Laboratory and Shop Notes

An Ion "Velocitron"

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June 16, 1948

THE mass spectrometer, in which ions are separated according to mass by passing the beam through a magnetic field, does not lend itself readily to the instantaneous display of the entire spectrum. Observation of the individual ion peaks is too slow when it is desirable to monitor a system in which the composition is changing rapidly as a function of time. The separation may be accomplished without the use of a magnetic field by projecting ion pulses of known energy down a long evacuated drift tube. Since the velocity is related to the charge, mass, and accelerating potential by the expression

$$v=(2eE/m)^{\frac{1}{2}},$$

it is, for constant conditions, inversely proportional to the square root of the mass. The time interval between the arrival of pulses of ions of masses m_1 and m_2 at the end of the tube will be proportional to $L[(m_1)^{\frac{1}{2}}-(m_2)^{\frac{1}{2}}]$ where L is the length of the drift tube from ion source to collector plate.

The pulses may be amplified and applied to the vertical deflection plates of an oscilloscope tube whose horizontal sweep is tripped by the pulse applied to the ion source. The horizontal sweep may be calibrated in microseconds to permit establishing the time of flight and, if the accelerating voltage and length of ion path are known, the mass of the ion corresponding to a pip location on the screen can be calculated.† The resolution between ions of mass difference, m_1-m_2, will be determined by the accelerating voltage, length of drift tube, and by the width in microseconds of the ion pulse which can be produced initially and resolved by the pulse amplifier. The source must produce ions which are nearly monoenergetic, since broadening of the received pulse will occur if this condition is not fulfilled.

A block diagram of the apparatus is shown in Fig. 1. The envelope around the ion source was glass with a standard taper cap to permit making changes in the source structure without glassblowing operations. Electrical leads were brought into the source through single wire tungsten leads arranged radially about the envelope. This region was effectively isolated from the drift tube, since the exit hole for the ion beam was 6 mm in diameter and relatively high pressures could be maintained in the ionization region without adversely affecting the vacuum in the drift tube. A pair of two-stage mercury diffusion pumps with liquid nitrogen traps maintained a pressure of 10^{-5} millimeter of mercury in the drift tube, while a single pump and trap were used to evacuate the source envelope.

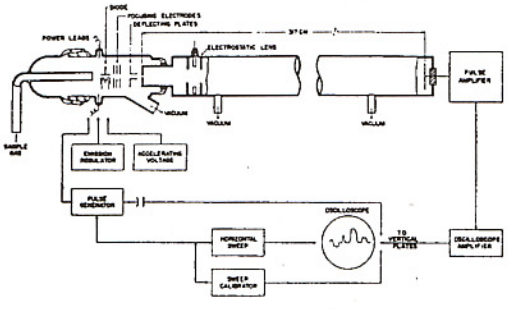

FIG. 1. Schematic diagram of ion "velocitron."

TABLE I.

t, microseconds	Equivalent mass, calc.	Ion	Equivalent mass
35	11	C^+	12
45	18.5	H_2O^+, OH^+Cl^{++}	17–19
60	33	N_2^+, Cl^+, CF^+	28–35
72	46.5	CF_2^+	50
97	86	CF_2Cl^+	85
		E (effective) =480 v	

Accelerating and focusing voltages were obtained from a divider connected across a bank of "B" batteries. The filament supply and the necessary electron accelerating voltages were obtained from an electronically stabilized "emission regulator." Several designs of ion source were tried with no marked improvement over the diode indicated in Fig. 1 in which an orifice between the filament and plate served to define the electron beam. Three apertures, $\frac{1}{8}$ inch in diameter and separated by $\frac{1}{8}$ inch, formed the accelerating and focusing electrodes for the ion beam. The last plate was at ground potential and the first two could be varied independently. The first plate normally operated at 300 volts positive and the second plate at about 500 volts negative to ground. The ion beam was interrupted by applying a 200-volt pulse to one of the two deflecting plates between the lens and the entrance to the drift tube. A unipotential electrostatic lens was installed about one foot from the ion source to insure good collimation of the ion beam. The first and third apertures were operated at ground potential and the second was run at about 500 volts negative.

The four-stage pulse amplifier had a high frequency pass of one megacycle and an input resistance of 1.6 megohms. This was lower than desirable for sensitivity but was necessary to reduce the time constant of the input circuit. This amplifier was coupled to the transmission line through a cathode follower stage. Further gain was obtained in the oscilloscope amplifier. The pattern on the 5LP-5 screen was photographed with a Graflex camera with f:4.5 lens using either orthochromatic or panchromatic film.

