REFERENCES

[1] *A. Stefani & P. Pino*, Helv. *55*, 1110 (1972).
[2] *H. Lehmkul & K. Ziegler*, in Houben-Weyl, «Methoden der Organischen Chemie», Vol. XIII/4, p. 144 Thieme-Verlag, Stuttgart 1970.
[3] *A. Stefani & P. Pino*, Helv. *55*, 1190 (1972).
[4] *F. Billeri, B. Macchia & F. Macchia*, Chim. Ind. (Milano) *50*, 1322 (1968).
[5] *R. Rossi*, Gazz. chim. ital. *97*, 1239 (1967).
[6] *R. Rossi & P. Pino*, Gazz. chim. ital. *98*, 398 (1968).
[7] *R. Maurel, A. Choque & M. Pecque*, C.r. hebd. Seances Acad. Sci. *259*, 2650 (1964).
[8] *M. Pecque, Y. Delfolie-Bove, J. Degrave & R. Maurel*, Bull. Soc. chim. France *1969*, 1333.
[9] *G. Natta, P. Pino, G. Mazzanti, P. Longi & F. Bernardini*, J. Amer. chem. Soc. *81*, 2561 (1959).
[10] Belg. Pat. 615484 (1962); Chem. Abstr. *58*, 1358c (1963).
[11] *C. Botteghi, G. Consiglio, G. Ceccarelli & A. Stefani*, J. org. Chemistry *37*, 1835 (1972).
[12] *H. Normant & C. Crisan*, Bull. Soc. chim. France *1959*, 459.
[13] *R. P. Mariella & J. L. Leech*, J. Amer. chem. Soc. *80*, 3558 (1949).
[14] *M. A. Perry, F. C. Canter, R. E. DeBusk & A. G. Robinson*, J. Amer. chem. Soc. *80*, 3618 (1958).
[15] *K. E. Pfitzner & J. G. Moffatt*, J. Amer. chem. Soc. *87*, 5670 (1965).
[16] *J. Kulesza & J. Gora*, Przemysl Chem. *42*, 218 (1963); Chem. Abstr. *60*, 5426h (1964).
[17] *J. W. Lawrence & J. R. Sheton*, Ind. Eng. Chemistry *42*, 136 (1950).

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120. Substoichiometric Extraction of Mercury by Diethyldithiocarbamic Acid

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(31. X. 72)

Summary. The substoichiometric extraction of Hg^{2+} using diethyldithiocarbamic acid and ^{203}Hg tracer was studied. Chloroform was employed to remove the complexes from the aqueous media which were 0.5 M H_2SO_4 or 1 M $HClO_4$ and 0 to 5 M NaCl. – Systems containing Cl^- allowed extraction of Hg^{2+} for all DDC/Hg molar ratios, the extracted complexes being HgCl(DDC) and $Hg(DDC)_2$. Their exchange constant was determined. – In the absence of Cl^-, no extraction could be effected in either system if the DDC/Hg molar ratio was < 1; the H_2SO_4 system remained clear, whereas a precipitate of $HgClO_4(DDC)$ formed in the $HClO_4$ system. For molar ratios > 1, the extraction of Hg^{2+} increased linearly with the addition of DDC, the extracted complex being $Hg(DDC)_2$.

1. Introduction. – The principle of substoichiometric extraction¹) was introduced into analytical chemistry by *Ruzicka & Stary* [1] and has been recently surveyed [2] [3]. Interest in this method is mainly due to its rapidity, simplicity and high selectivity. Furthermore, it eliminates the need to determine the yield of a radiochemical separation, a distinct advantage in activation analysis.

Application of high-resolution γ-ray spectroscopy to activation analysis diminishes the demand for very high decontamination factors in most radiochemical separations, often making rapid, one-step separations possible. Substoichiometric

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¹) Substoichiometric extraction involves the use of a chelating agent, the quantity of which is chosen so as to extract only a part of the metal present.

extraction was thought to be a suitable one-step separation technique for metals, provided that data concerning the behaviour of many different metals were available. This condition seemed to be approximately fulfilled for extractions with diethyldithiocarbamic acid²), extensively investigated by *Bode* [4], *Förster* [5] and *Hulanicki* [6].

