Use of Acoustic Fields to Gate, Focus, and Separate Ions at Atmospheric Pressure

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Approaches to control the motion and direction of ionized atoms and molecules are an essential aspect of ion-based analytical methods, such as mass spectrometry (MS) and ion-mobility spectrometry (IMS). Because these species are inherently charged, most ion-manipulation approaches rely upon electrostatic and/or Lorentz forces in electric fields and magnetic fields, respectively. The ability to produce intact gaseous ions for MS and IMS is often performed at atmospheric-pressure (AP) due ease of sample introduction, high ionization efficiencies, and minimal fragmentation. However, diffusion and electrostatic repulsion between ions hinders the transport of gaseous ions into the lower-pressure environment of the analyzers. Conventional ion optics, that use electric or magnetic fields, can guide ions at AP, but require high field strengths to overcome the dominating aerodynamic effects.

Here, we describe a remarkable phenomenon whereby low-power acoustic fields are used to move, shape, gate, and separate beams of gaseous ions at atmospheric pressure. We refer to this approach as Acoustic Ion Manipulation Spectrometry (AIMS). Gaseous ions formed by AP electrical plasmas and other ionization approaches are directed towards and separated by the presence of the acoustic field. To better understand the phenomenon, an ion-detector array provided a measure of bulk ion movement, while mass spectrometry (MS) offered chemical-specific information. As one example of an AIMS setup, a standing acoustic wave was formed with two ultrasonic speakers and placed between an ionization source and ion detector. Ion beams are deflected away from unstable pressure regions (i.e. antinodes) into the pressure-stable nodal areas. Shadowgraphy revealed that the ions are separated from a neutral gas stream. Specific examples of ion focusing, gating, and separation (based on ion size) will be shown. In addition, experimental findings will be used to postulate a theory to develop a better understand of the behavior of gas-phase ions in acoustic fields. This discovery could have profound impacts in analytical ion-based spectrometries, like MS and IMS, as well as in materials processing and characterization.