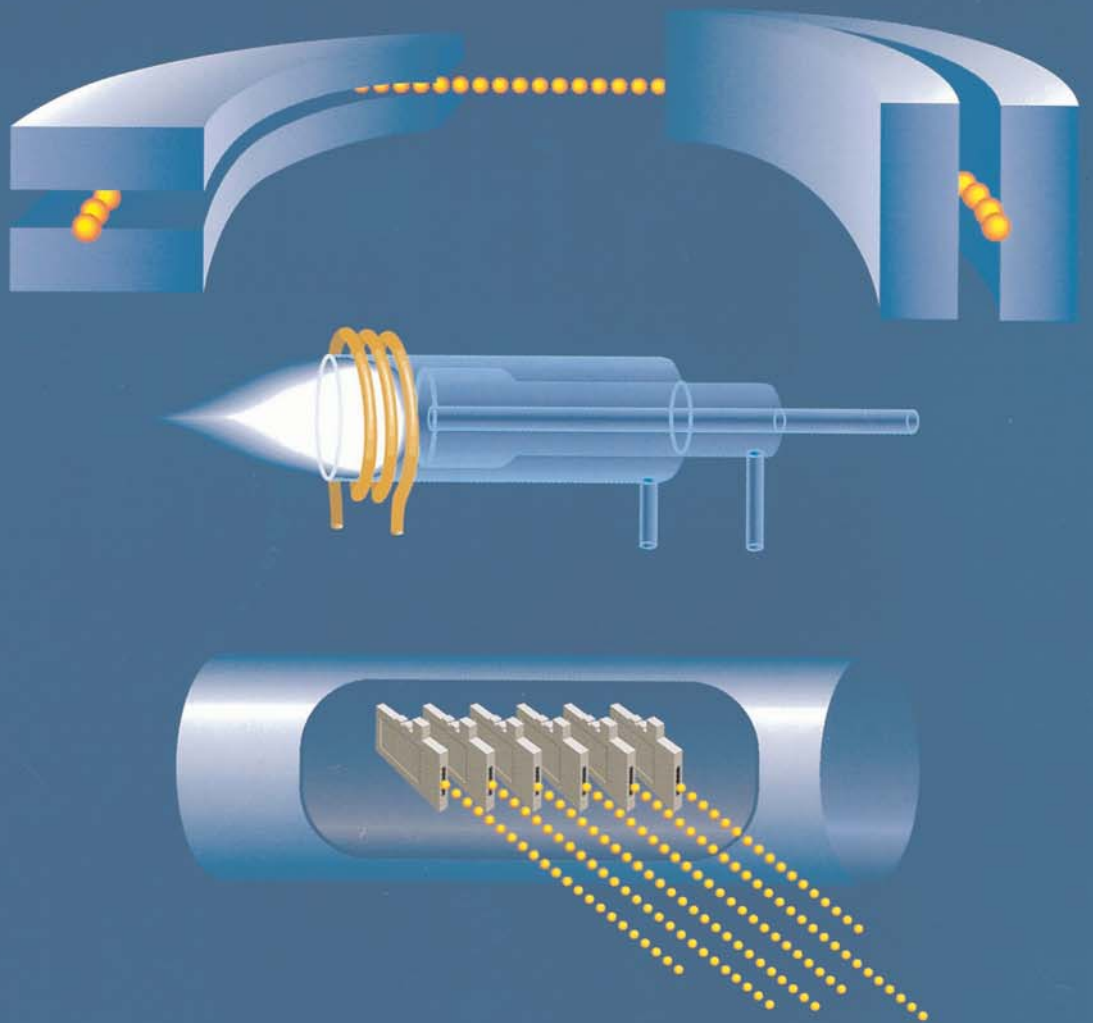


50

Years of MAT in Bremen



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In 1947 Dr Ludolf Jenckel, a young physicist at the Atlas-Werke in Bremen, Germany, had an idea: he rented a cellar in a hospital and in his spare time tried building a mass spectrometer. After completion of a primitive prototype, Jenckel talked the Atlas management into setting up a small division, MAT, to build mass spectrometers for sale. The prototype was redesigned and in 1950 the first series instrument, the CH3, came out. Throughout the first years of MAT the sales figures remained quite low. However Jenckel did not give up. He initiated the development of a successor model, the 60° sector CH4, which was introduced in 1958. Over 400 installations of this instrument strengthened MAT's position in the following years. In 1967 MAT was acquired by Varian Associates, Palo Alto and MAT continued to grow. Novel techniques were introduced, new mass spectrometers were developed for all kinds of applications and MAT became one of the leading producers of mass spectrometers in the world. By 1976 more than 1000 instruments had been delivered. In 1981 Finnigan in San Jose took over MAT and a fruitful technical cooperation between Bremen and San Jose began. This year MAT celebrates its 50th birthday. It is one of the few mass spectrometry companies which have stayed in the forefront over the years. © 1997 by John Wiley & Sons, Ltd.

Received 1 February 1997; Accepted 4 February 1997

Rapid. Commun. Mass Spectrom. 11, 694-707 (1997)

No. of Figures: 16 No. of Tables: 0 No. of Refs: 4

THE CITY OF BREMEN

Bremen is an old city. Its history goes back to the year 780, when Charlemagne made it a bishopric. In 1358, Bremen became a member of the Hanseatic League, which in those days controlled trade in the Baltic. Trade and marine activities determined life in Bremen for centuries. Merchants and captains played the predominant roles in public life. The city had no university, and science was of minor interest only.

Everybody in Bremen is familiar with the adventures of the Bremen Town Musicians (Fig. 1). The few early activities in natural sciences related to Bremen are well known only to those interested in astronomy: at the end of the 18th century the largest astronomical telescope on the European continent was built up in Bremen Lilienthal. In remembrance of its creator, Johann H. Schroeter (1745-1816), one of the deep valleys on the moon's surface was named after him. Friedrich W. Bessel (1784-1846) worked in Schroeter's observatory. Bessel later went to Königsberg and became one of the world's leading astronomers. Bessel's early teacher and friend was Heinrich W. M. Olbers (1758-1840), physician and astronomer in Bremen. He discovered the planetoids Pallas and Vesta and also five comets. One comet as well as a puzzling question carries his name ("Olbers paradox"): *"Why is the sky dark at night? It should be brightly illuminated by the great many stars!"*. The answer is by no means trivial and can only be given on the basis of modern cosmological theories.¹

World War II plunged Bremen into misery: 65% of the homes were destroyed, most of the rest were badly damaged. The year 1945 meant point zero for Bremen. The city began the long task of repairing the ravages of war and rebuilding its trade and commerce. New industrial enterprises were set up (e.g. modern production facilities for automobiles, aircraft and aerospace equipment). Despite these new activities, the centuries-old marine tradition is still present in many places. In 1971 the University of Bremen was founded and now has about 19 000 registered students.

THE FIRST YEARS OF MAT (1947-1957)

How Bremen became one of the centers of mass spectrometry in Europe is somewhat accidental: It happened to be the home-town of Dr Ludolf Jenckel (1912-1990), its founder. In 1947 Jenckel, a young physicist, asked the management of Atlas-Werke AG (originally a shipyard), where he was working on electromedical instrumentation, for permission to develop a mass spectrometer. This idea had been triggered by discussions with his friend Wilhelm Walcher, physics professor at Göttingen University, who since 1937 had pioneered isotope separator technology and sector field mass spectrometry in Germany. Jenckel's request was turned down by the management; such an apparently exotic project would deviate far too much from the company's main field of activity. Jenckel, being a determined person, did not give up. With permission of the management, he took leave of absence for half-days to follow up his ideas at his own risk. He rented a cellar in a hospital and, together with a co-worker, tried building a mass spectrometer. The magnet and other components were contributed by Walcher (the esteemed teacher of the author in the fifties).

The idea of building mass spectrometers in Germany for commercial use required extreme optimism because at that time well established companies in England (Metropolitan Vickers Electrical Company Ltd., Metro Vick) and in the US (Consolidated Engineering Corporation, CEC) were already producing commercial mass spectrometers. The technology of these instruments was based on the pioneering work of Thomson, Aston, Bainbridge, Dempster, Nier and others; all of whom had worked at research institutes either in England or the United States. The corresponding technology in Germany lagged behind. Despite all this, Jenckel continued. After about one year of hard work, a prototype instrument was completed. He contacted the management of Atlas again and eventually was able to talk them into setting up a small division, Atlas MAT (Mess- und Analysen-Technik) to build (and hopefully sell) mass spectrometers.



Figure 1. The Bremen Town Musicians in front of the historical Rathaus (building begun 1405, a Renaissance facade was added later in 1609). It houses the most famous of all wine cellars in Germany with 600 different wines, the oldest being from 1727.

