subtilisin[318] | | | | | | 8.4* | 4 | 4 |
| Subtilopeptidase[122] | *Pseudomonas aeruginosa* | | | | | 7 | 1 | 4 |
| Succinate thiokinase[319] | pig | heart | 78000 | | | 5.8, 5.9, 6.0, 6.12*, 6.36 | 5 | n.g. |
| Sulphatase A[320] | human | liver (lyso.) | 400000 | | | 4.7, 4.83, 4.98 | 3 | n.g. |
| Sulphatase A[321,322] | ox | liver | 107000 | 2 | 50000 | 3.6 | 1 | n.g. |
| Sulphatase B[321] | ox | liver | 25000 | | | 8.3 | 1 | n.g. |
| Superoxide dismutase[323] | ox | liver | 73000 | | | 7,9 | 1 | n.g. |
| Thromboplastin[308] | ox | serum | | | | 4,1 | 3 | 0 |
| Thymidine kinase[324] | monkey | kidney (cyto.) | 85000 | | | 9.8 | 1 | n.g. |
| | monkey | kidney (mitoch.) | 75000 | | | 6.0, 9.0, 9.8* | 3 | n.g. |
| Thymidine kinase[325] | mouse | LM cells (cyto.) | 86000 | | | 8.8, 9.0* | 2 | 4 |
| | | LM cells (mitoch.) | 69000 | | | 5.0*, 8.1 | 2 | 4 |
| | human | HeLa cells (cyto.) | 86000 | | | 9.6 | 1 | 4 |
| | | HeLa cells (mitoch.) | 69500 | | | 5.6, 8.4, 9.7* | 3 | 4 |
| Thyroglobulin[326] | hog | thyroid gland | | | | 4.5* | 3–4 | 22 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Thyroid stimulating hormone (TSH)[327] | sea whale | pituitary | | | | 8.17, 8.38*, 8.51*, 8.70 | 4 | n.g. |
| Thyrotropin (TSH)[328,329] | ox | pituitary | 32000 | 2 | 15000 | 8.28, 8.58*, 8.68*, 8.8 | 4 | 25 |
| Thyroxine binding globulin[330] | human | serum | | | | (4.2–5.2) 4.3*, 4.4*, 4.6* | 9 | n.g. |
| α-Toxin A[331] | *S. aureus* | | 28000 | | s.p.c. | 7.2 | 1 | n.g. |
| α-Toxin B[331] | *S. aureus* | | 28000 | | s.p.c. | 8.4 | 1 | n.g. |
| Transcobalamin II[332] | human | serum | 36000 | | | 6.25, 6.45 | 2 | r.t. |
| Transferrin (apo)[333] | rabbit | serum | | | | 6.0 | 1 | n.g. |
| Transferrin (1 $Fe^{2+}$)[333] | rabbit | serum | | | | 5.5 | 1 | n.g. |
| Transferrin (2 $Fe^{2+}$)[333] | rabbit | serum | | | | 5.0 | 1 | n.g. |
| Triosephosphate isomerase[334] | human | erythrocyte | 56000 | | | 5.5, 6.0*, 6.4 | 3 | 3 |
| Triosephosphate isomerase[334,335] | rabbit | muscle | 53000 | 2 | 26500 | 5.8, 6.2, 7.0*, 7.7, 8.0 | 5 | 3 |
| Triosephosphate isomerase[336] | pea | leaf (chloro.) | | | | 4.75* | 3 | 0 |
| | | leaf (cyto.) | | | | 4.8 | 1 | 0 |
| Triosephosphate isomerase[182] | *Euglena gracilis* | cytoplasm | 58000 | | | 4.8 | 1 | n.g. |
| | | chloroplast | 58000 | | | 4.45 | 1 | n.g. |
| Trypsin and chymotrypsin inhibitor[337] | groundnut | | 7500 | | s.p.c. | 8.5 | 1 | n.g. |
| Trypsinogen[77] | guinea pig | pancreas | | | 24500 | 8.7*, >9.3 | 2 | 5–10 |
| Tryptophanyl t-RNA synthetase[338,339] | *E. coli* B | | 74000 | 2 | 37000 | 6.2 | 3 | 0 |
| Tryptophanyl t-RNA synthetase[340] | human | placenta | 120000 | 2 | 58000 | 5.2 | 1 | 0 |
| Tyrosine α,β-amino mutase[341] | *Bacillus brevis* | str. Vm4 | 75000 | | s.p.c. | 4.6 | 1 | n.g. |
| L-Tyrosine methyl ester sulphotransferase[342] | rat | liver | | | | 5.3*, 5.8, 6.6 | 3 | n.g. |
| Urease[343] | jack bean | | 485000 | 4 | 120000 | 4.88 | 1 | n.g. |
| UDP-glucosyl transferase[344] | parsley | | 50000 | | | 5.0 | 1 | n.g. |
| Vitamin $B_{12}$-binding protein[345] | human | amniotic fluid | 59300 | | s.p.c. | 3.3, 3.7*, 3.9 | 3 | n.g. |
| Xylanase[62] | *Aspergillus niger* | | | | | 3.9*, 4.5* | 2 | 4 |
| | *St. sanguinolentum* | | | | | 3.62, 4.30* | 2 | 4 |
| | *Fomes annosus* | | | | | 4.1, 4.6, 7 | 3 | 4 |
| | *Chrysosporium lignorum* | | | | | 4.44, 6.0* | 2 | 4 |

* The pI value of the major component. When seven or more isozymes are given for a single entry, the range of pI is given in parentheses, followed by the pI values of only the major component(s). Thus. in the case of L-amino acid oxidase, which is resolved into 18 isozymes, the values (5.2–8.4) represent the pI range of the 18 components, while the values 5.60, 55.71 and 5.87 represent the pI values of the three major components.

covering the pH range of interest. Ideally, these pH markers should be coloured proteins or dyes. In the case of protein markers, they should not be heterogeneous, or at least have a major, easily identificable, band in order to avoid confusion in pH assessments. Studies on the use of pH markers have been reported by Conway-Jacobs and Lewin[25], Nakhleh *et al.*[26], Bours[10] and Radola[27]. We have listed the most common protein and dye markers in Table 1. This table will be followed by the compilation of data on pI and M.W. values of proteins.

In these tables, the most accessible references are given for each entry; they do not necessarily indicate the source most deserving of credit for the macromolecular parameters given. Some references might have been overlooked. We would appreciate comments from other laboratories on missing references and data or on possible errors in these tables. We hope that this compilation will prove useful for teaching and research purposes.

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## 3. SUMMARY

Proteins with known isoelectric points (p*I*), as determined by isoelectric focusing, have been tabulated. When available, the native molecular weight as well as subunit molecular weight and stoichiometry have been reported. For each entry, the source and, when applicable, the organ of origin and/or subcellular location are given.

The p*I* values are listed together with the respective temperature of pH measurement. Moreover, in the case of proteins displaying microheterogeneity, the major components have been indicated. The table lists a total of approximately 800 p*I* values.

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