

3. The appearance of shock waves when the gas flow accelerates to the speed of sound. This is especially the case when a big pressure drop is experienced from regions 5 to 1 (1000 to 1 mbar approximately).

[0043] Returning now to FIG. 1, the preferred embodiment of an ion transport arrangement will now be described in further detail. The features and configuration employed seek to address the limitations on ion transport efficiency identified above.

[0044] The first regions to consider are regions 4 and 3 which define, respectively, the vicinity of the entrance aperture 30 and the expansion chamber 40.

[0045] In order to address ion losses in front of the entrance orifice 30, it is desirable to increase the incoming gas flow into the entrance orifice 30. This is in accordance with the analysis above—for a given ion current, a higher gas flow rate at the entrance to the ion transport arrangement allows to capture larger volume of gas and, given that gas is filled with ions up to saturation, more ions. [Decreasing] the dwell time in regions 3 and 4 conditions the ion stream to a high but not supersonic velocity.

[0046] Thus improvements are possible in Regions 4 and 3, by optimising or including components between the API source 10 and the entrance to the conduit 60. Regions 4 and 3, which interface between Region 5 at atmosphere and Region 2, desirably provide a gas dynamic focusing of ions which are typically more than 4-10 times heavier than nitrogen molecules for most analytes of interest.

[0047] A first aim is to avoid a supersonic flow mode between regions 5 and 2, as this can cause an unexpected ion loss. This aim can be achieved by the use of an entrance funnel 48, located in the expansion chamber 40. Such a funnel 48 is illustrated in FIG. 1 as a series of parallel plates with differing central apertures; the purpose of such an arrangement (and some alternatives) is set out below in connection with FIGS. 2-4. Desirably, the funnel 48 is short (practically, for segmented arrangements such as is shown in FIG. 1, 3 mm is about as short as is possible)—and desirably less than 1 cm long.

[0048] The expansion chamber 40 is preferably pumped to around 300-600 mbar by a diaphragm, extraction or scroll pump (not shown) connected to a pumping port 45 of the expansion chamber. By appropriate shaping of the ion funnel 48, expansion of ions as they enter the expansion chamber 40 can be arranged so as to control or avoid altogether shock wave formation.

[0049] As shown in the above referenced paper by Sunner et. al, even at low spray currents, atmospheric pressure sources (e.g. electrospray or APCI) are space-charge limited. It has been determined experimentally by the present inventors that, even with application of the highest electric fields, API sources are not capable of carrying more than 0.1-0.5\*10<sup>-9</sup> Coulomb/(atm·|cm<sup>3</sup>|). To capture most of this current even for a nanospray source this requires that the entrance aperture 30 has a diameter of at least 0.6-0.7 mm and is followed by strong accelerating and focusing electric field (though it is necessary to keep the total voltage drop below the onset for electric breakdown).

[0050] FIG. 2 is a schematic illustration of a simple arrangement to achieve this strong accelerating and focussing electric field. Here, the inlet aperture 30 is held at a first DC voltage V1 whilst a plate electrode 90 is held at a voltage V2, within the expansion chamber 40 but adjacent to the entrance to the conduit 60. The inlet aperture 30 and the plate electrode

90, with voltage applied, together constitute a simple ion funnel 48. The plate electrode in FIG. 2 has a central aperture which is generally of similar dimension to and aligned with the inner diameter of the conduit 60 but nevertheless acts to funnel ions into the conduit 60. The electrical field between aperture 30 and plate 90 effectively accelerates charged particles, and the fringe field at the opening drags the charged particles into the conduit as these tend to travel parallel to the field lines, even in viscous flow. This electrically assisted acceleration into the conduit region is generally preferred.

[0051] As a development to the simple arrangement of FIG. 2, the space in the expansion chamber 40 between the entrance orifice 30 at voltage V1 and the plate electrode at voltage V2 can comprise further ion lenses or aerodynamic lenses, or combinations of the two. FIG. 3 shows this schematically: an array of plate electrodes 100 is mounted between the entrance orifice 30 and the plate electrode 90 to constitute an ion funnel 48. Each of the electrodes making up the array 100 of plate electrodes has a central aperture generally coaxial with those of the entrance orifice 30 and the plate electrode 90 but each is of differing diameter.

[0052] Various different shapes can be described by the array of plate electrodes 100: in the simplest case the funnel towards the conduit is just flared (linear taper). This is shown schematically in FIG. 4a and is described in further detail in Wu et al, "Incorporation of a Flared Inlet Capillary tube on a Fourier Transform Ion Cyclotron Resonance Mass Spectrometer, J. Am. Soc. Mass Spectrom. 2006 Vol 17, p 772-779. Alternative shapes are shown, likewise highly schematically, in FIGS. 4b and 4c, and are respectively a jet nozzle (Venturi device—see Zhou et al (Zhou, L.; Yue, B.; Dearden, D.; Lee, E.; Rockwood, A. & Lee, M. Incorporation of a Venturi Device in Electrospray Ionization *Analytical Chemistry*, 2003, 75, 5978-5983) and a trumpet or exponential shaped inlet.

[0053] Thus the effect of the arrangements of FIGS. 2 to 4 (and the arrangement shown in the expansion chamber 40 of FIG. 1) is to create a segmented funnel entrance to the conduit 60. In each case, the entrance aperture 30 could be smaller than the diameter of the focusing channel but large enough to allow significant gas flow. The objective of shaping the ion funnel is to convert the volume between the funnel exit and the entrance of the conduit 60 into an analog of a jet separator—a device still widely used in mass spectrometers coupled to gas chromatography. As molecules of analyte are significantly heavier than molecules of carrier gas (typically nitrogen), their divergence following expansion is much smaller than for the carrier gas, i.e. aerodynamic focusing takes place. This effect could be further facilitated by forming the carrier gas at least partially from helium, especially in case of the required voltages being low enough to cope with the lower glow discharge limit of noble gases. As a result, ions are held near the |axis| |and| can be transferred into the central portion of the focusing channel even for a channel diameter not much bigger than that of the funnel, e.g. 0.8-1.2 mm ID. Even though this diameter is larger than for traditional capillaries, the starting pressure is 2-3 times smaller so that it would still be possible to employ a vacuum pump at the end of the funnel of similar pumping capacity to those currently used, e.g. 28-40 m<sup>3</sup>/h. At the same time, active focusing of ions inside the funnel 48 allows the subsequent length of the conduit 60 to be increased without losses. This in turn improves the desolvation of any remaining droplets and clusters. In conse-