The sweep calibrator tripped the pulse generator and also the horizontal sweep of the oscilloscope. A pulse width of five microseconds was usually necessary in order to secure adequate intensity at the receiver. A portion of the pulse from the pulse generator was applied to the vertical deflecting plates of the oscilloscope, through a coupling condenser, to provide a zero time marker. The sweep calibrator applied pips at ten-microsecond intervals to the horizontal trace. Photographs were taken both with and without marker pips since these interfered somewhat with small peaks.

TABLE II.

t, microseconds	Equivalent mass, calc.	Ion	Equivalent mass
13	1.5	H^+, H_2^+	1–2
44	17.7	OH^+, H_2O^+	17–18
55	27.6	N_2^+	28
85	66.0	Hg^{+++}	66.6
103	99.6	Hg^{++}	100.3
150	200.0*	Hg^+	200.6

* Effective voltage calculated from this peak, 480 v. Figure 3B was taken before 3A and it will be noted that the peaks due to water vapor were reduced markedly between the two photographs.

The time delay inherent in the pulse amplifier was determined experimentally by coupling the generator to the first stage and measuring the time interval between the pulse applied directly to the oscilloscope and that applied through the amplifier. A delay of two microseconds was thus established. The patterns were analyzed by reading the time corresponding to the midpoint of rise of the peak. This was justified by the consideration that the pulses arriving at the receiver were broad and, therefore, were collected over an appreciable time interval. Masses were calculated from the observed time intervals by the expression

$$m = t^2E/(5.25\times10^4),$$

in which E is in volts and "t" is in microseconds. The constant contains the length, 317 cm, and the conversion factors necessary to give the expression in the specified units. The voltage was best determined as E (effective) by calculating from an ion peak of known mass. This was higher than that determined by direct reading on the ion source by an amount roughly equal to the energy of the ionizing electrons.

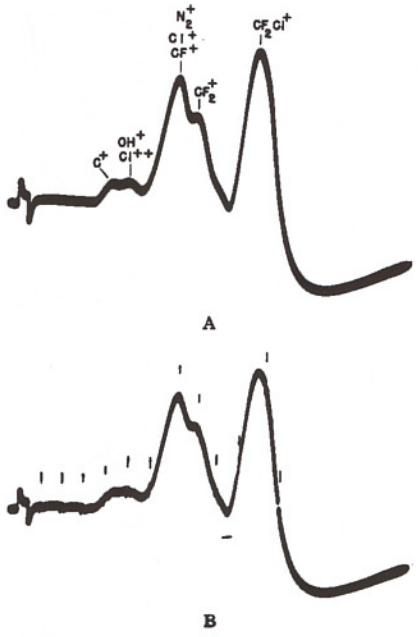

FIG. 2. Oscilloscope pattern with Freon-12 as sample gas. The pattern in A was taken without the 10-microsecond interval marker pips.

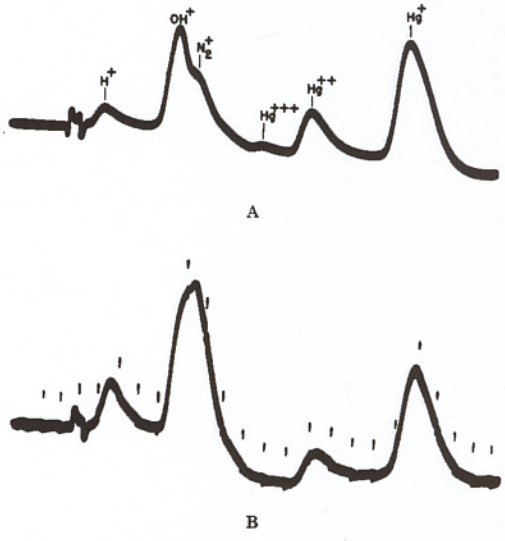

FIG. 3. Oscilloscope pattern obtained with mercury vapor. B was taken before A and includes the marker pips.

Sample gases were introduced through the glass sample line shown in the sketch, controlling the flow by a variable capillary leak. Some patterns were obtained by evaporating solids from an electrically heated furnace supported from the cap.

The pattern obtained with Freon-12 (dichlor-difluoromethane) is shown in Figs. 2A and 2B. The time markers in Fig. 2B were retouched to give them the contrast which they had in the original negative. Table I gives the time intervals observed and the masses calculated by the expression given above, together with the probable identification of the ions. The accelerating voltage directly observed was 320 for this measurement. The identification of the principal peaks may be considered reliable, with the exception of that calculated to be mass 18.5. Fluorine does not form a positive ion readily and the presence of OH^+ or H_2O^+ is rendered somewhat dubious by the absence of a peak corresponding to the hydrogen ion.