The prototype instrument, a 60° sector mounted on a wooden frame, was quite primitive (Fig. 2). A NiCd-battery served as power supply for the (laminated) magnet which was taken from an old echo-sounder. Magnetic scanning over a limited mass range could only be initiated by placing a shunt across the poles of the battery, which caused the voltage to slowly decrease. After various modifications this prototype was sold to the chemical company Bayer AG.

The prototype could not compete with the commercial instruments made in England and the US with respect to performance and reliability. However, those instruments required very careful and skilled handling to keep them running. One of the early users in the US came up with the now classic characterization of a mass spectrometer as a *"machine that almost doesn't quite work"*. Another well-known pioneer, working for CEC, groaned: *"There's got to be an easier way to make a living"*.²

Atlas had similar thoughts. The new MAT division produced losses. Atlas-Werke as a whole was in a critical situation since post-war regulations did not allow the company to continue with its marine product line, and lay-offs were frequent. Despite these very unfavorable conditions, MAT managed to support two R&D people, and in 1950 an improved version of the prototype instrument came out, the CH3 (Fig. 3). The sales volume was quite low and the division was close to dissolution all the time. Once, a single order at the very last moment averted a final shutdown. In 1952, the instrument was exhibited at a show (ACHEMA at Frankfurt) for the first time and some people became interested. One of the visitors, not personally known to the MAT engineer at the instrument, recognized the many vacuum connections and asked: *"What do you do in the case of leaks?"*

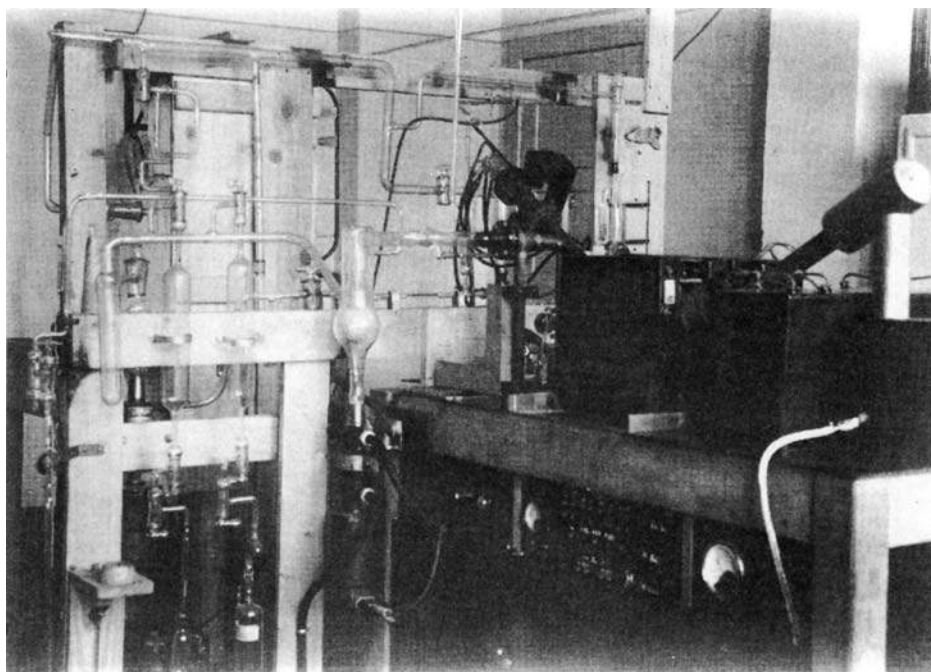


Figure 2. Prototype of the first 60° sector MS 1 (1948).

The engineer answered with a smile: "We do it like Dr. Paul does, with one hand we plug the leak and with the other one we perform the measurement". The visitor, laughing: "May I introduce myself? I am Dr. Paul". It was the same Paul (a friend of Jenckel's) who later invented the quadrupole mass spectrometer and the ion trap and was awarded the Nobel Prize in 1989.

The sales volume reached around \$100000 p.a. in 1954, not sufficient to sustain the 20 people working in the division. Thus, a decision had to be made: either to give up or to throw all the eggs into one basket. Jenckel initiated a "Mass Spectrometer Conference" in Bremen in order to attract the attention of the scientific community and the chemical industry. During the meeting, Jenckel set up guided tours through his operation and gave a bright and optimistic outlook of the future of mass spectrometry in Bremen. In the evening, an extremely sumptuous buffet was presented in one of Bremen's most famous and luxurious locations (its name, the "Golden Hall", by no means matched the financial situation of Atlas MAT). The author, who was attending the conference was so impressed that he decided to join MAT: a company which could afford to organize such an outstanding event, apparently must have ample means to support interesting projects. Although this reasoning was revealed to be wrong, the author stayed there for the following 35 years.

The main application of analytical mass spectrometers in those days was quantitative analysis of hydrocarbon mixtures. This application required good longterm stability of the cracking pattern and precise proportionality between sample pressure in the inlet system and recorded ion current. The CEC 21-103 from Consolidated Engineering Corporation met these requirements to a high degree and set a standard, with which the Atlas CH3 could not quite cope. One of the main drawbacks of the CH3 was that the higher the sample pressure (ion current), the more space-charge effects in the ion source deteriorated the ion focusing. In

addition the resolution (maximum 300) went down from time to time for various reasons. Once this happened during a visit of a prospective customer. In order to save the embarrassing situation somebody came up with a "good idea": Why not by-pass ion source - analyser - amplifier by directly connecting a voltage source to the galvanometer? Thus, a technician was placed behind the instrument (invisible to the visitor). While looking at Table of isotopes on his knees and activating a variable voltage divider accordingly, he could generate an acceptable mercury spectrum.

Mercury diffusion pumps caused the ample background normally required for the demonstration of resolution. Unwanted background in the mass range 64 to 70 u (zinc) also showed up from time to time when an instrument arrived from production, indicating that somebody by mistake had used the wrong solder or had made some analyser part of brass instead of stainless steel. To find and replace such parts was usually a time-consuming task.

Technical and organizational problems of all kinds had to be solved in the succeeding years. The goal of establishing a firm of good standing spurred the 28 people working in the department. They had survived a number of setbacks and the group started to yield some profit. In 1956, the department moved into a new building on the other side of the Weser River. Being now spatially separated from mother Atlas the MAT division had to prove that it could exist on its own.

UPSWING (1958-1967)

While sales figures grew slowly, MAT remained in the shadow of CEC and MetroVick. The mass spectrometers of these companies were still technically superior. The only way out was to design a new generation instrument. After two years of development the CH4 sector instrument came out (1958), and marked a milestone in the history of the company.

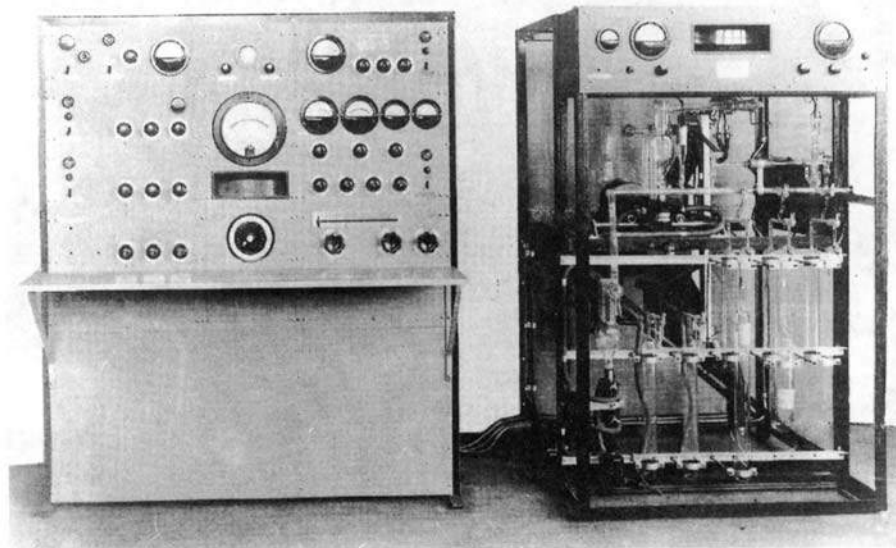


Figure 3. CH3 sector (1950).

The advanced CH₄ instrument (Fig. 4) was well accepted (more than 400 installations by 1967). Applications of the first instruments delivered included: headspace analyses of coffee aroma, detection of carcinogenic compounds in cigarette smoke, analysis of perfume mixtures etc. The success of the CH₄ allowed MAT to expand (Chamfort in 'Maximes et Pensées' 1803: "*Success breeds success, as money breeds money*"). Until the mid-sixties the previous main application of organic mass spectrometry, quantitative mixture analysis, had been replaced by qualitative analysis of organic compounds. Half a century before that time the father of mass spectrometry, J. J. Thomson, had already predicted: "*I feel sure that there are many problems in chemistry which could be solved with far greater ease by this (mass spectrometry) than by any other method*" (Cambridge, October 4, 1913). Not all mass spectrometrists after him felt that sure. Quite a number of them declared mass spectrometry not well suited for qualitative, especially structure, analyses, because the electron impact process in the source quite often caused structural changes of the compound to be analysed. It took years until practical application revealed that just this fact (the ion source as a test tube) could be used advantageously in many cases (John Keats: "*Nothing ever becomes real till it is experienced*").

