Evolutions in the Design of Electric Sectors for Mass Analysis

Shortly after Sir J. J. Thomson demonstrated the utility of the parabola mass spectrograph as a means for the analysis of the elements, there was increased interest in designing instruments with better resolving power and sensitivity throughout the physics community. The primary driving force was the observation by Aston of the isotopes of neon2 and the growing importance of the need by the nuclear physics community to know the exact masses of both the stable and radioactive elements.

Physicists soon recognized that improved resolving power for the mass spectrograph depended upon developing some means of energy focusing of ions. The primary means of ionization at the time was the gas discharge tube which created ions with a very large spread of energies. This led to broad diffuse mass spectral lines, with resolving powers on the order of 50 or less. Physicists soon recognized that improved resolving power for the mass spectrograph depended upon developing some means of energy focusing ions.

Accurate Mass Determination of the Elements and their Isotopes

ENGLAND Aston at Cambridge was among the first to employ the addition of an electric sector in the ion optics of his mass spectrograph³. In his first instrument, og 1919, the electric sector consisted of a set of parallel plates immediately after the ion source in the ion optical path. One plate was at ground and the other was at voltage. This device increased



Aston continued to improve on this design, obtaining a resolving power of 600 in his 2nd mass spectrograph4 and finally, in his 3rd instrument a resolving power of 2000 using curved parallel plates and improved ion optics5.

Plates J_1 and J_2 act as an energ spectrometer. By rotating the Slit S_5 , me can select ions with a small energy distribution. It is interesting to note that Aston's instruments had accelerating potentials up to 48 kVdc and the phote

plate was nearly linear in mass. With his 3rd instrument, he was able to accurately determine the isotopic weights



UNITED STATES Dempster at the University of Chicago was among the first outside of Cambridge to utilize mass spectrometry to determine atomic weights and abundances of the elements. His early instrument was actually a mass spectrometer and not a mass spectrograph, based on a simple 180° magnetic sector design6 that would later become famous as the Consolidated Electrodynamics Corporation 21-100 series of instruments. While this instrument had better resolving power than those of Aston at the time, Dempster realized the need to add energy focusing. He proposed such a design in 19227, but did not get around to constructing an instrument until several years later when he reported8 the masses of the isotopes of some of the heavier elements from cadium to uranium.

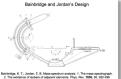
At about the same time, Bainbridge and Jordan at Harvard were developing a much more powerful double focusing mass spectrograph9 capable of resolving powers on the order of 10,000. With this instrument, they reported on six isotopes that were isobaric pairs, Cd113 -In113 In115 , Sn115 and Te123 , Sh123

Dempster modified his original 180° mass spectrometer to be a mass spectrograph in 1935 by adding the electrostatic analyzer in front of the magnetic sector and replacing the detector slit with a photo plate.



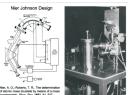
The Harvard mass spectrograph based on this ion optical geometry had a resolving power in excess of 10,000. The electrostatic sector voltages of +/-1215 Vdc were supplied by two sets of twenty seven 45 volt

JAPAN Workers in Japan at Osaka Imperial University¹² used an instrument of the Bainbridge Jordan design to refine the isotopic weights of chlorine, argon and iron in 1940. This instrument was subsequently moth-balled in 1943 and after World War II was reinstalled by Ogata and Matsuda with a resolving power of 58,00013. Matsuda went on to be a major force in the design of high resolving power magnetic sector instruments in Japan reporting in 1956 an instrument capable of 500,000 resolving power14



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Accurate Mass Determination for Elemental Composition of Organic Compounds



The two sector mass spectrometer based on this work was the inspiration for several commercial instruments made and marketed from the late '50s to the

thought that such an instrument could meet or exceed the resolving power of the mass spectrograph. An instrument based on this design was built in 1950 by Nier and Roberts. 16

As the result of the high resolving power mass spectrometer design first constructed by Nier and coworkers, the idea that accurate mass determination of organic molecules could be used as a means of ascertaining their elemental composition led to the development of a 90° electrostatic sector 90° magnetic sector instrument by Metropolitan Vickers, a British company. The prototype of this instrument, the MS-8, was placed in service with Beynon, and proved to be such a success that commercial versions of the instrument, known as the MS-9, were subsequently made and sold.



Nier, who took a National

Research Council Fellowship at

Harvard in 1936, returned to the

University of Minnesota and

spectrometers that could be

outside of the physics

worked on the development of compact inexpensive mass

made and used by investigators

community. In the early '50s, he and Edgar Johnson developed

the theory for a two sector mass

spectrometer15 with first order

velocity focusing and second

order angular focusing. They

to obtain second order double

the mass spectrograph. They

reasoned that it would be easier

focusing at a single point, a slit,

rather than across a plane, as in

Al Nier in his office at the University of Minnesota in the spring of 1989

As the popularity of the MS-9, a mass spectrometer grew, it began to compete with the CEC 21-110, a mass spectrograph, for the accurate mass determination of organic compounds. The MS-9 used an electron multiplier detector, amplifying the minuscule ion current at the image slit as the mass peak was scanned across it. The 21-110 had a photo plate detector which summed the ion current at each mass for the duration of the analysis. Consequently, the mass spectrograph was considered to be more sensitive than the mass spectrometer, since all of the ions formed during the analysis were integrated at the photoplate while only a fraction of the ions for any given mass were detected at the

The drawback of the photo plate used in the mass spectrograph was that it had to be developed in a dark room and subsequently scanned by a photo comparator to process the mass spectral data into electronic form. In the mass spectrometer, the mass spectral data was available in electronic form in real time, as the instrument was being scanned. However, the only way to obtain an accurate mass with the latter instrument was one mass peak at a time by a tedious process known as peak matching. The competition between the mass spectrograph and the mass spectrometer for high resolving power applications lasted for a time, but once computer-based data systems were developed that could process the electronic signals from the high resolving power mass spectrometer, it began to dominate the market for that application.

Scientists in Germany and Japan joined those in the United States and the United Kingdom in competing to develop a variety of double focusing instruments with ever increasing resolving power. Important milestones in the use of electrostatic analyzers for some companies are detailed in the timeline. With the advent of ionization methods that extended the range of applications to large biomolecules, having a large mass range became an important requirement in sector instrument design. The electrostatic analyzer plates on display are from a Vacuum Generators ZAB-SE double focusing mass spectrometer, capable of a mass range of 16,000 Da. In recent years, other mass analyzer concepts have superseded the sector design for achieving high resolving power with a large mass range. While double focusing sector instruments are no longer 'King of the Hill' as they were for several decades, they continue to provide useful data for a broad range of applications, both in academia and industry.





rporation in Monrovia California in 1957.	CEC later manufactured and sole
instrument based on the Mattauch Herzog	geometry in 1959

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1937	1942	1944	1946	1947	1948	1956	1959	1960	1962
CEC orbert Hoover, Jr. orms Consolidated	1st Commercial mass spectrometer	AETROPOLITAN VICKERS Metropolitan	METROPOLITAN VICKERS MS1 1st	ATLAS MAT Atlas Werke forms Atlas Mess und	ATLAS MAT 1st Instrument produced MS1 60°	METROPOLITAN VICKERS MSB 90" Magnetic	CEC 21-110 Mattauch Herzog geometry	CEC CEC became a subsidiary of field.	MS9 based MS8 to Shel