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edited by

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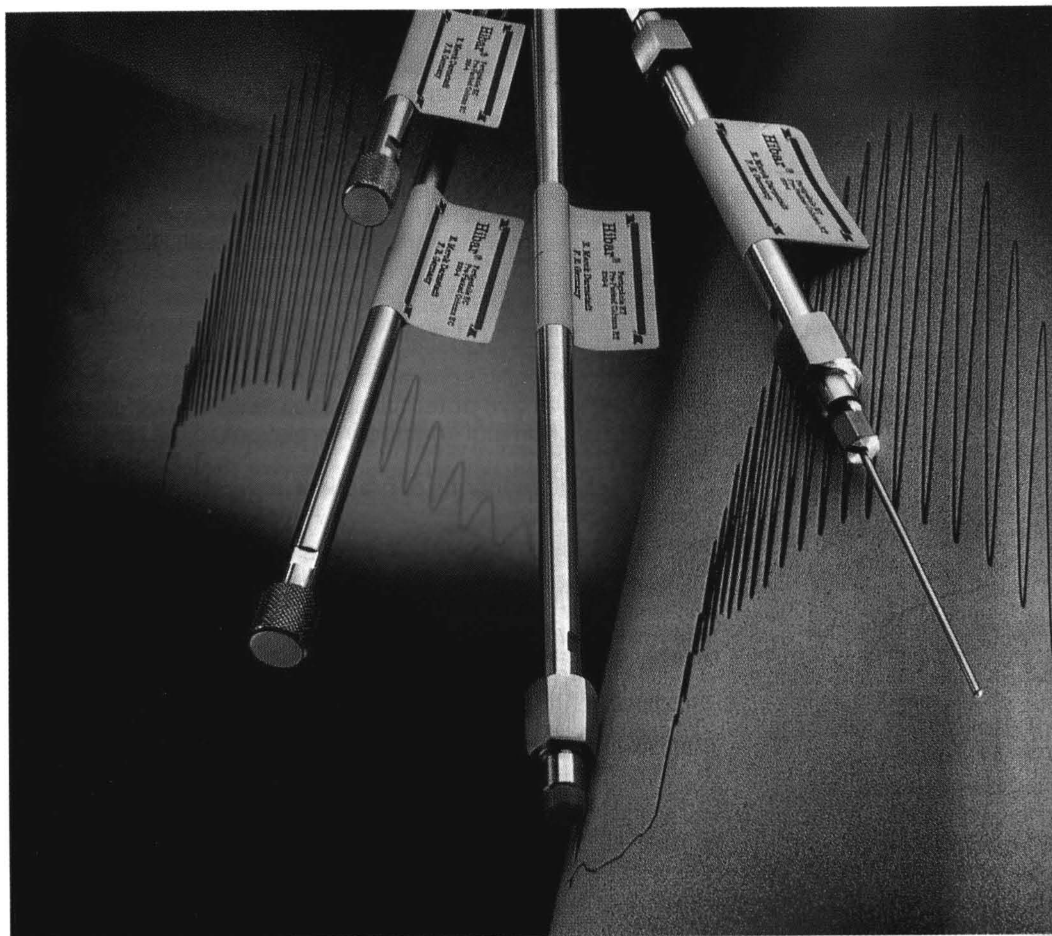

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CHREV. 146

DYNAMICS OF DISSEMINATION IN THE CASE OF AFFINITY CHROMATOGRAPHY

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(Received December 31st, 1980)

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1. INTRODUCTION

Within the structure of developing scientific knowledge, techniques are the links between the various subject areas and this is clearly shown in the citation networks. Thus if we link subject areas (research specialties) through the co-citations[1,*], then we find that biochemistry and biomedicine form a macro-cluster, consisting of individual clusters formed by the 29 most cited methodological articles[2].

Of all the scientific disciplines biochemistry and molecular biology are the most method-oriented: they show a clear predominance of methodological papers amongst the most cited articles. According to our estimates, made on the basis of the most cited articles in biochemistry, biomedicine and psychology (as indicated in *Current Contents*[3]) 75 % are intrinsically methodological and monopolize 85 % of the citations (the total number of 156 articles examined offer 210,759 citations, while the methodological articles (118) have 178,488 citations, *i.e.* on the average 1512 per paper). In the field of biochemistry, one such methodological paper gives 1996 references, while a non-methodological one has 949. (In biochemistry the proportion of references to methodological articles within the "classics" reaches 92 %[4].) Hence an understanding of the patterns involved in the creation and diffusion of new scientific methods in biochemistry and molecular biology is of great importance for the forecasting of developments and the planning of scientific policies.

Affinity chromatography represents an important methodological innovation in chemistry and biochemistry in the second half of the twentieth century. First

* The most commonly cited papers, when linked through co-citations in other publications, form consistent groups (clusters) of key works, representing the state-of-the-art of the corresponding subject area.

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developed at the end of the 1960s, it emerged on the "map" of biomedicine as a scientific speciality in its own right already in 1972. Its links with other areas of knowledge grew rapidly; in 1972 it was linked with the "immunology" cluster by 125 co-citations, in 1973 the linkage increased to 235 co-citations and a new link with the "cyclic AMP" cluster emerged with 192 citations[2].

There are a number of reasons why the history of the dissemination of affinity chromatography is of special interest for the study of science as a whole. First, as indicated above, the method has been used in many subject areas, it is part of the "methodological skeleton" of modern biochemistry and has quickly become an element of modern paradigm in this area. Secondly, affinity chromatography has a long prehistory —the scientific community had practically awaited the emergence of such a method— a fact that reduced to a minimum any delays in its dissemination, which might otherwise have occurred due to a non-awareness of its existence on the part of the research community. Thirdly, since the utilization of affinity chromatography does not involve the acquisition and mastering of sophisticated and expensive equipment, it represents a graphic example of "soft" technology. This eliminates yet another factor hampering the dissemination of this method. Apart from that, the method exhibits a specific and very interesting peculiarity due to the fact that it was arrived at almost simultaneously by two groups of workers, one in Sweden[5,6], the other in the U.S.A.[7], which makes it an ideal case for comparison of the dynamics of dissemination.

2. METHOD OF INVESTIGATION

The evidence which is found in the literature provides an objective insight into the way a given scientific method is utilized. Therefore, we adopted for our investigation the information approach, *i.e.* the study of the dynamics shown by references to publications of the inventors of affinity chromatography. The quantitative data characterizing the utilization of affinity chromatography from 1968 to 1979 were taken from the *Science Citation Index*[8]. We proceeded on the assumption that a worker using affinity chromatography would necessarily cite the authors of this method. This is especially true with new methods which have not yet become routine. The yearly number of citations was taken from the *Citation Index*, the patterns of co-authorship and titles of articles from the *Source Index*, and the countries in which the journals are published from the *Journal List*.

3. RESULTS AND DISCUSSION

In many studies on the dissemination of technological innovations, diffusion is described with the aid of a logistic curve, *i.e.* as a process which is accelerated in its initial stage[9]. Scientific methods such as affinity chromatography represent in their essence an integral technology of research (see ref. 10 for this concept). And indeed the number of citations of the first work on affinity chromatography[5] has grown exponentially (Fig. 1). This figure alone clearly demonstrates the speed with which affinity chromatography was introduced in the research laboratories.

However, a more comprehensive idea regarding the dynamics of its dissemination is provided by the extent to which all publications by P. Cuatrecasas, an

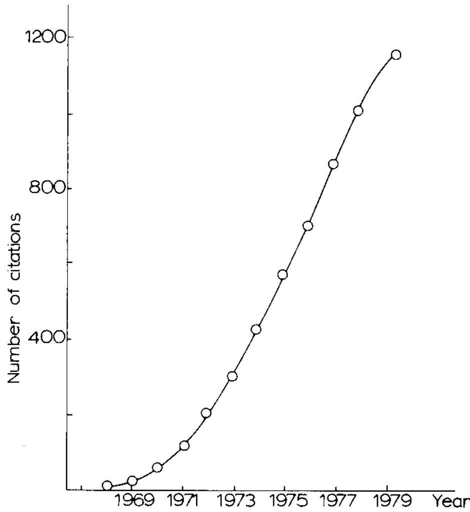

Fig. 1. Cumulative citation curve for Axén *et al.*'s paper[5].

author from the American group of inventors of the method, are cited. It is interesting to compare these dynamics with those of the dissemination of paper chromatography during its first years. Fig. 2 shows the rise in the total number of citations of the inventors' papers after the first publication on affinity chromatography (Curve 1) and the rise in the number of papers carrying references to paper chromatography (Curve 2).

Fig. 2 shows that, following the creation of paper chromatography in 1944, the method passed through a four-year induction period before its rapid dissemination began. Until 1947 the number of workers using this method remained almost constant. Conceptually and technologically affinity chromatography is far more intricate

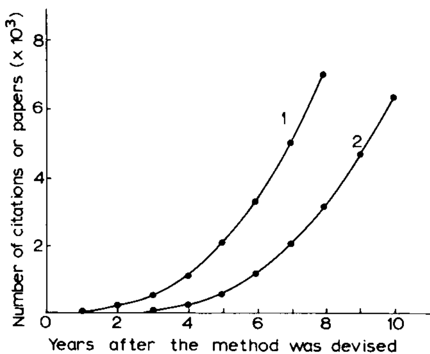

Fig. 2. Dynamics of dissemination of affinity chromatography (since 1968) and paper chromatography (since 1944). 1, Cumulative citation curve for Cuatrecasas *et al.*'s and Axén *et al.*'s papers. 2, Cumulative curve indicating the growth in the volume of publications on paper chromatography, as reflected in the bibliography in ref. 11.

than paper chromatography, but its dissemination was preceeded by a far shorter induction period. This goes to show that affinity chromatography was fully in accord with the methodological paradigm that had obtained in biochemistry by the 1960s whereas paper chromatography required a change in conceptual pattern for its mastery.

Innovators in the production field who have mastered an new technology earlier than others receive an additional remuneration. Transposing this to the scientific scene, if one takes the number of citations as a measure of professional remuneration in science, it may be expected that the faster the authors master a new method the more often they will be cited in the literature. To check this hypothesis, we selected at random 20 authors who cited ref. 7 in 1970 (group 1), and 20 authors who cited this work for the first time in 1974 (group 2). Table 1 indicates citation averages relating to the authors of both groups. As is evident from Table 1 "innovators" are cited considerably more often than those workers who mastered affinity chromatography only four years later. Of course, this correlation does not allow cause and effect to be identified, because productivity and innovation tend to complement each other. However, the fact that the correlation does exist at all is eloquent enough. One may also note that already a year after the publication of the papers in which affinity chromatography was utilized (1975) the citation frequency of the work of the second group of scientists increased considerably: from 16.4 to 23.1 citations per year.

TABLE 1

CITATION RATES OF PUBLICATIONS OF SCIENTISTS WHO BEGAN TO APPLY AFFINITY CHROMATOGRAPHY IN 1970 (GROUP 1) AND IN 1974 (GROUP 2)

Group	*Average number of citations per author per year*		
	1970–1974	*1975*	*1977*
Group 1	62.6	67.3	73.0
Group 2	16.4	23.1	35.0
Ratio of citation rates of group 1 to group 2*	3.8:1	2.9:1	2.1:1

* If, in an effort to reduce the influence of extreme values, we omit the values for the three most cited and the three least cited authors in each group, the following ratios are obtained: 6.1:1 (1970–1974), 2.8:1 (1975) and 2.2:1 (1977).

Technically the variants of affinity chromatography, as developed in the Swedish and the American laboratories, differed only insignificantly, in contrast to the dynamics of their dissemination, which differed sharply. Already in the first publications the differences in the citation pattern are clear (Fig. 3).

Whilst the annual number of citations of Axén *et al.*'s[5] paper increased until 1977, the number of citations of the paper of Cuatrecasas *et al.*[7] stabilized already by 1972. However, as was already pointed out above, it would be more rational to

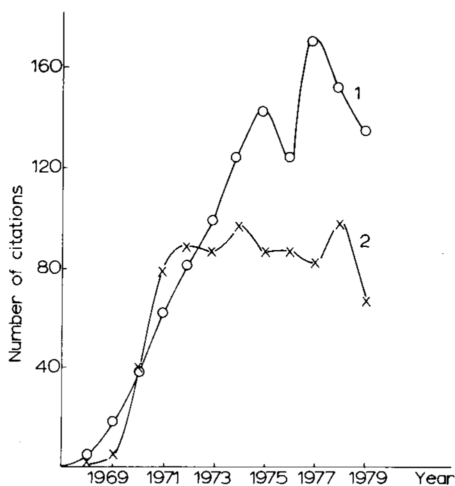

Fig. 3. Breakdown by years of citations of papers by Axén *et al.*[5] (curve 1), and Cuatrecasas *et al.*[7] (curve 2).

characterize the dissemination of both variants by the citation dynamics of all publications by Cuatrecasas, beginning in 1968, and by that of ref. 5. (For a more detailed validation of this approach see ref. 12.)

It is reasonable to assume that some references to the work of Cuatrecasas should be related to the results of his other research, rather than to affinity chromatography, but the error that this may cause is relatively small. A case in point is the fact that though the citation rate of Cuatrecasas' work published prior to 1968 is rather high (67 citations in 1970), it corresponds to the general laws of obsolescence, to which scientific information of "normal" values is subject (a two-fold reduction in the citation rate occurs every five years). No doubt, since 1968 Cuatrecasas published highly valuable results (due in no small measure to the utilisation of affinity chromatography, or methods allied to it; for example, the method involving the quantitative measuring of the coupling of insulin to its receptor on the surface of the cell[13]), but the mistake arising from the citation figures can surely be offset by the fact that we thus omit a large number of references to work on which his name was not the first on the list of authors*. However, a considerable number of those papers are devoted to applications of affinity chromatography.

Fig. 4 indicates the citation dynamics of the publications by Cuatrecasas and by the Swedish authors[5]. Towards the end of 1979, the number of citations of the American work reached 9000, while that of the Swedish work was only 1100**. How can this enormous difference in the dissemination of such similar variants of a method be accounted for? The difference is all the more surprising in view of the fact that the

* During the 1970–1974 period, Cuatrecasas published 96 articles, but in only 39 of them he was the first named on the list of authors.

** We leave out of account subsequent publications by the Swedish authors, because they, judging by their titles, apply to other topics (immobilized enzymes). However, even if they are taken into account, the parameters of curve 2 in Fig. 4 will not change substantially because Axén *et al.* were referred to 365 times up to and including 1976.

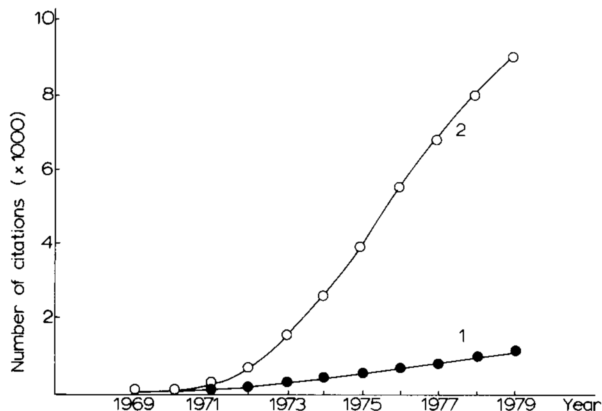

Fig. 4. Cumulative citation curves for papers by Axén *et al.*[5] (curve 1), and Cuatrecasas, published beginning from ref. 7 (curve 2).

article by the Swedish authors[5] appeared one year earlier in a widely read journal, and one of its authors was J. Porath, who had gained a world-wide reputation as the inventor of gel filtration.

The first reason for this lies in the fact that, despite the breadth of scientific contracts and the intensity of communications in modern science, geographical proximity to the place where a new method is developed, still tends to play a significant role.

Table 2 illustrates the citation dynamics of refs. 5 and 7, taken from journals published in various countries. It is evident that the American scientists tend to cite more often the American authors of affinity chromatography, while in the Scandinavian countries the Swedish authors are more often cited (7.7 times more). And furthermore the American "market" for the new research technique is substantially larger.

However, the main differences between the dissemination patterns of the two variants manifested themselves later. We believe that the reason for this lies in the

TABLE 2

BREAKDOWN OF REFERENCES TO THE FIRST PAPERS ON AFFINITY CHROMATOGRAPHY ACCORDING TO NATIONAL JOURNALS

Country of publication	*Total number of references for 1969–1974*	*Ratio of the number of references to ref. 5 to that of ref. 7*
U.S.A.	378	0.71
France	17	0.90
Great Britain	91	0.62
G.F.R.	25	1.27
Japan	25	1.50
Scandinavia	45	7.60
Others (taken together)	46	1.50
International journals	163	2.50

personal and active involvement of Cuatrecasas in the introduction of affinity chromatography for a wide range of problems, which cannot be said regarding the Swedish inventors of the method. Cuatrecasas personally helped a large number of workers in various areas of biochemistry and chemistry in overcoming the difficulties (mostly psychological) connected with the mastering of the new method, demonstrated its efficiency and created many "centers of proselytism", which played a large role in promoting a swifter adoption of the innovation. In fact, Cuatrecasas played the role of the innovation "champion" needed in a technology transfer. Indeed, that this function is indispensable has been confirmed in the course of numerous researches into the development of scientific and technological innovations. The difference of approach to the introduction of this method by the two groups of workers is seen already in the fact that the first main article by the Swedish inventors contains about 12.000 typographical symbols, while that of the Americans contains about 22.000.

The latter paper contains a detailed, step-by-step description of all the manipulations performed in applying affinity chromatography, which is of the utmost importance in overcoming the psychological barrier experienced by people mastering a new technology. A brief report has a much poorer didactic effect. However, what is most important, in our view, are the broad scientific contacts maintained by Cuatrecasas.

Evidence as to the breadth of such contacts can be found in the *Science Citation Index*. Fig. 5 shows a "map" of the contacts maintained by the authors of ref. 7. This shows not only the scientists who published certain papers in 1968 in co-authorship with Cuatrecasas, Anfinsen and Wilchek, but also some leading "co-authors of the co-authors".

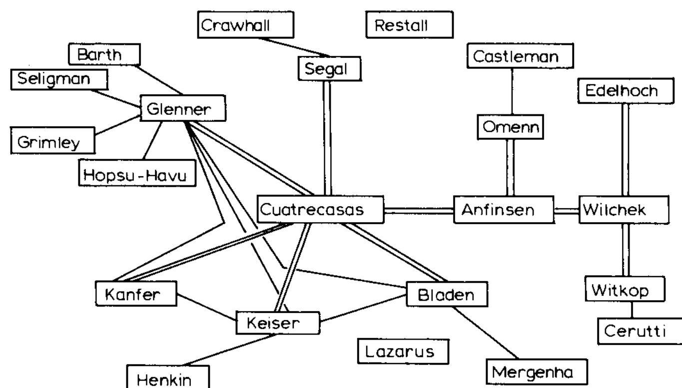

Fig. 5. Scientific contacts of the authors of ref. 7 in 1968. The double line is used to connect immediate co-authors and the single line the co-authors of Cuatrecasas', Anfinsen's and Wilchek's co-authors.

Indicating them on the "map", we proceeded from the assumption that a co-author of the co-author can be found in the group of scientific contacts of a given researcher because an informal contact can easily be established through a common acquaintance. It is evident from Fig. 5 that the group of Cuatrecasas' scientific contacts encompasses eminent scientists, working in many areas of research. This is confirmed by the data in Table 3, in which the lines of activity of these scientists and the number of articles published by them in 1968 are indicated.

TABLE 3

LINES OF ACTIVITY OF RESEARCHERS COMING WITHIN THE "FIELD" OF CUATRECASAS' SCIENTIFIC CONTACTS IN 1968

Name	*Number of papers published in 1968*	*Field of activity*
Glenner, G.	21	Histochemistry
Keiser, H. R.	6	Antibiotics
Bladen, H. A.	4	Bioorganic chemistry
Kanfer, J. N.	5	Lipids
Segal, S.	15	Active transport
Crawhall, J.	7	Medicine
Restall, C.	4	Anasthaesiology
Barth, W.	6	Connective tissues
Seligman, A.	16	Histochemistry
Grimley, P.	8	Cytology, virology
Hopsu-Havu, V.	10	Enzymology
Henkin, R.	9	Endocrinology
Lazarus, G.	6	Connective tissues
Mergenha, S.	12	Polysaccharides (endotoxins)
Castleman, B.	49	Medicine
Witkop, B.	27	Bioorganic chemistry
Cerutti, P.	6	Bioorganic chemistry
Edelhoch, H.	6	Bioorganic chemistry

It should be noted that the co-authorship "map" contains interesting evidence on the closeness of both variants of the affinity chromatography technique: Wilchek had as his co-author in 1968 an eminent specialist in bioorganic and fine organic chemistry, Witkop, who in 1966 and 1967 was a co-author of the Swedish research group.

The evidence characterizes Cuatrecasas as a scientist maintaining intense communications with a large number of research groups, which can, by itself, contribute to the dissemination of the method. In 1967 he published 13 articles as co-author of 15 other scientists. However, his activities after the year 1968 have assumed the character of a purpose-oriented co-operation with a large number of other scientists, largely for the popularization of affinity chromatography. Cuatrecasas published a large number of papers, while the list of his co-authors increases annually. Thus what we see here is a non-recurring co-operation rather than a broadening of constant contacts. Again, in the list of co-authors we see eminent scientists and heads of research groups.

Table 4 contains evidence as to the number of publications, the number of co-authors and the new co-authors of Cuatrecasas (those which first appeared in 1970 or later). It is noteworthy that, taken year by year, the number of "new co-authors" first showed a maximum and then started to decrease in recent years. This is easily explained; the method can now be considered to have been introduced into all of the main areas of its application: it has been given a large coverage in manuals and is included in the university curriculae. Thus theie is no longer a need for the urgency with which the author introduced the technique previously.

TABLE 4

NUMBERS OF PUBLICATIONS BY CUATRECASAS AND HIS CO-AUTHORS AFTER AFFINITY CHROMATOGRAPHY WAS DEVISED

Year	*Number of publications*	*Number of co-authors*	*Number of new co-authors**
1970	10	12	4
1971	21	17	6
1972	15	13	8
1973	28	15	10
1974	22	21	9
1975	23	14	5
1976	16	16	3
Total (1970–76)	135	108	45

* "New" co-authors are those who, in the period from 1968 and until the specified year, did not have any joint publications with Cuatrecasas.

The activities of the Swedish authors have developed differently. Since 1967 their publication activity or their co-operation with other scientists have evinced no changes. During 1968–1976, Axén published 22 papers (many in co-authorship with Porath), while Porath published 50 articles (of which only 16 were devoted to affinity chromatography as such). And those 16 pursued the objective of arriving at a new technique whereby active molecules can be bonded to their matrices, rather than the extension of the technique to new areas of application. This may explain the continuous growth until recently of the number of citations of ref. 5 as this seems the only work that could be cited by scientists working with this variant.

The retrospective comparison of the diffusion dynamics of the two variants of affinity chromatography highlights the regularity of the process of introduction of a technological innovation.

The combination of the two key roles in the person of Cuatrecasas, as creator of the method and as its propagatori, has resulted in a synergic effect that accelerated the introduction of this important scientific technique.

4. SUMMARY

The *Science Citation Index* was used to study the dynamics of the dissemination of scientific knowledge, using the two main affinity chromatography procedures developed by Axén, Porath and Ernback and Cuatrecasas, Wilchek and Anfinsen. It is suggested that the higher rate of citation of the latter group may be due to a more intensive method of propagation.

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CHREV. 147

THE ROLE OF CHROMATOGRAPHY IN BASF

CHROMATOGRAPHIC TECHNIQUES EMPLOYED IN BASF FOR INVESTIGATORY STUDIES AND FOR PROBLEM SOLVING*

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1. INTRODUCTION

Chromatography has been employed in the analytical laboratories of BASF for many years. For instance, between 1936 and 1939 Dr. B. Weiss separated wax components on alumina and silica, and by using various solvents he was able to achieve a group separation into alkanes, monocarboxylic acids and dicarboxylic acids and a partial separation into hydroxy and keto acids. It is interesting that these early unpublished studies involved a whole series of innovations that had not been described previously in the literature. These novel features were as follows: a steel column was used, the work was carried out under pressure, the column was heated at 70°C and colourless substances were investigated (Fig. 1). It should be remembered that at that time chromatography usually involved the investigation of coloured products.

In 1952 paper chromatography was introduced, and was used for the separation and semi-quantitative determination of dinitrophenylhydrazones of carbonyl compounds and also of alcohol dinitrobenzoate derivatives. Although these methods are still of importance today, high-performance liquid chromatography (HPLC) is now usually employed.

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* Presented at the *14th International Symposium on Advances in Chromatography, Lausanne, September 24–28, 1979*. The majority of the papers presented at this Symposium have been published in *J. Chromatogr.*, Vol. 186 (1979). A similar paper on Ciba-Geigy presented at this symposium was published in *J. Chromatogr.*, 184 (1980) 207.

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The first gas chromatograph was one which we built ourselves in 1955 and which incorporated a thermal conductivity cell. With the aid of this apparatus Dr. H. Kienitz carried out the first ethylene analyses. The first commercial instrument was purchased in 1956 and to our knowledge was the first gas chromatograph which was delivered to the G.F.R.

Further developments proceeded with, at times, dramatic speed, in particular as regards HPLC.

2. STATISTICS RELATING TO BASF AG

Some important statistics relating to BASF AG are presented in Table 1, which also includes some comparative data for the BASF Group. One figure which should be emphasized is the number of different products marketed by BASF, namely 6000. The number of individual chemical precursors and intermediates also produced by BASF has not been recorded. In addition it should be underlined that the 1600 buildings include an unspecified number of experimental and production plants as well as numerous research and analytical laboratories.

TABLE 1

STATISTICS FOR BASF AG AND BASF GROUP FOR 1978

	BASF AG	*BASF Group*
Employees	*ca.* 52,000	*ca.* 115,000
Total share capital	*ca.* $9000 \cdot 10^6$ DM	*ca.* $16{,}000 \cdot 10^6$ DM
Cash flow	*ca.* $10{,}000 \cdot 10^6$ DM	*ca.* $21{,}500 \cdot 10^6$ DM
Total area of works		6.3 km^2 (2.4 sq. miles)
No. of buildings	*ca.* 1600	
Total number of products marketed	*ca.* 6000	
Production volume	*ca.* $5.7 \cdot 10^6$ tonnes	

In this major chemical complex, which covers approximately 6.3 km^2 (2.4 square miles), fundamental analytical studies are carried out in two analytical centres. This arrangement has proved to be optimal in view of the size of the works. The Agricultural Division has its own analytical centre at Limburgerhof, outside Ludwigshafen.

Fig. 2 is an aerial view of BASF, which clearly shows the two laboratories that comprise the Analytical Centre in the northern part of the works and the Analytical Centre in the southern part.