The use of substoichiometric extraction of mercury by DDC-acid in activation analysis was reported by *Kukula* & *Simkova* [7]; difficulties in reproducing their work prompted the present investigation.

2. Experimental. – In most experiments the transfer of mercury from the aqueous to the organic phase was followed as a function of increasing amounts of DDC in the extraction system. Radioactive ^{203}Hg was employed as a tracer and the activity of the organic phase monitored with a NaI-well counter.

The following experimental conditions were observed: *Aqueous phase:* 20.0 mg Hg^{2+} as chloride, perchlorate or sulfate in 100 ml. Great care was taken not to introduce foreign anions with the tracer. – *Chelating agent:* $5.00 \cdot 10^{-3}$ M $Zn(DDC)_2$ in $CHCl_3$. In contact with aqueous solutions of [H] = 1, the complex is decomposed, yielding a solution of HDDC. – *Organic phase:* $CHCl_3$ *puriss.* In every case the initial volume of the organic phase was 30 ml and was increased to 60 ml by the progressive addition of the $Zn(DDC)_2$ solution. – *Shaking* was effected mechanically for periods varying from 30 s to 5 min; there was no statistically significant change in the extraction during this time interval. – *Temperature:* All experiments were carried out at room temperature, which was approximately 24 °C.

3. Results. – The results of most experiments are graphically represented by plotting F (the fraction of the total amount of Hg that is extracted into the organic phase) versus R (the molar ratio DDC/Hg of the components present in the whole system). Whenever feasible, straight lines were fitted by the method of least squares.

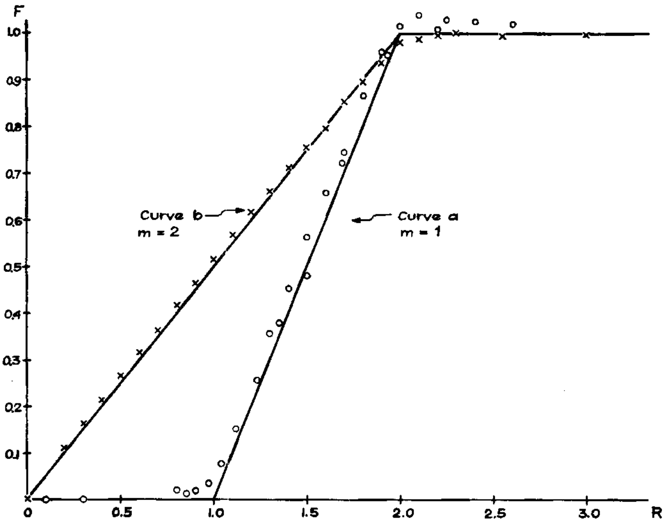

Fig. 1. *Extraction of mercury from 0.5* M *H_2SO_4 solutions*
The solid lines are the theoretical lines with slope m = 1 and m = 2
a) ○ : no Cl^-; b) × : 5 M NaCl

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²) DDC will be used for the diethyldithiocarbamate anion $(C_2H_5)_2NCS_2^-$ and HDDC for its protonated form.

3.1. *Extraction from 0.5* M *H_2SO_4*. The extraction from 0.5 M H_2SO_4 is represented in Fig. 1a, with the results of the least squares fit in the Table. It is remarkable that there is no extraction for $R < 0.97$; extraction is complete at $R = 1.96$. No precipitation is perceptible in the entire range of R values investigated.

Results of the least-squares analysis

System	r	m	a	b
0.5 M H_2SO_4, no Cl^-	0.994	0.985	0.97	1.96
0.5 M H_2SO_4, 5 M NaCl	0.999	2.03	– 0.03	2.02
1 M $HClO_4$, 5 M NaCl	0.999	2.04	– 0.01	2.03

r = the correlation coefficient
m = the inverse slope of the extraction curve. m is given in units of moles of DDC per mole of Hg
a = the value of R for which extraction begins, *i.e.* the intercept on the abscissa
b = the value for R for which $F = 1$ (complete extraction).