For qualitative analyses of "nonvolatile" samples (a magic word in those days) MAT developed a system through which such samples could be evaporated directly into the ionizing electron beam of the source. Memory effects were eliminated, because the whole ion volume, together with the sample, could be exchanged without breaking the vacuum. The system was rather complicated and resembled a small mortar (Fig. 5). A leading mass spectrometrist tried to convince the author that this was not the way to go. Solid samples should be chemically converted into volatile compounds which could then be very easily introduced into the source through

a heated all-glass inlet system (Winston Churchill: "*It is no use arguing with a prophet; you can only disbelieve him*"). More elegant and much simplified direct inlet systems later became standard for practically all organic mass spectrometers.

All-glass inlet systems were a nightmare for MAT. They frequently broke before installation. In the early days Jenckel did all of the glass-blowing work himself. Later MAT replaced the glass with stainless steel lined with enamel. However, the enamel quite often cracked after some weeks. It took more than a year before this new technology became reliable and MAT was able to offer the only 350°C inlet system on the market, that could be kicked around without danger of breakage.

Another new technique in the early sixties was the combination of gas chromatography and mass spectrometry (GC/MS), pioneered in the US. The majority of chemists in Germany were sitting on the fence. Jenckel travelled from one chemical company to the next trying to raise interest in this obviously promising new technique, but the response was rather poor. The demonstration of a CH₄ instrument coupled with a GC at theACHEMA exhibition in Frankfurt in the early sixties was regarded as a curiosity. The instrument was equipped with a novel "double ion source", i.e. two ion sources mounted piggyback and operated in parallel, one of them at an electron energy below 20 eV (elimination of the excessive He⁺ ion current) for the continuous recording of the GC-trace. This was done to avoid any split of the effluent between the mass spectrometer and the flame ionization detector (FID) of the GC (which led to synchronizing problems and also reduced the sensitivity of the mass spectrometer). However, this feature was not recognized by the visitors as being useful.

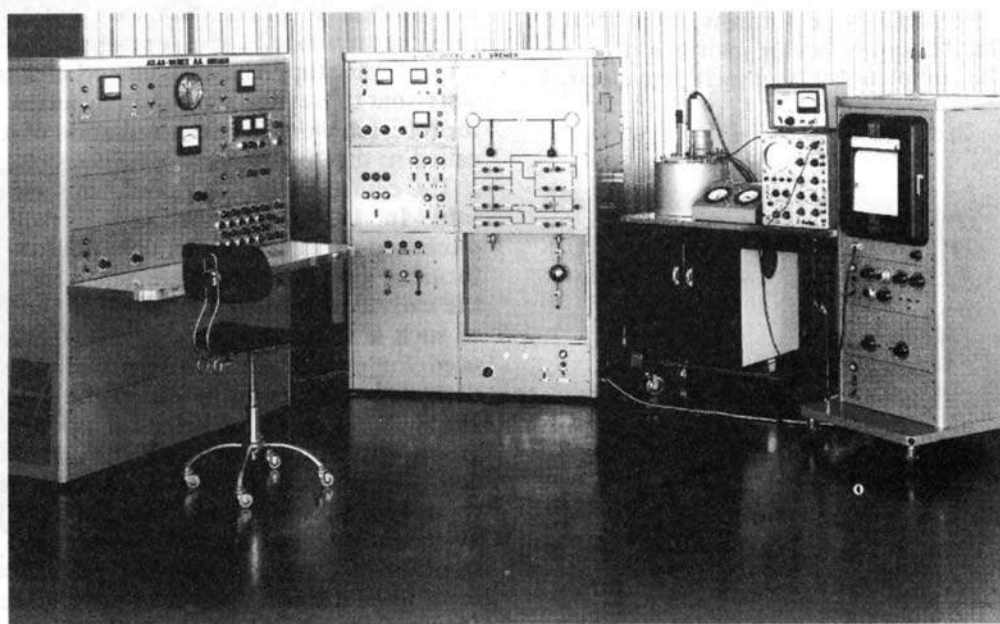


Figure 4. CH₄ mass spectrometer, connected to a capillary gas chromatograph (1962).

The ASTM conference held in San Francisco in 1963 changed the situation. In a bar room just opposite the conference hall, MAT had installed a CH₄ instrument coupled with a capillary column (without asking the organizers for permission). The evening before the conference opened the program chairman showed up and angrily demanded the removal of the instrument (display of instruments apparently was against the rules in 1963). Jenckel remained stubborn and the GC/MS system attracted many participants throughout the conference. At the conference a mutual marketing/selling agreement was set up with Applied Physics Corporation (Cary) in Monrovia, CA, USA.

The group now was reasonably well established. It had been converted into an independent subsidiary company of Atlas with Jenckel as general manager. He served in this position from 1962-1974. The CH₄ instrument continued to provide a solid platform for the development of other mass spectrometers. However, the danger of falling was waiting at the edge of the platform.

PLATFORM CH₄

In the sixties the company came out with a leak detector. The performance of the instrument was more than satisfactory. It was produced over a period of a couple of years. But in the long run the vacuum companies took over the market. They had better access to users in the corresponding field of application and were much better equipped for mass production. A residual gas analyser had the same fate as the leak detector: MAT developed the "smallest sector instrument in the world" with magnetic scan, the MAT 31. The magnet was so compact that it could fit into the pocket of an overcoat. A relatively small number of instruments were delivered for those vacuum technological applications which required outstanding sensitivity and long-term stability. For ordinary residual gas analyses the smaller and less expensive quadrupole systems offered by vacuum companies for the mass market were more suitable. Companies sometimes tend to stick to a certain technique they are accustomed to. Some twenty years or so ago, the leading producer of slide rules in

Germany offered a device which had an integrated electronic calculator on the rear side. Nobody needed such a device, of course.

Together with the "smallest sector instrument" MAT also developed the "cheapest sector instrument in the world" (cost of the complete analyser including electromagnetic: around \$1000). Varian was interested in offering it for teaching purposes at schools, but the project did not reach the production stage.

After the beginning of the sixties, the new technique of high resolution stirred the interest of organic mass spectrometrists. Although physicists had built high resolution mass spectrometers for exact determination of atomic masses since the early days, it was not before the end of the fifties that it was applied to problems in organic chemistry (Goethe: *"It is not enough to know, one has to apply; it is not enough to wish, one has to do"*). Based on the pioneering work of Beynon, AEI Ltd. (formerly MetroVick) in 1955 introduced a prototype double focusing instrument which enabled the user to determine the atomic composition of molecules through exact mass measurements. A wave of publications, mainly from the UK and the US, demonstrated the power of this new technique. MAT had no comparable instrument to offer. In a hurry, an electric field (toroidal condenser) was placed in front of the CH₄ instrument to make it double focusing. The system did not work.

Another attempt to catch up was to apply advanced ion-optical ideas which had been worked out by Ewald in Germany. From the theoretical point of view, the double focusing system calculated by Ewald was outstanding: ion focusing in two directions (electrical field of the toroidal condenser), enhanced mass dispersion (inhomogeneous magnetic field), excellent image error correction. MAT unsuccessfully tried out such a system which had been built by Ewald's group. In hindsight it became quite clear why no proper operation could be achieved. In theory the (large) image errors of the magnetic and electric fields should have cancelled each other. However, the slightest deviation of the real from the calculated fields caused the image errors to shoot up, thus destroying the ion focusing.

Why not "think big" and build a sledge hammer to fight the competition (Ovid: *"Isn't the best defence always a good attack?"*)? MAT designed and built a large double focusing machine (radius of 70 cm) which was supposed to outperform other high resolution instruments. The first results were promising. However, the company rated the financial risk too high and the project was stopped: MAT missed a chance. The parts were sold to Beynon's group in Swansea and later used for research work in laser irradiation of ions (the group called it: the "big banana").

The centre of the CH₄ platform seemed to be more safe. In 1931 Mattauch and Herzog had already published excellent results obtained with their double focusing system (photoplate recording). Moreover, in the early sixties Biemann demonstrated the superiority of such a high resolution system (CEC 21-110) when used for qualitative analyses. Thus MAT decided to design an instrument based on the proven Mattauch-Herzog ion optics, Jenckel set up a separate R&D group in Munich (not to be disturbed by day-to-day activities in Bremen) and in 1966 the new instrument came out

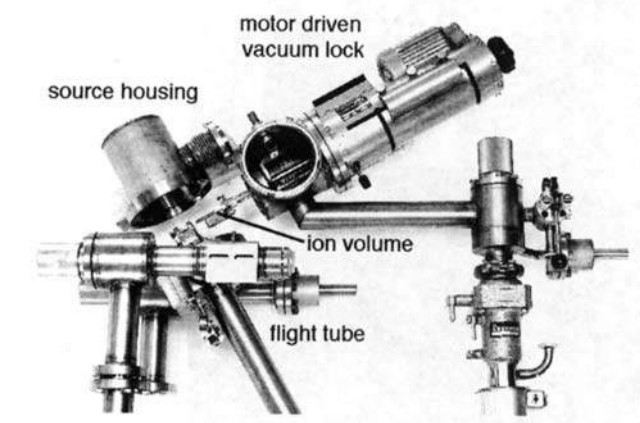


Figure 5. Vacuum lock for the direct introduction of solid samples (1960).