Later data are intended to give an impression of the number of chromatographic instruments employed in BASF. In some instances, however, it was only possible to obtain statistical data tracing back developments over a relatively short period of time. The available data that cover the longest period are those referring to the increase in the number of gas chromatographs in the Central Analytical Laboratory (WHU) situated in the southern part of BASF.

These statistical data, covering a period of 20 years, are presented in Fig. 3 and

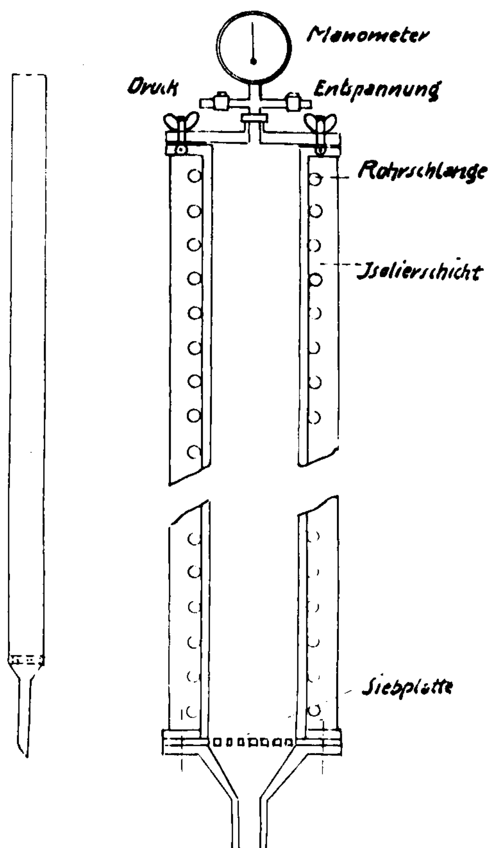


Fig. 1. Example of early chromatographic experiments at BASF AG (I.G. Farbenindustrie A.G., Ludwigshafen a. Rh.) in the period 1936–1939: low-pressure liquid chromatography at elevated temperature. Original drawing by Dr. B. Weiss ("Entspannung" = pressure release valve; "Druck" = pressure; "Rohrschlange" = coiled tube for the heating of the liquid; "Isolierschicht" = insulation layer; "Siebplatte" = sieve support).

are corrected values including active instruments only. This figure also illustrates developments in the number of samples received for analysis. In addition, the point at which the link-up with our IBM 1800 computer unit took place is indicated. The line that has been drawn gives an indication of the increase in the number of instruments and corresponds to a rate of increase of approximately 2.5 chromatographs per year.

The curve showing the number of samples received for analysis over the last 20 years is a reflection not only of the various developments that have taken place in the field of chromatography, but also of various other factors, such as the spread of gas chromatography (GC) within BASF and the automation of GC analysis. Particularly since 1970 the use of GC techniques has spread rapidly through the many research laboratories at BASF and as a result the number of samples received by the Central Analytical Laboratory has decreased. Nevertheless, the cost units charged continued to rise, because in many instances analysis of the sample required considerably more complex chromatographic techniques, such as the use of several different columns

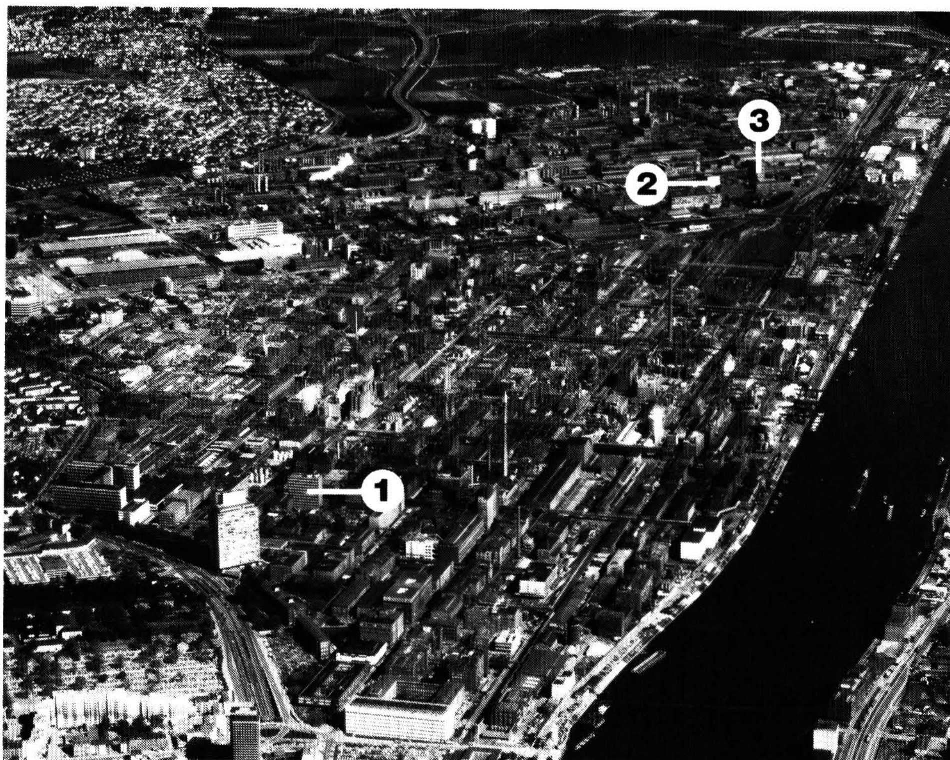


Fig. 2. Aerial view of BASF. 1 = Central Analytical Laboratory South (Untersuchungslaboratorium, WHU, E 210); 2 = Central Analytical Laboratory North, Physico-Chemical Department (Analytisches Labor, WAA, M 325); 3 = Central Analytical Laboratory North, Chemical Department (Analytisches Labor, WAA, M 320). The analytical centre of the Agricultural Division is situated at Limburgerhof Versuchsstation, outside Ludwigshafen.

and specific detectors. Following the introduction of computer evaluation and the automation of various operations there was a sharp increase in the number of samples, as it was then possible to carry out routine series of analyses. It has been our experience in the Central Analytical Laboratory, however, that the time that elapses between the introduction of a particular technical innovation and its universal application has grown steadily shorter. In this instance it was a matter of only 2–3 years before automation and the use of automatic evaluation devices became widespread throughout the works. Despite fluctuations in the number of samples received, the actual number of cost units charged for GC analysis has risen steadily, except for one or two discontinuities in the curve (Fig. 3). To complete the picture, Fig. 4 shows the increase in the number of automated injection systems for GC employed in the Analytical Centre WHU South.

Parallel to the developments that have taken place in the Analytical Centre in the southern part of the works there has been a considerable increase in the number of gas chromatographs employed in the Analytical Centre North (Oppau), as shown in Fig. 5. As precise figures are available only from about 1968 onwards, the data for earlier years have had to be estimated. The line indicating the growth rate cor-

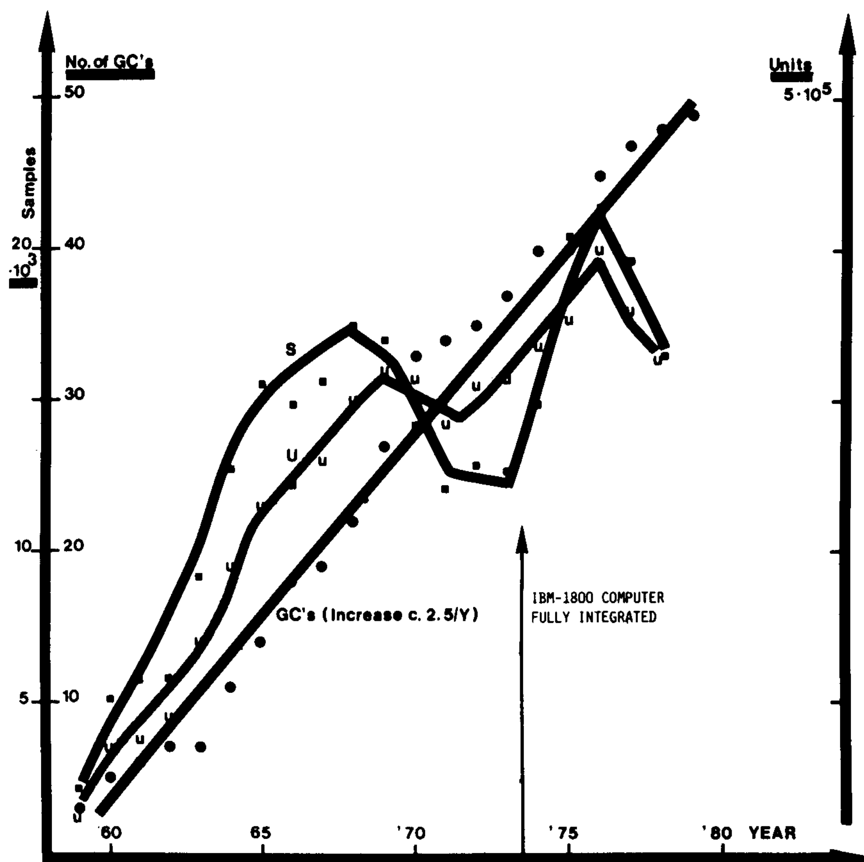
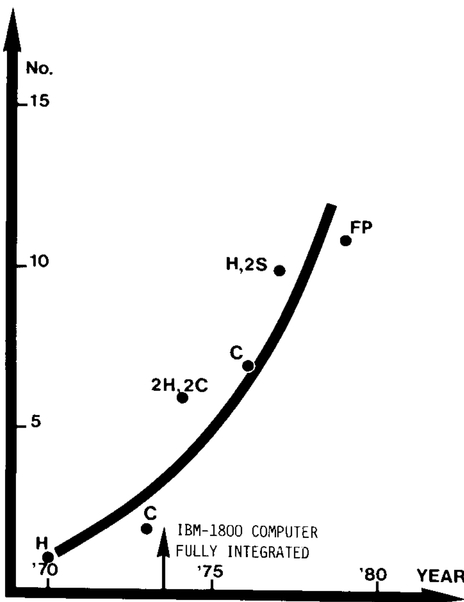


Fig. 3. Increase in the number of gas chromatographs between 1959 and 1979 in the BASF Analytical Centre, WHU South. Number of samples analysed (S) and cost units charged (U) are also compared.

responds to an increase of approximately seven gas chromatographs per year. The reason for this is that in addition to a special GC laboratory there is also a large gas-analysis laboratory.

If instead of merely considering the growth rates of the two central analytical laboratories, one looks at the overall increase in the number of gas chromatographs installed throughout BASF AG, then a statistically much more balanced picture is obtained (Fig. 6). In this case the rate of increase in the total number of instruments is approximately 30 per year, and is thus considerably greater than the growth rate in the central analytical laboratories. Approximately three quarters of the instruments are employed not in the central analytical laboratories, but instead are distributed in a decentralized fashion amongst roughly a dozen analytical subcentres and a great variety of production points. There are altogether approximately 92 laboratories in which GC studies are carried out. Electronic integrators of various degrees of sophistication are available for approximately 400 gas chromatographs (channels). Seven medium-sized computers are in operation in the two analytical centres and three subcentres (Table 2).



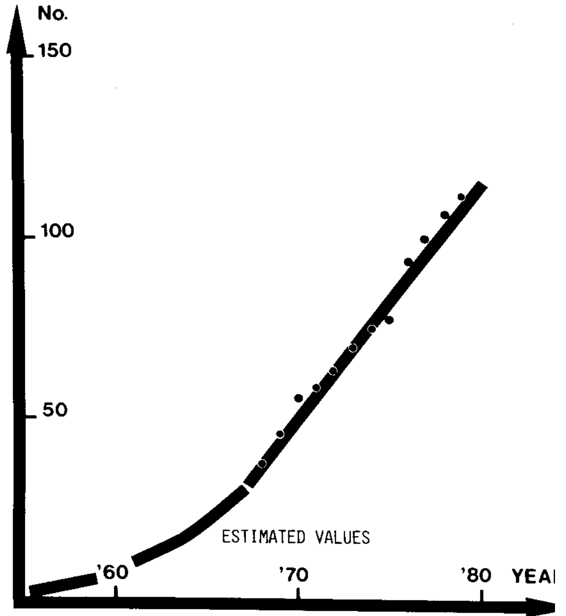


Fig. 4. Increase in the number of automated injection systems for GC between 1970 and 1979. Data from BASF Analytical Centre WHU South. Types of injection systems: H = headspace device; C = capsule device; S = syringe device; FP = flow-through plunger.

Fig. 5. Total number of gas chromatographs installed between 1955 and 1973 in BASF Analytical Centre, WAA North. Increase: *ca.* 7 gas chromatographs per year.

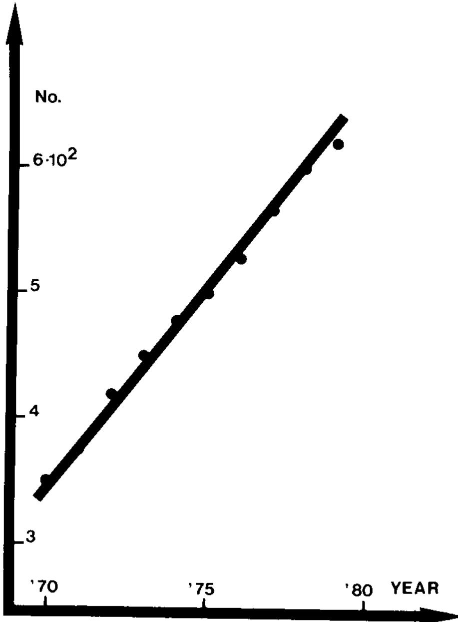


Fig. 6. Total number of gas chromatographs installed between 1970 and 1979 in BASF AG. Increase: *ca.* 30 gas chromatographs per year. No. of automated injection systems in BASF in 1979: 66 GC injectors, 10 headspace devices.

TABLE 2

TOTAL NUMBER OF INSTALLED GC AND HPLC INSTRUMENTS AND COSTS OF TLC IN BASF AG AND THE ANALYTICAL CENTRE WHU SOUTH

Type of process	*Instruments*	*No. of instruments*
GC	GC instruments	Total 620
	Automated injection + headspace systems	66 + 10
	Integrators (channels)	260 (400)
	Computers	7
HPLC, WHU/WAA Lab. only	HPLC instruments	20–30*
	Integrators, multi-channel	2*
Gel permeation chromatography	Instruments	15–20
Process GC	Instruments installed	*ca.* 80
TLC	TLC scanners	5
	TLC costs (1978), including plates + (reagents and instrumental aids)**	40,000 DM (20,000–40,000 DM)

* The total value for BASF is estimated at about 2–3 times this value.
** No other figures available for the estimation of the use of TLC at BASF AG.

At present, approximately 65 automated injection systems of various types, together with about ten headspace injection devices, are employed for GC. It is estimated that between five and ten automatic injectors for liquid chromatography are now in use.

Process GC, which should be regarded as a technical variant of GC, is employed in approximately ten installations for monitoring air quality and in about 70 units for process monitoring and regulation.

Fig. 7 shows the growth in the number of high-performance liquid chromatographic (HPLC) installations in the Analytical Centre South and the total number of samples analysed. The latter data are also broken down into the percentage of samples analysed by means of low-pressure liquid chromatography and the percentage using HPLC. The figures naturally cover only a relatively brief period, but nevertheless the curves demonstrate the rapidly increasing importance of this technique. Also in this instance the number of samples received is not a true reflection of the extent to which HPLC is employed.

These data may lead to the remarkable conclusion that, at least as far as chromatography is concerned, the bulk of the analytical work is not in fact performed in the analytical laboratories but is, instead, carried out in the various plants and subcentres. This naturally prompts the question as to what role the central analytical laboratories play in the firm. Of the roughly 700 staff employed in the two central analytical laboratories, approximately 15–20% are involved in chromatographic work. From this figure and from the volume of GC data, it is possible to estimate that

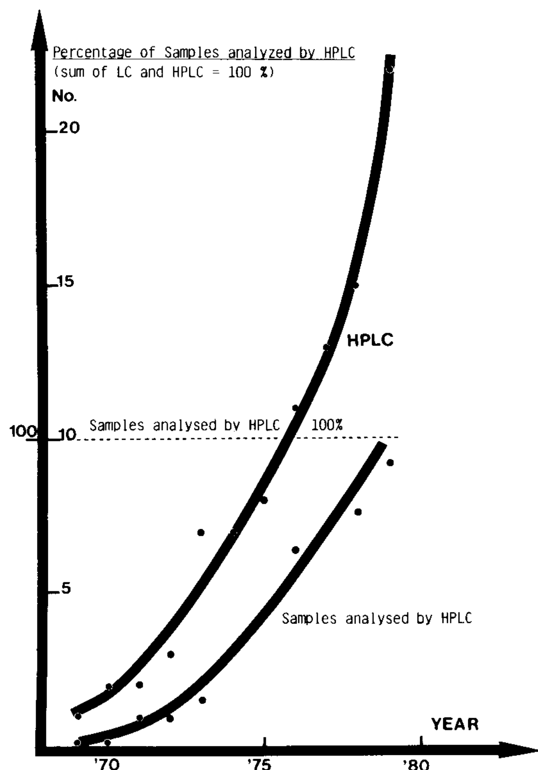


Fig. 7. Total of HPLC installations in BASF Analytical Centre WHU South.

altogether about 1000–1500 persons are partly or wholly engaged in carrying out chromatographic studies.

What the ideal number of professional analysts should be in comparison with the number of plant analysts is a particularly difficult question, to which there is no generally applicable answer. When, however, the works exceeds a certain size then a compromise develops automatically as a function of the two basic preconditions for optimal analysis, namely maximal understanding of the problem and maximal understanding of the method on the one hand, and the need to obtain rapid results on the other. One of these compromises at BASF has been the development of analytical subcentres, which function as an intermediate link between the central analytical laboratories and the analytical laboratories in the plants. At the moment there are approximately twelve such subcentres in BASF. These subcentres carry out both in-plant analyses and process control as well as analyses for production-oriented research and technical applications research.

3. FUNCTIONS AND APPLICATIONS OF CHROMATOGRAPHIC TECHNIQUES IN BASF

Naturally, for most of the problems encountered in research and development, every possible promising chromatographic technique is employed, irrespective of

whether the method will be used later for control and production purposes. A particularly important field for chromatography is in the department of technical applications, as it is here that a new product is subjected for the first time to a whole combination of investigations. These studies are carried out to resolve questions regarding production, quality control, product applicability for the customer, official approval for the product, environmental factors, etc. Examples of such tests include the analysis of monomers, studies on the migration of monomers and chemical auxiliaries from plastic utensils into foods cosmetics and drugs and consumer protection by means of predictive measurements.

Just how important these investigations are, and just how much effort these chromatographic studies involve, may be illustrated by mentioning a few examples of world-wide significance, such as the analysis of vinyl chloride in PVC and of acrylonitrile in polyacrylonitrile plastics, or the development, testing and approval of plant protection agents such as Bentazon or phenoxyalkanoic acids. Fig. 8 shows as an example acrylonitrile analysis in sunflower oil after a migration test.

In this connection, one must also mention the very active part BASF has played in the work of the Analytical Commission of the German Federal Health Authority over the last 22 years. This Commission has worked out guidelines for the analysis of everyday articles, particularly those made of plastic.

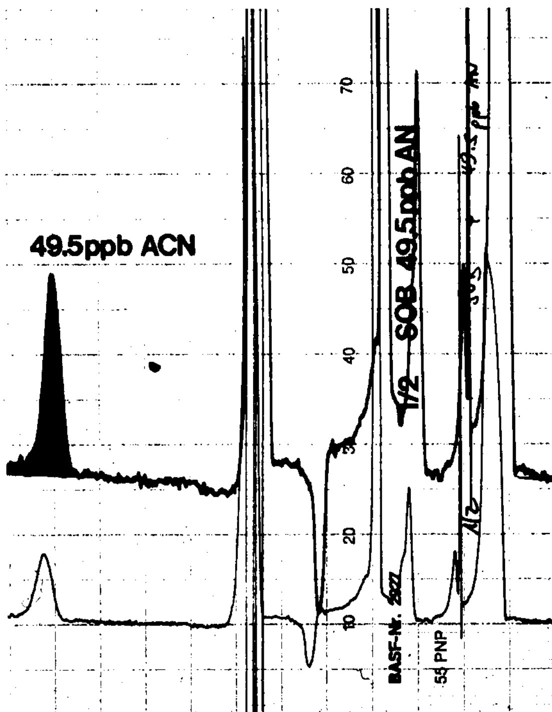


Fig. 8. Determination of *ca.* 50 ppb (10^9) of acrylonitrile (ACN, AN) in sunflower oil (Sonnenblumenöl, SOB) after a migration test. Selective measurements were made using a nitrogen-selective TID in combination with the GC headspace technique.

Types of N-selective Detectors

	E A J	E A J	E A J	E A J	E A J	E A J	E A J
Alkali metal source	RbBr	$RbSO_4$?	$RbSO_4$?	$RbSO_4$/RbBr	Na_2SO_4, KCl, RbCl, CsBr	Rb-Ceramic	RbBr
Form of application	Crystal	Salt-cup	Salt-cup	Pt/Ir pan	Impregnated spiral	Ceramic bed, impregnated	Quartz ampoule
Ionization, plasma	Direct flame	Direct flame	Plasma around the bed	Hydrogen plasma around the pan	Direct, flame	Direct, electric heating	Indirect electric heating
Selectivity, N/C for nitrogen	5000:1	100:1	25,000:1	20,000:1	1000:1	50,000:1	100,000:1

Fig. 9. Types of nitrogen-selective detectors. A = Alkali metal source; J = jet; E = electrode. The table shows the corresponding form of alkali metal application and, if known, the composition of the alkali metal source.

4. REVIEW OF ANALYTICAL CHROMATOGRAPHIC TECHNIQUES EMPLOYED IN BASF

Table 3 shows the GC–detector combinations which are most frequently employed. These combinations involve one- and multi-dimensional detectors. It goes without saying that GC–mass spectrometry (MS) coupling and its different variations play a very important role, both in research and also to some extent for monitoring concentrations of substances down to trace levels.

TABLE 3

GAS CHROMATOGRAPHY–DETECTOR COMBINATIONS USED AT BASF AG

GC–MS	*GC–IR and TEA*	*Selective detectors*	*GC–TLC and smell analysis*
Electron impact and chemical ionization techniques, magnetic and quadrupole instruments, high-resolution instruments	IR: Fourier transform instrument TEA: thermal-energy analyser for nitrosamine analysis	N- and P-selective detectors (TIDs) (different types), ECDs, flame photometric detectors, microwave plasma detectors, detectors for halogens and sulfur	GC–TLC combination mainly for aromatic compounds and amines; smell analysis with special smell test-tubes

Recently we have started to employ GC–infrared (IR) coupling. The Fourier transform instrument is capable of yielding complete IR spectra even when only small amounts of substance are available. Readily interpretable IR spectra can be obtained for GC peaks with a mass flow of 200 ng/sec. In addition, it is possible to exploit the high degree of separation which can now be achieved at very low sample concentrations.

BASF has traditionally produced a very wide range of nitrogen compounds, and hence nitrogen-selective detectors are of particular interest. Virtually every type of nitrogen-selective detector has been tested in our laboratories (Fig. 9).

The need for an element-specific detector, capable of responding simultaneously and specifically to different elements, has, in the meantime, been fulfilled by the microwave plasma detector. The sole disadvantage of this detector is that, depending on the element concerned, the sensitivity is 10–1000 times lower than that of a flame-ionization detector (FID).

We have continued to employ GC–thin-layer chromatography (TLC) coupling on a small scale, in particular since it has proved possible to develop this technique, which has long been known, into a GC–"smell" analysis. By means of this method it was possible to solve a series of complex smell problems, with the assistance of the human nose, but under much better defined conditions. This technique is shown in Figs. 10 and 11.

HPLC has reached a very high level of sophistication and is widely employed. Although it is perhaps almost trivial to enumerate the serious shortcomings associated with the method, nevertheless some of them should be mentioned.

The most serious problem is still the search for a detector with characteristics that can compare, even to a first approximation, with those of the FID. The chances of developing such a detector, however, appear to be slim when one considers the difference between the mobile phase in HPLC and GC.

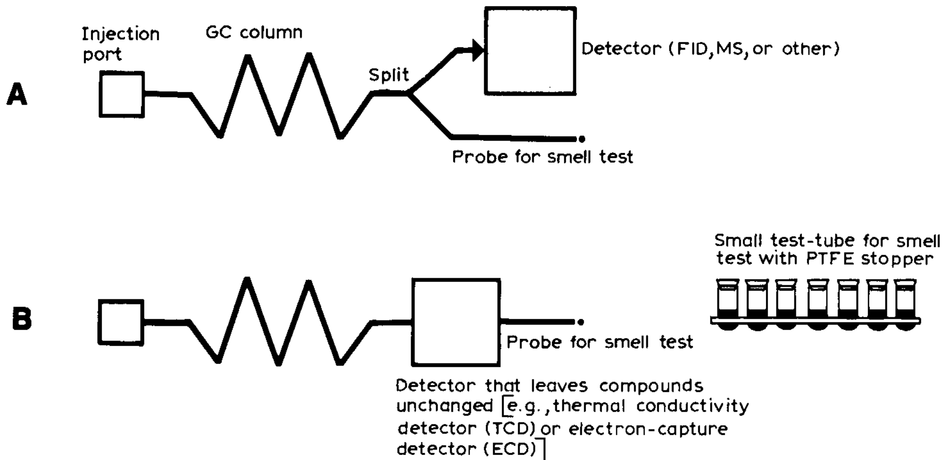


Fig. 10. Different types of experimental design for smell analysis. In order to avoid interferences due to laboratory air (smell), heat from instruments, extraneous odours, etc., the individual odour fractions (peaks) are adsorbed in small sample tubes containing an adsorbent such as silica gel. It is only in this way that the smell of the individual fractions can be assessed in a neutral atmosphere. Some of the fractions are eluted at intervals of only a few seconds (*e.g.*, with capillary columns). In this case the functional capacity of the human nose is often overstressed after a few peaks. When assessing the odour, the adsorbed substances must first be desorbed by the addition of a few drops of water. In some instances the sample must be warmed[3]. Mode A: device with split and very sensitive detector; the main stream is flowing directly to the smell probe. Mode B: the total amount of sample is passing through a non-destructive detector to the probe.

A problem of almost equal gravity is the qualitative identification of the separated substance. HPLC–MS coupling, even if one day it should become a routine method, will surely never achieve the same significance as GC–MS coupling, for many reasons.

In comparison with these classical shortcomings of HPLC, experimental difficulties such as the moderate lifetime of the columns used for the widely used reversed-phase chromatography are almost insignificant. If a more exact control of the flow-rate could be achieved, this would lead to a highly desirable improvement in the precision of the method.