3.2. *Extraction from 1* M *$HClO_4$*. The curve for extraction from 1 M $HClO_4$ is identical with that from 0.5 M H_2SO_4. However, in the former case a white precipitate forms as soon as the reagent is added; this precipitate remains up to $R = 2$, when it disappears completely; by the addition of Cl^-, the precipitate is dissolved at any R.

3.3. *Extraction from systems containing Cl^- ions*. Although the curves for the extractions from systems containing Cl^- ions are rather lacking in uniformity (see Fig. 2), they demonstrate that there is no extraction for $R = 0$, that extraction is only complete at $R \geqslant 2$, and that there is no precipitate formed. The dissimilarities of the extraction curves are clearly correlated with the Cl^- content of the aqueous

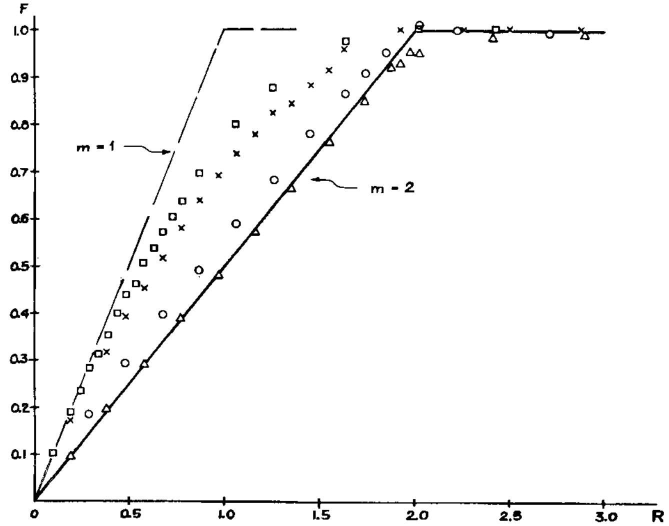

Fig. 2. *Extraction of mercury from 1* M *$HClO_4$ solutions*

The solid lines are the theoretical lines with slope m = 1 and m = 2
a) □: 0.0024 M Cl^-; b) × : 0.12 M Cl^-; c) ○: 0.96 M Cl^-; d) △: 5.0 M Cl^-

phase. Straight extraction curves are only found for systems with a high Cl^- content, *i.e.* 0.5 M H_2SO_4, 5 M NaCl and 1 M $HClO_4$, 5 M NaCl (see Figs. 1b and 2d, Table 1).

Reducing the Cl^- content of the aqueous phase increases the initial slope and makes the curves convex (see Fig. 2a, b, c). No attempt was made to fit to a straight line in these cases.

4. Discussion. – 4.1. *Extraction from 0,5 M H_2SO_4* can be represented³) by

$$Hg^{2+} + (DDC)^- \rightleftharpoons Hg(DDC)^+ \qquad (1)$$

$$Hg(DDC)^+ + (DDC)^- \rightleftharpoons \{Hg(DDC)_2\}aq \qquad (2)$$

$$\{Hg(DDC)_2\}aq \rightleftharpoons \{Hg(DDC)_2\}org \qquad (3)$$

The cumulative constants β_n for the two complexes have been determined [8] and found to be $\beta_1 = 10^{22.3}$ and $\beta_2 = 10^{38.1}$.

For $R < 1$, where there is no extraction, only equilibrium (1) has to be taken into account. For $1 < R < 2$, extraction is proportional to the amount of DDC in excess of the equimolar amount; the experimental slope of the extraction curve is found to be 0.985, in satisfactory agreement with the value of unity predicted by equations (2) and (3).

