

**[0031]** FIG. 6 shows a first embodiment of an alternating voltage conduit which forms a part of the ion transfer arrangement of FIG. 1;

**[0032]** FIG. 7 shows a second embodiment of an alternating voltage conduit,

**[0033]** FIG. 8 depicts a top view of an alternative implementation of the alternating voltage conduit of FIGS. 7 and 8;

**[0034]** FIGS. 9a, 9b, 9c and 9d show alternative embodiments of an ion transfer arrangement in accordance with the present invention; and

**[0035]** FIG. 10 shows exemplary trajectories of ions through an ion transfer arrangement.

#### DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

**[0036]** FIG. 1 shows an ion transfer arrangement embodying various aspects of the present invention, for carrying ions between an atmospheric pressure ion source (e.g. electrospray) and the high vacuum of a subsequent vacuum chamber in which one or more stages of mass spectrometry are situated. In FIG. 1, an ion source 10 such as (but not limited to) an electrospray source, atmospheric pressure chemical ionization (APCI) or atmospheric pressure photoionization (APPI) source is situated at atmospheric pressure. This produces ions in well known manner, and the ions enter an ion transfer arrangement (indicated generally at reference numeral 20) via entrance aperture 30. Ions then pass through a first pumped transport chamber 40 (hereinafter referred to as an expansion chamber 40) and on into a second vacuum chamber 50 containing an ion conduit 60. Ions exit the conduit 60 and pass through an exit aperture 70 of the ion transfer arrangement where they enter (via a series of ion lenses—not shown) a first stage of mass spectrometry (hereinafter referred to as MS1) 80. As will be readily understood by the skilled person, MS1 will usually be followed by subsequent stages of mass spectrometry (MS2, MS3 . . . ) though these do not form a part of the present invention and are not shown in FIG. 1 for clarity therefore.

**[0037]** A more detailed explanation of the configuration of components in the ion transfer arrangement 20 of FIG. 1 will be provided below. In order better to understand that configuration, however a general discussion of the manner of ion transport in different pressure regions between atmosphere and forevacuum (say, below about 1-10 mbar) will first be provided.

**[0038]** Ion transport is characteristically different in the different pressure regions in and surrounding the ion transport arrangement 20 of FIG. 1. Although in practice the pressure does not of course change instantaneously at any point between the ion source and MS1 80, nonetheless five distinct pressure regions can be defined, with different ion transport characteristics in each. The five regions are marked in FIG. 1 and are as follows:

**Region 1.** This is the region where entrance ion optics of MS1 is situated, with pressures below approx. 1-10 mbar. This region is not addressed by the present invention.

**Region 5.** This is the atmospheric pressure region and is mostly dominated by dynamic flow and the electrospray or other atmospheric pressure ionization source itself. As with Region 1, it is not directly addressed by the present invention. This leaves Regions 2, 3 and 4.

**Region 4:** This is in the vicinity of the entrance orifice 30 to the ion transport arrangement 20.

**Region 2:** This is the region in which the conduit 60 is situated, which abuts the exit aperture 70 of the ion transport arrangement 20 into MS1. Finally,

**Region 3:** This is the region between the entrance orifice 30 (Region 4) of the ion transport arrangement 20, and Region 2 as described above.

**[0039]** Measurements of the ion current entering the ion transport arrangement (at the entrance orifice 30) of a typical commercially available capillary indicate that it is in the range of  $I_0 \approx 2.5$  nA. Hence, knowing the incoming gas flow value  $Q = 8 \text{ atm} \cdot \text{cm}^3/\text{S}$ , and the inner diameter of the conduit of 0.5 mm, the range of the initial charge density  $\rho_0$  may be estimated as  $0.3 \cdot 10^{-9} \text{ C/cm}^3 = (0.3 \cdot \cdot \cdot 1) \cdot 10^{-3} \text{ C/m}^3$ . Knowing the dwell time of the ions inside the conduit,  $t = 0.113 \text{ m}/50 \text{ m/s} \approx 2 \cdot 10^{-3} \text{ s}$ , and the average ion mobility value at atmospheric pressure  $K = 10^{-4} \text{ m}^2/\text{s}$ , the limit of the transmission efficiency because of the space charge repulsion can be determined from:

$$\left[ \frac{\rho}{\rho_0} \right]_{sc} = \frac{1}{1 + \frac{\rho_0 K t}{\epsilon_0}} = \frac{1}{1 + \frac{\rho_0 \cdot 10^{-4} \cdot 2 \cdot 10^{-3}}{8.85 \cdot 10^{-12}}} \approx 0.13$$

**[0040]** Thus to improve ion current (which is an aim of aspects of the present invention), the ion mobility and ion dwell time in the conduit are preferably optimized.

**[0041]** An essential part of the ion loss in an atmospheric pressure ionization (API) source takes place in the ionisation chamber in front of the entrance orifice 30 of the interface. This proportion of the ion loss is determined by the ion/droplet drift time from the Taylor cone of the API source to the entrance orifice 30. The gas flow velocity distribution in vicinity of the entrance orifice 30 is

$$V_{gas} = \frac{Q_{gas}}{2\pi R^2} = C(P)\Delta P \frac{d^4}{R^2},$$

where  $d$  is the diameter of the conduit, and  $R$  is the distance from the point to the entrance orifice 30,  $C$  is a constant and  $\Delta P$  is pressure drop. The ion velocity is  $V_{ion} = V_{gas} + KE$ , where  $K$  is the ion mobility, and  $E$  is the electrical field strength. Assuming that  $K \sim 10^{-4} \text{ m}^2/\text{s}$ , and  $E \sim 5 \cdot 10^5 \text{ V/m}$ , the velocity caused by the electrical field is  $\sim 50 \text{ m/s}$ . The gas flow velocity inside the 0.5 mm ID conduit is about the same value, but at a distance 5 mm from the entrance orifice 30, ions travelling with the gas are about 10 times slower than their drift in the electrical field. Hence, the ion dwell time in this region is in the range of  $10^{-4} \text{ s}$ , which results in an ion loss of about 50% because of space charge repulsion according to equation (2) above.

**[0042]** In other words, analytical consideration of the ion transfer arrangement suggests that space charge repulsion is the main ion loss mechanism. The main parameters determining the ion transmission efficiency are ion dwell time  $t$  in the conduit, and ion mobility  $K$ . Thus one way to improve ion transport efficiency would be to decrease  $t$ . However, there is a series of limitations on the indefinite increase of  $t$ :

1. The time needed to evaporate droplets;
2. The critical velocity at which laminar gas flow transforms into turbulent gas flow; and