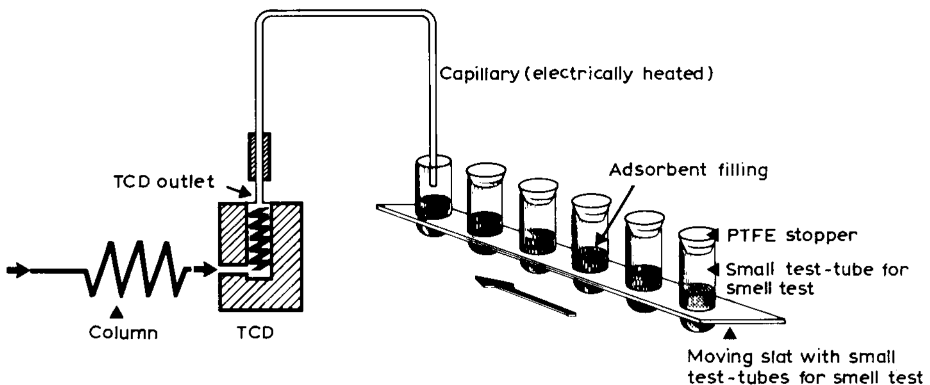


Fig. 11. Collection of fractions for subsequent sensory analysis. See also the legend to Fig. 10.

TLC is, of course, extensively employed and is unrivalled as both a qualitative and a semi-quantitative method. Nevertheless, when employed as a quantitative procedure, TLC possesses obvious disadvantages, such as only moderate accuracy, a small dynamic range, a complicated calibration procedure and a large human factor. In certain analyses these shortcomings can, in fact, be tolerated and quantitative determinations are still frequently carried out. Compared with the relative simplicity of the separation procedure it seems that the scanner operates in a very complicated fashion. The ultimate solution could be a "computerized image analyser" in which the whole adjustment and calibration process is performed by the computer. On the other hand, however, the combination of an extremely simple method of separation with an extremely complex evaluation procedure is highly undesirable.

Even though it is not immediately evident, considering the total number of GC instruments in operation, both mechanization and automation* are extensively applied not only for sample injection but also for result evaluation purposes. This has been particularly the case in the central analytical laboratories and analytical subcentres. The different types of instruments are shown schematically in Fig. 12.

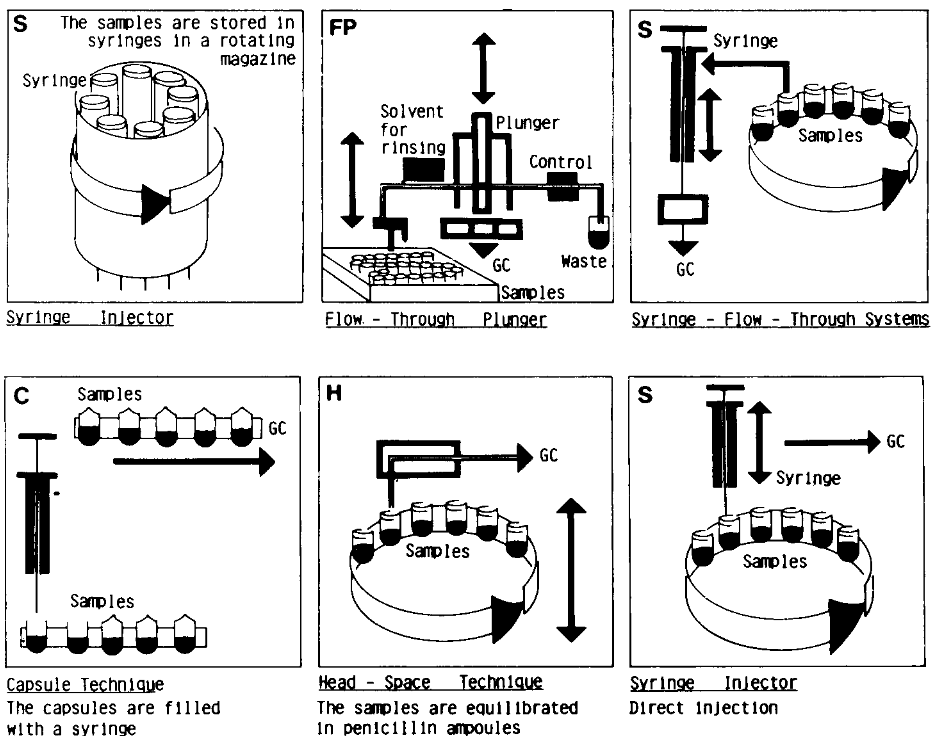


Fig. 12. Schematic representation of automated injection systems for GC. The optimal injection system must be selected with respect to the sample matrix (*e.g.*, viscosity, physical state) and the volatility of the compounds.

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* Mechanization: substitution of manual work by a machine or apparatus. Automation: substitution of manual (mechanical) work, human influence and control by a device or apparatus with feed-back of results capable to make decisions (Fennel[4] and others[5–7]).

The computer link-up (*e.g.*, in WHU) enabled automatic injectors to be employed for the first time on a large scale. Following this development, the use of these devices in production and control laboratories spread very rapidly. The introduction of automated chromatographs in the central analytical laboratories brought with it the following benefits:

In special routine analyses it was possible to carry out many more determinations at a lower cost, owing to continuous day and night operation. For instance, the introduction of the first automated capsule system meant that the cost of some routine series could be cut by 60%. During the period from Friday evening to Monday morning it was possible for one unsupervised instrument to perform between 100 and 200 analyses automatically and to provide fully evaluated sets of results. Of course, it goes without saying that for work of this kind it is essential to have a flexibly programmable computer, which prints out a complete analytical report as well as a list of control functions for the evaluation algorithms.

A further advantage is the fact that when such automatic analysers are employed, better reproducibility and hence in some instances also higher accuracy can be achieved, if it is possible to reduce the measuring error by means of appropriate calibration and test runs.

Two examples are given in Tables 4, 5 and 6, for the analysis of Bentazon and vitamin E acetate, and a gas chromatogram is shown in Fig. 13.

TABLE 4

CALIBRATION FACTORS FOR BENTAZON AS METHYL DERIVATIVE

Fluctuations during a continuous cycle of measurements of the same sample (automated injection, computer evaluation). The cycle was: cal. 1, sample 1A, sample 1B, cal. 2, sample 2A, etc. A constant calibration factor ($f = 1.73$) was used to show the oscillations of the analytical results during repeated analysis of one sample during an uninterrupted cycle of measurement.

Time (min)	*Calibration No.*	*Nominal value for Bentazon (%)*	*Effective value found for Bentazon (%)*
0	1	99.4	100.2
99	2	99.4	100.0
205	3	99.4	99.7
417	4	99.4	100.7
524	5	99.4	99.5
630	6	99.4	98.0
737	7	99.4	97.3
843	8	99.4	99.8
950	9	99.4	98.3

The search for the best combination of separation parameters could be considerably accelerated and also reduced in cost by employing an "automatic method optimizer". Such a device would pre-programme temperatures, temperature programmes, gas pressures and flow-rates as well as eluent flow-rates and gradients for a large number of analytical runs. First steps have already been taken in this direction,

TABLE 5

CALIBRATION FACTORS FOR BENTAZON (AS METHYL DERIVATIVE) WITH OCTADECANE AS INTERNAL STANDARD[1]

Measurements on different days, during which the column was held at a working temperature of 205°C. Day-to-day oscillations of the calibration factor; these oscillations can be eliminated by differential calibration and analytical cycles with the following order of measurement: standard mixture 1 (f_1), sample A1, sample A2, standard mixture 2 (f_2), sample B1, sample B2, etc. The mean of results A1 and A2 is corrected by the mean of factors 1 and 2 (measured with standard mixtures 1 and 2).

Date	*Time (h)*	*Calibration factors*			*Samples measured*
		f_1	f_2	$\bar{f}$	
7.3.78	f_1: 18.40	1.742	1.731	1.74	2
	f_2: 20.16				
	f_3: 21.56	f_3 1.726		1.73	2
9.3.78	f_1: 11.48	1.750	1.706	1.73	
	f_2: 13.30				2
10.3.78	f_1: 11.28	1.740	1.674	1.71	
	f_2: 13.10				2
11.3.78	f_1: 10.58	1.734	1.726	1.73	
	f_2: 12.37				2

TABLE 6

CALIBRATION FACTORS (f) FOR THE DETERMINATION OF VITAMIN E ACETATE WITH SQUALANE AS INTERNAL STANDARD

The table shows the extreme discrepancies that can occur if the analytical result is obtained with automated injection plus computer evaluation on the one hand, and manual injection and planimetry on the other. These differences in reproducibility occur especially during analysis with an internal standard (see corresponding chromatogram in Fig. 13).

$f = \frac{F_{St}\ M_V}{F_V\ M_{St}}$, where F_{St} = peak area of standard peak (squalane), F_V = peak area of vitamin E acetate, M_{St} = mass of standard, M_V = mass of vitamin E acetate.

f	
Manual injection, evaluation of peaks by planimetry	*Automated injection, evaluation of peaks by computer*
1.143	1.114
1.163	1.121
1.171	1.106
1.259	1.095
1.062	1.125
1.271	1.119
1.186	1.117
	1.119
Mean: 1.179	1.115
S*: 0.071	0.010
$S_{rel.}$**: 6.0%	0.87%

* Standard deviation.

** Coefficient of variation (%).

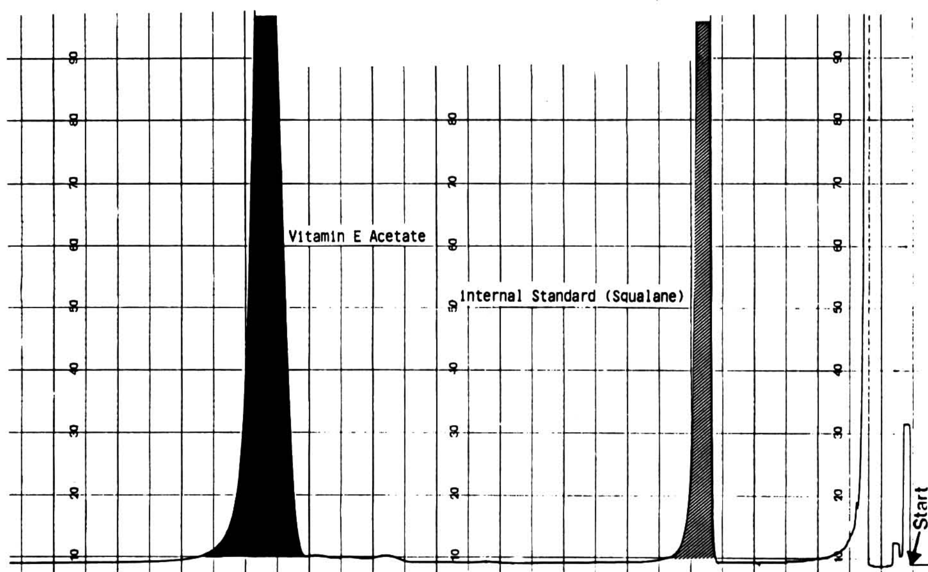

Fig. 13. Gas chromatogram of a vitamin E acetate test sample. Conditions: glass column (2 m × 4 mm I.D.) coated with 5% SE-30; temperature, 252°C (isothermal).

even though the instruments are not completely satisfactory and to date only limited experience has been gained in their use.

A particular publication[2] illustrates very clearly the fact that all the problems and questions associated with GC, such as automation, calibration, choice of test substances, switching technique, column preparation and separation theory, are also arising in HPLC, albeit much more rapidly.

Of the many special chromatographic techniques which are known some are employed extensively in BASF, whilst others are themselves the objects of further research (Table 7).

Pyrolysis gas chromatography is employed in all its forms, using packed and capillary columns as well as in combination with every conceivable microchemical reaction.

In recent years, the headspace technique has gained considerably importance,

TABLE 7

SPECIAL CHROMATOGRAPHIC TECHNIQUES USED AT BASF AG

1.	Pyrolysis gas chromatography*
2.	Reversion gas chromatography[8]
3.	Headspace technique*
4.	Hyperfluid chromatography
5.	Column-switching according to Deans*
6.	Preparative HPLC
7.	Gel-permeation chromatography*

* Widely used.

particularly with automated instruments. Whilst the first automated headspace instrument was employed at BASF as early as 1970, this technique has only achieved worldwide popularity in the last few years. This has been the result of migration experiments carried out in connection with trace- and ultra-trace determinations of monomers such as vinyl chloride and acrylonitrile in plastic goods and in other products into which monomers may migrate.

Although GC techniques have reached a highly advanced level, there are nevertheless areas where interesting technical developments are still taking place, for instance the column-switching technique of Deans. Despite several years of research and development in this field, only recently have relatively simple routine instruments that do not require complicated procedures for the adjustment and optimization of the switching time become commercially available. The Deans column-switching technique is now beginning to be employed for laboratory purposes at BASF. On the other hand, in our central analytical laboratories this method is at present the principal competitor to the capillary technique.

Preparative HPLC has recently attracted growing interest. The application of Fourier transform technique in infrared and nuclear magnetic resonance spectroscopy often enables very impressive spectra to be obtained using only microgram amounts of sample, and therefore minor components of complex mixtures can also be identified. One of the liquid-phase chromatographic techniques employed extensively is gel-permeation chromatography. This method is not restricted to the characterization of molecular weight distributions, but in addition the aim is always to achieve a qualitative identification of separated components using a specific detector such as a laser detector.

As modern analysis is expensive, it seems justifiable to ask how the maximum of information can be obtained at minimal cost. The main problem here is surely one of achieving the closest possible cooperation between the analyst and the chemist who synthesizes the sample. In this way it would also be possible to reduce the risk of producing exactly reproducible, but incorrect, analytical results.

5. PROBLEMS, REQUIREMENTS, INSTRUMENTATION (EXAMPLES)

First, some questions can be posed. Is the high cost of chromatography the result of the high cost of the instruments? Is the large amount of work which chromatography entails due to the tendency of the instruments to develop faults and require repairs, or is it a consequence of the instruments being inadequately adapted to the analytical problems encountered? Why do workers in the field of chromatography have to waste so much of their time on problems involving purely technical details, upon which the success or failure of a method often depends?

For a start, one often has the feeling that the actual chromatographic parts of the instrument, namely the separation columns with their inlets and outlets, are not considered the key section of the whole apparatus. All sorts of publications and discussions had dealt for a long time with topics such as dead space and peak broadening, techniques for their measurement and calculation, and the effects of contaminated connection capillaries. It never ceases to amaze one that successful principles of instrument construction are discarded after only one or two production series, and are only readopted after prolonged discussions or as a consequence of

economic failures in certain laboratories or companies. Completely different schools of thought exist even with regard to fundamental questions of standardization, such as modular construction, modular dimensions and amount of space required for modules. It is practically impossible to install an FID amplifier from company X in an instrument from company Y without the assistance of an electronics expert. With standardization of electronic–electrical connections it would merely be necessary to insert a normed module. It seems to be a law of nature that FIDs in instruments from different manufacturers are not interchangeable! Even detectors from relatively similar models made by the same firm are usually not interchangeable. There is a similar lack of standardization of the connections for glass columns. Only a small number of companies have at least standardized the distance between the two connections so that glass columns may be interchanged. With hundreds or even thousands of glass columns in a large analytical laboratory and with up to ten different types of gas chromatographs, it requires considerable effort to maintain flexibility. The large analytical laboratories are therefore particularly anxious to see standardization of constructional elements and connection sizes in the above-mentioned areas.

In HPLC the relative ease of combination of the various instrumental units has led to competition between the manufacturers, and this has certainly been the decisive factor contributing to the exceptionally rapid development of HPLC instruments.

In view of the extremely positive developments that have occurred in liquid and thin-layer chromatography, we should also like to see clear and precise specification (standardization) of the stationary phases used in GC. Unfortunately, research in this area has been largely neglected. In connection with these remarks, a further problem, which still remains completely unsolved, should be mentioned, namely the standardization of glass capillary columns.

As increasing costs render mechanization and automation[4–7] of chromatographic processes essential, further development work in this direction must be carried out, particularly in GC and HPLC.

We still experience considerable difficulties with automatic injectors, especially with matrix and viscosity problems, and cross-contamination continues to cause many problems. Unfortunately some autosamplers cannot tolerate even limited variations in the viscosity of the samples. In certain instances instruments cannot be employed as a consequence of cross-contamination at the trace level. There is still no problem-free, routine injection device available for quantitative capillary GC.

It is well known, of course, that the computer is only as good as the program supplied by the analyst, and that computers often produce rubbish, albeit very reproducibly. The instruments should not degenerate to "black boxes" and the analyst must retain a complete understanding of their mode of operation. We shall not discuss here the subject of the "apparent achievements" of the microprocessor, which sometimes seem to lead to easier operation, but often are only a hindrance when one is working.

6. SUMMARY

The statistical data presented and the widespread use of all the major available chromatographic techniques underline that chromatography is a very powerful analytical tool at BASF. In order to develop effective analytical methods economically

and to avoid developments in the wrong direction, it is necessary in the future to have more direct cooperation between analysts, instrument manufacturers and chemists working on synthesis.

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CHREV. 149

ISOELECTRIC POINTS AND MOLECULAR WEIGHTS OF PROTEINS

A NEW TABLE

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1. COMPILATION OF THE TABLE

After the great interest in our first table on isoelectric points (p*I*) and molecular weights (MW) of proteins[946] (more than 2000 reprint requests were received), we have undertaken the task of updating this collection (Table 1).

The present table starts from where we finished the previous collection[946], and covers a 4-year period, from 1976 to 1979. We were aided in this extensive survey by a literature reference list, *Acta Ampholinae*, published by LKB Produkter (Bromma, Sweden). In that list, we started from No. 1800 and screened all the articles up to No. 4000 (end of 1979). We have thus gone through about 2200 publications and selected 945 articles containing the information we were looking for. It might be of interest to the reader to know some statistics on this article. Even though our list of references quotes 120 different journals, 60% of the total citations are contained in a small core of only five journals. The most often cited is *J. Biol. Chem.*, which produced 20% of the total entries, closely followed by *Biochim. Biophys. Acta* (16%), then *Eur. J. Biochem.* (10%) and finally *Biochemistry* (8%). The Japanese journal *J. Biochem.* scores a good 5%. Considering that mostly Japanese scientists publish in *J. Biochem.*, this is not a small achievement for a regional journal.

These data fully support what E. Garfield (the Editor of *Current Contents*) has been propounding for many years, that there is only a small core of scientific journals that carry most (and the most qualified) of the scientific information[947]. We should also like to add some more comments, stemming from the knowledge we have accumulated during this extensive screening. From a point of view of "readability", nothing beats an abstract in *J. Biol. Chem.* It seems as if the authors who publish in this journal have been specially trained to squeeze all the relevant information into their abstracts. *J. Biol. Chem.*, *Biochim. Biophys. Acta* and *Eur. J. Biochem.* also share

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TABLE I

p*I* AND MW VALUES OF PROTEINS

p*I* = isoelectric point; MW = molecular weight; IEF = isoelectric focusing; n.g. = not given; r.t. = room temperature; s.p.c. = single peptide chain. When a p*I* value is followed by the symbol $^{+}$, it represents a major isozyme band. When individual p*I* values are not reported, but a p*I* range is given in parentheses, it means either that there were too many isoproteins separated (usually >10) or that it was difficult to establish the actual p*I* values from the original graphs reported in the articles. In these instances, we have at least tried to report the p*I*(s) of the major band(s).

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit No.*	*Subunit MW*	*pI*	*No. of iso-enzymes*	*Temperature (°C)*
N-Acetylaspartate amidohydrolase[1]	Rat	Brain				5.1	1	r.t.
Acetylcholine receptor protein (AChR)[2]	*Torpedo marmorata*	Electric organ membrane fragments		1	40,000	~5.4	1	n.g.
				1	50,000			
				1	60,000			
Acetylcholine receptor[3]	Mammalian	Skeletal muscle				5.3	1	n.g.
Acetylcholine receptors:[4]	Rat							
Functional receptor		Diaphragm muscle				5.09	1	n.g.
Extrajunctional receptor		Denervated diaphragm muscle				5.32	1	n.g.
Acetylcholinesterase (AChE)[5,6]	Human	Erythrocyte			80,000	4.55, 4.68^{+}, 4.81^{+}, 4.98, 5.18	5	n.g.
Acetylcholinesterase[7]	Cobra (*Naja naja atra*)	Venom	144,000	2	~69,000	6.25–6.4	>10	n.g.
Acetylcholinesterase[8]	Cobra (*Naja naja oxiana*)	Venom	67,000		s.p.c.	5.2–6.2	14–16	n.g.
Acetylcholinesterase[8,9]	Cobra	Venom						
	(*Naja melanoleuca*)					4.2–5.2	7	n.g.
	(*Bungarus fasciatus*)		126,000[8]	2	63,000	4.3–5.3	10	
Acetylcholinesterase (11S)[10]	*Electrophorus electricus*	Electric eel tissue	~280,000	4	70,000	5.5–6.0	5 major, 3 minor	n.g.
Acetyl-CoA acetyltransferase (I, A, B)[11]	Bovine	Liver mitochondria	152,000	4	~38,000	6.9, 7.5, 8.8	3	4
Acetyl-CoA: choline O-acetyltransferase[12,13]	Squid	Head ganglia	93,000[13]	1	37,000	(5.0–6.2)	6	n.g.
				1	56,000	5.2^{+}, 5.7^{+}, 6.2^{+}		
α-N-Acetylgalactosaminidase[14]	Limpet (*Patella vulgata*)		200,000	4	50,000	5.5	1	n.g.

α-N-Acetylglucosaminidase (I, II)[15]	Bovine	Spleen	127,000(I) 64,500(II)			4.8 for both forms	1	n.g.
α-N-Acetylglucosaminidase[16,17]	Human	Urine	307,000[16]			(3.3–6.0), 4.8^{+}[17]	4 major 2 minor	n.g.
β-N-Acetylglucosaminidase (A and B)[18,19]	Bull	Sperm	190,000[18]			7.96[18]	1	
			200,000(A)		53,000 13,400	5.31(A)	1	n.g.
			190,000(B)		53,000 13,000	6.78(B)	1	
β-N-Acetylglucosaminidase[20]	Human	Serum, liver				4.5	1	n.g.
N-Acetyl-β-D-hexosaminidase[21]	Human	Leucocytes,				5.2^{+}, 7.2	2	
		amniotic fluid,				4.3, 5.2, 7.2^{+}	3	4
		fibroblasts				5.0^{+}, 7.2	2	
N-Acetyl-β-D-hexosaminidase (A, B)[22]	Human	Liver				4.9–5.5 (A) 7.0–7.3 (B)	4	0
N-Acetyl-β-D-hexosaminidase (A, B)[23]	Human	Colonic carcinoma				5.2 (A) 7.7 (B)	2	n.g.
N-Acetyl-β-D-hexosaminidase[24]	Human	Fibroblast cultures				5.0, 7.8	2	
		Sandhoff disease:						
		Infantile				4.4^{+}	2	
		Juvenile				5.0^{+}	2	n.g.
N-Acetyl-β-D-hexosaminidase (A, B)[25]	Human	Brain (variant AB of infantile G_{M2} gangliosidosis)				5.0^{+} (A) 7.2 (B)	2	n.g.
N-Acetyl-β-D-hexosaminidase[26]	Human	Pregnancy serum and Tay-Sachs disease				5.0^{+}, 5.4, 5.7, 6.1^{+}, 6.3, 6.7, 7.0	7	n.g.
N-Acetyl-β-D-hexosaminidase, P[27]	Human	Pregnancy serum	150,000			6.3^{+}, 6.7^{+}	2	n.g.
N-Acetyl-β-D-hexosaminidase, S-like (1), A-like (2)[28]	Human	Urine, deficiency disease				4.1 (1) 4.7 (2)	2	n.g.
N-Acetyl-β-D-hexosaminidase (A, B)[29]	Human	Placenta				5.4 (A) 7.9 (B)	1	n.g.
N-Acetyl-β-D-hexosaminidase (surface-bound)[30]	*Bacillus cereus* T	Spores	40,000			9.7	1	n.g.
N-Acetyl-β-D-hexosaminidase (I, II, III, IV)[31]	*Trigonella foenum graecum*	Seeds	84,000(I)	3	28,000	6.78 (I)	1	4
			72,000(II)	3	24,000	6.30 (II)		
			180,000(III)	6	30,500	4.90 (III)		
			150,000(IV)	6	30,000	4.65 (IV)		

(Continued on p. 118)

TABLE I (continued)

Protein	Source	Organ and/or subcellular location	MW	Subunit		pI	No. of iso-enzymes	Temperature (°C)
				No.	MW			
Acid deoxyribonuclease[32]	Human	Gastric mucosa, cervix uteri	38,000			6.86, 7.02^{+}	2	n.g.
Acid DNase inhibitor[33]	Chicken	Brain				4.2	1	n.g.
Acid phosphatase[34]	Human	Erythrocyte				5.45, 5.66, 6.43, 6.57, 7.11	5	15
Acid phosphatase[21]	Human	Fibroblasts, leucocytes, amniotic fluid				4.8^{+}, 6.3^{+}, 7.5, 5.1^{+}, 6.0^{+}, 7.5, 3.5, 5.1, 6.0^{+}	3	n.g.
Acid phosphatase (type A, B and C)[35]	Human	Red blood cell				5.36, 5.77, 6.47, 6.66, 7.16, 7.31, 7.58 (A)	7	
						5.34, 5.67, 6.26, 6.50 (B)	4	n.g.
						5.37, 5.79, 6.36, 6.62 (C)	4	
Acid phosphatase[36–39]	Human	Prostate gland	104,000	2	52,000	(4.1–5.5) 4.9^{+}	> 8	n.g.
Acid phosphatase[40]	Rat	Liver lysosomes				4.47^{+}, 5.62, 6.02, 6.78, 7.12, 7.83^{+}	6	4
Acid phosphatase[41]	Tasmanian devil	Plasma				5.5–6.5	4 major 4 minor	
		Liver				5.2–7.9	5 major 10 minor	
		Intestine				5.2–7.9	7 major 6 minor	n.g.
		Kidney				4.9–5.9	7 major 2 minor	
Acid phosphatase isozymes (1′, 2′, 3′a, 3′b, 4′a, 4′b)[42]	Rice	Cell wall	94,000 96,000 (1′) 100,000 (2′) 65,000 (3′ a) 155,000 (4′ a) 96,000 (4′ b)			8 (1′), 7.5 (2′), 7.2 (3′ a), 7.1 (3′ b) 6.8 (4′ a), 6.7 (4′ b)	6	n.g.
Acid phosphomonoesterase[43]	Human	Seminal plasma				4.6–5.25	16–20	n.g.