4.2. *Extraction from 1 M $HClO_4$* is similar to the extraction from H_2SO_4 except for the formation of a precipitate. This precipitate is insoluble in H_2O and $CHCl_3$, and can be assigned⁴) the composition $HgClO_4(DDC)$.

As there is no extraction for $R < 1$, we have only to consider

$$Hg^{2+} + ClO_4^- + (DDC)^- \longrightarrow HgClO_4(DDC)\ (s) \qquad (4)$$

and in the range $1 < R < 2$, where there is extraction as well as dissolution of the precipitate, we can write

$$HgClO_4(DDC)\ (s) + (DDC)^- \rightleftharpoons \{Hg(DDC)_2\}_{org} + ClO_4^- \qquad (5)$$

4.3. *Extraction from Cl^- containing systems* cannot be explained by reactions (1) to (3) because there is extraction in the range $0 < R < 1$. It is proposed that the extraction be represented by

$$HgCl_x^{(2-x)+} + (DDC)^- \rightleftharpoons \{HgCl(DDC)\}_{org} + (x-1)Cl^- \qquad (6)$$

and

$$\{HgCl(DDC)\}_{org} + (DDC)^- \rightleftharpoons \{Hg(DDC)_2\}_{org} + Cl^- \qquad (7)$$

giving an overall reaction of

$$HgCl_x^{(2-x)+} + 2\,(DDC)^- \rightleftharpoons \{Hg(DDC)_2\}_{org} + xCl^- \qquad (8)$$

In systems with a high Cl^- concentration (5 M NaCl), the slope of the extraction curve was 2.03 for 0.5 M H_2SO_4 and 2.04 for 1 M $HClO_4$ which agrees with the value of 2 expected from equation (8). In presence of large amounts of Cl^-, the extracted species certainly is $Hg(DDC)_2$, and no mixed complex seems to be formed.

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³) The subscript 'org' represents the organic phase, 'aq' the aqueous phase; for reasons of clarity, 'aq' is omitted in most cases.

⁴) Elemental analysis gave the following results (expected values for the composition $HgClO_4(DDC)$ are given in brackets): Hg: 44.3% (44.7%), S: 14.6% (14.3%), Cl: 7.7% (7.9%).

In systems with lower Cl^- concentrations, the initial slope of the extraction curve is closer to 1, the value expected for reaction (6); however, the slope changes with increasing R and extraction is not complete before R = 2 (see Fig. 2). It is therefore concluded that under these conditions there is a simultaneous extraction of HgCl(DDC) and $Hg(DDC)_2$ according to reactions (6) and (7).

Although the synthesis of the solid compound HgCl(DDC) was reported by *Tamminen et al.* [9], the role of the complex HgCl(DDC) in the extraction of mercury has not been previously reported. The following observations show that in presence of chloride the mixed as well as the chlorine-free complex is extracted.

4.4. *The coextraction of Cl^-*: If extraction proceeds according to reaction (6), there must be an extraction of Cl^- laong with Hg by the organic phase. This was proved by marking the Cl^- of the aqueous phase with $^{38}Cl^-$ and measuring its extraction as a function of R. The results (see Fig. 3) reflect the different quantities of HgCl(DDC) present in the organic phase for different values of R, the chloride concentration in the aqueous phase being 0.0024 M.

