where

$$a_k^1 = t_k \quad a_k^l = \partial x_k / \partial a_{l-1} \quad (l \neq 1).$$

By the formula for differentiating determinants

$$(d/ds)(1/Q) = \sum_{jk} A_j^k (d/ds) a_k^j$$

where A_j^k is the co-factor of a_k^j. Now

$$\frac{d}{ds} a_k^1 = \frac{dt_k}{ds} = \sum_m \frac{\partial t_k}{\partial x_m} \frac{dx_m}{ds} = \sum_m \frac{\partial a_k^1}{\partial x_m} a_m^1.$$

Also, for $l \neq 1$,

$$\frac{d}{ds} a_k^l = \frac{d}{ds} \frac{\partial x_k}{\partial a_{l-1}} = \frac{\partial}{\partial a_{l-1}} \frac{dx_k}{ds} = \sum_m \frac{\partial t_k}{\partial x_m} \frac{\partial x_m}{\partial a_{l-1}} = \sum_m \frac{\partial a_k^1}{\partial x_m} a_m^l,$$

provided that the x_i are uniformly continuous in s and the a_j. Hence, for all values of j,

$$\frac{d}{ds} a_k^j = \sum_m \frac{\partial a_k^1}{\partial x_m} a_m^j$$

$$\therefore \quad \frac{d}{ds} \frac{1}{Q} = \sum_{jkm} A_j^k a_m^j \frac{\partial a_k^1}{\partial x_m} = \sum_{km} \frac{1}{Q} \delta_m^k \frac{\partial a_k^1}{\partial x_m}$$

$$= \frac{1}{Q} \sum \frac{\partial a_k^1}{\partial x_k} = \frac{1}{Q} \Delta \cdot \mathbf{t}.$$

[1] B. Liebowitz, Phys. Rev. 66, 343 (1944).

Detection of Metastable Ions with the Mass Spectrometer

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June 4, 1945

IT has usually been customary to operate mass spectrometers with the filament and electron gun at a positive potential with respect to the analyzer section which is grounded. Under these conditions the ions pass through the exit slit and strike the ion-collector plate with the full energy acquired in the ion gun since this plate is at ground potential. Recently with an instrument of the sector type employing a magnetic deflection of 90°, the first slit in the ion gun was connected to ground while the analyzer section was made negative with respect to ground. Since the ions are formed in a region one or two volts above ground, they reach the collector plate in this arrangement with an energy of only a few electron volts.

This change has had a very interesting effect on the spectra of hydrocarbons. In Fig. 1 a portion of the spectrum of normal butane is shown. The lower curve shows the baseline with the conventional arrangement, and the upper curve shows the improved baseline when the ion source is grounded. These curves were obtained with an automatic recorder employing a non-linear scale with provision for recording large peaks (such as mass 43 which was allowed to go off scale since it is of no concern at the moment). The "hump" on the side of the peak at mass 39 has not previously been investigated carefully but was usually attributed to the formation of $C_3H_3^+$ with kinetic energy. However, it should still be present in the upper curve of Fig. 1 if this explanation is correct. Its disappearance means it must be associated with a loss in energy. Similarly, the disappearance of the diffuse peaks around 30.5 and 32 requires a loss in energy.

The experimental results may be explained by supposing that some of the ions dissociate after acquiring energy in the ion gun, i.e., if metastable ions are formed in the ion source. If this dissociation occurs in the region of the instrument between the ion source and the magnet, the ion will have an apparent mass m^* which has the following relation to m_0, the mass of metastable ion, and m_1, the mass of the ion to which the metastable dissociates,

$$m^* = m_1^2 / m_0.$$

This simple relation assumes that the metastable ion dissociates into two fragments with negligible release of internal kinetic energy. In general, of course, there may be some energy release. Also the dissociation processes in general will follow an exponential decay distribution in time, and so some will occur in the magnetic analyzer and other parts of the instrument giving rise to the observed unsharpness of the peaks. On dissociation the ion has therefore only that fraction of the kinetic energy represented by its fraction of the original mass and is therefore unable to reach the collector when there is a full retarding field between the main analyzer tube and the collector.

The peak around mass 32 can be explained by the dissociation

$$C_4H_{10}^+ \rightarrow C_3H_7^+ + CH_3,$$

giving

$$m^* = (43)^2/58 = 31.9.$$

In this case the parent ion dissociates, and one fragment is the most abundant ion in the *n*-butane spectrum.

Similarly the ionization around mass 30.5 in the spectrum can be explained by the dissociation

$$C_4H_{10}^+ \rightarrow C_3H_6^+ + CH_4,$$

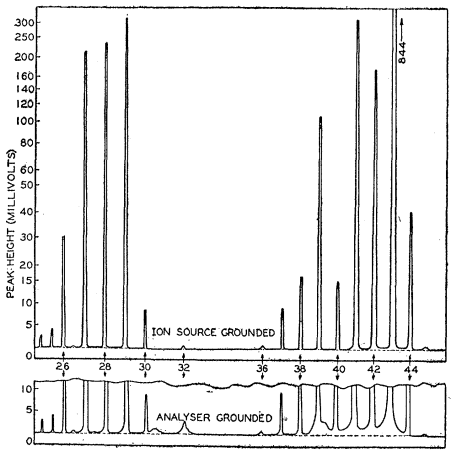

FIG. 1. Portion of the spectrum of normal butane obtained on an automatic recorder employing a non-linear scale. The two curves show the effect on the spectrum of operation of the mass spectrometer with and without the ion source grounded. The disappearance of the diffuse peak at mass 32, for instance, is attributed to the presence of metastable ions in the mass spectrometer. The small residual peak at mass 32 is caused by O_2-impurity in the tube. The original charts have been retouched for reproduction.