Acid protease (A_1, A_2)[43]	*Aspergillus oryzae*		63,000 (A_1)			3.15(A_{1a}), 3.50(A_{1b})	2	n.g.
			32,000 (A_2)			3.9(A_2)	1	
Acid protease[44]	*Penicillium duponti*					3.81	1	n.g.
Aconitase (mitochondrial; $ACON_M$ and soluble: $ACON_S$)[45]	Human	Kidney, liver, placenta				5.1 ($ACON_S$)	1	n.g.
						6.9 ($ACON_M$)	1	
Actin (β and γ)[46]	Human	Platelets				5.63(β), 5.65(γ)	1	n.g.
Actin (α, β, γ)[47–50]	Mammals, bird, fish, slime mould	Skeletal muscle and heart muscle (α) Non-muscle tissue (β, γ)	~ 45,500[50]			5.47(α), 5.53(γ), 5.50(β)	1	n.g.
Acyl-CoA hydrolase[51]	Rat	Liver mitochondria	19,000		s.p.c.	6.0	1	4
Adenosine deaminase[52] (Adase A, B, C)	Human Rat	Colon tumours	>100,000 (A) 72,000 (B) 35,000 (C)			4.8⁺, 4.7 (rat)	2	n.g.
Adenosine deaminase[53]	Rabbit	Kidney	~215,000	2	110,000	4.15, 4.50, 5.05, 5.65	4	n.g.
Adenosylhomocysteinase[54]	*Lupinus lutens*	Seeds	110,000	2	55,000	4.9	1	r.t.
Adenosylhomocysteinase[55]	Calf	Liver	237,500	4	~60,000	5.8, 6.0	2	n.g.
Adenylate cyclase[56]	Mouse	Parotid				5.9	1	n.g.
Adenylate kinase[57]	Human	Muscle	~ 31,000 (Muscle to Erythrocytes)			6.3, 8.6, 10.5	3	
		Heart				6.4, 7.2, 8.6, 9.5	4	
		Kidney				5.9, 7.2, 8.2	3	
		Liver				4.7, 5.8, 8.8	3	
		Bladder				4.8, 9.2	2	
		Erythrocytes				9.5		
	Dog	Heart and liver	~ 31,000 (Heart and liver to Liver)			6.5	1	
		Kidney				4.9	1	
		Intestine				5.8	1	
	Cow	Heart				8.5	1	
		Liver				5.3, 6.8, 7.4, 8.2	4	

(Continued on p. 120)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Adenylate kinase[58]	Rat	Muscle, brain, heart, lungs, uterus, cytoplasm				7.4		
		Liver, kidney, mitochondria				8.2		
		Hepatomas, foetal tissues, cytoplasm				9.3		n.g.
Adenylosuccinate synthetase[59]	*Leishmania donovani*	Promastigotes	>250,000			8.7	1	n.g.
Agarose-degrading enzymes (I, IIb)[60]	*Pseudomonas*-like bacteria		210,000 (I)	2				
			63,000 (IIb)			5.1(IIb)	1	r.t.
Agglutinin[61]	*Limulus Polyphemus*	Haemolymph	22,000			4.83	1	4
Agglutinin wheat germ (WGA I, IIa, IIb, III)[62]	Plant	Wheat germ	36,000	2	18,000	8.7(I, IIa, III) 7.7(IIb)	1	n.g.
Agglutinin wheat germ (succinylated)[63]	Plant	Wheat germ	36,000	2	18,000	4.0	1	n.g.
D-Alanyl-*meso*-A_2pm endopeptidase[64]	*Streptomyces*					7.9	1	1
Albumin[65]	Human	Plasma				4.8^+, 5.6^+	2 major	4
Albumin[66]	Human	Bisalbuminaemia serum				5.65, 5.84	2	n.g.
Albumin:[67]	Wheat							
Mb 0,19						7.3		
Specific albumin						4.7	1	n.g.
Alcohol dehydrogenase (ADH)[68]	Human	Liver				9.0, 9.8, 9.9, 10.15^+	4	4
Alcohol dehydrogenase[69]	*Rhodopseudomonas acidophila*		~120,000	2	63,000	9.3	1	n.g.
Alcohol dehydrogenase[70]	Wheat					6.18, 6.28, 6.38, 6.58, 6.73, 6.80	6	n.g.
Aldehyde dehydrogenase[71]	Bovine	Liver	220,000	4	55,000	5.4	1	n.g.

Aldehyde dehydrogenase[72]	Sheep	Liver						
		Cytoplasmic	212,000	4	53,000	5.25	1	n.g.
		Mitochondrial	205,000					
Aldehyde dehydrogenase (I, II, III, IV)[73–75]	Rat	Liver						
		Normal liver, hepatomas[73]				5.4(I), 6.9(II, III, IV)	4	
		Cytoplasmic[74]				8.5(I), 5.8(II)	2	
		Mitochondrial[75]	320,000 (I)			6.06(I)	1	
			67,000 (II)			6.64(II)	1	
		Microsomal[74]				4.0	1	4[74]
(Aromatic) aldehyde–ketone[76] reductases (AR1, AR2)	Guinea pig	Liver				8.1(AR2)	1	4
						9.0(AR1)	1	
Aldehyde reductase[77]	Human	Liver	36,200		s.p.c.	5.3	1	n.g.
Aldolase A[78]	Human	Erythrocytes	158,000	4	39,500	8.9	1	4
Aldolase B[79]	Human	Liver				6.3(β'^4), 6.5($\beta\beta'^3$), 6.8($\beta^2\beta'^2$), 7.0($\beta^3\beta'$) 7.3(β^4)	5	n.g.
Aldolase C[80]	Rat	Brain	148,000	4	37,000	4.28	1	n.g.
Aldolase[81]	Rabbit	Muscle				8.40, 8.65, 8.90, 9.0, 9.15	5	n.g.
Aldolase[81]	Nematode (*Turbatrix aceti*)					7.10	1	n.g.
Aldose reductase (AR I, AR II)[82]	Calf	Brain	29,000 (AR I)			4.88(AR II)		
			30,000 (AR II)			6.18(AR I)	1	n.g.
Aldose reductase[83]	Bovine	Eye lens	37,000		s.p.c.	4.85	1	n.g.
Alkaline phosphatase[84]	Rabbit	Lung	210,000(1) 185,000(2) 185,000(3)			5.0(1), 5.5(2), 5.8(3)	3	n.g.
Alkaline phosphatase[85]	Rat	Kidney			48,000	~5.15(A)		
					100,000	~5.95(B)	2	n.g.

(Continued on p. 122)

TABLE I (*continued*)

Protein	Source	Organ and/or subcellular location	*MW*	Subunit No.	Subunit *MW*	p*I*	No. of iso-enzymes	Temperature (°C)
Alkaline phosphatase[86–88]	Human	Liver	136,000[86–88]	4	34,000	4.2[86]		
						4.7[87]		
		Intestinal[87]				4.5	1	r.t.[87]
Alkaline phosphatase (I variant)[89]	Human	Placenta	120,000	2	60,000	3.4, 4.3, 4.6$^+$, 5.4, 6.0$^+$	6	n.g.
Alkaline phosphatase HeLa 65[90]	Human	HeLa cells	120,000			4.3	1	n.g.
Alkaline phosphatase KB cell[91]	Human	Nasopharyngeal tumour	136,000	1	64,000	4.3	1	n.g.
				1	72,000			
Alkaline phosphatase[92]	*Thermus aquaticus*					8.4	1	n.g.
Alkaline ribonuclease[93]	Bullfrog (*Rana catesbeiana*)	Hepatic cytosol	12,000		s.p.c.	9.4	1	n.g.
Allergen: Asc-1, A[1][94]	*Ascaris suum*	Perienteric fluid	14,000A[1] 18,000Asc-1			6$^+$	3	n.g.
Allergen Ra 5[95]	Ragweed	Pollen	5,000			9.5	1	n.g.
Alloantigens HLA-linked B lymphocyte[96]	Human		64,000	1	29,000	6.1		
				1	34,000	5.2	2	n.g.
Allophycocyanin II (A II) and its α- and β-subunits[97]	Blue-green alga		102,500 (A II)		16,000 (α) 31,000 (β)	4.64(α), 4.65(A II) 4.82(β)	3	n.g.
Alveolysin[98]	*Bacillus alvei*		60,000			5.1, 7.0	2	n.g.
α-Aminoadipate aminotransferase[99]	Rat	Kidney	85,000	2	~45,000	6.56	1	4
Aminoazo dye-binding protein A[100]	Rat	Liver	14,000			5.0, 5.9, 7.6	3	n.g.
4-Aminobutyrate transaminase (I, II)[101]	Pig	Liver	110,000	2	55,000	6.10, 6.30(I), 5.90, 6.34(II)	4	n.g.
δ-Aminolaevulinic acid synthetase[102]	Rat	Liver mitochondria	120,000	2	58,000	4.5	1	n.g.
δ-Aminolaevulinate dehydrase[103]	Human	Erythrocytes	252,000	8	31,000	4.9	1	4
5-Aminolaevulinate synthetase[104]	*Rhodopseudomonas spheroides*		65,000		s.p.c.	5.2, 5.35, 5.45, 5.55	4	n.g.
Aminopeptidase[105]	*Physarum polycephalum*					(5–6.5), 5.6$^+$	4	n.g.

Aminopeptidase B-like enzyme[106]	Rat	Leukocytes				5.0	1	n.g.
5′-AMP aminohydrolase[107]	Human	Erythrocyte	285,000	4	70,000	5.5	1	n.g.
α-Amylases (1A, 1B, 2A, 2B)[108]	Human	Submandibular saliva	~220,000	2	57,000 (1A, 1B)	5.9 (1A, 2A)		
				2	54,000 (2A, 2B)	6.4 (1B, 2B)	4	n.g.
α-Amylase[109–113]	Human	Serum				5.88, 6.4$^+$, 6.88	3	
		Urine				5.93, 6.48$^+$, 6.98	3	
		Saliva	125,000[110]	1	61,000 (A)	5.9, 6.4$^+$ (A)	2	
				1	64,000 (B)	5.9$^+$, 6.4(B)[110]	2	
		Pancreas	60,000[110]			6.0, 6.5, 6.88$^+$	3	20[112]
α-Amylase[114]	Rabbit	Pancreas	56,500			6.8, 8.5	2	n.g.
Angiotensinogen[115]	Rat	Plasma			56,400	4.85	1	n.g.
Angiotensinogen[116,117]	Human	Plasma	66,000[117]			4.3, 4.5, 4.6$^+$, 4.7$^+$, 4.8$^+$, 4.9$^+$, 5.0$^+$	7	r.t.[117]
Angiotensinogen[117] (II)	Hog	Plasma	48,000			4.09, 5.05$^+$, 5.2$^+$, 5.35$^+$	4	
	Rabbit		56,000			5.0, 5.1$^+$, 5.35$^+$, 5.5$^+$	4	r.t.
Antigen alkali-soluble, water-soluble (B-ASWS)[118]	*Blastomyces dermatitidis*	Cells walls				4.01$^+$, 4.69$^+$	2	n.g.
I-Antigen 51 A[119]	*Paramecium tetraurelia*		300,000			4.1$^+$, 4.3$^+$, 4.4	3	n.g.
Antigen K 99[120]	*E. coli*					4.2	1	n.g.
Antigen carcinoembryonic (CEA)[121]	Human	Colon carcinomas				(2.5–4.5) 3.45$^+$		n.g.
Antigen, histocompatibility-2 (H-2)[122]	Mouse	Liver			40,000 12,000	4.9$^+$	> 1	n.g.
Antigen hepatitis B core and surface (HB_cAg, HB_sAg)[123,124]	Human	Sera				4.4(HB_cAg)[123]	1	
						3.7$^+$, 4.0$^+$, 4.4$^+$, 4.9, 5.1, 5.3(HB_sAg)[124]	6	n.g.
Antigens HLA-A9 and HLA-B12[125]	Human	Urine	32,000			5.1(HLA-A9), 4.7(HLA-B12)	1	n.g.
Antigen Rh (D)[126]	Human	Erythrocyte membrane	10,000–20,000			2.8, 3.8, 5.2, 7.3$^+$	4	n.g.

(Continued on p. 124)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit No.*	*Subunit MW*	*pI*	*No. of iso-enzymes*	*Temperature (°C)*
Antigen-tumour[127]	Human	Epidermoid carcinomas	25,000–50,000			8.36–8.40		n.g.
F antigen[128]	Human	Liver	40,000–80,000			6.6	1	0
Antithrombin III[129]	Guinea pig	Plasma				5.15	1	n.g.
Antithrombin III[130]	Human	Plasma	58,000	2	29,000	4.9, 5.1^{+}, 5.3	3	4
Antithrombin III[130]	Bovine	Plasma	56,000	2	28,000	4.5, 4.6^{+}, 4.7^{+}, 4.8^{+}, 4.9^{+}, 5.0	6	4
α-1 Antitrypsin[131]	Dog	Plasma	58,000			4.40, 4.52	2	4
α-1 Antitrypsin (F, M, S, Z)[132]	Human	Plasma				4.54(F), 4.59(M), 4.66(S), 4.74(Z)	1	n.g.
Apolipoprotein[133]:	Rat	Serum apoHDL, apoVLDL						
C-I					7,000	>6.0		
A-I					27,000	5.55, 5,65, 5.75, 5.82	4	
ARP and A-IV					35,000 (ARP)	5.31, 5.36, 5.39, 5.41	4	
					46,000 (A-IV)			r.t.[133]
A-II			8000			4.83	1	
C-II			8000			4.74	1	
C-III (0, 1, 2, 3, 4)			10,000 (CHIII0)			4.57, 4.61, 4.67	3	
			11,000 (CIII3)			4.43, 4.50	2	
Apolipoprotein[135]:	Vervet apoHDL	Plasma						
A-I			27,800			5.9–6.3		
DI-1			13,900			6.94	1	
DI-2			9900			5.17	1	n.g.
DII-1			11,500			6.44	1	
DII-2			8000			5.20	1	
DIII			9500			5.05		

Apolipoproteins, AI, A2 (threonine-poor)[136]	Human	Plasma	10,000 (AI)			6.0(AI)		
		apo-HDL	40,000 (AII)	2	20,000	6.5(AII)$^+$		
Apolipoprotein A-IV[137]	Human	Mesenteric lymph chylomicrons	46,000			5.15	1	n.g.
Apoliproteins C-I, C-II, C-III. CIV, CV, E[138–140]	Human	Plasma apo-VLDL				CI: 6,5	1	
						CII: 4.78	1	
						CIII: 4.54, 4.72, 4.93	3	n.g.
						CIV[138]: 4.61		
						CV[139]: 4.44		
						E: 5.7, 5.8, 5.9, 6.0, 6.2[139]	5	
Apolipoprotein D peak II protein[141]	Human	Plasma apoVLDL			33,000	9.5	1	n.g.
Apolipoprotein F[142]	Human	Plasma HDL	26,000–32,000			3.7	1	n.g.
α-L-Arabinofuranosidase[143]	*Scopolia japonica*	Calluses				5.7, 6.0, 8.0$^+$	3	n.g.
AraC protein[144]	*E. coli*		56,000	2	28,000	7.1	1	n.g.
Arylamidase[145,146]	Human	Cancerous lung[145]	240,000[146]			4.2	1	
		Ascites				3.7, 3.9$^+$, 4.2$^+$	3	4[146]
Arylsulphatase A (AS-A)[147]	Human	Urine (u)				4.7, 4.8, 4.9 (u)	3	
		Liver (l)				4.4, 4.5, 4.6$^+$, 4.7$^+$, 4.8$^+$, 4.9 (l)	6	n.g.
Arylsulphatase B (AS-B)[148]	Human	Placenta (p)				8.2 (p)	1	
		Brain (b)				6.8, 7.0, 7.2 (b)	3	n.g.
Arylsulphatases A and B (AS-A, AS-B)[149]	Human	Leucocytes				5.2 (AS-A)		
						8.2, 9.4 (AS-B)	2	n.g.
Arylsulphatases A and B (AS-A, AS-B)[150]	Rat	Basophil leukaemia tumour	116,000 (AS-A)			4.2 (AS-A)	1	
			50,000 (AS-B)			6.4 (AS-B)	1	n.g.
Aspartate aminotransferase[151–153]:	Pig	Heart	82,000	2	41,000	5.68(1)		
Pyridoxal homomer (1)						5.79(2)	1	
Apo/pyridoxal hybrid (2)						5.92(3)		
Apo homomer (3)								r.t.[153]
Aspartate aminotransferase[154]	Sheep	Liver	87,000			9.14	1	n.g.

(Continued on p. 126)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temper-ature (°C)*
				No.	*MW*			
Ca^{2+}-ATPase and Mg^{2+}-ATPase[155]	Bovine	Brain (microsomes)	105,000			4.8, 6.3	2	n.g.
ATPase (single-stranded DNA-dependent)[156]	Mouse	Myeloma				6.5	1	n.g.
Ca^{2+}-ATPase[157]	Rabbit	Sarcoplasmic reticulum	115,000			$5.0, 5.1, 5.2^{+}$ 5.4, 5.5	5	n.g.
ATPase inhibitor (F_1)[158]	*Saccharomyces cerevisiae*		7000			9.05	1	n.g.
Bacitracin A[159]	*Bacillus licheniformis* *B. subtilis*					$6.0^{+}, 6.5, 6.8, 7.1^{+}$	4	n.g.
Bacteriorhodopsin[160]	*Halobacterium halobium*					$3.98^{+}, 4.98, 5.45$	3	n.g.
α-N-Benzoylarginine-2-naphthyl-amide hydrolase (I and II)[161]	Rat	Skin	27,000			6.2(II), 7.5(I)	2	n.g.
Betaine aldehyde dehydrogenase[162]	*Pseudomonas aeruginosa* A-16		145,000			5.1	1	n.g.
Bilirubin glucuronoside glucuro-nosyltransferase[163]	Rat	Liver	160,000	6	28,000	7.9	1	n.g.
Biotin-binding protein[164]	Chicken	Egg (yolk)	74,300	4	18,575	4.6	1	n.g.
2,3-Bisphosphoglycerate phos-phatase and bisphosphoglycero-mutase (peak III)[165]	Human	Erythrocytes	63,000	2	29,000	5.1	1	25
2,3-Bisphosphoglycerate synthase[166]	Human	Erythrocytes				$4.6, 4.9, 5.0^{+}$	3	20
α-Bungarotoxin-binding protein[167]	*Drosophila melanogaster*	Heads				6.6	1	n.g.
α-Bungarotoxin-binding protein[168]	Mouse	Brain	700,000			5.6	1	n.g.
γ-Butyrobetaine hydroxylase[169]	*Pseudomonas* sp. AK 1		90,000	1	39,000			
				1	37,000	5.1	1	n.g.
Butyrylcholine-hydrolysine enzyme[170]	*Pseudomonas polycolor*		59,000			5.1	1	4
Cadmium-binding protein[171]	Rat	Liver				$4.2^{+}, 4.7$	2	n.g.
Cadmium-binding protein[172]	Rat	Liver				$5.3, 5.7^{+}, 6.2$	3	n.g.

Calcium-binding protein[173]	Chick	Chorioallantoic membrane	100,000	4	25,000	8.06	1	n.g.
Calcium-binding protein[174]	Soy					5.1^{+}, 5.2^{+}, 5.8^{+}	3	
	Leaf					3.7^{+}, 3.9, 5.2	3	
	Wheat					6.5, 6.6^{+}, 7.7, 8.0^{+}	4	n.g.
Calcium-modulated protein (calmodulin)[175]	Chicken embryo	Fibroblasts				3.8, 4.1^{+}	2	n.g.
Carbonic anhydrase III[176]	Rabbit	Skeletal muscle	58,000	2	29,000	8.41 (monomer), 9.34 (dimer)	1	n.g.
Carbonic anhydrase: C_1, C_2, C_3 isozymes[177]	Equine	Erythrocyte				8.52(C_3), 9.0(C_2), 9.63(C_1)	3	n.g.
Carbonic anhydrase[178]	Rat	Kidney	25,700			7.2, 6.9	2	
		Erythrocyte RBC-C	26,000			7.2, 6.9	2	n.g.
		Erythrocyte RBC-B	24,000			7.2^{+}, 7.0	2	
Carbonic anhydrase[179]	Male rat	Liver	29,000			5.97, 6.28^{+}, 6.60^{+}, 7.25	4	n.g.
Carboxylesterase[180]	Human	Brain	340,000			3.9^{+}, 4.0, 4.1, 4.2 4.5, 4.7	6	25
Carboxylesterase[181]	Human	Pancreas	54,000			4.65	1	n.g.
Carboxylesterase[182]	Rat	Serum	84,000			4.4	1	n.g.
Carboxypeptidase N[183]	Human	Serum				3.8^{+}, 4.3^{+}	2	r.t.
Carboxypeptidase[184]	*Streptomyces griseus* K-1		34,000			5.2	1	20
Cardiotoxin (Mojave toxin)[185]	*Crotalus scutulatus*	Venom	22,000	2	12,000	4.7	1	n.g.
Carnitine acetyltransferase[186]	Ox	Heart				5.2, 8.1	2	
		Liver				4.9, 7.6	2	
	Sheep	Liver				5.0, 7.9	2	n.g.
	Pigeon	Breast muscle: Crude				5.0, 8.1	2	
		Purified				8.0	1	
Carnosinase[187]	Hog	Kidney	84,000			5.8	1	n.g.
Catalase[188]	*Neurospora crassa*		320,000	4	80,000	5.0	1	n.g.
Catalase[189]	Human	Granulocyte from myeloid leukaemia	263,000	4	65,500	6.7	1	n.g.

(Continued on p. 128)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temper-ature (°C)*
				No.	*MW*			
Catalase[190]	Mouse	Liver				6.25, 6.35$^+$, 6.40$^+$ 6.50$^+$, 6.65, 6.80, 6.90, 7.15, 7.45	9	n.g.
Catalase[191]	Rat	Liver				6.49, 6.64, 6.74	3	0
Catechol O-methyltransferase:[192]	Rat	Liver						
COMT I			24,000			4.9		
COMT-II			47,500			4.8	2	n.g.
Cathepsin B[193]	Squid (*Dorytheuthis bleekri*)	Liver	13,600			6.8	1	n.g.
Cathepsin B1 (F-4.5)[194]		Liver	50,000	2	25,000	4.5	1	n.g.
Cathepsin B1[195]	Squid (*Ommatostrephes sloani pacificus*)	Liver	18,000			5.7	1	n.g.
Cathepsin B1[196]	Human	Foetal membranes of placenta				5.1$^+$, 5.4, 5.5	3	n.g.
Cathepsin B[197]	Human	Placenta	24,500			5.4	1	
Cathepsin collagenolytic[197]	Human	Placenta	34,600			5.1	1	n.g.
Cathepsin B forms I, II, III[198]	Pig	Liver	29,000 (I, II)	1 1	25,000 4,000	5.2(I), 5.4(II)		
			29,000 (III)		s.p.c.	5.8(III)	1	n.g.
Cathepsin B[199]	Rat	Liver	22,500			4.9, 5.0$^+$, 5.1, 5.3	4	n.g.
Cathepsin D I and D II[200]	Rat	Spleen	44,000		s.p.c.	4.2, 4.9, 6.1, 6.5 (DI)	4	
						4.6, 5.6, 5.8(DII)	3	n.g.
Cathepsin L[201]	Rat	Liver lysosomes			23,500	5.8–6.1	4	n.g.
Cellobiose oxidase[202]	*Sporotrichum pulverulentum*		93,000			4.5	1	20
Cellobiose: quinone oxido-reductase[203]	*Sporotrichum pulverulentum*		58,000			4.0, 5.7, 6.4	3	4
Cellulase[204]:								
Endoglucanase (1)	*Chaetomium*		41,000(1)			~4.55	1	n.g.

Exoglucanase(2)			67,000(2)			~4.55	1	
Cellulase: β-glucosidase (GB-2 component)[205]	*Pyricularia oryzae*		240,000	2	120,000	4.05	1	n.g.
Cellulase: C_1 component[206]	*Fusarium solani*					4.75⁺, 4.82. 4.90⁺, 4.95	4	n.g.
Chitinase[207]	Goat	Serum	60,000			4.85	1	4
Chitinase[208]	Calf	Serum	47,000			5.3	1	n.g.
Chitin synthetase-activating factor inhibitor[209]	*Saccharomyces cerevisiae*		8,500			7.1	1	n.g.
Cholesterol-binding protein[210]	Rat	Liver, cytosol			26,500	5.75, 5.80	2	n.g.
Cholesterol esterase[211]	Rat	Adipose tissue				5.1⁺, 4.7	2	n.g.
Cholesterol ester exchange factor[212]	Rabbit	Plasma				5.2	1	n.g.
Choline oxidase[213]	*Arthrobacter globiformis*		83,000		s.p.c.	4.5	1	5
Cholinesterase (ChE)[214]	Earthworm (*Eisenia foetida*)		108,000			(4.9–5.5) 5.1⁺, 5.2⁺, 5.3⁺	8	0.5–1.0
Cholinesterase[215]	Frog	Brain (b)	394,000(b_1) 550,000(b_2) 550,000(b_3)			5.9, 6.0, 6.1 (b)	3	
		Retina (r)	292,000(r_1) 470,000(r_2)			6.0, 6.1 (r)	2	n.g.
Chymotrypsin[216]	Mouse (strains NZB and A/Sn)	Pancreas				7.4(A/Sn 1) 4.9(A/Sn II)	2	
						6.5(NZB I) 4.5(NZB II)	2	n.g.
Chymotrypsin-like esterase[217]	Beef	Lung	> 104,000	> 2	~52,000	6.20, 6.33, 6.42, 6.54	4	n.g.
Coagulogen[218]	Japanese horseshoe crab	Amoebocyte lysate	15,300		s.p.c.	10.0	1	n.g.
Cobalophilin (R-protein)[219]	Pig	Ileal and pyloric mucosa	120,000			4.1	1	r.t.
Cobra venom factor (CVF)[220]	Cobra (*Naja naja*)	Venom				5.0, 5.2, 5.3, 5.5, 6.4⁺	5	n.g.
Colicin E4[221]	Citrobacter		56,000			8.2, 9.4	2	n.g.
Colicin O 111[222]	*E. coli* O 111: B4:H2		69,000			9.50	1	25

(Continued on p. 130)

TABLE I *(continued)*

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Collagenase precursor[223]	Human	Skin fibroblast	50,000		s.p.c.	6.7	1	n.g.
Colony stimulating factors (CSF)[224]	Mouse	L cells	70,000	2	35,000	4.0^+, 4.2^+, 4.8, 5.1	4	n.g.
Colony stimulating factors (CSF)[225]	Human	Cultured pancreatic carcinoma cells	50,000			3.7–4.6		n.g.
Complement, $C1\bar{r}$ subcomponent[226]	Human	Serum	110,000	1	68,000	4.9	1	0
				1	41,000			
Conalbumin[227]	Chicken	Egg						
Native						6.0, 6.3, 6.6^+	3	n.g.
γ-Irradiated						7.1^+, 7.4^+, 7.8	3	
β-Conglycinin, α,α',β[228]	Soybean		57,000			4.90(α)	1	
			(α,α')			5.18(α')	1	20
			42,000(β)			5.66–6.00(β)	4	
Corticosteroid-binding protein[229]	Rat	Brain				4.3, 5.8, 6.75^+	3	n.g.
		Pituitary cytosol				4.2^+, 6.5^+, 8.2	3	
C-reactive protein (CRP)[230]	Mouse	Liver, serum				4.8, 5.62	2	n.g.
Creatine kinase[231]	Rabbit	Skeletal muscle				6.1, 6.3^+, 6.4^+, 6.5^+	4	n.g.
Creatine kinase (CK): MM isozymes[232]	Human	Serum				6.24(MM_1), 6.45(MM_2), 6.86(MM_3)	3	n.g.
Creatine phosphokinase (CPK)[233]	Human	Heart				6.9(CPK-2)		
		Skeletal muscle				7.2(CPK-1)	2	4–8
Creatinine amidohydrolase (creatininase)[234]	*Pseudomonas putida*, strain C-83		175,000	8	22,000	4.7	1	n.g.
δ-Crystallin[235–237]	Avian, reptilian	Lens	200,000	4	50,000	5–7		
	embryonic mallard	Lens	200,000	4	50,000	(5.0–5.8)	5 major 9 minor	
	Embryonic chick	Lens	200,000	4	50,000	5.1–5.4	7	r.t.[237]
Cyclic AMP-adenosine binding protein[238]	Mouse	Liver	180,000	4	45,000	5.7	1	n.g.
Cyclic nucleotide phosphodiesterase[239]	Rat	Brain				5.2, 6.5	2	n.g.