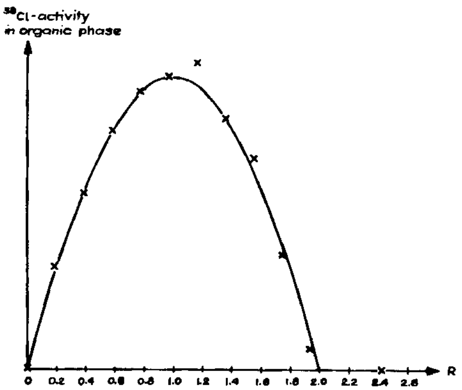

Fig. 3. *Extraction of chloride from a solution 1 M $HClO_4$, 0.0024 M NaCl*

4.5. *The absorption spectra of HgCl(DDC) and $Hg(DDC)_2$*: Two samples were prepared under conditions chosen to give practically pure samples of HgCl(DDC) and of $Hg(DDC)_2$ in $CHCl_3$. These conditions were $[Cl^-] = 2.4 \cdot 10^{-3}$ M and R = 0.19 for HgCl(DDC), and $[Cl^-] = 5$ M and R = 0.19 for $Hg(DDC)_2$. The absorption spectra of the two solutions in the UV.-region are given in Fig. 4. The spectrum of the $Hg(DDC)_2$ shows a maximum absorption at 275 nm and $\varepsilon = 28{,}000$ l $mol^{-1}cm^{-1}$; this is in agreement with values given by *Hakila & Waterburg* [10], who found a maximum at 278 nm and an absorption of approximately 33,000. The spectrum of the HgCl(DDC) is markedly different; the extinction at 275 nm is greatly reduced and a new maximum appears at 250 nm with $\varepsilon \sim 15{,}000$.

4.6. *When there is no Cl^- present*, there is no extraction of mercury at R < 1. Adding now small amounts of Cl^-, the mixed complex is formed according to equation (6). However, with increasing Cl^- concentration the amount of extracted mercury drops, which can only be due to a disproportionation according to

$$2\,\{\mathrm{Hg(DDC)Cl}\}_{\mathrm{org}} + x\mathrm{Cl}^- \rightleftharpoons \{\mathrm{Hg(DDC)_2}\}_{\mathrm{org}} + \mathrm{HgCl}_{x+2}^{x-} \qquad (9)$$

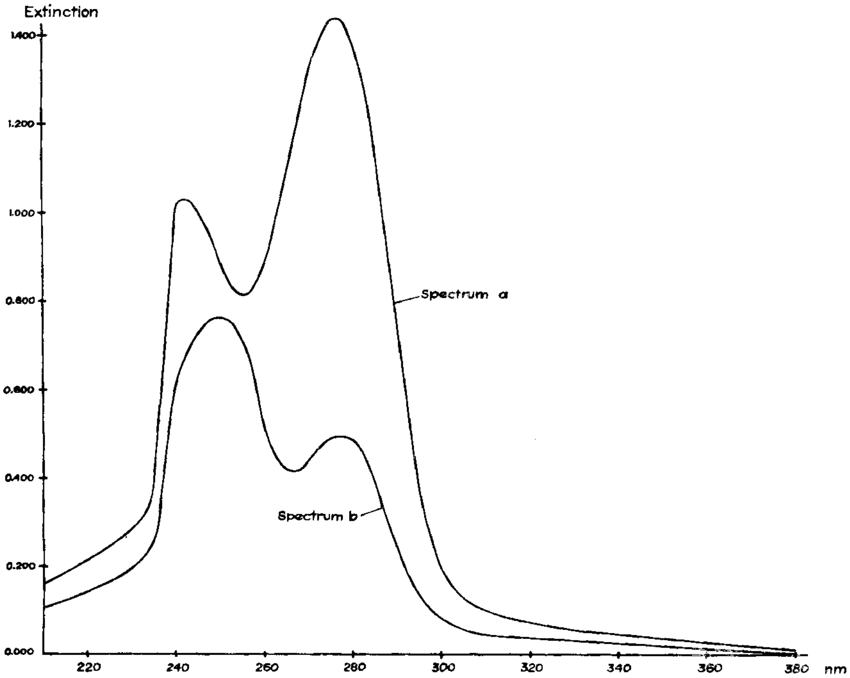

Fig. 4. *Absorption spectra of* $Hg(DDC)_2$ *(spectrum a) and of* $HgCl(DDC)$ *(spectrum b) in* $CHCl_3$
Both solutions are $5.1 \cdot 10^{-5}$ M

There exists an equilibrium between the two complexes in the organic phase and the free aquo-ions in water according to

$$2\,\{HgCl(DDC)\}_{org} \rightleftharpoons \{Hg(DDC)_2\}_{org} + Hg^{2+} + 2\,Cl^- \tag{10}$$