(the SMI, see Fig. 6). Two versions were available: one for organic analyses and the other for spark source work (SMI F). MAT could now be considered a serious player in the high resolution field. In some analytical techniques MAT was even able to take a leading position, e.g. application of field ionization/desorption and high resolution. The SMI later was redesigned and offered as the MAT 731 (photoplate recording, see Fig. 7) and the MAT 711 (magnetic scan) until 1977.

Today it seems amazing that the complicated and time-consuming technique of photoplate recording, which in addition required the purchase of a rather expensive photoplate reader, was able to compete with the much more elegant scan technique. However, the benefit of integrating the ion current which led to excellent sensitivity and mass accuracy together with the high reliability of photoplate recording, compensated for its drawbacks. Remember that in those days the scan technique, in contrast to the photoplate technique, could not provide the exact masses of the whole spectrum. Time consuming "peak matching" of single peaks still was the method of choice. Great efforts were required until later AEI was able to demonstrate, that even from the few ions per peak, which reach the collector during a rapid high resolution scan, the exact masses could be determined.

Handling and storage of the sensitive photoplates of the MAT 731 required some care. One evening somebody in the demonstration laboratory left a photoplate on the table. The next morning the charwoman said to the engineer: *"Sorry, I have not been able to scrub the grime off the glass ruler over*

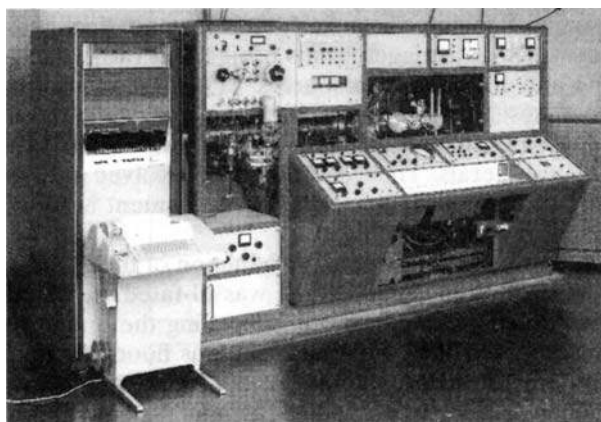


Figure 6. Matthauch-Herzog system SM 1 (1966).

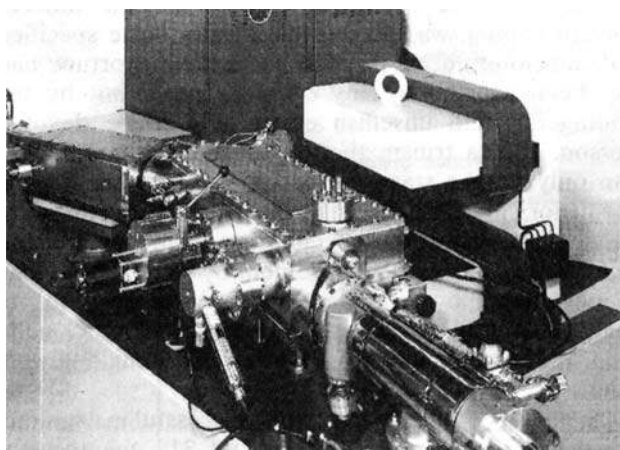


Figure 7. Analyser of the MAT 731 (1971). in front: housing of the vacuum lock for the exchange of photoplates.

there". It took 20 years before the drawbacks could be eliminated by "electric photoplates", which the major mass spectrometry companies began to offer.

In 1965 MAT's sales volume had reached 4 Mio \$ p.a. and 400 people worked for the company. The CH₄ sector instrument still served as backbone of the business, but it was now seven years old. New applications required free access to the ion source and the collector region. Instruments from other companies had demonstrated the advantage of an open design with the analyser mounted horizontally. Thus, in order not to miss the boat, a project was started to replace the successful CH₄. After two years a totally new instrument came out, the single-focusing sector CH₅ (Fig. 8).

The somewhat risky philosophy behind this CH₅ instrument was to make it more powerful (and consequently more expensive) than the market was asking for at that time. The fully transistorized circuits (not yet common) were more stable, the mechanical precision higher than required etc. (Voltaire: *"The superfluous, a very necessary thing"*). As a result, impressive performance data could be achieved: e.g. the resolution could be pushed to 10000. Although only few people utilized such performance of a ("low resolution") single focusing sector instrument and despite its high price, it was accepted by the market and built without major changes until 1975.

This philosophy was not the result of a profound market research, nor was the project based on profit forecasts. Prospective R&D costs had not been estimated in detail. In those days, MAT was driven mainly by technology, or in other words, by the enthusiasm of physicists, chemists and engineers, who wanted to explore the limits of their capabilities (Henry Poincaré, the great mathematician: *"The scientist does not study nature, because it is useful; he studies it, because he delights in it, and he delights in it, because it is beautiful"*). In many cases this worked, in some cases, it led to failures. In the late sixties MAT built a combined electron/ion microprobe (analysis of inorganic solid material by rastering the surface with a collimated particle beam). The instrument was based on the advanced design of Liebl, one of the leading ion optics researchers in Germany. However, the technical problems involved had been greatly underestimated and the project was given up. The outcome of all the effort was a publication and some experience, which did not compensate for the substantial financial loss.

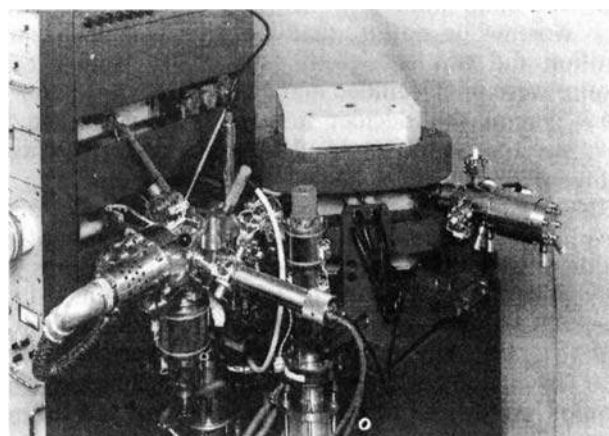


Figure 8. Analyser of the 90° sector CH 5 (1967).

Another activity, which was "interesting" from the technical, but not from the financial, point of view: the development of special peripherals for the CH4/CH5 instruments on request (e.g. Knudsen cell for high temperature studies, Fox-type ion source for appearance energy measurements, flash pyrolysis system for the mass spectrometric characterization of bacteria).

VARIAN MAT (1967-1981)

Mass spectrometry was expanding rapidly in the midsixties, and other analytical instrument companies became interested in entering the growing market. A number of them negotiated with MAT about an acquisition. Varian Associates (Palo Alto, California), world-renowned producer of NMR equipment, gas chromatographs and computers, won the game and acquired MAT from the Krupp group in 1967 (a year earlier, Krupp had bought Atlas including MAT).

Supported by the world-wide marketing activities of Varian, MAT became one of the leading producers of mass spectrometers. Soon after the acquisition, a fruitful exchange of technical ideas between Varian and MAT began. However, one disturbing problem had shown up. During the time MAT was developing the CH5 instrument, Varian was working on a new type of mass spectrometer for chemical analysis. The ion optics of this instrument (M 66) were based on the laws of cycloidal ion motion (crossed electric and magnetic field). Both instruments were designed for the same market and they came out at about the same time. In other words, they were competing against each other. It was rather obvious that only one instrument would survive. The cycloidal system of the M 66 offered perfectly double focusing ion optics (no image errors, at least in theory) and the engineering of that instrument was of very high standard with a modern outer appearance. Practice won over theory: the cycloidal principle required placement of the ion source and the collector within the magnetic field, with the consequence that exchange of these parts was difficult. Moreover the use of advanced inlet systems (e.g. direct probes) and other detectors (secondary electron multiplier instead of Faraday collector) caused technical problems. As a result of these drawbacks only a relatively small number of instruments were delivered. It is worthwhile noting, that the inter-company competition did not cause any frustration. Both R&D groups were open-minded and appreciated each other's work. The market decided in favor of the CH5, which gave rise to a family of MAT instruments for the next eighteen years.