Cyclic AMP phosphodiesterase 1 and 2[240]	*Dictyostelium purpureum*		60,000(1) 50,000(2a) 48,000(2b)			8.5(1) 7,5(2a, 2b)	1 1	n.g.
Cyclic AMP phosphodiesterase[241]	*Dictyostelium discoideum*					4.6, 6.5, 8.3	3	n.g.
Cyclic AMP phosphodiesterase F1, F2-I, F2-II forms[242]	Rat	Pancreatic cytosol	500,000(F1) 70,000 (F2-I, F2-II)			3.9(F2-II)	1	n.g.
Cyclic nucleotide phosphodiesterases[243,244]	Rat	Cerebellum[243]				4.4, 4.8^+, 5.0^+, 6.1^+, 8.3, 9.0	6	
	Rat	Cerebrum[244]				5.1, 5.6^+, 6.1^+, 6.6^+, 8.0, 9.0	6	n.g.
Cyclic nucleotide phosphodiesterase[245]	Rat	Neostriatum				4.30^+, 4.45^+, 4.70, 4.85^+, 5.50	5	n.g.
		Cerebellum				4.1, 4.35^+, 4.5^+, 4.7, 4.9^+, 5.5	6	
Cyclic nucleotide phosphodiesterase activator[246]	Bovine	Brain	15,000		s.p.c.	4.3	1	n.g.
Cyclooxygenase, prostaglandin-forming[247]	Sheep	Vesicular glands				6.3^+, 6.5, 6.7	3	n.g.
Cystathionine β-synthase:								
Normal (1)	Human	Skin fibroblasts	123,000	1	53,000	5.7 (1)	1	
Deficient homocystinuria (2)[248]				1	70,000	4.9 (2)	1	n.g.
Cystic fibrosis protein: CF ACTOR[249–255]	Human	Sera from cystic fibrosis	3,500–10,000			8.46	1	4[249,250] 5[254]
Cytochrome b_5-like haemoprotein[256]	Rat	Liver-mitochondrial outer membranes	60,000	4	16,000	3.6	1	5
Cytochrome b_{556}[257]	*E. coli* K 12				17,500	8.5	1	n.g.
Cytochrome *c*[258]	*Tetrahymena pyriformis*		11,300		s.p.c.	6.5	1	n.g.
Cytochrome *c*[259]	*Dyctyostelium discoideum*					10.2	1	n.g.
Cytochrome *c* peroxidase[260]	*Pseudomonas denitrificans*		63,000			5.6	1	n.g.

(Continued on p. 132)

TABLE I (continued)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temper-ature (°C)*
				No.	*MW*			
Cytochrome[261]:								
$c_{550(a)}$, $c_{551(b)}$, $c_{555(c)}$ Oxidized form; Azurin (d)	*Pseudomonas aeruginosa* and *fluorescens*					5.6(d), 5.7(c), 6.5(a), 7.3(b)	1	12(b) 14(a,c) 18(d)
Cytochrome *f*[262]	*Sinapis arvensis* L.	Leaves	27,000		s.p.c.	5.50	1	n.g.
Cytochrome *P*-450[263]	*Bacillus megaterium* ATCC 13368				52,000	4.9	1	n.g.
Cytochrome *P*-450: I, II[264–266]	Bovine	Adrenocortical mitochondria	850,000[266]	16	53,000	4.0(I), 7.0(II)[264,265]	2	n.g.
Cytochrome *P*-450[267]	Rat	Liver, microsomal				4.8^+, 5.4^+, 5.6^+	3	4
Cytochrome oxidase[268]	*Pseudomonas*		120,000	2	60,000	6.9	1	n.g.
Cytosol receptors for testosterone[269]	Rat	Kidney, submaxilari gland(1), prostate(2)				4.6, 5.1(1) 5.8(2)	2 1	n.g.
Cytosol thyronine-binding protein[270]	Dog	Kidney, cytosol	70,000			3.0^+, 3.8^+, 4.4 4.7, 5.3, 5.7	6	n.g.
Dehydrogenase (apo-NADH)[271]	*Peptostreptococcus elsdenii*		75,000	1 1	41,000 33,000	4.9, 5.4	2	n.g.
3′-Deocymononucleotide-producing nuclease[272]	*Verongia aerophoba*		62,000			6.1	1	n.g.
Desulphoviridin[273]	*Desulfovibrio vulgaris*					4.4^+, 4.55	2	n.g.
Detoxifying enzymes[274]:	*E. coli*							
Mercuric reductase			180,000	3	60,000	5.3	1	
Organomercurial hydrolase			43,000			5.5	1	r.t.
Diglyceride kinase[275]	*E. coli*	Membrane	15,400		s.p.c.	4.0	1	n.g.
Dihydrofolate reductase[276]	Beef	Liver	22,500		s.p.c.	5.70, 6.80^+	2	n.g.
Dihydrofolate reductase[277]	Chicken	Liver	22,474		s.p.c.	6.3, 6.8, 7.4, 8.4^+	4	n.g.
Dihydrofolate reductase (1, 2)[278]	*E. coli* B (RT-500)		18,500			4.6(1), 4.7(2)	2	n.g.
Dihydropteridine reductase[279]	Rat	Liver	51,000	2	25,000	6.35	1	n.g.
Dihydropteridine reductase[279]	Sheep	Liver	52,000	2	25,000	5.4	1	n.g.
Diisopropyl fluorophosphatase (DFPase)[280]	*E. coli*					5.3^+, 5.7, 6.1^+, 7.8	4	n.g.

Dipeptidyl carboxypeptidase[281]	Human	Seminal plasma	330,000			4.6, 5.0	1	n.g.
o-Diphenol-oxygen-oxidoreductase[282]	*Agaricus bisporus*	Fruiting bodies	118,700			5.12, 5.41, 6.25	3	n.g.
DNase[283]	*Aspergillus oryzae*		48,000		s.p.c.	9.2	1	n.g.
DNase[284]	*Chlamydomonas reinhardii*		35,000		s.p.c.	9.5	1	n.g.
DNase V[285]	Calf	Thymus	53,000	4	13,000	10.3 ± 0.2	1	n.g.
DNase B[286]	Streptococci							
	Group A					4.4, 5.8, 7.9$^+$, 9.0$^+$	4	4
	Group C					4.4, 5.8	2	
DNAase[287]	Human	Urine	38,000			3.9	1	n.g.
DNAase[288]	Human	Pancreatic secretion				4.58, 4.68, 4.79$^+$, 4.86$^+$, 5.00, 5.08	6	23
DNA-binding protein (DNA-110 protein)[289]	Rat	Brain, cytosol	68,000			5.9	1	n.g.
DNA-binding proteins (1 and 2)[290]	Human	Serum			126,000 (1)	7.01(1)	1	
					86,000 (2)	5.97, 6.03, 6.09(2)	3	r.t.
DNA ligase[291]	*E. coli* B/6, T-4-amber-N82 mutant		60,000			6.0	1	n.g.
DNA polymerase[292]	Calf	Thymus (cyto)	160,000	1	90,000	5.3$^+$, 5.8, 6.3$^+$	3	n.g.
				1	60,000			
DNA polymerase (I and II)[293]	Yeast		> 100,000			5.1	1	n.g.
DNA polymerase III[294]	Mouse	Myeloma	270,000			5.8	1	n.g.
DNA polymerases (A, B, and C)[295]	Wheat	Embryos				5.2(B), 7.0(A,C)	3	n.g.
DNA polymerase-α[296]	Human	KB cells	140,000	1	76,000	5.1	1	n.g.
				1	66,000			
DNA polymerase-β[297]	Rat	Cortex neuronal nuclei	51,000			8.3	1	n.g.
DNA polymerase-β[298]	Human	Novikoff hepatoma cells				7.5(7.35-S form) 8.5(4.15-S form)	2	n.g.
DNA polymerase-γ[299]	Rat	Brain nuclei	180,000			5.4	1	n.g.
DNA polymerase inhibitor[300]	*Physarum polycephalum*	Slime mould	16,000			10.1	1	n.g.
Elastase[301]	Human	Granulocyte lysosomal				8.2, 9.0	2	n.g.

(Continued on p. 134)

TABLE I *(continued)*

Protein	Source	Organ and/or subcellular location	MW	Subunit No.	Subunit MW	pI	No. of iso-enzymes	Temperature (°C)
Elastase II[302]	Porcine	Pancreas	26,500			8.5	1	n.g.
Elongation factor 2 (EF-2)[303]	Hen	Oviduct	93,000		s.p.c.	6.75	1	n.g.
Elongation factor 1-βγ[304] (EF-1-βγ)	Pig	Liver	90,000	1 1	30,000 55,000	5.0(EF-1-β) 7.0(EF-1γ)	2	n.g.
Elongation factor eEF-Ts[305]	Mouse	Krebs II-ascites tumour cells	52,000	2	26,000	4.7	1	n.g.
Endochitinase[306]	Wheat germ		30,000		s.p.c.	7.5–9.2		n.g.
Endo-α-N-acetyl-D-Galactos-aminidase[307]	*Diplococcus pneumoniae*		160,000			8.5	1	r.t.
Endopolygalacturonase[308]	*Rhizoctonia fragariae*		36,000		s.p.c.	6.76, 7.08	2	n.g.
Endoribonuclease[309]	Bovine	Adrenal cortex cytosol				8.3	1	n.g.
Enolase[310]	*Turbatrix aceti*					5.6	1	4
Enolase[311]	Rabbit	Muscle	85,000	2	42,500	7.7, 8.4, 8.8+,	3	n.g.
		Liver				6.3, 6.7+	2	n.g.
Enolase A[312]	Yeast					6.1+, 6.3, 7.0	3	22–25
Enterotoxin A[313]	*Staphylococcus aureus*					6.5, 7.0, 8.0	3	n.g.
Enterotoxin A[314]	*Staphylococcus aureus*					6.8, 7.2, 7.6, 8.1+ 8.6+	5	25
Epidermal growth factor (EGF)-binding protein[315]	Mice	Submaxillary glands	29,300			5.6	1	n.g.
Epidermal growth factor (EGF)[316]	Mice	Submaxillary glands	74,000 (complex)	2 2	6,045 29,300 (binding protein)	4.60	1	n.g.
Erythrocruorin[317]	Leech *(Dina dusia)*			1 1 1 1 1	13,000 21,000 23,000 25,000 31,000	5.87	1	n.g.

Erythrocruorin[318]	Leech (*Haemopis grandis*)			1 1 1 1	13,500 21,000 23,000 27,000	6.0	1	n.g.
Esterase (I and II)[319]	Rat	Liver	70,000(I) 160,000(II)			5.82(I), 6.32(II)	1	0
Esterase, non-specific (NSE)[320]	*Fasciola hepatica*					5.10^+, 5.15^+, 5.25^+, 5.40, 5.55, 5.65, 5.75	7	20
Esterase B_4[321]	Human	Liver	20,000		s.p.c.	8.7	1	8
Esterase[286]	*Streptococci* (group C)					5.8	1	4
Estrogen binding protein[321]	Calf	Uterus	115,000			4.9	1	4
Estrogen receptor[322]	Lamb	Uterus	35,300			5.5^+, 5.8^+, 6.2	3	n.g.
	Rat	Uterus	49,600			6.4	1	
Exonuclease[323]	Beef	Spleen				6.67	1	n.g.
Factor IX pools: I, II, III[324]	Human	Plasma				3.98^+, 4.16^+, 4.50(I) 3.85^+, 4.12, 4.42^+, 5.35, 5.80, 6.04(II) 3.85, 4.10, 4.36^+, 4.83^+(III)	3 6 4	n.g.
Factor D[325]	Human	Serum	24,000		s.p.c.	7.4	1	4
Fatty acid synthetase[326]	*Mycobacterium smegmatis*				290,000	4.8	1	n.g.
Fatty acid-binding protein[327]	Rat	Heart	12,000		s.p.c.	5.0	1	n.g.
Feline sarcoma virus-coded precursor polyprotein[328]	Feline sarcoma virus		130,000			3.9	1	n.g.
Ferredoxin[329]	*Clostridium pasteurianum*					2.75	1	10
Ferredoxin-NADP$^+$ reductase[330]	Spinach	Leaves			34,000 (b) 37,000 (c, d)	4.8(e), 5.0(d), 5.2(c), 5.5(b), 6.0(a)	5	2
Ferritin[331]	Rat	Heart	530,000–626,000			4.6, 4.8	2	r.t.
Ferritin[332,333]	Human (1) Rat (2) Horse (3)	Liver and heart	450,000–620,000	24	H:21,000 L:19,000	4.8–5.8(1) 5.1–5.9(2) 4.1–5.1(3)	~ 6–10 ~15–18 15–18	2

(Continued on p. 136)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temper-ature (°C)*
				No.	*MW*			
Ferritin[334]	Human	Placenta				4.7–5.0	~ 6–7	n.g.
Ferritin[335]	Human	Tumour and normal sera				4.90–5.10 (tumour), 5.25–5.65 (normal)	Several	n.g.
α-Fetoprotein[336]	Mouse	Foetal plasma, amniotic fluid			70,000	4.4–5.4	5–8	r.t.
α-Fetoprotein[337]	Mouse	Hepatoma BW7756	72,000		s.p.c.	(4.3–5.2), 4.6^{+}	4–6	n.g.
α-Fetoprotein[338]	Human	Cord serum	71,000		s.p.c.	4.85	1	n.g.
α-Fetoprotein[339]	Human	Hepatoma serum and ascitic fluid	67,500		s.p.c.	4.57^{+}, 5.2	2	n.g.
α-Fetoprotein[340]	Human	Foetal tissue				4.7^{+}, 5.3	2	n.g.
Fetuin-like antigen[341]	Human	Nephro blastoma (Wilm's tumour)				3.8^{+}, 4.2	2	n.g.
F_0F_1 ATPase complex[342]	*Rhodospirillum rubrum*	Chromatophores	480,000 ± 30,000			5.4	1	n.g.
ex-Flagellin[343]	*Rhizobium lupini* (H13-3)	Flagella			43,000	4.5, 4.65^{+}, 4.8^{+}	3	10
Flavivirus structural proteins:[344]	Virus		7,000			3.8		
Envelope glycoprotein			53,000			7.8	3	n.g.
Nucleocapsid protein			14,000			10.3		
Flavocytochrome C[345]	*Chromatium vinosum*			1 1	21,000 46,000	5.0, 5.2^{+}, 5.6^{+}	3	n.g.
Flavodoxin[329]	*Clostridium pasteurianum*					3.1	1	10
Folate-binding protein[346]	Goat	Milk	37,000		s.p.c.	6.6, 7.3, 8.4	3	n.g.
Formaldehyde dehydrogenase[347]	Human	Liver	81,400	2	40,000	6.35	1	n.g.
F. pili[348]	*E. coli*	Filamentous organs			11,800	3.6	1	4
Fructokinase[349]	Bovine	Liver	56,000	2	28,000	5.7	1	n.g.
Fructose 1,6-bisphosphatase[350]	Mouse	Liver	143,000	4	37,500	6.1	1	n.g.
L-Fucose dehydrogenase (NAD-dependent)[351]	Sheep	Liver	123,000	4	30,000	5.8	1	n.g.
α-Fucosidase[352–354]	Human	Fucosidosis sera				4.35–4.95	6	n.g.
α-Fucosidase[21]	Human	Leucocytes				5.6	1	
		Fibroblasts				**5.7^{+}, 7.0, 7.6**	**3**	**4**
		Amniotic fluid				**5.6**	**1**	

α-L-Fucosidase[20,355,356]	Human	Liver	200,000	4	50,000	5.2, 5.4, 5.6$^+$, 5.9$^+$, 6.2$^+$, 6.4	6	n.g.
α-L-Fucosidase[357]	Human	Foetal liver				5.0, 5.2, 5.5, 5.7, 6.0$^+$, 6.4$^+$, 6.7	7	n.g.
α-L-Fucosidase[358]	Human	Serum	296,000		56,500 54,000	5.0$^+$, 5.4 5.7, 5.9, 6.2, 6.4, 6.8	7	n.g.
α-L-Fucosidase[359]	Human	Brain			51,000	4.7, 5.2, 5.4, 5.75$^+$, 6.0$^+$, 6.3$^+$, 6.65	7	0–2
α-L-Fucosidase[360]	Human	Skin fibroblasts, amniotic fluid cells				4.9, 5.2, 5.4, 5.8, 6.1, 6.5, 7.1	7	n.g.
Fucosyl transferase[361]	Human	Plasma				4.7$^+$, 5.1, 5.5	3	n.g.
D-Galactonate dehydrase[362]	*Pseudomonas*		240,000	4	57,000	4.5	1	4
Galactose-1-phosphate uridylyl transferase[363]	Human	Erythrocyte				5.7$^+$, 6.2	2	n.g.
Galactose-1-phosphate urydylyl transferase[364,365]	Human	Liver Red cell Erythroblast Reticulocytes				5.30–5.80 5.0–5.45 5.55–5.90 5.30–5.50	5	n.g.
α-Galactosidase[20]	Human	Liver, serum				5.0	1	n.g.
α-Galactosidase A[366]	Human	Liver				4.7	1	n.g.
α-Galactosidase (I, II, IV forms)[367]	Human	Leukocytes				5.0(I), 4.5(II), 3.95(IV)	3	n.g.
α-Galactosidase[368]	*E. coli* K 12		329,000	4	82,000	5.1	1	n.g.
β-Galactosidase[22]	Human	Liver				4.4–4.7	4–5	0
β-Galactosidase[369]	Human	Leukocyte				3.9, 4.5$^+$	2	n.g.
β-Galactosidase[370]	Human	KB cells				4.3$^+$, 4.8	2	20
β-Galactosidase (peaks I and II)[371]	Human	Placenta	420,000–480,000(I) 220,000(II)		77,000 31,000 22,000 77,000	3.6, 4.7(I) 4.64(II)	2 1	n.g.
β-Galactosidase[372]	Rabbit	Brain				6.3	1	3–4
β-Galactosidase[373]	*Aspergillus niger*		124,000(1) 150,000(2) 173,000(3)			~4.6	1	n.g.
β-Galactosidase[374]	*Aspergillus oryzae* RT 102					4.2	1	0
β-Galactosidase[375]	*Curvularia inaequalis*		120,000			4.4	1	n.g.

(*Continued on p. 138*)

TABLE I (continued)

Protein	Source	Organ and/or subcellular location	MW	Subunit		pI	No. of iso-enzymes	Temperature (°C)
				No.	MW			
γ-Globin (G_γ, A_γ)[376]	Human	Foetal hemoglobin				6.85(A_γ), 6.95(G_γ)	2	r.t.
Globulin (Narbonin)[377]	*Vicia narbonensis* L.	Seeds	33,500		s.p.c.	5.17	1	n.g.
Glucacone-like polypeptides (I, II, III, IV fractions)[378]	Porcine	Colon			12,000 (I)	4.5, 4.9, 5.2, 6.1 6.8(I)	5	
					8000 (II)	6.2(II)	1	
					5000 (III)	4.8, 5.6, 10(III)	3	4
					3000 (IV)	10(IV)	1	
1,3-β-Glucanase[379]	*Bacillus* No. 221				36,000	4.1	1	n.g.
1,4-β-Glucan glucanohydrolase (I, II)[380]	*Trichoderma viride*		12,500(I) 50,000(II)		s.p.c.	4.60(I) 3.39(II)	2	10
1,4-β-Glucan glucanohydrolase[381]	*Trichoderma viride* QM 9414		20,000			7.52	1	20
1,4-α-Glucan phosphorylase[382]	*Klebsiella pneumoniae*		180,000	2	90,000	5.3	1	n.g.
Glucoamylase ($Gluc_1$, $Gluc_2$, $Gluc_3$)[383]	*Rhizopus*		74,000 ($Gluc_1$) 58,600 ($Gluc_2$) 61,400 ($Gluc_3$)			8.7($Gluc_1$, $Gluc_2$) 8.8($Gluc_3$)	2	n.g.
Glucoamylase[384]	*Endomycopsis* sp. 20-9		53,000			3.81	1	n.g.
Glucocorticoid receptor[385,386]	Rat	Liver and hippocampus			89,000	5.8	1	2–4
Glucosaminephosphate isomerase[387]	Rat	Hepatoma(1), liver (2)				4.1, 4.5^+ (1) 5.0^+ (2)	2 1	12

α-Glucosidase[388]	*Saccharomyces carlsbergensis*		63,000		s.p.c.	7.0	1	n.g.
α,β-Glucosidase[20]	Human	Liver, serum				5.0	1	n.g.
β-D-Glucosidase[389]	Almond		135,180	2	65,150	7.3	1	n.g.
β-D-Glucosidase[390]	*Stachybotrys atra*		67,000			4.8	1	n.g.
1,4-β-Glucosidase[391]	*Sporotrichum pulverulentum*				165,000–182,000	4.52–5.15	5	n.g.
β-Glucosidase (I and II)[392]	*Picea Abies*	Seeds	58,570(I)		s.p.c.	10.0(I), 10.3(II)	2	n.g.
β-Glucosidase[393]	*Cicer arietinum* L.		110,000	1	63,000	9.0, 9.3	3	n.g.
				1	43,000	10.0		
β-Glucuronidase[394]	Human	Fibroblast				6.0–6.5	4	n.g.
		Platelet				6.0–6.5	6	
		Liver				6.5–7.5	3	
		Placenta				7.0–7.5	4	
β-Glucuronidase[395]	Mouse	Urine	280,000	4	70,000	5.5–6.0		n.g.
β-Glucuronidase[396]	Rat	Liver lysosomes				5.58, 5.78^+, 5.95^+ 6.02	4	n.g.
β-Glucuronidase[397]	Rat (female)	Preputial gland	283,000	4	72,000	6.15	1	n.g.
β-Glucuronidase[398]	Rat	Liver:						
		Golgi				(5.7–6.6), 6.0^+, 6.3^+, 6.4^+	6	
		Lysosomal				(5.8–6.8), 6.0^+, 6.3^+, 6.4^+, 6.7^+	13	
		Microsomal				(6.9–7.6), 7.0^+, 7.4^+	5	n.g.
β-Glucuronidase[399]	*Littorina littorea* L.	Liver	250,000			4.2, 5.5	2	2
L-Glutamate decarboxylase[400]	Human	Brain	~140,000	2	67,000	5.0^+, 5.1^+, 5.2, 5.4	4	n.g.
L-Glutamate dehydrogenase[401]	Human	Liver	330,000			4.83	1	n.g.
Glutamate dehydrogenase[402]	Rat	Liver				4.88, 4.96, 5.12	3	4
Glutamate dehydrogenase[403]	*Bacillus subtilis* PCI 219		250,000		57,000	3.7	1	n.g.
Glutamate dehydrogenase[404]	Oat	Leaves	230,000			6.5, 6.8	2	n.g.
L-Glutaminase (I, II, III)[405]	*Pseudomonas* ATCC 21025		146,000	4	36,400	7.8(III), 8.05(II), 8.35^+(I)	3	n.g.
Glutamine synthetase[406]	*Azotobacter vinelandii*		640,000	12	53,000	4.6	1	n.g.
Glutamine synthetase[407]	*Rhizobium japonicum* 61A76					5.4, 6.1	2	n.g.