The exchange constant K, given by

$$K = \frac{[HgCl(DDC)]^2_{org}}{[Hg(DDC)_2]_{org}\,[Cl^-]^2\,[Hg^{2+}]} \tag{11}$$

was determined from the data of 3 experiments, namely:

i) Extraction as a function of R from 1 M $HClO_4$, $2.4 \cdot 10^{-3}$ M NaCl (see Fig. 2a).

ii) Extraction as a function of R from 1 M $HClO_4$, 0.12 M NaCl (see Fig. 2b).

iii) Extraction as a function of Cl^-, which was varied from $9 \cdot 10^{-3}$ M to 5 M, at R = 0.97, $HClO_4$ 1 M.

The quantities entering into equation (11) were calculated in the following way:

$[Hg(DDC)_2]$ and $[HgCl(DDC)]$ from the total amount of mercury in the organic phase and the total amount of (DDC) added to the system.

$[Cl^-]$ from the total amount of Cl^- originally present in the aqueous phase minus the Cl^- bound in HgCl(DDC) and in $HgCl_x^{(2-x)+}$.

$[Hg^{2+}]$ from the total amount of Hg remaining in the aqueous phase after extraction, which quantity will be denoted as $[Hg]_T$.

$$[Hg]_T = \sum_{x=0}^{4} [HgCl_x^{(2-x)+}] \tag{12}$$

$$[Hg^{2+}] = [Hg]_T/\alpha \tag{13}$$

$$\text{with } \alpha = 1 + 10^{6.7}\,[Cl^-] + 10^{13.2}\,[Cl^-]^2 + 10^{14.1}\,[Cl^-]^3 + 10^{15.1}\,[Cl^-]^4 \tag{14}$$

The coefficients of equation (14) were taken from *Marcus* [13]. It will be realized that according to equations (13) and (14) $[Hg^{2+}]$ diminishes very rapidly with increasing $[Cl^-]$; increasing the Cl^- concentration therefore shifts the equilibrium (10) to the *right* hand side and favours the formation of the chloride-free complex $Hg(DDC)_2$ in the organic phase.

These experiments, which covered a factor of 550 in $[Cl^-]$ and 80 in $[Hg]_T$ yielded the following values for $\log K$:

i) 14.41 ± 0.17 (8 measurements).
ii) 14.37 ± 0.04 (11 measurements).
iii) 14.43 ± 0.07 (9 measurements).

Pooling all 28 measurements yielded $\log K = 14.40 \pm 0.10$, wherein the error indicated is the standard deviation of a single measurement.

4.7. *The mechanism postulated here for the extraction of mercury from Cl^- containing systems* is somewhat similar to that encountered in the system Pd^{2+}-DDC, for which *Briscoe & Humphries* [14] demonstrated the existence of two extractable complexes PdCl(DDC) and $Pd(DDC)_2$. Under substoichiometric conditions, $Pd(DDC)_2$ is formed first and then transformed within a few minutes into PdCl(DDC); the reverse transformation, PdCl(DDC) to $Pd(DDC)_2$, apparently does not occur. The present authors found that in the case of mercury these equilibria are established rapidly (*i.e.* certainly within 15 seconds) and are completely reversible.

4.8. *Application of substoichiometric extraction in activation analysis* requires that equal amounts of reagent extract equal amounts of metal from several different samples. It follows from the present work that in the extraction of Hg^{2+} with HDDC this requirement can only be met either by rigorously excluding Cl^- from all samples or by keeping their Cl^- content the same within narrow limits; neither of these possibilities seems very attractive from a practical standpoint. It is therefore proposed to carry out the extraction in two steps: 1. Extract Hg^{2+} from the sample by a substoichiometric amount of DDC, ensuring that the sample contains *some* Cl^-. 2. Drain the organic phase and wash it with 5 M NaCl or 5 M HCl. Reaction (9) ensures that in the washing step all HgCl(DDC) that may have been extracted together with $Hg(DDC)_2$ is converted into $Hg(DDC)_2$ and that there is strictly one mole of Hg^{2+} extracted for 2 moles of DDC^- used in the extraction step.