It sometimes happens that industrial products which have inherent theoretical advantages over competitive products do not win, because of technical problems. In the sixties the motor of Felix Wankel came out. It had no crankshaft and no pistons, only a few rotating parts and was very light. Car producers all over the world were fascinated and began to work on this motor. The Wankel motor was to be the car motor of the future. However, *practical* problems (reliability of the rotor sealing, high gasoline consumption) could not be solved. Hence the good old Otto- and Diesel-motors are still unbeaten today.

After the acquisition by Varian, the sales volume continued to climb and reached 10 Mio \$ in 1971, at which point there were more than 600 employees.

In spite of these facts, MAT was not yet fully competitive in the growing high resolution market. Although the performance of MAT's Mattauch-Herzog instruments, the 711 and 731, was good (especially with respect to reliability), their production cost and hence their price was too high. The market was still dominated by the well engineered instrument, the MS 9 from AEI.

A couple of years earlier MAT had tried to make the workhorse CH4 double focusing by placing an electric field in front of the magnet. Why not try it again with the new workhorse CH5, but now place the electric field *behind* the magnet? According to a basic law of ion optics (as in the case of light optics) focusing properties are maintained, when a system is operated in reverse. Such BE configuration had been tried out by Beynon before but had not yet been realized commercially. When the first MAT system (called CH5-DF) was tested, it behaved according to theory. Moreover, it turned out that this configuration had inherent advantages: It could be used in the tandem mode (MS/MS) and enabled the so-called mass-analysed ion kinetic energy (MIKE) measurements. MAT received compliments from one of the pioneers of this technique for its assumed farsightedness. In fact, it was not farsightedness which had triggered this project but rather lack of time and shortage of resources. The simplest way had been chosen: the *attachment* of an electric field did not require any changes of the basic CH5 with all its frontend peripherals. The CH5-DF later evolved into the more integrated double focusing instrument MAT 311 (for family trees see Fig. 9).

The preparation for the introduction of the MAT 311 at an exhibition (ACHEMA) was ill-fated. A vacuum valve failed in the afternoon preceding the opening of the show, and the whole analyser was flooded with oil from the diffusion pumps. A dedicated engineer in Bremen rushed to the show, a baby bath tub and a container with solvent in his luggage. During a dramatic overnight action the analyser was cleaned in the open tub. The next morning the engineer, plagued by a severe headache (obviously caused by the inhaled solvent vapor), was able to demonstrate the specified 20 000 resolution. As in other cases the misfortune had not been averted by any *ordre de mufti* but by the courageous and unselfish effort of a single devoted person. It is a truism that "management techniques" can only set the stage for personal initiatives. During the history of MAT and under the wings of the different owners a variety of these techniques, from management *par ordre de mufti*, to management by chaos³, from lean management, over management by motivation, to management by objectives have been tried out. Conclusion: in the first place it is the devoted individual that counts.

The MAT 311 became a rather successful instrument. It was later converted into the MAT 312, the ancestor of the double focusing 8200 instrument, built until 1986. In order to serve the growing interest in hybrid techniques (MS/MS analyses) a BE-QQ version of this instrument was also available (HSQ 30).

Besides these high resolution double focusing instruments the MAT CH5 had other off-spring: the CH7 (simplified version) and the CH6 ("export version"). The latter owes its existence to an international regulation regarding export to "eastern bloc" countries. The radius of the magnet should not exceed 12.5 cm (radius of the CEC 21-103). Apparently the ion optical knowledge of the lawyers involved was limited. They were not aware of the fact that even with a relatively small radius a sufficient dispersion and hence resolution could be realized, e.g. by oblique entrance of the ion beam into the magnetic field. Such a system had been tried out by MAT before (MAT 31). Now it was realized on a larger scale with the CH6. This instrument was a standard CH5 with the only modification that the 21 cm magnet had been replaced by a 12.4 cm magnet having oblique field bound-

aries, whereby the dispersion was doubled. Moreover it resulted in a two-directional focusing of the ion beam. Drawback (mother nature cannot be cheated): the comparatively small radius cut the mass range in half.

The features of two-directional focusing (enhanced sensitivity) and increased dispersion later turned out to be extremely advantageous, when realized with instruments for isotopic analysis (only low mass range required). It is generally applied by all manufacturers today.

Throughout the Varian period, instruments for applications other than organic chemistry came out, e.g. a small (180° permanent magnet) sector machine (GD 150) for gas analyses. This instrument was the basis for other small mass spectrometers: the M3 for lung function diagnosis and the P2 for on-line blast furnace control. The later two were

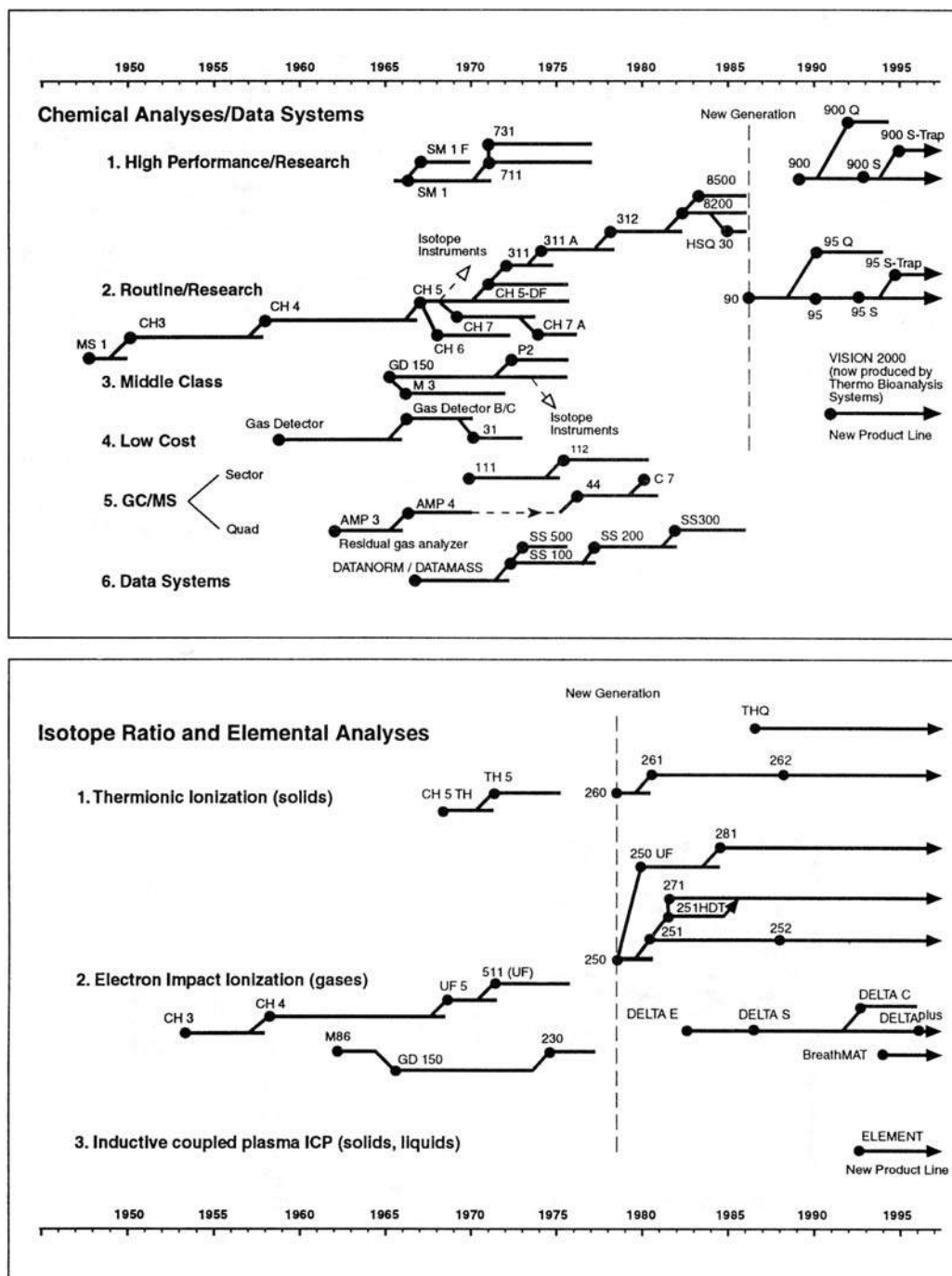


Figure 9. Family trees of MAT instruments 1947-1997.

equipped with a novel collector system. The positions of the four collector cups could be changed during operation in order to select four different ion species for simultaneous collection (Fig. 10). The P2 instrument created an enormous interest in the USSR. The officials there planned to equip all blast furnaces in the USSR with that instrument. After time-consuming negotiations a license agreement was signed and one instrument together with all production documentation was delivered. However, the lofty plan never became reality.