(Continued on p. 140)

TABLE I (continued)

Protein	Source	Organ and/or subcellular location	MW	Subunit No.	Subunit MW	pI	No. of iso-enzymes	Temperature (°C)
γ-Glutamyl cyclotransferase[408]	Rat	Kidney				4.6, 5.1	2	n.g.
γ-Glutamyl transferase[409]	Beef	Colostrum	80,000	1	25,000	3.85	1	n.g.
				1	55,000			
γ-Glutamyl transpeptidase[410]	Rat	Kidney	68,000	1	46,000	5.40, 5.50, 5.65, 5.85$^+$		
				1	22,000	6.12$^+$, 6.32$^+$, 6.51$^+$,		
						6.71$^+$, 7.0$^+$, 7.27,		
						7.68, 9.20	12	n.g.
Glutathione peroxidase[411]	Human	Placenta	85,000	4	22,000	4.8	1	n.g.
Glutathione reductase[412]	Mouse	Liver	105,000			6.46	1	n.g.
Glutathione reductase[413]	Baker's yeast		120,000			4.9$^+$, 5.9	2	4
Glutathione-S-arene oxidase transferase[414]	Sheep	Liver	40,000			6.3, 6.9$^+$, 7.1, 7.3, 7.5$^+$	5	4
Glutathione S-transferase[415]	Rat	Liver	45,000	2	25,000	8.9, 9.8	2	n.g.
Glutathione synthetase[416]	Bovine	Eye lens	180,000			4.75, 4.80	2	n.g.
Glutathionethiol esterase[417]	Human	Red blood cells				7.0–8.4	9	4
Glutathione transferase[418]	Human	Erythrocytes	47,500	2	23,750	4.5	1	n.g.
Glyceraldehyde 3-phosphate dehydrogenase[419]	Fish	Muscle	160,000	4	39,000	7.9, 8.25$^+$, 8.42$^+$	3	4
		Liver				6.3, 6.5, 6.6, 6.8, 7.1	5	
Glycerol 3-phosphate dehydrogenase[420]	Rabbit	Liver				6.3, 6.58$^+$	2	n.g.
		Heart				6.1$^+$, 6.58	2	
sn-Glycerol 3-phosphate dehydrogenase[421]	E. coli		51,000	2	25,500	6.0	1	n.g.
α-Glycerol phosphate dehydrogenase[422]	Drosophila melanogaster					5.4	1	n.g.
α-Glycerol phosphate dehydrogenase[423]	Colias butterflies					5.8, 6.1, 6.2, 6.4	4	r.t.
Glycogen phosphorylase[424]	Rat	Muscle (1)	185,000(1,2)			5.60(3), 5.90(2),	3	n.g.
		Liver (2)	200,000(3)			6.15(1)		
		Novikoff hepatoma (3)						
Glycogen phosphorylase b[425]	Human (A)	Brain (1)				5.6(A,B,1)		
		Liver (2)				6.1–6.3(A,2)		

	Rabbit (B)	Muscle (3)				6.3(A,B,3) 6.1(B,2)		n.g.
Glycogen synthase[426]	Swine	Adipose tissue			90,000	4.8	1	n.g.
Glycoprotein[427]	Human	Blood platelets	450,000	3	150,000	4.7	1	n.g.
α-2-Glycoprotein[428]	Human	Pregnancy sera	490,000		90,000	4.8	1	n.g.
Glycoprotein[429]	Mouse	Submandibular glands			28,000	4.85	1	n.g.
Glycoprotein (secretory, AM_2 protein)[430]	Mouse	Submandibular glands			80,000 40,000	4.7	1	n.g.
Glycoprotein[431]	Chicken	Egg white	27,800			4.8	1	n.g.
Glycoproteins (envelope E_1, E_2)[432]	Sindbis virus					6.0(E_1), 9.0(E_2)	2	4
Glycoprotein[433]	*Cercopithecus aethiops*	Submandibular gland secretion				10.0, 11.0	2	4
Glycosulphatases (I, II)[434]	Marine gastropod (*Charonia lampas*)	Liver	112,000(I) 79,000(II)			6.3(II)	1	n.g.
Glyoxalase (I)[435]	*Saccharomyces cerevisiae*		32,000		s.p.c.	7.0	1	
	Human, pig	Erythrocytes	46,000	2	23,000	4.8	1	4
Gonadotropin[436]	Fish	Pituitary gland	40,000	2	18,000	4.38, 4.57, 4.67^+, 4.78^+, 4.80^+, 5.05	6	n.g.
Gonadotropin[437]	Rat	Hypophysis				2.8(FSH), 4.4(LTH), 4.8(GH), 9.0(LH)		n.g.
Gonadotropin, chorionic (hCG) isohormones[438,439]	Human		65,000			4.4, 4.5, 4.6, 4.8, 5.05, 5.3, 5.65, 5.95, 6.3	9	n.g.
Green-fluorescent protein (GFP)[440]	*Renilla reniformis*		54,000	2	27,000	5.34	1	n.g.
Green haemoprotein[441]	Bovine	Erythrocytes	27,000		s.p.c.	5.74, 5.83^+, 5.95^+	3	2
Group-specific component (Gc-globulin) (vitamin D-binding protein)[442–444]	Human	Serum				4.95(Gc-1 Fast) 5.03(Gc-1 Slow)	2	
						5.10(Gc-2)	1	4
						4.95, 5.03, 5.10(Gcl-2)	3	
Growth hormone[445]	Monkey	Pituitary				5.03, 5.23, 5.44^+, 5.78	4	
	Human	Pituitary				4.58, 4.80^+, 5.05, 5.40	4	n.g.
Growth hormone receptor[446]	Rabbit	Liver, membranes	300,000	4	75,000	4.6	1	n.g.

(Continued on p. 142)

TABLE I *(continued)*

Protein	Source	Organ and/or subcellular location	MW	Subunit No.	Subunit MW	pI	No. of iso-enzymes	Temperature (°C)
Guanine aminohydrolase[447]	Rabbit	Liver	112,000	2	53,000	4.78	1	n.g.
Haemagglutinin[448]	*Maclura pomifera*	Seeds	40,000	2	12,000	4.75	1	n.g.
				2	10,000			
Haemagglutinin[449]	*Wistaria floribunda*	Seeds			28,000	5.4	1	n.g.
Haemocyanins[450]	Spiders: *Dugesiella californica* (1) *Cupiennius* (2)	Haemolymph	71,000(1) 72,000(2)			5.2(2) 5.5(1)	1	n.g.
Haemoglobin[451]	*Dicrocoelium dendriticum*		22,000		15,000	4.51, 4.53	2	12–14
Haemoglobin[452]	Annelid (*Eunice aphroditois*)		$3.49 \cdot 10^6$			7.7^+	> 3	n.g.
Haemoglobin[453]	Bloodworm (*Glycera gigantea*)	Coelomic cells	55,000	4	13,000	5.60, 5.90^+, 6.12^+, 6.2, 6.32^-, 6.63^+, 6.78^+, 6.92, 7.08, 7.36	>10	10
Haemoglobin[454]	Bloodworm (*Glycera rouxii*)	Coelomic cells	34,500	2	17,000	6.72^+, 7.26, 7.67	3	15
Haemoglobin[455]	Bloodworms (*Glycera dibranchiata*)	Coelomic cells			15,600	5.4, 6.0, 6.4, 6.5, 7.05^+, 7.4, 8.1	7	
			125,000	4	31,000	(4.9–5.9) 4.9^+, 5.2^+, 5.5^+, 5.9^+	> 4	25
Haemoglobin (I, II, III, IV)[456]	Killifish (*Fundulus heteroclitus*)	Red cells	64,000	4	16,000	8.20 (I)	1	n.g.
						7.52 (II)	1	
						6.48 (III)	1	
						5.82 (IV)	1	
Haemoglobin III (liganded states):	*Chironomus thummi thummi*							
O_2-haemoglobin (II)						5.87	1	25
CO-haemoglobin (II)						5.92	1	
Deoxyhaemoglobin (II)[457]						5.93	1	
Haemoglobin	Hamster	Peripheral blood				6.80, 7.18^+, 7.30, 7.41, 7.50	5	r.t.

Haemoglobin[459]	Hamster	Peripheral blood				6.67, 7.18+, 7.38, 7.58, 7.81	5	n.g.
Haemoglobin[460]	Dog	Red blood cells				6.91+	> 2	6
Haemoglobin Alberta[461] ($\alpha_2\beta_2{}^{101\ Glu \rightarrow Gly}$)	Human	Red blood cells				7.05	1	n.g.
Haemoglobin J. Cairo[462]	Human	Red blood cells				6.75	1	n.g.
Haemorrhagic component (HR1)[463]	*Trimeresurus flavoviridis*	Venom			60,000	4.4	1	n.g.
Haptoglobins[464]	Human	Ascitic fluids				4.03–4.24		
	Porcine	Plasma				4.0–4.30		n.g.
	Equine	Serum				3.80–4.15		
Haptoglobin (type 1-1)[465]	Human	Serum	98,200	2	9,100	4.25	1	n.g.
				2	40,000			
Haptoglobin–apohemoglobin complex (Hp–apoHb)[466]	Human	Serum				5.10	1	n.g.
Herbage protein[467]:	*Medicago sativa*							
Fraction I						5.5+	2	
Fraction II						4.4+, 4.8+, 5.0+, 5.1+	15	n.g.
Hexokinase (P-I, P-II)[468]	Yeast		104,000	2	52,000	5.0(P-II), 5.3(P-I)	2	n.g.
Hexokinase[469]	*Ascaris suum*	Muscle			100,000	5.9	1	4
Hexokinase:								
Young cells (1)[470]	Human	Erythrocyte	120,000(1)			5.75 (1)		
Total cells (2)			115,000(2)			5.75 (2)	1	n.g.
Old cells (3)			111,500(3)			5.60 (3)		
Hibernation-inducing triggers[471]	Woodchucks	Plasma				4.5, 5.2	2	4
High-density lipoproteins: HDL_2[472]	Human	Plasma				4.03, 4.32, 4.54+, 4.89, 5.02, 5.22+, 5.41, 5.52+, 5.67, 6.67	10	n.g.
Histidine decarboxylase[473]	Rat	Gastric mucosa	94,000		s.p.c.	5.4, 5.75, 6.0	3	n.g.
Histidyl-t-RNA synthetase[474]	Rabbit	Reticulocytes	122,000	2	64,000	5.0	1	n.g.
Histoplasmin: HPD αII[475]	*Histoplasma capsulatum*		12,000		s.p.c.	5.68	1	n.g.
Homoserine dehydrogenase[476]	*Rhodospirillum rubrum*		110,000	2	55,000	5.0, 5.3, 5.7, 6.1+	4	n.g.
Hormone (growth)[477]	Human	Pituitary				4.95, 5.1+, 5.2+	3	4

(Continued on p. 144)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit No.*	*Subunit MW*	*pI*	*No. of iso-enzymes*	*Temperature (°C)*
Hormone (growth; variant)[478]	Human	Pituitary extracts	22,000			5.85	1	r.t.
Hormone (luteinizing)[479]	Human	Urine				6.71^+, 7.26^+, 7.72^+, 8.14^+	> 4	n.g.
Hormone (luteinizing) (IR-LH)[480]	Rat	Anterior pituitary				7.9, 8.5^+, 8.8^+, 9.1^+, 9.35^+, 9.6, 9.8	7	n.g.
Horseradish peroxidase C[481]	Horseradish	Root	34,000		s.p.c.	9	1	n.g.
Hyaluronate lyase[286]	Streptococci:							
	Group A					4.4	1	4
	Group C					4.3		
Hyaluronidase[482]	Human	Placenta	70,000			5.2	1	4
Hydrogenase[483]	*Desulfovibrio vulgaris*		89,000	1 1	59,000 28,000	6.2^+, 5.8	2	n.g.
Hydrogenase[484]	*Chromatium*		100,000	2	50,000	4.2, 4.4	2	n.g.
Hydrogenase[485]	*E. coli*	Membrane-bound	113,000	2	56,000	4.2	1	n.g.
Hydrogenase[487]	*Alcaligenes eutrophus* H 16	Soluble form	205,000			4.85	1	6
Hydrolases: cathepsin B1 (1) and BANA (2)[488]	Rabbit	Lung, lysosomes	26,000–29,000			5.0–5.5 (1) 5.8–6.5 (2)	4 6	n.g.
3-Hydroxy-3-methylglutaryl-CoA reductase[489]	Chicken	Liver, microsomes				6.7	1	n.g.
β-Hydroxy-β-methylglutaryl-CoA reductase[490]	Rat	Liver, microsomes	200,000	4	51,000	6.2	1	n.g.
4-Hydroxyphenylpyruvate dioxygenase[491,492]	Human	Liver	87,000	2	43,000	7.1 (ref. 491) 6.5–7.5 (ref. 492)	1 3	n.g. r.t.
4-Hydroxyphenylpyruvate dioxygenase[493]	*Pseudomonas* sp. P.J. 874		150,000	4	36,000	4.8	1	n.g.
17α-Hydroxysteroid dehydrogenase[494]	Rabbit	Liver				4.7^+, 4.85^+, 5.0^+, 6.1^+	> 4	n.g.
3(17)β-Hydroxysteroid dehydrogenase[495]	*Pseudomonas testosteroni*		98,500	4	23,500	7.0^+, 7.5^+ (of subunits)	6	n.g.

Hypoxanthine–guanine phosphoribosyl transferase (HGPRT)[496]	Human	Skin fibroblasts				6.25	1	n.g.
	Mouse	L cells				6.6		
Hypoxanthine guanine phosphoribosyl transferase (HGPRT)[497]	Chinese hamster	Liver, V 79 tissue, culture cells	78,000	3	25,000	6.2^+, 6.3^+, 6.6^+	6	n.g.
Hypoxanthine–guanine phosphoribosyl transferase (HGPRT)[498]	*Saccharomyces cerevisiae*		51,000		s.p.c.	5.1	1	n.g.
Hypoxanthine phosphoribosyl transferase[499]	Human	HeLa cells			26,000	6.0	1	n.g.
Hypoxanthine phosphoribosyl transferase[500]	Human	Erythrocytes	81,000	3	26,000	5.6, 5.7^+, 5.9^+	3	n.g.
Immunoglobulin G: Fc, Fab fragments[501]	Human	Serum	50,000 (Fab) 340,000 (Fc)			7.0(Fc), 8.2^+ 9.0^+, 9.5^+ (Fab)	> 4	5
Immunoglobulin G (monoclonal)[486]	Human	Myeloma serum				7.5, 7.6, 7.7, 7.8, 7.86	5	n.g.
Immunoglobulin M (antilactose antibody)[502,503]:	Equine	Serum						
H chains						5.4–6.2	10	r.t.
J chains						4.8, 4.9, 5.0	3	r.t.
Immunoreactive glucagon fractions (IRGs)[504]	Dog	Pancreas (1) gastric fundus (2)	3500(1a) 9000(1b) 3500(2a) 9000(2b) 65,000(2c)			6.25(1a) 4.65(1b) 6.15(2a) 4.50(2b) 6.40(2c)		n.g.
Immunoreactive insuline[505]	Dog	Pancreatic juice				4.8^+, 5.7^+	> 2	25
Immunoreactive somatostatin[505]	Dog	Pancreatic juice				9.7^+, 10.2^+	> 2	25
Inhibitory factor[506]	Human	Granulocytes	102,000–128,000			6.3	1	n.g.
myo-Inositol 3-methyltransferase[507]	*Pisum sativum*		42,000		s.p.c.	6.95	1	n.g.
myo-Inositol 1-methyltransferase[507]	*Vinca minor*		27,000		s.p.c.	7.10	1	n.g.
Interferon[508]	Rainbow trout	Serum	26,000			(4.5–6.2) 5.3^+		n.g.

(Continued on p. 146)

TABLE I *(continued)*

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Interferon[509]	Mouse	Ehrlich ascites tumour cells	25,000–35,000			9.8^{+}		n.g.
Interferon[510,511]	Human	Leukocyte	17,500–23,000		s.p.c.	5.5^{+}, 6.2^{+}, 6.6^{+} 7.0	4	
		Fibroblasts				(6.8–7.8)	Several	4
Interferon[512]	Human	Lymphoblastoid cells	18,000–22,000			5.7^{+}, 6.0^{+}, 6.3^{+}	8	n.g.
Invertase:								
FH4C external (1)	Yeast, FH4C strain (1,2)					2.7, 3.32, 3.65 (1)	3	
FH4C internal (2)						4.5 (2)	1	n.g.
External (3)[513]	*S. cerevisiae* (3)					3.9–4.5 (3)	4	
Iron-binding protein[514]	Guinea pig	Intestinal mucosa	80,000	2	40,000	6.16, 6.23	2	n.g.
Iron–sulphur protein (high potential type) (HiPIP)[515]	Beef	Heart mitochondria	89,000			8.55	1	n.g.
(Iso)ferritins[516]	Human							
		Normal liver				5.35, 5.54, 5.56	3	
		Normal kidney				5.12, 5.22^{+}, 5.25^{+}	3	
		Normal pancreas				5.19, 5.25^{+}, 5.30^{+} 5.34^{+}, 5.55	5	
		Normal serum				5.04, 5.16, 5.28, 5.35, 5.45, 5.56^{+}, 5.62^{+}	7	n.g.
		Normal colon				5.20, 5.35^{+}, 5.45, 5.55	4	
		Renal carcinoma				5.25, 5.35, 5.54^{+}	3	
		Pancreatic carcinoma				5.19, 5.25, 5.30, 5.35^{+}, 5.54^{+}	5	n.g.
		Colonic carcinoma				5.25, 5.36^{+}, 5.45, 5.54^{+}	4	
(Iso)ferritins[517]	Human	Normal liver, Normal spleen (1)				5.25, 5.33, 5.47 5.65 (1,3)	4	
		Foetal liver,				4.9, 5.1, 5.25, 5.33,		

		hepatoma (2)				5.47, 5.65 (2)	6	
		Leukaemia serum, Liver, spleen (3)						
(Iso)ferritins[518]	Horse	Spleen	450,000			4.10, 4.25, 4.35, 4.40, 4.45, 4.60	6	20
Isoleucine aminopeptidase[519]	*Ulex minor*	Root				4.28, 4.51, 4.78	3	4
Isomerase (acylthioester)[520]	Hog	Liver	90,000	2	45,000	6.57, 6.83, 7.01, 7.21	4	4
Isorenin (acid proteinase)[521]	Rat	Brain			45,000	5.45, 5.87, 6.16, 7.05	4	2
Kallikrein[522]	Rat	Urine	33,100			4.18^{+}	1	n.g.
Kallikrein[523]	Rat	Pancreas	27,000			4.05, 4.15	2	
	Dog	Pancreas	30,000			4.1, 4.2, 4.4^{+}	3	10
Kallikrein[524]	Cat	Submaxillary gland	50,000		s.p.c.	4.2–5.1	6–7	n.g.
Kallikrein (d_1,d_2 forms)[525]	Porcine	Pancreas	34,500(d_1) 31,000(d_2)			3.75, 3.82, 3.92^{+} 3.97^{+}, 4.11^{+}(d_1)	5	25
						3.93, 4.01^{+}, 4.11^{+}(d_2)	3	
Kallikrein[526]	Human	Urine	43,600			3.80^{+}, 3.95^{+}, 4.06	3	n.g.
Kallikrein[527,528]	Human	Urine	27,000 (HUK-1; HUK-2)			3.9(HUK-1) 4.0(HUK-2)	3	n.g.
			29,000 (HUK-3)			4.2(HUK-3)		
Kallikrein[529]	Human	Urine	64,000	1	29,000	3.8, 3.9, 4.05	3	n.g.
				1	45,000			
Kallikrein inhibitor[530]	Rat	Plasma	73,000			4.4	1	4
Kanamycin acetyltransferase II[531]	*Moraxella*					7.6	1	n.g.
Δ^5-3-Ketosteroid isomerase[532]	*Pseudomonas testosteroni*					4.75^{+}	3	n.g.
Kininogen[533]	Human	Plasma	50,000			4.4, 4.9^{+}	> 2	n.g.
Kininogen[534]	Human	Plasma	120,000			4.7	1	r.t.
Kynurenine pyruvate aminotransferase[535]	Rat	Kidney	76,000			5.2	1	4
β-Lactamase[536]	*E. coli* RTEM					5.4	1	n.g.
β-Lactamase[537–539]	*E. coli* P111 (TEM1)					5.4		
	E. coli RP 4 (TEM2)					5.6		
	Ps. aeruginosa RL 113					5.7		

(Continued on p. 148)

TABLE I *(continued)*

Protein	Source	Organ and/or subcellular location	MW	Subunit No.	Subunit MW	pI	No. of iso-enzymes	Temperature (°C)
	E. coli P 453 (type 2)					7.7	1	n.g.
	P. morganii NCTC 235					8.3		
	Ps. aeruginosa NCTC 8203					8.7		
	Ps. aeruginosa NCTC 10701					9.4		
	Ps. aeruginosa HL					5.3		
Lactase[540]	Rat	Enterocytes (brush border)				4.8	1	n.g.
Lactate dehydrogenase (LDH-1)[541]	Human	Heart muscle				4.6	1	n.g.
Lactate dehydrogenase[542]	Cestoda (*Hymenolepis diminuta*)					7.0	1	n.g.
Lactate dehydrogenase[543]	*Lactobacillus*		140,000	4	36,000			
	L. plantarum					4.4	1	n.g.
	L. curvatus					4.9		
	L. acidophilus					5.1		
	L. casei					5.3		
Lactate dehydrogenase[544]	*Ambystoma mexicanum*					5.24 (LDH-1)	1	n.g.
						5.58, 5.62 (LDH-2)	2	
						5.74, 5.80 (LDH-3)	2	
						6.07, 6.14 (LDH-4)	2	
						6.52, 6.60 (LDH-5)	2	
L-Lactate dehydrogenase, membrane bound[545]	*E. coli*	Membranes	480,000	12	43,000	8.3	1	n.g.
Lactogen[546]	Ovine	Placenta			22,500	6.8 (monomer) 7.7 (aggregate)	1	10
Lactogen[547]	Human	Placenta				5.0, 5.5, 5.8 6.0, 6.1, 6.2	6	n.g.

Lactoperoxidases[548]	Monkey:	Parotid saliva	79,000			6.1, 7.3, 8.4(1)	3	
	M. mulatta (1),					7.9(2)	1	n.g.
	M. fascicularis (2)							
Lectin[549,550]	*Ricinus communis*	Seeds	130,000	2	33,500	7.1 (ricin)		
	Abrus			2	32,000	7.5 (ricin A chain)		
	precatorius					4.8 (ricin B chain)		
						6.1 (abrin)		
						4.6 (abrin A chain)	1	n.g.
						7.2 (abrin B chain)		
						5.0 (abrus)		
Lectin[551]	*Eunonymus*	Seeds	166,000		35,000	4.4^{+}, 4.7^{+},	6	n.g.
	europeus				17,000	4.9^{+}		
Lectin[552]	*Pisum sativum*	Seeds	49,000	2	7,000 (α)	4.1^{+}, 5.1, 5.8	4	n.g.
				2	17,000 (β)	6.5^{+}		
Lectin[553]	*Vicia cracca*	Seeds	125,000	4	32,000	5.2–5.6		n.g.
Lectin[554]	*Anguilla anguilla*	Serum	50,000	2	23,000	5.6–6.0		
	Clitocybe nebularis	Fruiting bodies	70,000		19,000	4.3, 4.5	2	
					14,500			
	Fomes fomentarius	Fruiting bodies	60,000	1	35,000	5.8, 6.3, 6.5	3	
				1	21,000			
				1	10,000			n.g.
	Maclura pomifera	Seeds	60,000	5	12,000	5.3–5.8		
	Marasmius oreades	Fruiting bodies	50,000	1	33,000	5.2–5.4		
				1	23,000			
	Ononis spinosa	Root	110,000	4	30,000	4.0–4.4		
	Sarothamnus scoparius	Seeds	120,000	4	28,000	6.3	1	
Lectin[555]	Embryonic chick	Pectoral muscle	30,000	2	15,000	4.0	1	n.g.
Lectin[556]	Barley	Seeds	31,000			4.95	1	n.g.
Lectin[557]	*Phaseolus vulgaris*	Seeds	119,000			4.6–5.2	5	r.t.
Lectin, α-D-galactosyl-binding[558]	*Bandeiraea simplicifolia*	Seeds	114,000	4	28,500	4.9–5.1	4	n.g.
Leghaemoglobin: Lba, Lbc[559]	Soybean	Root nodules				4.88 (Lba, high spin)		
						4.99 (Lba, low spin)	4	2
						4.50 (Lbc, high spin)		
						4.64 (Lbc, low spin)		

(Continued on p. 150)

TABLE I *(continued)*

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Leghaemoglobin [iron(III) form][560]	Soybean	Nodules				4.90 (a) 4.73 (b) 4.62 (C_1) 4.59 (C_2) 4.56 (C_3) 4.50 (d_1) 4.47 (d_2) 4.44 (d_3)	8	2
Leghaemoglobin[561]	*Phaseolus vulgaris*	Root nodules	16,900 (Lba)			4.70 (Lba) 4.55 (Lbb)	2	2
Leucine aminopeptidase[540]	Rat	Enterocytes (brush border)				4.78	1	n.g.
Leucyl-tRNA synthetase[562]	*Tetrahymena pyriformis*	Mitochondria Cytoplasm	100,000		s.p.c.	6.5 8.8	1 1	n.g.
Ligandin[563–565]	Rat	Liver cytosol	46,000	1 1	22,000 25,000	7.3, 8.0, 8.4, 9.5^+, 9.7^+ 10.3^+	6	n.g.
Light-harvesting pigment protein complex[566]	*Rhodopseudomonas sphaeroides* strain 2.4.1					7.2 ± 0.25 7.8 ± 0.2	2	n.g.
Lectin, sialic acid-binding (limulin)[567]	Crab (*Limulus polyphemus*)	Haemolymph	335,000		19,000	5.0–5.1	3	n.g.
Lipase[568]	Human	Serum (pancreatic disease)	46,000			6.4, 6.8, 7.4	3	n.g.
Lipase (A, B)[569]	Pig	Adipose tissue	60,000			5.2 (A) 5.5 (B)	1	n.g.
Lipase, hormone-sensitive[570]	Rat	Adipose tissue				6.7	1	4
Lipid-exchange protein[571]	Rat	Hepatoma	11,200		s.p.c.	5.2	1	n.g.
Lipoprotein lipase[572]	Pig	Adipose tissue	61,000			4.0	1	n.g.
Lipoprotein lipase[573]	Human	Post-heparin plasma	67,000			4.5	1	n.g.

Lipoproteins: LDL. VLDL (fractions I and II)[574]	Human	Serum				LDL-I: 4.1		
						4.5	3	
						4.6		
						LDL-II: 4.9		
						5.2		
						5.3		
						5.35	6	
						5.45		
						6.1		r.t.
						VLDL-I: 4.2		
						4.4	3	
						4.5		
						VLDL-II: 4.9		
						5.0		
						5.1	6	
						5.4		
						5.45		
						6.1		
Lipoproteins, VLDL[575]	Human	Double pre-β-lipoproteinaemia, primary dys-β-lipoproteinaemia				5.57–6.03	3–4	n.g.
Lipoprotein (apo-CIII, CII)[576]	Human	Blood plasma				4.69 (C III) 4.86 (C II)	2	n.g.
Lipoprotein–proteoglycan complex[577]	Human	Serum				5.4–6.4	7	n.g.
Lipoxygenase[578]	Rabbit	Reticulocytes	78,000			5.5	1	n.g.
Luciferin-binding protein[579]	*Renilla reniformis*		18,500		s.p.c.	4.3	1	n.g.
Luteinizing hormone[580]	Human	Pituitary gland, plasma				6.75, 7.33, 7.80, 8.23, 8.81, 9.17, 9.55	7	4
Lutropin[581]	Bovine	Anterior pituitary gland				8.3^{+}	> 1	n.g.
Lymphocyte activating factor[582]	Mouse	Tumour cells	100,000			4.9	1	n.g.
	Human	Leukocytes	13,000			6.85	1	
Lysine decarboxylase, inducible[583]	*E. coli*		780,000	10	78,000	4.5	1	n.g.
Lysophospholipases: I, II[584]	Beef	Liver	25,000(I) 60,000(II)			5.2(I) 4.5(II)	1	n.g.