BIBLIOGRAPHY

[1] *J. Ruzicka & J. Stary*, 'Substoichiometry in Radiochemical Analysis', Pergamon, Oxford 1968.
[2] *J. Stary & J. Ruzicka*, Talanta *18*, 1 (1971).
[3] *N. Suzuki*, Japan Analyst *21*, 532 (1972).

[4] *H. Bode & F. Neumann*, Z. analyt. Chem. *172*, 1 (1960).
[5] *H. Förster*, J. Radioanal. Chem. *4*, 1 (1970).
[6] *A. Hulanicki*, Talanta *14*, 1371 (1967).
[7] *F. Kukula & M. Simkova*, J. Radioanal. Chem. *4*, 271 (1970).
[8] *W. Kemula, A. Hulanicki & W. Nawrot*, Roczniki Chem. *36*, 1717 (1962); *38*, 1065 (1964) (taken from ref. 6).
[9] *V. Tamminen & E. Hjeld*, Suomen Kemi, *23 B*, 39 (1950).
[10] *E. A. Hakkila & G. R. Waterburg*, Anal. Chem. *32*, 1340 (1960).
[11] *G. Schwarzenbach*, 'Complexometric Titrations', Interscience, New York 1957.
[12] *A. Ringbom*, 'Complexation in Analytical Chemistry', Interscience, New York–London 1963.
[13] *Y. Marcus*, Acta chem. scand. *11*, 599 (1957).
[14] *G. B. Briscoe & S. Humphries*, Talanta *16*, 1403 (1969).

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121. Zur Problematik der Peptidsynthese an Trägern: Beitrag eines neuen Verfahrens mit löslichen Trägern

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(26. I. 73)

Summary. A new procedure for the synthesis of peptides on a soluble carrier is described. It relies on gel filtration for the removal of low molecular weight reactants from the peptide-polymer complex after each cycle. The advantages of the method are assessed and the insight into the problematics of the carrier synthesis which it provides are discussed. Finally, the use of a monovalent, soluble carrier molecule of defined chemistry is proposed. Such a carrier should reduce the problems of carrier synthesis to the purely chemical ones commonly associated with peptide synthesis.

1. Einleitung. – Der Darstellung von Peptiden in reiner Form mittels der Festphasenmethode nach *Merrifield* [1]–[4] sind enge Grenzen gesetzt. Diese werden gesteckt durch:

a) Chemische Gegebenheiten wie Nebenreaktionen, unvollständig ablaufende Umsetzungen und Racemisierungen.

b) Physikalische Gegebenheiten wie beschränkte Diffusion der Reaktionskomponenten in die feste Matrix, limitierte Zugänglichkeit gewisser an der festen Phase verankerten Aminosäuren oder Peptide aus sterischen oder Solvatationsgründen.

Einschränkend für die Methode und deren Ausbau zu einem tauglichen Instrument der Peptidsynthese ist auch der Umstand, dass chemisch-analytische Bestimmungen (Umsatzkontrolle durch Restgruppenbestimmung) als Wegbereiter für Verbesserungen unbefriedigend sind, da sie mit den gleichen Unsicherheitsfaktoren behaftet sind, wie die Reaktion, die es zu untersuchen gilt. Die Strategie des stufenweisen Aufbaus, wie er in der Festphasenmethode ausschliesslich verwendet wird, bringt es mit sich, dass entstehende Fehlsequenzen mit dem gewünschten Produkt strukturell eng verwandt sind und deshalb die Abtrennung von Fehlsequenzen schon bei relativ kurzkettigen Peptiden schwierig wird. Die generelle Problematik der Peptidsynthese einschliesslich jener am Träger hat kürzlich *Wünsch* [5] in einer Übersicht kritisch beleuchtet.