The pattern shown in Figs. 3A and 3B is that obtained with mercury vapor by removing the refrigerant from the trap on the source pumping system. As the trap warmed and evolved gases and vapors, a succession of peaks was observed. The final pattern was that shown in 3A. Table II gives the time intervals and the calculated masses.

The limitations of the instrument are readily apparent from an examination of the experimental results. The pulse applied to the ion source was never more than five microseconds wide but the observed peaks are from 20 to 30 microseconds in width. This indicates that the ions were not strictly monoenergetic or that they followed paths of different lengths. Improvements in source structure would undoubtedly reduce this effect. Narrowing the control pulse reduces the intensity and, therefore, the sensitivity, and this cannot be compensated for by increasing the input resistance of the pulse amplifier without unduly increasing the time constant of the first stage. The instrument does, however, lend itself to the display of a mass spectrum

which can be readily observed even though it changes rapidly as a function of time. It was applied with some success to the identification of impurities in volatile inorganic halides.

This document is based on work performed under Contract Number W-7401-eng-23 for the Atomic Energy Project, and the information covered therein will appear in Division I, Book III, of the National Nuclear Energy Series (Manhattan Project Technical Section) as part of the contribution of the Tennessee Eastman Corporation.

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† An apparatus similar to this was proposed by W. E. Stephens of the University of Pennsylvania at a meeting of the Physical Society in Cambridge, Massachusetts, in May 1946. The apparatus described in this paper was near completion at that time. (W. E. Stephens, Phys. Rev. 69, 691 (1946).)

X-Ray Diffraction Film-to-Specimen Gauge

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July 6, 1948

A SIMPLE gauge that allows a rapid and accurate setting of the film-to-specimen distance while taking an x-ray diffraction picture is illustrated in Fig. 1. The stem of the gauge is inserted in the hole of the back reflection film cassette (Fig. 2). The head assembly is

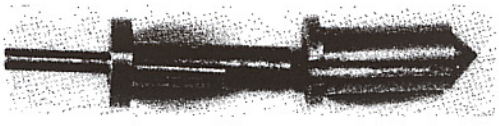

Fig. 1.

extended until the collar passes the fixed rod; the specimen can then be moved up until it touches the tip of the head, and can be locked at this distance. The fixed rod presses against the collar on the head and thus keeps the specimen at the predetermined distance from the film holder. A slight twist of the head will align the rod and a slot so that the head can be slipped back over the fixed rod. This allows enough clearance to remove the entire gauge without disturbing the film of the specimen.

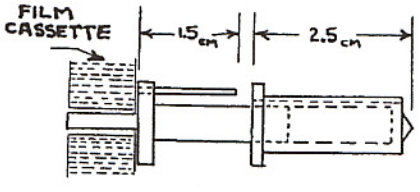

Fig. 2. Film-to-specimen gauge.

The gauge described was turned out of a piece of cold-rolled steel on a lathe. A few modifications of the lengths of the various elements will make it possible to use this gauge for any film-to-specimen distance.

A Method of Increasing Betatron Yield

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July 9, 1948

EARLY in 1945, a device called an orbit contractor, which increases output, was developed for the 22-Mev betatrons under contract OEM-sr-241. It has been found useful on subsequent 22-Mev models. It consists of a wire on each pole face above and below the equilibrium orbit through which a rapidly rising current is started when the electrons are injected. The direction of the current is such as to retard the rate of rise of flux within the orbit. This causes electrons in orbits outside the equilibrium orbit to be suddenly drawn in toward the equilibrium orbit. A large change in the ratio of magnetic field to contained flux is responsible for contraction of orbits at larger radii than that of the coil. For inside orbits this ratio is not changed appreciably; hence the contraction is quite small.

Increasing the current in the coils also decreases the radial variation of magnetic field strength. This should cause a damping of the radial oscillations of the injected electrons. Both the contracting and the field shaping effect should help to avoid collisions between the electrons and the injection electrodes from which they started.

The basic circuit used to induce the reshaping as described is shown in Fig. 1. The plate voltage E is supplied by the turns on the pole faces. When the thyratron is triggered, the current must satisfy $E=L(di/dt)+R'i$, where L and R' are the total inductance and resistance in the loop. Steady currents in the coils have given no increase in yield, whereas starting the transient at the proper time has. The E/L used on the 22-Mev betatron gives about half as many ampere turns per microsecond as are delivered by the main exciting coils.

Some experience with the contractor has led to the following points:

1. An inert gas-filled thyratron operates better than a mercury thyratron.

2. The minimum value of the resistance R is determined by the maximum change in n which seems allowable, n being defined by the radial field variation in the neighbor-

Table I.

Amperes injected	Relative output: With contractor	Relative output: Without contractor	Output ratio
0.51	48	36	1.33
0.04	24	8	3.0
0.02	8	1	8.0