Varian, being one of the leading gas chromatograph producers, was interested to have a low-priced dedicated GC/MS instrument in its product line and initiated a corresponding MAT project. The Swedish company LKB had already shown that the way to go was: integration of GC and MS. Their sector instrument LKB 9000 (equipped with the novel Ryhage-separator) performed very well. However it was not low-priced. MAT's answer was the GNOME (MAT 111, Fig. 11), a compact single-focusing GC/MS instrument, which was first exhibited in 1971*. It won the I • R 100 award as One of the 100 Most Significant New Technical Products of the Year. In order to enhance the scanning speed of this instrument a laminated magnet had been tried out during the development phase. The performance did not meet expectations and the idea was given up for a couple of years. It was the VG company in Manchester which was more successful and later introduced laminated magnet technology commercially.

In 1975 the MAT 111 was converted into a small double focusing instrument (MAT 112), which was built for a couple of years. Although the accelerating voltage of this machine was only 800 V (for obtaining an appropriate mass range) a resolution of 10 000 could be specified.

*Random House Dictionary: Gnome, legendary species of a diminutive being, usually described as a shrivelled old man (right, the basis of the 111 was a CH5 analyser reduced in size).

Also in 1975 the company purchased 58000 m² ground from the city of Bremen and put up a 14000 m² building. In October 1976 the official opening was celebrated with city representatives, customers and employees. At that time more than 1000 mass spectrometers had been produced by MAT.

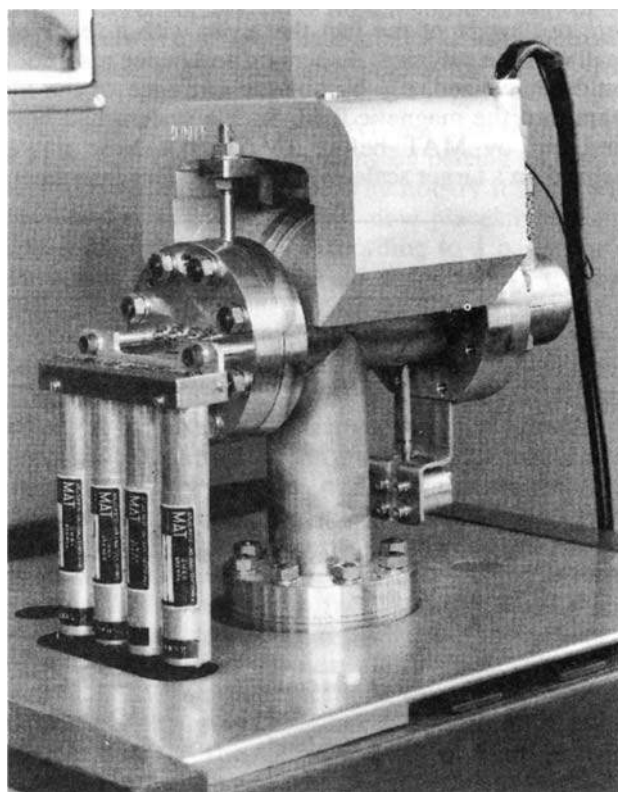


Figure 10. Analyser of the M3 with permanent magnet and four collectors (1966).

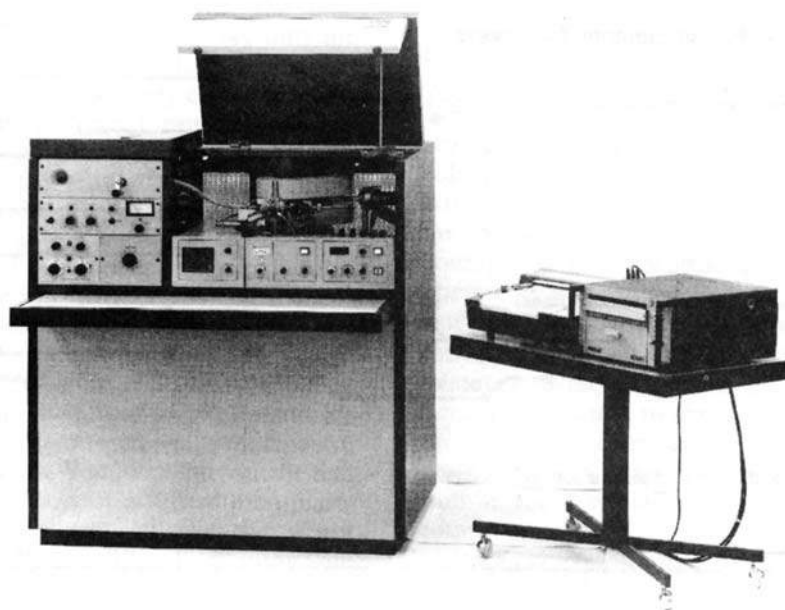


Figure 11. MAT 111, the GC/MS system GNOME (1970).

DATA PROCESSING

In the mid sixties it became obvious that the time-consuming manual evaluation of the enormous amount of mass spectrometric data, commonly recorded on strip charts, was no longer appropriate. Up to this time, people assigned masses to the peaks through "counting" and measuring peak heights with a ruler (the author's secretary left the company in despair after a few weeks of this boring activity). To make life more comfortable, MAT developed a "digitizer" which sampled the mass spectrum and printed peak height and mass number in an encoded form on a metallized paper strip. The "analogue" user could not read such a strip and the device was a flop. MAT was more lucky with a novel unit for the automatic assignment of masses to the peaks. Although the initial adjustment of the complex resistor chain of this "mass marker" took hours it became a useful tool and was used for many years.

The real entry into the digital world did not happen until after the first "compact" computers became available. The publications of Biemann, Burlingame and others who had applied this new technology, triggered activities in labs throughout the world. MAT starts its activities in 1967, using a 16-bit Honeywell computer, which was the size of a refrigerator and cost more than \$100000. All kinds of programming tricks were required to squeeze an appropriate (assembler) program into the 4k memory. Later the well known Varian computer 620 i came into use. With such a 4k-system, by 1970 a low resolution spectrum could be recorded on-line without intermediate storage on tape (MAT Datanorm and Datamass). An additional 4k enabled the on-line evaluation of a high resolution scan (10 s per decade). By 1973 around 100 data systems had been installed. Stand-alone systems (SS100/200/300) were built until 1986, when they became an integrated part of the mass spectrometer.

In those pioneering days hot discussions took place between experts as to whether small dedicated computer systems or powerful central systems (serving a whole analytical lab) should be preferred. The availability of low-priced computers ended the dispute in the seventies and cleared the way to the fully computercontrolled mass spectrometers of today. The first system of this type came from Bremen, the MAT 44, a quadrupole instrument for GC/MS analyses.

QUADRUPOLES (1962-1981)

MAT, the "sector field company", introduced a commercial quadrupole analyser in 1962, the AMP 3 (Fig. 12), which led to the AMP 4. The system with its open ion source, primarily had been designed for residual gas analyses, not for applications in organic chemistry. Except for the excellent detection limit, which was around 10^{-13} mBar, the overall performance could not compete with that of sector instruments. As a consequence, MAT underestimated the analytical potential of the quadrupole and did not initiate a long-range program. It was the Finnigan company, founded in 1967 by Robert Finnigan together with colleagues, which successfully developed quadrupole technology. R. Finnigan later said :⁴ *"We felt that its inherent advantages of simplici-*

ty, low cost, compactness, capability of operating at relatively high ion source pressures, and most importantly, ease of computerization would make it a logical choice for GC/MS application".

Finnigan's success prompted MAT to reactivate its quadrupole activities. In order to replace the MAT 111 sector a remarkable quadrupole instrument for GC/MS was introduced in 1977, the MAT 44. It was the first fully computer controlled analytical mass spectrometer in the market and also won the I • R 100 award. However the market seemingly was not yet ready for such a system (Shakespeare: *"Too swift carries as tardy as too slow"*). Users were accustomed to knobs and did not trust an instrument which could only be operated through a keyboard. They were not completely wrong. The reliability of the keyboard control was not always sufficient. Partly this was due to the fact that in those days proven computer boards to be incorporated into an instrument were not yet on the market. They became available just at the time when the MAT 44 was launched - too late.

The performance of the MAT 44 analyser, especially with respect to resolution, was quite impressive. For example: a maximum resolution of 12000 (50% peak width) could be achieved at masses around 1200 daltons. The reason: hyperbolic quadrupole rods were used instead of the commonly employed round ones. Only two people in the company (father and son) were able to operate the ultrahigh precision grinder which had been installed to make the rods with a mechanical tolerance of 0.001 mm. The grinder had been placed in a separate room, which was strictly off limits for curious visitors.