giving

$$m^* = (42)^2/58 = 30.4.$$

The hump on the side of mass 39 might be explained by

$$m^* = (40)^2/41 = 39,$$

or

$$m^* = (41)^2/43 = 39.2.$$

Similar peaks have been noticed in the spectra of a great many hydrocarbons, and in all cases the explanation appears to fit into the pattern outlined above. Some other observations on mass spectra of hydrocarbons, such as variation of relative peak heights from one instrument to another, and with initial temperature of the gas, find plausible interpretation as effects due to dissociation of metastable ions.

We wish to thank H. A. Thomas and R. E. Fox for their assistance in this experiment. A more complete report on metastable ions in the mass spectrometer is in preparation.

Further Work on the Artificial Production of Mesotrons

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July 3, 1945

AS reported in an earlier publication, one of us observed a new penetrating radiation in the neighborhood of a cyclotron a few years ago.[1] A detailed investigation showed that this neutral radiation definitely had properties different from those of neutrons and gamma rays.[1,2] The suggestion was made that the radiation consisted of low mass uncharged mesotrons, a hypothesis which was strengthened by the reported occurrence of charged mesotrons of from 10 to 20 electron masses in cosmic radiation.[3] Recently, cloud chamber pictures have been reported[4] which are claimed to confirm the existence of low mass neutral mesotrons. These pictures show electron pairs of high energy emerging in opposite directions from an aluminum plate placed in a cloud chamber situated some distance from the cyclotron and in line with the beam striking the target.

In our earlier publication,[1] it was stated that the electrons which caused the coincidences were of energy greater than 5 Mev. With the arrangement described at that time, experiments have been made to investigate the properties of these electrons by interposing slabs of aluminum between the two coincidence counters. Figure 1 shows the dependence of the coincidence counting rate upon thickness of aluminum (including the equivalent thickness of the two counter walls), when a Mn target is bombarded by the cyclotron. It is seen that the counting rate decreases gradually at first and then quickly drops to zero at a thickness of about 12 mm.

If this behavior is interpreted in terms of a process which leads to the production of single electrons only, then these electrons must be nearly all of the same energy. The second scale of abscissae represents the energy of an electron which is just able to penetrate the corresponding thickness of aluminum, showing that the energy of this homogeneous group would be approximately 6.5 Mev.

If, on the other hand, the much more probable process of the decay of the neutral mesotron into a pair of electrons is assumed, some of the coincidences are caused by one of the pair electrons penetrating both counters and the rest by pairs created between the counters, one electron tripping each counter. From a certain thickness of aluminum on, all the counts will be due to mesotrons decaying between the counters. The third energy scale gives the energy of one of a pair of electrons which could just penetrate half of the corresponding thickness of aluminum having been created in the center of the slab. If this second interpretation is correct, the rest energy of the mesotrons is $2(3.5+.5) = 8$ Mev $= 16\ mc^2$.

An estimate of the cross section for the production of neutral mesotrons is now possible, since the energy of the electrons determines the thickness of lead near the counters which is effective as an electron producing layer and thus determines the effective solid angle subtended by the counter arrangement at the target. If we assume that all counts recorded behind 19 cm of lead[1] are due to the decay of neutral mesotrons which have been slowed down or stopped in the lead, the counting rate behind 28.5 cm of lead gives a measure of the rate of absorption of the mesotrons and enables one to calculate the number of mesotrons leaving the target. Because of the small mass of the particle, the forward direction is probably preferred in the emission process; if we estimate that mesotrons leave the target in the forward direction ten times more often than the number per unit solid angle averaged over all directions, the total cross section for production is found to be 10^{-30} cm^2. The mechanism by which the particles are created is probably similar to the "bremsstrahlung" process postulated in the case of cosmic ray mesotrons.

We have also performed an experiment on the production of charged mesotrons by 11-Mev deuterons using a method of delayed coincidences. For this work, a portion of the deuteron beam was deflected in a magnetic analyzer and piped through the water tanks which surround the cyclotron.[5] The beam was made to strike foils of Al, Ni, Cu, and Pb just thick enough to stop the deuterons. In line

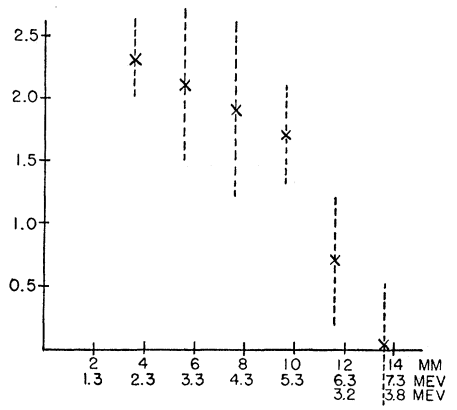

FIG. 1. Coincidences per 10^{17} deuterons striking the target as a function of thickness of aluminum between the counters.