(*Continued on p. 152*)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Lysozyme[585]	*Ceratitis capitata*	Eggs	23,200		s.p.c.	> 11	1	n.g.
α_2-Macroglobulin[586]	Human	Plasma				5.3	1	5
α_2-Macroglobulin[587]	Human	Serum				4.1–4.9	7	10
Macromomycin[588–590]	*Streptomyces macromomyceticus*		12,500 or 16,000		s.p.c.	5.4	1	n.g.
Malate dehydrogenase[591]	*Saccharomyces cerevisiae*	Mitochondrial	68,000	2	34,000	6.8	1	
		Cytoplasmic	75,000	2	37,500	6.75–7.1	> 1	4
Malate dehydrogenase[422]	*Drosophila*	Cytoplasmic				5.7	1	n.g.
Malate dehydrogenase	Cestoda (*Hymenolepis diminuta*)					7.45	1	n.g.
Malate dehydrogenase[592]	Rat	Liver				6.3	1	r.t.
Malate dehydrogenase (MOR-2-AB)[593]	Bovine	Mitochondrial	70,000	2	35,000	8.0–8.5	2	n.g.
Malic enzyme[594]	Cherry	Fruits	180,000			4.6	1	10
Malonyl-CoA decarboxylase[595]	*Mycobacterium tuberculosis*		44,000			6.7	1	n.g.
Mammary stimulating factor (MSF)[596]	Mouse	Serum	10,200			5.7	> 1	n.g.
α-Mannosidase[21]	Human	Leukocytes				5.4^+, 6.7	2	
		Fibroblasts				6.3	1	4
		Amniotic fluid				4.1, 5.25^+, 6.25^+	3	
α-Mannosidase[20]	Human	Liver				4.5	1	n.g.
α-Mannosidase[597]	Calf	Plasma from mannosidosis				5.0, 5.9^+, 7.0^+, 7.9	4	n.g.
α-D-Mannosidase[598]	Rat	Liver, Golgi membranes	300,000		75,000 145,000	5.8	1	n.g.
α-Mannosidase I, II[599]	*Phaseolus vulgaris*		220,000	2	110,000	5.1(I) 6.1(II)	1	n.g.
β-D-Mannosidase[600]	*Aspergillus niger*		130,000			4.7	1	n.g.

Melanocyte-stimulating hormone (MSH) release-inhibiting factor[601]	Bovine	Kidney	300,000	5	56,000	4.1	1	n.g.
Mercaptoethanol-releasing factor[602]	Human	Serum				4.65, 4.85$^-$	2	25
Metalloproteins: Zn/Cd and Zn/Hg[603]	Rainbow trout	Liver, kidney, gills, gut				4.8$^+$, 5.3$^+$, 5.6$^+$ 6.3	4	n.g.
Metalloprotein[604]	Tea	Leaves				9.6$^-$, 8.7, 8.4	3	4
Metallothionein[605]	Mouse	Liver				4.0$^+$, 6.0$^+$	2	n.g.
Methionyl-tRNA$_f^{MET}$ deacylase[606]	Human	HeLa cells	80,000	2	40,000	9.0	1	n.g.
Methylase EcoRI[607]	*E. coli*		39,000		s.p.c.	8.7$^-$	> 1	n.g.
Methyltransferase, cytochrome c-specific protein–lysine[608]	*Neurospora crassa*		120,000			4.8	1	n.g.
Metridiolysin[609]	Sea anemone (*Metridium senile*)		80,000			5.0	1	n.g.
α_1-Microglobulin[610]	Guinea pig, human	Urine, sera	25,500		s.p.c.	4.3–4.8		n.g.
β_2-Microglobulin[611]	Guinea pig	Urine	11,500			6.6	1	n.g.
β_2-Microglobulin[612]	Human	Urine from normal and renal transplantation subjects	12,000			5.3, 5.7$^+$	2	n.g.
β_2-Microglobulin[613]	Human	Urine				5.75$^-$, 6.0	2	n.g.
β_2-Microglobulin-like protein[614]	Chicken	Sera			11,400	5.0$^+$, 6.0	2	n.g.
α_1-Microglycoprotein[615]	Human	Urine from leukaemia			27,000	4.45$^+$, 4.7$^+$, 4.85$^+$, 6.0	4	n.g.
Migration inhibition factor[616]	Mice	Lymph node lymphocytes	50,000–100,000			6.45	1	n.g.
Migration inhibitory factor:	Guinea pig	Lymph node cells						
3 MIF			65,000			3.0–4.5	4–5	
5 MIF			25,000–43,000			5.0–5.5	2	
Mitogenetic factor (MF)[618]	Human	Lymphocytes	25,000			4.8$^+$, 5.8$^+$, 8.0$^+$, 8.3	4	n.g.
Myelin basic protein[619]	Dog	Spinal cord	18,000			9.5	1	n.g.
Myoglobin[620]	Yellowfin tuna (*Thunnus albacares*)		16,200			8.6	1	n.g.
Myoglobin[621]	Chicken	Muscle				7.70$^+$	3	n.g.
Myoglobin[622]	Penguin	Breast muscle				8.5$^-$(I), 8.0(II) 7.7(III)	3	15

(Continued on p. 154)

TABLE I (*continued*)

Protein	Source	Organ and/or subcellular location	*MW*	Subunit No.	Subunit *MW*	*pI*	No. of iso-enzymes	Temperature (°C)
Myokinase (MK)[233]	Human	Skeletal muscle, heart				8.9 (MK-2) 9.8 (MK-1)	2	4–8
Myosin, subfragment-1[623]	Pig	Cardiac muscle	119,000			6.45, 6.70	2	4
Myotoxin[624]	Prairie rattlesnake		4,100			9.6	1	n.g.
Myrosinase[625]	*Sinapis alba*		120,000			4.9^{-}, 6.2	2	6
NADase (NAD glycohydrolase)[286]	Streptococci:							
	Group A					8.4, 8.9	2	
	Group C					8.6, 9.3	2	4
NADH-cytochrome *c* Reductase[626]	*Pseudomonas arvilla* C-1		38,000		s.p.c.	4.2	1	n.g.
NADPH-adrenodoxin reductase[627]	Bovine	Adrenocortical mitochondria	51,000			5.4	1	n.g.
NADPH-flavin reductase[628]	Human	Erythrocytes	22,000		s.p.c.	8.1	1	n.g.
Neocarzinostatin[629–631]	*Streptomyces carzinostaticus*		10,700		s.p.c.	3.3	1	n.g.
Neocarzinostatin[632]	*Streptomyces carzinostaticus*					3.13, 3.28	2	
Nerve growth factor[633]	*Bungarus multicinctus*	Venom	21,000	2	10,500	*ca.* 10	1	n.g.
Nerve growth factor[634]	Cobra (*Naja naja atra*)	Venom	22,000	2	11,000	7.02	1	n.g.
Nerve growth factor[635]	Human	Placental tissue	150,000			9.5	1	n.g.
Neuraminidase[636,637]	*Arthrobacter*		88,000		s.p.c.	5.35^{-}, 5.25–5.70	7	n.g.
	Clostridium perfringens					5.1^{-}	3	
Neurocuprein[638]	Bovine	White and grey matter	9,500			3.5	1	n.g.
Neurophysin precursor[639]	Rat	Brain	~ 18,500			5.1^{+}, 5.4^{+}, 5.6^{-}, 6.1^{+}, 6.9	5	n.g.
Neurotoxin:[640]	*Bungarus multicinctus*	Venom						
α-Type synaptic neurotoxins			8000			9.0–9.2	1	
β-Type synaptic neurotoxins			21000			8.8–9.7	> 1	n.g.

Neurotoxin (major toxin)[641]	*Pelamis platurus*	Venom	6600			9.69	1	n.g.
(anti-)Neurotoxin factor[642]	*Vipera palaestinae*	Serum	56,000			4.0	1	4
Nicotinic acetylcholine receptor[643]	Gold fish	Brain	340,000			5.0	1	n.g.
Nitrate reductase[644]	*Clostridium perfringens*		90,000		s.p.c.	5.5	1	n.g.
Nitrate reductase (ferredoxin)[645]	*Clostridium perfringens*		6000			3.0	1	n.g.
Nitrogenase:[646]	*Azotobacter vinelandii*							
Mo-Fe protein			216,000	4	56,000	5.2		
Fe protein			66,000	2	33,000	4.7	1	n.g.
Nitrogenase (Mo-Fe protein)[647]	*Anabaena cylindrica*		220,000			4.8	1	n.g.
Norephinephrine N-methyl transferase[648]	Rabbit:	Adrenal gland	35,000–40,000		s.p.c.			
	Adult					4.7+, 5.0+, 5.25+, 5.65	4	n.g.
	Young					5.05, 5.45	2	
Nuclease S_1[649]	*Aspergillus oryzae*	Mycelia	25,000–41,000			4.35	1	n.g.
Nuclease inhibitor[650]	*Aspergillus oryzae*		22,000			4.09	1	4
Nucleosidases:[651]	*Leishmania donovani*							
Pyrimidine ribonucleosidase			180,000			6.3	1	
Purine ribonucleosidase			205,000			4.4	1	n.g.
Purine 2'-deoxyribonucleosidase			33,000			4.3	1	
Nucleoside diphosphatase[652]	Rat	Liver cytosol	120,000	4	30,000	4.7, 5.0	2	n.g.
Nucleoside phosphorylase[653]	Human	Placental	93,000	3	31,000	5.64, 5.74, 5.86	3	n.g.
		erythrocyte				5.24, 5.34, 5.44, 5.64, 5.74, 5.86	6	n.g.
Nucleoside phosphotransferase[654]:	Chick	Embryo cells						
C^a		Cytosol, mitochondria, nucleus				5.0	1	n.g.
D		Cytosol				4.1		

(Continued on p. 156)

TABLE I (continued)

Protein	Source	Organ and/or subcellular location	MW	Subunit No.	Subunit MW	pI	No. of iso-enzymes	Temperature (°C)
5'-Nucleotidase[655]	Rat	Brain, microsomes				6.4	1	n.g.
5'-Nucleotidase[656]	Human	Placental, microsomes				5.4, 5.62, 5.91, 6.26, 6.48	5	4
Octopine dehydrogenase[657] isoenzyme 2	Squid (*Loligo vulgaris* Lam)					8.3, 8.7	2	n.g.
[^{3}H]Oestradiol receptor complex[658]	Guinea pig	Foetal, uterus, cytosol fraction				6.15	1	n.g.
[^{3}H]Oestradiol-17β receptor[659]	Rat	Uterus,cytosols:				6.3, 7.7, 8.0	3	
		Mature				5.5, 5.8$^+$, 6.0$^+$,		4
		Immature				6.4, 7.5$^+$	5	
Ornithine transcarbamylase[660]	Rat	Liver	112,000	3	39,000	7.2	1	n.g.
Ornithine transcarbamylase[661]	Human	Liver	114,000	3	38,000	6.8	1	n.g.
Ornithine transcarbamylase[662]	Human	Normal liver	110,000	3	36,500	7.95	1	
		Reye's syndrome liver				8.05	1	4
Ovomucoid[663]	Chicken					3.52, 3.82$^-$, 4.0, 4.15$^+$, 4.35$^+$, 4.50	6	n.g.
Oxaloacetate decarboxylase[664]	Fish	Muscle			63,000	6.59	1	n.g.
Pallidin (carbohydrate-binding protein)[665]	*Polysphondylium pallidum*		250,000		24,800	7.0	1	n.g.
Palmityl-CoA-ACP-transacylase[666]	*Mycobacterium smegmatis*					4.7	1	n.g.
Pantothenase[667]	*Pseudomonas fluorescens*		100,000	2	50,000	4.7	1	10
Parathyroid hormone (BPTH)[668]	Bovine					8.73	1	n.g.
Parvalbumin[669]		Skeletal muscle						
	Turtle		12,000			4.4		
	Chicken		12,000			4.9	1	n.g.
	Rabbit		12,000			4.9		
Parvalbumin (IVa, IVb)[670]	Frog (*Rana temporaria*)	Skeletal muscle				4.97(IVa) 4.75(IVb)	2	n.g.

Parvalbumins[671]	Fish:	White muscle						
	Haddock III		11,348			4.20		
	Whiting III_b		11,340			4.44		
	Cod III		11,211			4.1		
	Haddock II		11,904			4.35	1	n.g.
	Cod II		11,513			4.4		
Pectinase[672]	Fungi (*Aspergillus niger*)		33,000			4.5–7	15	n.g.
Pectolytic enzyme-stimulating factor[673]	*Aspergillus japonicus*					3.2, 3.7, 4.1^{+}	3	n.g.
P-enolpyruvate carboxykinase ferroactivator[674]	Rat	Liver (cytosol)	82,000		23,600	7.5^{+}, 7.7^{+}, 7.9^{+}, 8.4	4	5
Pepsin[675]	Bovine					2.80^{+}, 2.90^{+}, 2.99^{+}, 3.09	4	20
	Pig					3.02^{+}, 3.2	2	
	Chicken					4.03^{-}	> 1	
Peptidase[676]	Human	Liver	130,000			5.6	1	n.g.
Peroxidase[677]:	Melon:							
S_1	Infected					3.9^{+}, 4.9, 8.1, 10.9^{+}	4	
	Not infected					10.0	1	n.g.
S_3	Infected					3.6, 9.2^{+}, 9.9^{+}, 11.0^{+}	4	
	Not infected					9.2	1	
Peroxidase[678]	*Phellinus igniarus*		39,000			2.85^{+}	2	n.g.
Peroxidase[679]	Soybean					3.2^{+}, 4.2^{+}, 4.5^{+}, 5.0^{+}, 7.1^{+}	12	n.g.
Peroxidase[680]	Horseradish					6.5, 7.1	2	n.g.
Phenol sulphotransferase I[681]	Rat	Liver	65,000	2	32,500	8.05	1	n.g.
Phenylalanine hydroxylase[682]	*Chromobacterium violaceum*		32,000		s.p.c.	4.5	1	n.g.
Phenylalanine hydroxylase[683]	Rat	Hepatoma				5.2	1	
		Liver				5.2^{+}, 5.3^{+}, 5.6	3	r.t.
		Kidney				5.35	1	
Phenylalanine ammonia-lyase[684]	Mustard	Cotyledons				5.5^{+}	> 1	n.g.
Phenylalanine(histidine): pyruvate aminotransferase[685]	Mouse	Liver, mitochondria	80,000	2	40,000	5.6, 6.0^{+}, 6.2^{+}, 6.5^{+}, 6.7	5	n.g.
Phenylalanine racemase[686]	*Bacillus brevis*					4.6	1	4

(Continued on p. 158)

TABLE I *(continued)*

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Phosphatidase C[687]	*Erwinia carotovora*					7.5	1	n.g.
Phosphatidylcholine exchange protein[688]	Bovine	Brain, liver, heart				5.3, 5.6^{-}	2	n.g.
Phosphatidylinositol exchange protein[688]	Bovine	Brain, liver, heart				5.2^{+}, 5.5	2	n.g.
Phosphodiesterase[689]	Tobacco	Cell culture			72,000	8.8	1	n.g.
Phosphodiesterase[56]	Mouse	Parotid				5.0^{+}, 5.25^{-}, 5.4, 5.65^{-}	7	n.g.
Phosphodiesterase II[690]	Rat	Intestine	160,000			3.4, 4.2–4.5, 7.2		n.g.
Phosphodiesterase–phosphomonoesterase[691,692]	*Fusarium moniliforme*		106,000			5.9, 6.2^{+}, 6.3^{+}, 6.6^{+}	4	n.g.
Phosphofructokinase[693]	*Lactobacillus acidophilus*, *L. plantarum*		154,000	4	38,500	4.9–5.1		n.g.
Phosphoglucomutase[34]	Human	Erythrocytes				5.05, 5.19, 5.45, 5.56, 5.69, 5.73, 5.96	7	15
Phosphoglucose isomerase[694]	Schistosoma					6.5^{+}, 6.8^{+}, 7.0^{+}, 7.4^{+}	>15	n.g.
Phosphoglucose isomerase[695]	Human	Erythrocytes	131,000	2	65,500			
Wild type						9.25	1	n.g.
Singh variant						9.25, 9.40^{-}, 9.57	3	
Phosphoglucose isomerase[422]	*Drosophila*					6.3	1	n.g.
D-3-Phosphoglycerate dehydrogenase[696,697]	Chicken	Liver	165,000	4	41,000	8.95	1	n.g.
3-Phosphoglycerate kinase[698]	Yeast		47,000			7.01	1	n.g.
Phosphoglycerate kinase[699]	Yeast					6.94	1	4
Phosphoglycerate kinase[700]	Human	Erythrocytes				8.75	1	n.g.
Phosphoglycerate mutase[701]	Human	Erythrocytes						
Monophosphoglycerate			57,000			6.2	1	4
Biphosphoglycerate			54,000			4.9	1	
Phosphoglycerate mutase[166]	Human	Red cells				5.6, 5.9, 6.2^{+}	3	20
Phosphoglycerate mutase[702]	*Bacillus subtilis*		75,000			5.6	1	n.g.
Phosphoglyceromutase[165]	Human	Erythrocytes				5.1	1	25
Phosphoglycolate phosphatase[703]	Tobacco	Leaves	86,300	4	20,500	3.85	1	n.g.
O-Phosphohydroxylysine phospholyase[704]	Rat	Liver	140,000			5.5	1	0

Phospholipase A_2[705]	Horse	Pancreas, pancreatic juice				5.5	1	n.g.
Phospholipase A_2[706]	*Vipera berus*	Venom	13,400		s.p.c.	9.2	1	5
Phospholipase A (detergent-resistant)[707]	*E. coli* K 12				21,000	5.0	1	n.g.
Phospholipase D[708]	*Bacillus subtilis* G-22		21,500		s.p.c.	4.2	1	n.g.
Phospholipase D[709]	*Streptomyces chromofuscus*		50,000		s.p.c.	5.1	1	n.g.
Phospholipase D[710]	Peanut	Seeds	200,000		48,500	4.65	1	n.g.
Phospholipid exchange protein[711]	Rat	Liver, cytosol			18,700	4.2–5.6, 8.3–9.0	> 6	n.g.
Phospholipid exchange protein[712]	Bovine	Heart				3.9, 4.2, 4.55*, 5.0*	4	n.g.
Phospholipid exchange protein[713]	Bovine	Heart	23,500			5.3, 5.6	2	n.g.
Phospholipid transfer protein (I, II)[714]	Bovine	Brain cortex	29,900(I) 30,000(II)			5.2 (I) 5.5 (II)	1	n.g.
Phospholipid transfer protein[715]	Rat	Liver	13,000		s.p.c.	8.8	1	n.g.
Phosphoprotein[716]	Rat	Incisor dentin				1.1	1	4
Phosphorylase[717]	Swine	Adipose tissue			90,000	6.3	1	n.g.
Phosphorylase phosphatase[718]	Rabbit	Muscle			33,000	5.0	1	n.g.
Phosphorylated (1) and dephosphorylated (2) cAMP-binding proteins[719]	Bovine	Cardiac muscle	56,000(1) 54,000(2)			5.35(1) 5.40(2)	1 1	n.g.
Phosphotransferase (GTP-AMP)[720]	Beef	Heart, mitochondria	26,000			9.8	1	n.g.
R-Phycocyanin[721]	Red alga (*Porphyridium cruentum*)		103,000		18,200 (α) 20,500 (β)	5.2 (α) (blue) 5.3 (β) (purple)	2	n.g.
Phycoerythrin-545[722]	*Cryptomonas maculata*		44,500	2 2	9,900 (α) 15,700 (β)	4.84, 5.05*, 7.83	3	n.g.
B Phycoerythrin[723]	*Porphyridium cruentum*					4.3+, 4.6+, 5.3+	> 6	n.g.
Phytohaemagglutinin[724]	Sunn hemp (*Crotalaria juncea*)	Seed	120,000			8.8	1	n.g.
Phytohaemagglutinin[725]	Pea (*Pisum sativum*)					5.90+, 6.35, 7.00*	3	n.g.

(*Continued on p. 160*)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit No.*	*Subunit MW*	*pI*	*No. of iso-enzymes*	*Temperature (°C)*
Pilin[726]	*Bacteroides nodosus*		19,000			4.5	1	4
Plasminogen (F-1, F-2)[727]	Rabbit	Plasma				8.51, 8.91^{+}, 9.14^{+} (F-1) 8.64, 8.97^{+}, 9.19^{+} (F-2)	3 3	22
Plasminogen[728]	Human	Plasma				6.40^{+}, 6.55^{+}, 6.70^{+}	6	n.g.
Plasminogen activator[729]	Human	Psoriatic scale extract				6.5–6.6 5.4–6.2 4.9	> 3	2
Plasminogen activator[730]	Human	Vascular vessel	70,000		s.p.c.	8.2^{+}	> 1	n.g.
Plasminogen activator[731]	Human	Pancreatic carcinoma cells	55,000			8.7	1	n.g.
Plasminostreptin, proteinase inhibitor[732]	*Streptomyces antifibrinolyticus*		25,000	2	12,500	6.3	1	5
Platelet adhesiveness inhibitor[733]	Human	Plasma	150,000		31,000 24,000	5.1	1	n.g.
Platelet factor 4 (low affinity)[734]	Human	Platelets			9000	8.0	1	n.g.
Poliovirus polypeptides[735]	Poliovirus	Capsid				8.1(VP_1), 6.4 (VP_2), 6.0(VP_3), 7.3(VP_4)	4	n.g.
Polyamine oxidase[736]	Rat	Liver	60,000		s.p.c.	4.9	1	4
endo-Polygalacturonate trans-eliminase[687]	*Erwinia carotovora*					9.5	1	
Poly(A)polymerase[737]	Hamster	Fibroblasts	145,000 (IIA) 155,000 (IIB)			~6	2	n.g.
Poly(ADP-ribose)polymerase[738]	Human	Ehrlich ascites tumour cells			130,000	9.40	1	n.g.
Poly(ADP-ribose)polymerase[739]	Pig	Thymus nuclei	60,000		s.p.c.	8.4	1	4
Polynucleotide phosphorylase[740]	*Thermus thermophilus*		190,000	1 1 1	92,000 73,000 35,000	4.3^{+}, 4.7	2	n.g.

Polypeptide, organic solvent soluble[741]	*Rhodospirillum rubrum*	Photoreceptor complexes, chromatophores			12,000	7.10	1	n.g.
Polypeptide p30[742]	Mouse	C-type endogenous viruses:						
		Class I				6.1^{+}, 5.6, 6.6	3	
		Class II				5.7	1	
		Class III:						
		NIH Swiss				5.5	1	
		ATS				5.5	1	
		NZB[124]				5.5^{+}, 6.1	2	n.g.
Polyphenoloxidase[743]	Mushroom					4.4, 4.5, 4.55 (high) 4.3, 4.65, 4.7, 4.75, 4.9 (medium) 5.05, 5.9 (low)	10	
	Potato					4.95, 5.05, 5.15 (high) 4.9, 5.4, 5.7 (medium) 5.9, 6.0, 6.2, 6.8 (low)	10	4
Polyprotein precursor to cytochrome c oxidase ($P_{r\ IV-VII}$)[744]	*Saccharomyces cerevisiae*	Postmitochondrial supernatant			55,000	6.2	1	n.g.
Poly(vinyl alcohol)-degrading enzyme[745]	*Pseudomonas*		30,000			10.3	1	n.g.
Porins[746]	*Salmonella typhymurium:*	Membrane						
	SH 5551 SH 6377 SH 6017		39,800 39,300 38,000			4.78 4.77 4.85	1	n.g.
Postproline-cleaving enzyme[747]	Lamb	Kidney			58,000	4.8	1	n.g.
Postproline dipeptidyl aminopeptidase(dipeptidyl aminopeptidase IV)[748]	Lamb	Kidney	230,000	2	115,000	4.9	1	n.g.
Prenyltransferase[749]	Chicken	Liver	86,000	2	43,000	5.72	1	n.g.
Progesterone-binding protein[750]	Human	Mammary cytosol				5.0^{+}, 6.5	2	n.g.
Progesterone receptor[751,752]	Chick	Oviduct (cytosol)				6.0(A), 7.0(B)	2	n.g.
Progestin receptor[753]	Human	Endometrial carcinoma				5.0^{+}, 6.3	2	20

(Continued on p. 162)

TABLE I *(continued)*

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Prolactin[754,755]	Human	Amniotic fluid	27,000(c) 36,000 (A, B, D)			5.3, 5.7, 6.2	3	n.g.
Prolactin[445]	Monkey	Pituitary				5.78, 6.07^+, 6.78	3	n.g.
	Human	Pituitary				5.45, 5.82, 5.93^+	3	
Prolyl dipeptidase[756]	Bovine	Kidney	100,000			4.25	1	n.g.
Prolyl hydroxylase[757]	Chick	Embryos	248,000	2	64,000 (α)	4.7, 5.5(subunits p*I*)	2	n.g.
				2	60,000 (β)			
Prostaglandin synthetase (aspirin-acetylated)[758]	Sheep	Vesicular gland	85,000			6.6–7.2		n.g.
Prostatic-binding protein[759]	Rat	Ventral prostate	51,000	1	19,000 (F)	4.6(F)		
				1	20,000 (S)	4.9(S)	2	n.g.
Protease[687]	*Erwinia carotovora*					8.3	1	n.g.
Protease[760]	*Staphylococcus aureus*				29,000	4.6	1	n.g.
Protease[761]	*A. oryzae*				22,000	5.7^+	15	n.g.
	B. subtilis				16,000	(7.0–10.0), 8.2^+	10	
Protease[762]	*Lupinus augustifolius*	Seeds	27,500		s.p.c.	9.0	1	n.g.
Protease[763]	*Agave americana variegata*	Leaves	57,000			5.25	1	5
Protease inhibitor: I_1, I_2[764]	Rat	Skin	74,000(I_1) 13,400(I_2)			4.6(I_1) 4.9(I_2)	2	n.g.
Protease inhibitor, I–V[765]	Soybean	Seeds	7000–8000			4.2–6.2	5	n.g.
Protease trypsin-like[766]	*Streptomyces griseus*					6.5, 7.5, 9.2^+	3	n.g.
Protein (basic)[767]	Rat	Stratum corneum, epidermis			50,000	9.38, 9.60, 10.5^+	3	n.g.
Protein (gene 32)[768]	Bacteriophage T4				35,000	5.0^+, 4.95	2	n.g.

Protein (nuclear)[769]	*Physarum polycephalum*	Nuclei			34,000	8.35	1	n.g.
Proteins:	*Spinacia oleracea*	Leaves, chloroplast membrane						
Photosystem I					68,000 / 60,000	5.6		
					33,000– / 44,000	5.9–6.8		22
Photosystem II[770]					33,000 / 23,000	5.3, 6.3		
Protein A[771]	*Staphylococcus aureus*, A676		41,000			5.1	1	n.g.
Protein–arginine methyl-transferase[772]	Calf	Brain				5.1	1	n.g.
Proteinase A inhibitors (I_2^A,I_3^A)[773]	Yeast		23,000	4	6000	5.7$^+$, 6.0, 6.5 (I_2^A) 5.6, 5.99, 6.3$^+$ (I_3^A)	3 3	n.g.
Proteinase inhibitors[774]	*Stephanurus dentatus*	Excretory gland cells			9500	6.45(I) 6.20(II) 5.34(III)	3	n.g.
Proteinase inhibitor[775]	Horse	Leukocyte, cytosol			35,200	5.38	1	n.g.
Proteinase (metallo, extra-cellular, I–IV)[776]	*Chromobacterium livium* (NCIB 10926)		75,000(I) 72,000(II) 67,000(III)			8.05(I) 7.15(II) 6.15(III) 4.35(IV)	4	4
Protein, bactericidal and membrane-active[777]	Human	Granules of poly-morphonuclear leukocytes	59,000		s.p.c.	9.8	1	n.g.
Protein, fraction I: Large subunits (L 1, 2, 3)	Tobacco		56,000 (L1, L2, L3)			6.36(L1), 6.30(L2) 6.23(L3)		
Small subunits (S 1, 2)[778]			12,500 (S1, S2)			5.50(S1), 5.44(S2)	5	n.g.