FINNIGAN MAT (1981 - PRESENT)

Being aware of the shortcomings of the MAT 44 the company developed a completely new computer control system, while keeping the hyperbolic rods of the analyser. The aim was to gather a considerable share of the GC/MS market, which was dominated by Finnigan. The preparation for the introduction of this system (internally named C7) was more extensive than ever before in the history of MAT: Seven systems were built and tested for demonstration and exhibition

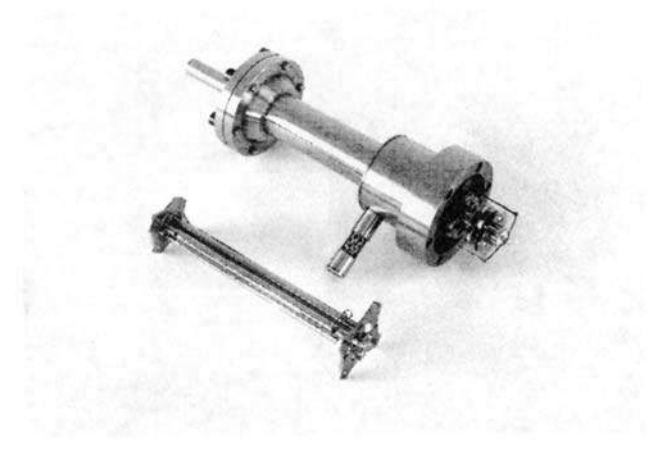


Figure 12. Rod system and vacuum housing of the AMP 3 quadrupole (1962).

purposes (Fig. 13). However in spring 1981, just before the announcement of this new GC/MS-system, Varian sold MAT to Finnigan. The hardware and software structure of the Finnigan and MAT quadrupoles were not compatible, the introduction of the C7 was called off. The seven completed instruments were scrapped. However, the heart of the C7 analyser survived. Finnigan's top-of-the-line quadrupoles were equipped with hyperbolic rod systems from Bremen until the nineties.

Soon after the merger of Finnigan and MAT a fruitful technical cooperation between Finnigan in San Jose and MAT in Bremen was established. R&D people from both organizations met regularly, and some of them worked for weeks or months at a time on either side of the ocean. Bremen especially made use of the broad software expertise which resided in San Jose. Joint "strategy conferences" were set up and an annual research meeting of leading scientists was organized in close coordination between the groups. Modern management techniques were adopted by the Bremen organization, e.g. the execution of R&D programs through teams having no hierarchical structure. MAT people also learned about some subtleties of the American language. For example: the word "problem" had to be replaced by "challenge".

Various new mass spectrometric techniques (such as fast-atom bombardment, LC/MS, MS/MS through QQ-attachments, ion storage, electrospray, atmospheric pressure ionization and others) were spreading during the eighties, and the major mass spectrometry companies were busy developing the required options for their instruments. One of the main instrumental problems (brought up by biochemistry applications) was: How to extend the mass range by increasing the magnetic radius while keeping the overall size of the instrument relatively compact? VG in Manchester, which had become the main competitor of MAT, solved the problem by using an oblique entrance of the ion beam into the magnetic field (entrance angle in the opposite direction as compared to isotope machines). MAT tried out another solution by incorporating an *inhomogeneous* magnetic field (Goethe: "*Who can't make it better, at least makes it different*"). However, the required extremely high accuracy of the contoured pole face could not be machined routinely. Only

one instrument was delivered (MAT 8500). Kratos company (formerly AEI) in Manchester, after long and painstaking development work, finally was able to produce contoured segmented pole faces, which then were used in the successful MS9 instrument: an admirable ion optical and technological achievement.

The high mass market was still expanding. Thus MAT set out for a "quantum leap": A new generation sector instrument for the next ten years was to be developed. A relatively large R&D team was put together for this project. It had not been possible to start the project earlier since most members of the team had been tied up by developing the above-mentioned C 7 quadrupole instrument throughout the preceding two years. When the first design studies were presented to the Finnigan management the reaction was: "Excellent, but cut the price in half!" (Goethe: "*It's impossible, hence it's worth believing*"). Thus the work started all over again. Very detailed ion optical studies were performed in cooperation with leading university experts. Brainstorming sessions were set up under the motto: "Forget what you have done so far, make everything new, better, and - most important - easier to manufacture". One of the suggestions made was to put all electronics on a single board, which should be placed as a kind of "roof" on top of the instrument with the connecting electrical cables simply "dangling down" onto source, tube, magnet and collector (in order to avoid expensive cableforms). The roof later evolved to a flat backplane at the rear of the analyser, which enabled free access to all electronic subunits. The new system, named MAT 90, was presented at the Pittsburgh Conference 1986. It was the world's first commercial double focusing mass spectrometer, completely under computer control.

An enlarged version of this instrument with an extended mass range, representing MAT's top-of-the-line sector, came out a couple of years later (MAT 900). It could be equipped with a novel "electric photo plate", that provided spectrum integration even in the *scanning mode*. The MAT 90 later evolved into the MAT 95 S, which is still in production. A detection limit of about 10^{-15} g for GC/MS trace analyses had been reached with these new instruments, orders of magnitude lower compared to that of the older types. Three MAT 95 S systems were employed for doping control at the Olympic Games in Atlanta in 1996. Excellent detection sensitivity is required for such analyses.

Throughout the last decade, the combination of a magnetic analyser with a quadrupole or ion trap analyser as second stage proved to be a powerful tool for advanced MS/MS analyses (combinatorial chemistry). Such hybrid systems, based on the MAT 95 S and 900 S instruments, have recently been realized by MAT.

ISOTOPES

Mother nature operates a huge isotope lab on earth: All chemical (or nuclear) reactions shift isotope ratios somewhat. Thus, in many cases, the pathway of the reaction can be reconstructed from isotope measurements. Questions that can be answered by isotope mass spectrometry are spread over various disciplines. For example: What is the age of the Alps? (rubidiumstrontium method). What was the climate



Figure 13. C 7 quadrupole GC/MS system, which did not go into production (1981).

like 10000 years ago? ($^{18}\text{O}/^{16}\text{O}$). What was the sea level rise in the Caribbean during the last deglaciation? (uranium-thorium method). What is the percentage of anthropogenic methane on earth? ($^{13}\text{C}/^{12}\text{C}$). Is this honey adulterated? ($^{13}\text{C}/^{12}\text{C}$). How old is the Turin Shroud? ($^{14}\text{C}/^{12}\text{C}$, accelerator mass spectrometry). Where did this explosive come from? ($^{13}\text{C}/^{15}\text{N}$) etc. Besides naturally occurring shifts of isotope ratios, man-made alterations gave rise to an enormous growth of isotope mass spectrometry throughout the last decades (e.g. control of the nuclear fuel cycle, ultratrace analyses by isotope dilution, tracer work in biology and medicine).

Since the changes of the isotope ratios are often very small, users of isotope instruments have to get the utmost in precision and accuracy out of their machines. For a rather long period of time, isotope experts preferred home-made instruments because the opinion was widespread that commercial machines were not up to their demanding standards.

Throughout the history of MAT, isotope activities played an important role, but were much less influenced by priorities of the different owners (Atlas, Krupp, Varian, Finnigan). MAT started its isotope activities in the early fifties, i.e. about 40 years after Aston's confirmation that in fact various individual elements do consist of atoms having different masses. The early isotope machines of MAT were based on modified standard instruments (CH3, CH4). The first instrument, designed solely for isotope work, came out in 1962 (Fig. 14). It was baptized the M86 by the marketing manager because its price was 86 kDM. In those days, the marketing manager was not only responsible for marketing (and naming), but also for various other activities, from house-keeping, purchasing of parts, to transport etc. One of his more unpleasant tasks was to calm down customers when instruments could not be delivered in time (a not unusual situation in the pioneering days). In order to facilitate that duty one day his secretary presented a special gift to him: a turnable drum with a crank to be placed on the desk. Written on

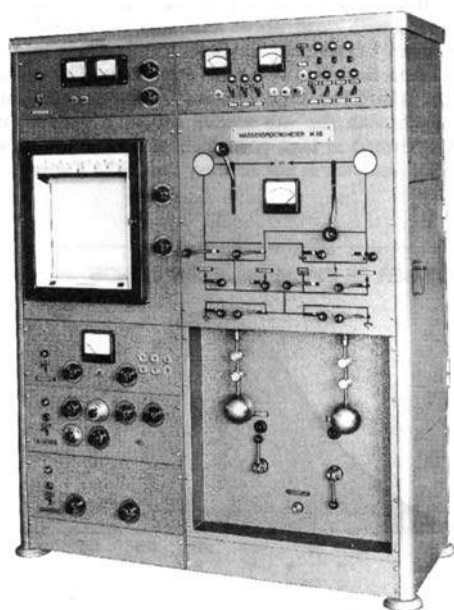


Figure 14. Isotope mass spectrometer M86 for gases (1962).

it were all the excuses he had in his repertoire from: unforeseen breakdown of the transport truck, illness of the test engineer, missing stock parts, defective material etc.

