Particle Accelerators as Mass Analyzers

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THE appropriate resonance condition for many of the known particle accelerating machines contains the factor e/m. If a mixture of particles of different masses is injected, the resulting beam should be mass selective. One may speculate on new mass-spectrographic apparatus on this basis. A mass spectrographic apparatus employing this principle would be designed for high beam intensity and mass selectivity rather than high particle velocity, and the dimensions and limitations of such a modified accelerator would differ from those of the familiar high velocity accelerator. The mass constituents of the resulting beam could be "scanned" by changing another parameter in the resonance condition. For example, for a mass analyzer based on the cyclotron principle of operation, governed by the resonance condition $f=eH/2\pi m$, H or f might be varied.

Since it is very desirable to do away with the necessity of having a magnet, a modification of the linear accelerator principle is particularly interesting. Hartman and Smith[1] have briefly described the mass selective properties of the familiar linear accelerator consisting of successive alternately phased cylindrical electrodes and operation with a continuous ion beam. For a given accelerator with ten gaps they have calculated an intensity reduction of the emerging beam of roughly 60 percent when the initial beam consisted of masses of $1.5\,M_0$ as compared to a beam of masses M_0, the latter mass satisfying the resonance condition for maximum acceleration. They have, furthermore, pointed out that no clean mass separation is possible because of the unhindered passage of a portion of ions of masses $M<M_0$ and of certain "harmonic masses" $M=(2m-1)^2M_0$. However, upon dismissing the usual considerations relating to the attainment of high particle velocity, in favor of those pertaining to mass discriminating ability of the system, it appears that useful variations of the familiar accelerator design may result. Recently, W. E. Stephens described[2] work on a mass spectrograph utilizing the velocity modulation of a pulsed beam of mixed ions after traversing a single accelerating field, and measurement of resulting arrival times. An extension of this principle to the use of successive and phased accelerating fields leads to such a system. A pulsed ion beam initially accelerated by a voltage E_1 could be made to travel through a series of n gaps in such a manner that for a given mass M_0 the ion pulses arrive at all gaps at zero phase. In contrast to the usual type accelerator, ions of mass M_0 would now be subject to no additional acceleration. However, dE/dt would be a maximum rather than a minimum at the time of their arrival at the gaps. A frequency of period T would be applied to the gaps of equal spacing S, such that $T=S/v_0$, and the travel time to the first gap may also be made equal to T. An ion with mass differing from M_0 by $\pm\Delta M/M_0$ will experience a phase-shift in arrival time at gap 1 corresponding to a fraction K_1 of a cycle equal to $\mp(\Delta M/M_0)^{\frac{1}{2}}$. These ions will receive an additional acceleration of $\mp E_0 \sin 2\pi K_1$, and thus the resulting arrival times will be shifted in phase by ever increasing amounts at subsequent gaps. At gap n the arrival time will be (as a fraction of T)

$$k_n=\left(\sum_1^{n-1} K_p\right)+\left(1+\frac{E_0}{E_1}\sin 2\pi K_{n-1}\right)^{-\frac{1}{2}}.$$

For the condition: Initial accelerating field $E_1=1.00$ kev, and r-f voltage on electrodes $=1.00 \sin \omega t$ kev, where ω satisfies the resonance condition for ions of mass M_0, we find the following: Ions of mass M_0 emerge with a final velocity of 1.00 kev. For a mass smaller than M by 2 percent, the velocity dispersion after initial 1-kev acceleration, i.e., at the time of arrival at gap 1, is 1 percent. The additional acceleration in the first gap is 0.07 kev; the arrival time at gap 2 is shifted by 4.4 percent, the resulting additional acceleration is 0.26 kev; the arrival time at gap 3 is shifted by 17.4 percent, the additional acceleration is 0.89 kev. Thus after 3 gaps the ions with 2 percent smaller mass emerge with an energy of about 2.2 kev, as compared to 1.0 kev for ions of mass M_0. Ions of 2 percent larger mass are rejected by the third gap. Differentiation of the 1.0-kev beam component in the process of detection would now be relatively simple. With a gap-to-gap distance of 30 cm, the above example would require a frequency range of 4.75 mc to 0.475 mc for masses from 1 to 100.

A device of this nature might therefore be designed to increase the velocity dispersion in existing types of mass analyzers. Passage of "harmonic masses" other than M_0 is possible whenever $M=M_0(m/2)^2$, for all integer m for which M becomes integer. However, the use of a pulsating beam and a method of detection which involves the arrival time of the ions, such as Stephens' method, eliminate any ambiguity introduced by "harmonic masses."

[1] P. L. Hartman and L. P. Smith, Rev. Sci. Inst. **10**, 223 (1939).
[2] W. E. Stephens, paper presented before American Physical Society, Cambridge, Massachusetts, April 26, 1946.

Dispersion of the Velocity of Sound in Normal and Para-Hydrogen

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CONTINUATION of the study of ultrasonic waves in this laboratory has confirmed the dispersion of sound in hydrogen reported by Stewart, Stewart, and Hubbard.[1] In the range of frequency-to-pressure ratio from one to sixty megacycles per atmosphere and at temperatures of 195°, 273°, and 297° absolute we have observed dispersion curves that can be identified with the failure of the rotational specific heat to follow the sound wave. Relaxation times for the transitions of rotational quantum numbers 0–2 and 2–4 for para-hydrogen and 0–2, 1–3, and 2–4 for ortho-para-hydrogen mixtures are being measured.

[1] E. S. Stewart, J. L. Stewart, and J. C. Hubbard, Phys. Rev. **68**, 231 (1945).