(Continued on p. 164)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Protein kinase[779]	Rat	Liver:						
		microsomes				No cAMP:		
		MI				8.05	1	
		MII				5.50	1	
		MIII				4.80	1	
						+ cAMP:		
		MI				8.05	1	
		MII				5.50	1	
		MIII				8.10, 7.35	2	
		Cytosol:				No cAMP:		
		CIa				8.10	1	0
		CIIa				5.10	1	
		CIIb				5.45	1	
		CIII				4.90	1	
						+ cAMP:		
		CIa				8.15	1	
		CIIa				8.15, 7.35	2	
		CIIb				5.45	1	
		CIII				8.15, 7.35	2	
Protein kinase, cAMP-dependent[780]	Bovine	Heart	39,000			7.01^{+}, 7.48^{+}, 7.78^{+}	> 3	n.g.
Protein kinase, cAMP-dependent:[781]	Bovine	Cerebral cortex						
Holoenzyme			87,000			5.5		
cAMP-independent catalytic subunit					40,000	7.0	1	n.g.
cAMP-binding regulatory subunit					52,000	4.8		
Protein kinase, cAMP dependent	Calf	Ovarian cytosols				5.0(I)		
						4.9–5.0(II)		n.g.
						5.3(V)		
Protein kinase, cAMP dependent[783]	Rabbit	Skletal muscle	11,300			4.24	1	n.g.
Protein kinase, cAMP dependent[784]	Rabbit	Skeletal muscle	226,000		180,000	5.27	1	r.t.
					48,000			
					42,000			

Protein	Source	Tissue	MW	Subunits	Subunit MW	pI	No. of forms	Temp
Protein kinase, cAMP dependent[785]	Yeast					7.7	1	n.g.
Protein kinase, cGMP-dependent[786]	Bovine	Lung	150,000	2	74,000	5.4	1	n.g.
Protein kinase cAMP dependent[56]	Mouse	Parotid				5.00, 5.15, 5.32	3	n.g.
Protein kinase (cGMP-dependent) stimulatory modulator[787]	Dog	Heart	69,000	2	34,000	4.0	1	n.g.
Protein kinase, nucleoside-dependent[788]	*Trypanosoma gambiense*		90,000			4.85	1	2
Protein, low-sulphur[789]	Sheep	Wool				5.35(5), 5.05(7a), 5.05(7b), 4.9(7c), 5.0(8a), 4.8(8b) 4.7(8c-1), 4.7(8c-2)	8	20
Protein M[790]	*Streptococci* (group A)		70,000	2	36,000	4.5⁺, 4.7 5.2–5.9	> 3	n.g.
Protein, mRNP-48[791]	Rabbit	Reticulocytes			48,000	5.0	1	n.g.
Protein S (vitamin K-dependent)[792]	Bovine	Plasma	64,000		s.p.c.	5.4–5.9		n.g.
	Human	Plasma	69,000		s.p.c.	5.0–5.5		
Protein, stimulating aerobic plasmalogen biosynthesis[793]	Pig	Kidney	27,000			5.1(I), 4.9(II)	2	n.g.
Protein, structural (major component)[794]	Giant land snail (*Strophocheilus oblongus*)	Calcified eggs			53,000	6.9	1	n.g.
Proteins, structural:[795]	Western equine encephalitis virus							
E₁ protein						6.5	1	n.g.
Nucleocapsid protein						4.0	1	
Protein, TCDD receptor[796]	Rat	Liver, cytosol				5.15–5.25	1	0–2
		Serum				5.7–5.8	1	
Proteolipid apoprotein[797,798]	Bovine	Brain, white matter				8.9–9.2	1	25
Pseudocholinesterase[799]	Human	Sera				3.95	1	n.g.
		Genetic variant				4.4–4.9	6	
Pteroyl-γ-oligoglutamyl endo-peptidase[800]	Chicken	Intestine	80,000			4.8	1	n.g.
Purine nucleoside phosphorylase[801]	Human	Erythrocytes	90,000	3	30,000	5.85⁺, 5.92⁺, 6.02⁺, 6.08⁺, 6.14, 6.25	6	
	Rat	Erythrocytes				5.6, 5.7	2	
	Bovine	Spleen	90,000	3	30,000	5.4	1	n.g.

(Continued on p. 166)

TABLE I *(continued)*

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit No.*	*Subunit MW*	*pI*	*No. of iso-enzymes*	*Temperature (°C)*
Purine nucleoside phosphorylase[802,803]	Human	Erythrocytes	93,000	3	30,000	6.20$^+$, 6.29$^+$, 6.41$^+$, 6.63$^+$, 6.83, 6.95 (subunit p*I*s)	6	n.g.
Purine phosphoribosyltransferase[804]	Human: Gilles de la Tourette syndrome	Erythrocytes				5.6, 5.8$^+$, 6.0$^+$, 6.1$^+$, 6.2	5	n.g.
Pyrophosphatase (inorganic)[805]	*Thiobacillus thiooxidans*		88,000	4	22,000	5.05	1	n.g.
Pyrophosphatase (inorganic)[806]	Brewer's yeast	Hyaloplasm			60,000	5.0	3	n.g.
Pyrrolidonecarboxylate peptidase[807]	*Klebsiella cloacae*		74,000			4.7	1	2.5
Pyruvate kinase[808]	*Neurospora crassa*					6.40(free) 5.50(FDP complex)	1	n.g.
Pyruvate kinase[809]	Yeast		220,000	4	57,000	6.6	1	n.g.
Pyruvate kinase[810]	Chicken	Skeletal muscle	212,000	4	53,000	8.45, 8.77$^+$	2	n.g.
Pyruvate kinase[811]	Turtle	Heart				6.05	1	n.g.
Pyruvate kinase[812]	Rat	Liver				5.2, 5.3, 5.9$^+$	3	n.g.
Pyruvate kinase[813]	Rat	Liver				6.3, 6.6$^+$ (subunit p*I*s)	2	n.g.
Pyruvate kinase[814]	Rat	Muscle:						
		foetal				5.2$^+$, 6.0, 6.8, 7.3	4	
		adult				7.3$^+$	1	
Pyruvate kinase (type A)[815]	Pig	Kidney	249,000	4	60,000	5.6	1	n.g.
Pyruvate kinase (type L)[816]	Human	Liver	240,000	4	60,000	5.85$^+$, 6.28	2	0
Pyruvate oxidase[817]	*E. coli*		240,000	4	60,000	5.6	1	n.g.
PZ-peptidase[818]	Chick	Embryos	77,000			5.0	1	n.g.
Quinate (shikimate)dehydrogenase[819]	*Neurospora crassa*		41,000		s.p.c.	4.79$^+$, 4.88$^+$, 5.09$^+$	5	n.g.
Quinolinic acid phosphoribosyltransferase[820]	Castor bean	Endosperm	70,000	2	35,000	5.9	1	r.t.
Receptor, cholinergic[821]	Housefly	Heads, central nervous system	350,000		82,000 90,000	4.8$^+$, 6.8, 9.4	3	n.g.

Reductase, -azo and -nitro[822]	*Ascaris lumbricoides var. suum*					4.75	1	
	Moniezia expansa					4.50	1	n.g.
Renin[823]	Human	Juxtaglomerular cell tumour	40,000	1 1	20,000 25,000	4.95, 5.10, 5.35, 5.55, 5.70	5	n.g.
Renin[824]	Human	Plasma				4.79, 4.88, 4.94, 5.02	4	n.g.
Renin[825]	Hog	Kidney	40,000			4.70, 4.95^{+}	2	n.g.
Renin[826,827]	Hog	Kidney	36,400			5.2	1	4
Renin[828]	Rabbit	Kidney	37,000			5.1, 5.3^{+}, 5.42^{+}, 5.5^{+}	4	r.t.
Rennetts[829,830]	Calf	Stomach				4.70^{+}	> 1	
	Endothia parasitica					4.89^{+}	> 1	r.t.
	Mucor miehei					4.20^{+}	> 1	
	Mucor pusillus Lindt					3.95^{+}	> 1	
Retinol binding protein[831]	Rat	Testis, cytosol	14,600			4.8, 4.9	2	n.g.
Rh-antigen[832]:	Human	Erythrocyte membrane						
E			50,000–100,000			7.7		
C			50,000–100,000			7.6		
e			20,000–30,000			7.5	1	n.g.
c			20,000–30,000			7.5		
D			10,000–30,000			7.3		
Rh(e) antigen[833]	Human	Erythrocyte membrane	20,000–30,000			5.3, 6.4, 7.2^{+}, 7.5^{+}, 8.2	5	n.g.
Rhodopsin[834,835]	Bovine	Retina				5.07^{+}, 5.36^{+}, 5.95	3	n.g.
Rhodpsin[836]	Bovine	Retina				4.5, 4.7, 4.9, 5.2, 6.0^{+}	5	n.g.
Riboadenylate transferase[837]	Calf	Thymus	62,000		s.p.c.	7.4	1	n.g.
Ribonuclease[838,839]	Human	Urine	21,500			4.1	1	n.g.
Ribonuclease[840]:	*Vicia faba*	Root cells						
A_1,A_2,A_3						$\sim 4^{+}$	3	n.g.
C_1,C_2						$\sim 8^{+}$	2	

(Continued on p. 168)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit No.*	*Subunit MW*	*pI*	*No. of iso-enzymes*	*Temperature (°C)*
Ribonuclease[841]	Plant (*Ipomoea tricolor*)	Petals				4.95^{+}, 5.2, 5.39^{+}	3	n.g.
Ribonuclease (I, II)[842]	*Physarum polycephalum*	Exoplasmodial	25,000			4.3(I), 3.8(II)	1	n.g.
Ribonuclease inhibitor[843]	Human	Placenta	50,000			4.8	1	0–4
Ribulose 1,5-diphosphate carboxylase[844]	*Nicotiana tabacum*	Leaves				6.0, 6.5^{+} (subunit p*I*s)	2	n.g.
mRNA-binding protein[845]	Rabbit	Reticulocyte polyribosomes			39,000 51,000	6.35	1	n.g.
mRNA-binding protein[846]	Rabbit	Reticulocyte polyribosomes	120,000	1 1	66,000 56,000	5.35	1	n.g.
tRNA ligase: A, B[847]	Wheat germ		105,000(A) 70,000(B)		s.p.c. s.p.c.	6.0(A) 5.85(B)	1 1	n.g.
tRNA nucleotidyltransferase[848]	*E. coli*				52,000	5.85	1	n.g.
RNA polymerases (A,B)[849]	Yeast			1 1 1	27,000 23,000 14,500	9.2 4.5 4.6 (subunit p*I*s)	3	n.g.
Rubredoxin[850]	*Pseudomonas oleovorans*		19,000			4.2	1	n.g.
Saccharopine dehydrogenase[851]	Baker's yeast		39,000		s.p.c.	10.1	1	0
Secretory component (FSC)[852]	Chicken	Intestine				4.5	1	n.g.
Serine protease[853]	Human	Hepatoma 8999 (mitochondrial fraction)	24,000			10.6	1	n.g.
Serine proteinase[854]	*Phycomyces blakesleeanus*		18,000 22,000 60,000			7.6 5.1 4.4	3	n.g.
Serine proteinase inhibitor[854]	*Phycomyces blakesleeanus*		10,000(I) 10,000(II)			4.50 4.95	2	n.g.
Serine–pyruvate aminotransferase[855]	Mouse	Liver	80,000	2	40,000	6.1, 6.3, 6.6^{+}, 6.9^{+}	4	0–4
	Dog	Liver	80,000	2	40,000	6.6, 6.9^{+}	2	
	Cat	Liver	80,000	2	40,000	6.6, 6.9^{+}	2	

Sialyltransferase[856]	Human	Liver				5.0–8.6	8	0–2
Skeletin[857,858]	Cow	Heart purkinje fibres	55,000			6.35	1	n.g.
Somatic extracts of adult worms (SEAW)[859]	*Dipetalonema vitae*					3.3^{+}, 4.0^{+}, 4.3^{+}, 4.4^{+}, 5.2^{+}	9	n.g.
Somatic extracts microfilariae (SEM)[859]						3.2^{+}, 4.4^{+}	9	5
Somatomedin[860]	Rat	Plasma	160,000		9000	9.0^{+} (subunit p*I*)	> 1	n.g.
Spectrin: I, II[861,862]	Human	Erythrocyte	237,500(I) 238,600(II)		s.p.c. s.p.c.	5.6	1	n.g.
Sperm-activating substance (SAS)[863]	*Pseudo-centrotus*	Eggs	630			5.3	1	n.g.
Sphingomyelinase[864]	*Bacillus cereus*		24,000			5.6	1	r.t.
Sphingomyelinase[865]	Human	Skin fibroblasts				4.85, 6.15^{+}, 6.80, 7.25, 7.75, 8.25, 8.50	7	n.g.
Sphingomyelinase[866]	Human	Liver				4.6^{+}, 5.2^{+}	> 2	2
Spinin[867]	Marine bacterium D 71		19,000		s.p.c.	3.45	1	4
S-Succinylglutathione hydrolase[868]	Human	Liver	17,000		s.p.c.	8.7	1	n.g.
Staphylocoagulase[869]	*Staphylococcus aureus*		61,000			4.53	1	n.g.
17β-Hydroxy-C_{19}-steroid dehydrogenase[870]	Guinea pig	Liver	32,000 (Pre-1, Pre-2, EI-1, EII-1) 35,000 (EI-2, EII-2, EIII)	 1 1	s.p.c. 24,000 11,000	8.3(Pre-1) 6.6(EI-1) 6.8(EI-2) 5.9(EII-1) 6.3(EII-2)		n.g.
Steroid–receptor complex[871]	Rat	Prostate gland cytoplasm				5.81	1	n.g.
Stimulatory factor for RNA polymerase II[872]	Lamb	Thymus	24,000			8.0	1	n.g.
Streptokinase[286]:	Streptococci							
Group A						5.8	1	
Group C						5.4	1	4
Streptolysin O[286]	Streptococci					6.0^{+}, 7.5	2	4
Strictosidine synthetase[873]	*Catharanthus roseus*		38,000			4.6	1	n.g.

(Continued on p. 170)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temper-ature (°C)*
				No.	*MW*			
Subtilisins[874]:	*Bacillus* species							
Carlsberg						6.7	1	
Novo						8.1	1	n.g.
Sucrase[875]	Honey bee (*Apis mellifera*)	Head, abdomen	51,000–82,000			6.5	1	n.g.
Sulphating enzyme of bile salts[876]	Rat	Liver, cytosol	130,000			5.3	1	0
Sulphogalactosylsphingosine sulphatase[877]	Human	Skin fibroblasts				4.8	1	n.g.
Supernatant protein factor (SPF)[878]	Rat	Liver	47,000		s.p.c.	6.74	1	n.g.
Superoxide dismutases[879]	Fruit fly (*Ceratitis capitata* L.)		35,000			5.4, 5.9^{+}	2	n.g.
Superoxide dismutase[880]	Red alga (*Porphyridium cruentum*)		40,000	2	20,000	4.2	1	n.g.
Superoxide dismutase[881]	Blue-green alga (spirulina)				32,000	4.35, 4.60	2	n.g.
Superoxide dismutase[882]	Rat	Liver				4.65, 4.75 4.85^{+}, 5.15^{+}	4	n.g.
Taurocyamine kinase[883]	Lugworm (*Arenicola marina*)	Body-wall musculature	60,000		22,000 14,000 11,000	(6.1–7.8) 7.3^{+}	8	n.g.
T cell-replacing factor (TRF-II)[884]	Mice	Spleen	45,000 35,000 25,000			4.4, 5.1^{+}, 6.3, 6.9^{+}	4	4
Tetrahydrofolate[885]: Dehydrogenase, Cyclohydrolase, Synthetase	Porcine	Liver	150,000		s.p.c.	6.6	1	n.g.
Tetrahydrofolate reductase[886]	Pig	Liver	180,000			4.8	1	n.g.
Testosterone–estradiol-binding globulin (TeBG)[887]	**Human**	**Plasma**	94,000			5.51	1	n.g.

Thiamine-binding protein[888]	*E. coli*					6.0	1	n.g.
Thioredoxin reductase[889]	Rat	Novikoff tumour	116,000	2	58,000	5.1	1	n.g.
Thrombin[890]	Bovine	Plasma				7.05	1	8
α-Thrombin[891]	Human	Plasma	36,600	1	32,000	6.35, 6.55, 7.0$^+$,		
				1	4600	7.3$^+$, 7.6$^+$	5	n.g.
Thymidylate kinase[892]	Mouse	LMTK mouse cells	71,000			7.7, 8.2$^+$	2	n.g.
Thymidylate synthetase[893]	*E. coli*		64,000	2	32,000	4.7	1	n.g.
Thymidine kinase: F, A[654]	Chick	Embryo cells				9.7(F) 6.5(A)	1	n.g.
Thymine dimer excising nuclease[894]	Human	KB cells				6.0(A,C), 9.0(B)	3	n.g.
Thyrotropin[896]	Calf	Thymus	3,350			4.2	1	n.g.
Thyrotropin[896]	Human					7.25$^-$(I), 6.62$^-$(II) 6.08$^+$(III), 5.93(IIIa), 5.45(IV), 5.18(V^b)	6	n.g.
Thyrotropin-releasing hormone deamidase[897]	Rat	Brain	73,500		s.p.c.	4.5	1	n.g.
Toxin[898]	*Pseudomonas aeruginosa*					5.8	1	n.g.
α-Toxin[899]	*Clostridium perfringens*	Venom				4.8(α_0), 4.81$^+$(α_1), 4.82$^+$(α_2), 4.83(α_3)	4	r.t.
α-Toxin[900]	*Staphylococcal*		36,000			7.98	1	10
Toxin[901]	Scorpion (*Palamineus gravivamus*)	Venom	7000			10.6	1	n.g.
Toxin, delta[902]	*Clostridium perfringens*				42,000	8.8, 9.4	2	n.g.
Toxin, epidermolytic[903]	*Staphylococcus aureus*		25,000			6.0, 7.0$^+$	2	n.g.
Toxin, haemolytic[904]	Sea anemone (*Stoichactis helianthus*)		16,000			9.8	1	n.g.
Toxin, haemorragic[905]	*Crotalus atrox*	Venom	25,700		s.p.c.	5.6	1	n.g.
Toxin, paralysing[906]	Wasp (*Microbracon hebetor*)	Venom	61,000			6.8	1	n.g.

(*Continued on p. 172*)

TABLE I (*continued*)

Protein	*Source*	*Organ and/or subcellular location*	*MW*	*Subunit*		*pI*	*No. of iso-enzymes*	*Temperature (°C)*
				No.	*MW*			
Toxin (pyrogenic exatoxin type C)[907]	*Streptococcal* Group A		13,200		s.p.c.	6.7	1	n.g.
Transaldolase, type III[908]	*Candida utilis*		63.600			3.95	1	n.g.
Transcobalamin I and II[909]	Porcine	Serum	135,000(I)			3.23, 3.42, 3.69(I)	3	
			38,000(II)			3.47(II)	1	4
Transcobalamin II-cyanocobalamin[910]	Human	Plasma			37,000 29,000	(6.2–6.8), 6.30⁺, 6.45⁺	4	n.g.
Transferrin Tf[C3 911,912]	Human	Serum				5.2, 5.6, 5.9, 6.0, 6.1, 6.2	6	n.g.
Transferrin[913]	Rat	Serum				5.8, 6.0	2	n.g.
Transglutaminase[914]	Rabbit	Liver	80,000		s.p.c.	5.35	1	n.g.
Triglyceride lipase[572]	Human	Post-heparin plasma	69,000			4.95, 5.3, 7.6	3	n.g.
Trehalase[540]	Rat	Enterocytes (brush border)				4.99	1	n.g.
Triacylglycerol acylhydrolase[915]	*Pseudomonas fluorescens*		33,000		s.p.c.	4.46	1	4
Triacylglycerol lipase[916]	Rat	Liver, cytosol	42,000			7.2	1	n.g.
Triacylglycerol lipase[917]	*Mycobacterium phlei*		40,000			3.8	1	n.g.
Triosephosphate isomerase[918]	Human	Erythrocytes				6.0⁺, 5.6	1	n.g.
Tropomyosin[919]	Canine	Cardiac	70,000	2	35,000	5.4, 5.6	2	n.g.
Trypsin inhibitor[920]	Eggplant	Exocarps	5,000–10,000			4.2, 4.7⁺, 6.0	3	n.g.
Tryptophan aminotransferase[921]	Rat	Brain	55,000			6.2	1	0
Tubulin[922]	Bovine	Brain			56,000	5.2, 5.4 (subunit p*I*s)	2	n.g.
Tyrosinase[923]	*Porcellio laevis*	Cuticle	122,000	4	31,000	6.1⁺, 7.1	2	4
Tyrosine[924]	Frog	Epidermis	200,000	4	50,000	9.25	1	n.g.
L (−)-Tyrosine decarboxylase[925]	*Streptococcus faecalis*					4.5, 3.2	2	1
Tyrosine hydroxylase[926]	Beef	Adrenal gland			60,000	6.6	1	n.g.
UDP-glucose-4-epimerase[927]	*Physarum policephalum*					6.0, 6.7⁺, 7.6	3	0

UDP-glucuronosyltransferase[928]	Rat	Liver, microsomes	59,000		s.p.c.	6.31, 6.56, 6.68	3	n.g.
UMP:pyrophosphate phosphoribosyltransferase[929]	Yeast		80,000	1	58,000	5.27+, 5.35	2	n.g.
				1	25,000			
Uricase[930]	Mackerel	Liver, peroxisomes	127,000			7.8	1	n.g.
Uridine nucleosidase[931]	Yeast		44,000		s.p.c.	4.03	1	n.g.
Urokinase[932]	Human	Urine	47,000	1	33,000	8.60−, 8.90	2	
				1	18,000			
			33,400		s.p.c.	8.05, 8.35+, 8.60+, 8.70+	4	25
Valyl-tRNA synthetase[933]	*E. coli*		112,000		s.p.c.	4.8	1	n.g.
Vicilin peptidohydrolase[934]	Mung-bean	Cotyledons	23,000			3.75	1	n.g.
Vitamin B_{12}-binding protein[935,936]	Human	Gastric mucosa	63,000			4.84, 4.94+, 5.06+, 5.10, 5.18, 5.44, 5.64	7	n.g.
Vitamin B_{12}-binding protein[937]	Human	Plasma	120,000 (TCI)			3.0, 3.3+, 3.6	3	n.g.
			35,000 (TCII)			3.3, 3.6+, 3.9, 4.2	4	n.g.
Vitamin D-binding protein[938]	Rat	Serum	52,000		s.p.c.	5.2	1	4
Vitellin[939]	*Locusta migratoria*	Oocyte		1	110,000			
				1	130,000			
			530,000	1	120,000	6.9	1	n.g.
				1	55,000			
				1	65,000			
Xanthine dehydrogenase[940]	*Streptomyces cyanogenus*		125,000	2	67,000	4.4	1	n.g.
endo-1,4-β-Xylanase[941]	*Aspergillus niger* Str. 14		27,000		s.p.c.	4.2	1	n.g.
β-Xylosidase[942]	*Penicillium wortmanni*		100,000			5.0	1	n.g.
Zeins[943–945]	Maize	Endosperm, protein bodies			9600	6–9	15	r.t.
					13,500			
					21,000−			
					22,000+			

a useful feature for the reader: all the relevant information about the article (volume, year, first and last page, etc.) is neatly printed in the upper left (or right) corner of the first page, thus greatly facilitating its quotation. The prize for "unreadability", unfortunately, goes to *Biochemistry*, whose abstracts are far from being fully informative, and whose ideas for classifying an article are unfortunate: the same vital information (volume, year, first and last page, etc.) is scattered throughout the pages of the article, rendering its collection more difficult. Perhaps the Editors of the journal still live with the presumption that a reader of a given article will go through its whole length, whereas it is common knowledge today that even Nobel Laureates barely manage to carry their readership to the end of the summary in their articles.

A few words should be said about pH (and thus pI) measurements in isoelectric focusing (IEF). We have already dealt with it extensively in our first paper[946], to which the reader is referred. It is frustrating that most scientists still do not report the temperature of pH measurement after IEF (albeit in most instances it could be presumed to be room temperature, *i.e.*, 20–25°C outside the tropics). Fredriksson[948] has published tables which allow a pH course mapped at room temperature to be converted into the one existing during the focusing experiment (usually at 4°C) and *vice versa*. The pI values of proteins should be expected to decrease with increasing temperature. The magnitude of the temperature coefficient dpI/dT depends on the protolytic composition of the protein and, to a lesser extent, on the temperature. For a strongly acidic protein, dpI/dT should be *ca.* -0.005 pH unit per degree at about 4°C, whereas for a strongly basic protein it should be *ca.* -0.03 pH unit per degree. When performing IEF in presence of additives (glycerol, sucrose, ethylene glycol, urea, etc.), the pH readings should be corrected for the variation of the dielectric constant of water, as this in turn influences the pK of ionizable groups. Gelsema's group has published a series of papers on this topic[949,950]. The interference of carbon dioxide absorption on pI values determined at alkaline pH in thin-layer gel IEF has been measured by Delincée and Radola[951].

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This project would have been impossible without generous help from LKB Produkter (Bromma, Sweden), who put at our disposal a collection of more than 4000 articles on IEF, and two copying machines. Another lucky event was a 2-month visiting professorship for P.G.R. at the Department of Biochemistry, University of Uppsala, Sweden, which allowed week-end trips to Stockholm to "digest" the literature in the field, together with K.E. P.G.R. is supported by grants from the Consiglio Nazionale delle Ricerche (CNR) and Ministero della Pubblica Istruzione (MPI, Rome).

3. SUMMARY

Proteins with known isoelectric points (pI), as determined by isoelectric focusing, are tabulated. When available, the native molecular weight and the subunit molecular weight and stoichiometry are reported. For each entry, the source and, when applicable, the organ of origin and/or subcellular location are given. A previous table [P. G. Righetti and T. Caravaggio, *J. Chromatogr.*, 127 (1976) 1–28] covered the years from 1966 (the introduction of isoelectric focusing) to 1975. The present compilation spans the years 1976–1979 and contains approximately three times as many references and entries (>900).

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Ionic Hydration in Chemistry and Biophysics

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