86 kDM was considered somewhat expensive. The need for a low-cost instrument for measurements of C, O, N, and H (as CO_2 , N_2 and H_2) therefore led to the conversion of the small GD 150 into a gas isotope instrument, which was built until 1975. During this period the first desktop computer for scientific applications came out, the HP 9815 (1.8 k memory). Immediately that amazing box was hooked up to the GD 150 and MAT proudly was able to announce the first "computer controlled" commercial mass spectrometer on the market (with the HP computer controlling the switching of the inlet valves and the on-line data processing).

In the late sixties MAT had been asked whether a special mass spectrometer for isotope analysis of gaseous uranium hexafluoride could be produced. UF_6 is nasty stuff. Because insulating layers will build up, a normal electron impact ion source is blocked within a relatively short time after introduction of this gas, and the instrument breaks down (Shakespeare: "What is the body, when the head is off?"). The layers also cause excessive memory effects. MAT developed a unique molecular beam system for the introduction of the sample (its nozzle consisted of 100 microchannels, made of ultrathin corrugated gold sheets). By means of this device the corrosive UF_6 could no more come into contact with the (open) ion source. The technique led to excellent results and is still in use today in the MAT 281.

Although MAT was quite successful with this and other isotope mass spectrometers, VG in the beginning of the seventies were the market leaders in this area of application. VG had developed a number of special instruments for isotope work. Another successful competitor was Nuclide, a small company in the US, specializing in isotope instruments. In contrast to these companies, MAT had derived their isotope instruments from their organic product line (e.g. the CH5-TH/TH5 and the UF5/511 from the successful CH 5). In order to gain a larger share of the isotope market, Varian MAT launched a long-range program in 1975. A completely new generation of isotope instruments for gases and solids was developed and finally introduced in 1978 (MAT 250 for gases and MAT 260 for solids). Both instruments were designed around the same powerful analyser, which had a very high transmission and an enhanced dispersion (oblique magnet boundaries). Moreover, measurements with these instruments were completely under computer control. However, many solid source experts were rather sceptical about computer control, because solid source work was regarded as a kind of art, which obviously could not be mimicked by an ignorant computer. Some experts also gave the advice to the upstart MAT to copy proven designs rather than to come out with unusual ones and customers were reluctant to accept the different approaches of MAT despite good results. Another source of scepticism: The gas instrument MAT 250 (Fig. 15) was regarded as "too big", but MAT had enlarged the size in order to reach an *ultimate* precision and accuracy for measurement of isotope ratios. The MAT 250 set a new standard and a remarkable number of orders from leading laboratories all over the world came in. Despite its relatively large size, the product cost of the

instrument could be kept moderate, since the analysers of the MAT 250 and 260 were more or less identical and thus could be produced on a larger scale. Because of the outstanding measuring accuracy, the MAT 250 led to the MAT 251 HDT for hydrogen/ deuterium/tritium measurements and the MAT 271 for precise gas mixture analyses.

As is well known, the later fate of a technical product is more or less inherent in the basic design principles realized. In favorable cases, when these principles exactly fit future needs, the product may have an "eternal" life (e.g. Volkswagen Beetle). The 250/60 design principle was of this kind and lives on today in the MAT 252 and MAT 262, twenty years later. Recently a novel retarding potential quadrupole as an attachment (RPQ) for the MAT 262 came out. This special collector system improves the abundance sensitivity to better than 10^{-8} which is required for the application of the uranium-thorium disequilibrium where isotope ratios $< 10^{-5}$ have to be determined. An offspring of the MAT 260/262 solid source instruments came out in 1986, the compact THQ, designed primarily for thermionic isotope dilution analyses.

Because most isotope ratio applications require specific sample preparation prior to mass spectrometry, many different preparation devices had been built in research laboratories. The expansion of isotope applications led to a standardization of the methods and also more automation. Thus, from around 1980 onwards, more and more users were asking for integrated systems to handle the natural material (e.g. H_2O , $CaCO_3$, organic matter). Thus, various automated preparation systems have been developed by MAT up to the present day.

In order to replace the low-cost GD 150 (and its successor MAT 230) a few dedicated people within the R&D group started a "skunk works" for a project not officially approved by the management (verdict: "working on such a system is regarded as reading newspapers during working hours"). After one year of "newspaper reading", a prototype of a compact gas isotope instrument was completed, which then was converted into a product, the DELTA (1983). Its successor DELTA^{plus} is one of the main products of MAT's isotope line today.

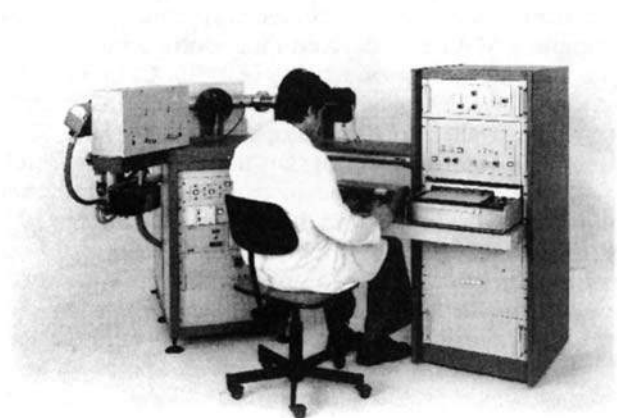


Figure 15. Isotope mass spectrometer MAT 250 for gases (1978).

Another small gas isotope instrument was recently introduced, the BreathMAT, specifically for ^{13}C -tracer measurement of CO_2 in breath (e.g. detection of the bacterium *H. pylori*, now widely believed to play a central role in gastric ulcers).

RECENT DEVELOPMENTS

Throughout the 90's MAT was looking to broaden its mass spectrometry product line. A new horizon had been opened up in biochemistry applications by the new MALDI-technique (matrix-assisted laser desorption and ionization), which for the first time allowed the analysis of very high molecular weight compounds (up to 1 million daltons). This means that after about 100 years development, the majority of chemical compounds on earth are now accessible to mass spectrometry (Fig. 16). In close contact with the pioneers of this technique (Hillenkamp's group in Munster, not far from Bremen) the "sector company" MAT introduced a time-of-flight instrument for biochemistry research in 1991 (VISION 2000, now produced by Thermo Bioanalysis, UK).

Another technology which raised the interest of MAT was elemental trace analysis by ICP-MS (inductive coupled plasma) and GD-MS (glow discharge). All initial ICP work published in the eighties, had been performed with quadrupole analysers (low resolution). As in many organic applications too, isobaric interferences often limit the detection sensitivity. The obvious way out is high resolution. However, the coupling of an ICP torch with the ion source focusing system (normally operated at high potential) of a double focusing magnetic analyser is not an easy task. MAT solved the problem by keeping the source region at ground and floating the complete analyser at high potential. The corresponding mass spectrometer (ELEMENT) came out in 1993. Typical applications of this instrument are in ultra trace analyses down to 1 part in 10^{16} . A number of options (glow discharge source, laser ablation system) recently has enlarged the application range of this instrument.

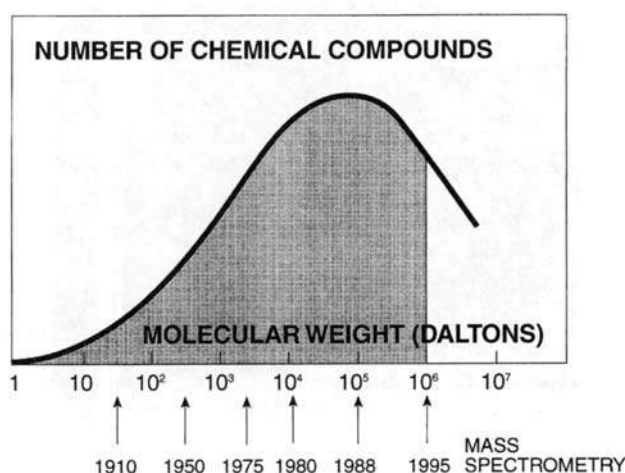


Figure 16. Distribution of chemical compounds on earth (schematic).

This year Finnigan MAT is celebrating its 50th birthday (Finnigan Corporation is now part of ThermoQuest Corporation, a subsidiary of Thermo Instruments Systems Inc., part of ThermoElectron, who bought Finnigan in 1990). It is one of the few mass spectrometry companies which have stayed in the forefront over the years. MAT instruments have been installed in about sixty countries all over the world. Looking back at MAT's eventful history, the statement again comes up (this time with a question mark): *"There's got to be an easier way to make a living?"*. Yes, of course! But not too many activities offer the chance to come into close contact with more or less the whole field of natural sciences from chemistry, biology, medicine, physics, physical chemistry to archaeology, geoscience and even cosmology. Working in this field is rewarding.

Acknowledgements

The author is indebted to the late Erika Jenckel (died 9 February 1997) and Wilhelm Watcher for their inputs. Thanks to his former colleagues Karleugen Habfast, Stefan Meier, Ernst Schroder, and Karl-Heinz Katenkamp for discussions and to Chuck Douthitt for his knowledgeable revision of the text.

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