

$$R_d = \sqrt{\frac{zeEL_d}{kT \ln 2}},$$

where z is the number of elementary charges e , E the electric field strength, L_d the length of the drift region, k the Boltzmann constant, and T the temperature of the gas in the drift region. A high mobility resolution may be achieved using a high field strength E , long drift regions L_d , or low temperatures T . The part R_d of the mobility resolution that is given by the diffusion is independent of the type and pressure of gas in the drift region. The mobility K_0 itself, however, is dependent on the temperature, the pressure and the type of gas in the drift region.

[0014] Compared to the numerical values for mass resolutions in mass spectrometry, the mobility resolutions that are achieved in practice are generally relatively low. Typically, commercial ion mobility spectrometers for bioorganic ions have mobility resolutions of R_{mob} equal to 10 to 15. With a mobility resolution of $R_{mob}=10$, two ion species whose collision cross-sections differ by only 20 percent can be separated relatively well.

[0015] Some highly specialized academic groups have been able to achieve significantly higher mobility resolutions of between R_{mob} between 60 and 100, and in rare individual cases up to R_{mob} equal to 150, with drift lengths roughly between two and six meters and field strengths between approximately 2,000 and 4,000 volts per meter. Under these conditions, ion species whose mobilities differ by merely one to three percent may be differentiated. Hereinafter, the term "high resolution" shall refer to resolutions of R_{mob} above 60.

[0016] A strong transverse diffusion may also occur in long mobility drift regions. Longer drift regions therefore should have a large diameter such that the ions do not touch the wall electrodes. The ions may be guided back to the axis of the drift region after having travelled approximately two meters through the drift region. This is accomplished using an "ion funnel". An ion funnel includes a plurality of parallel ring diaphragms, where each diaphragm is separated from adjacent diaphragms by a relatively small distance (e.g., in the order of millimeters). The ring diaphragms have aperture diameters that continuously taper from the diameter of the drift region (e.g., 30 to 40 centimeters) down to around two to five millimeters, which forms a funnel-shaped enclosed volume. The two phases of an RF voltage, usually of several megahertz and between a few tens of volts and one hundred volts, are applied alternately to the apertured diaphragms, thus generating a pseudopotential that keeps the ions away from the funnel wall. A DC electric field is superimposed on the RF voltage by a DC voltage gradient. The electric field pushes the ions slowly towards and then through the narrow exit of the funnel. Alternatively, such an ion funnel does not measurably reduce the mobility resolution of a long drift region.

[0017] Ion funnels are also used in mass spectrometers to capture larger ion clouds and to thread these ion clouds into narrow ion guides. Referring to FIG. 5, ion funnels are often found in mass spectrometers with electrospray ion sources. The ions generated outside the vacuum system are transferred, together with a curtain gas, through inlet capillaries and into the vacuum. The ions are then captured by ion funnels and freed of most of the curtain gas. Some mass spec-

trometers may include two ion funnels, placed in series, in order to move the ions quickly from regions with higher pressure of several hectopascals at the end of the inlet capillary to regions with lower pressure of around 10^{-2} to 10^{-6} pascal.

[0018] High-resolution time-of-flight mass spectrometers with perpendicular injection of the ions (OTOF-MS), for example, have successfully been combined with mass spectrometers. Disadvantageously, however, such high-resolution ion mobility spectrometers are typically several meters long and, thus, are not commercially viable. Even ion mobility spectrometers having a straight drift region with moderate resolutions are approximately one meter long.

[0019] There is a need for a high resolution ion mobility spectrometry.

SUMMARY OF THE INVENTION

[0020] The present invention includes methods and devices for generating (a) a gas jet having molecules with substantially equal velocities and (b) a field barrier having a substantially uniform height across the cross-section of the gas jet. Under these conditions, the ions in the gas can be sorted according to their mobilities with a high mobility resolution. The gas jet is generated using a sharply focused supersonic gas jet from a Laval nozzle. Such a supersonic gas jet has a low temperature of a few Kelvin, a low pressure and substantially equal velocities for the molecules, with only a relatively small statistical variance in the velocity due to the low temperature. The field barrier is generated by applying suitable voltages on at least three thin apertured diaphragms. Where, for example, the apertured diaphragms R_2 , R_3 and R_4 have the same aperture diameter, are separated by distances d_2 and d_3 respectively, and have potentials U_2 , U_3 and U_4 applied to them, a field barrier with uniform height can be generated in the middle aperture diaphragm across the entire apertured diaphragm when the relation $(U_4-U_3)/(U_3-U_2)=d_3/d_2$ is maintained.

[0021] The ion mobility spectra are acquired by measuring the current of the ions that are pushed over the field barrier in the apertured diaphragm R_3 by the supersonic gas jet. The ions are pushed as a function of the height of the voltage $V=(U_4-U_2)$ at the apertured diaphragms, which is proportional to the height of the potential barrier. During this process, the ions are constantly replenished by the ion source. When the field barrier is changed continuously or incrementally, a total ion current curve is measured at the ion detector. The total ion current curve represents an integral over the mobility spectrum. Differentiation of the total ion current curve with respect to the height of the potential barrier provides the mobility spectrum of the ions. The method of acquiring mobility spectra may be calibrated using ions of known mobility. The mobilities of the ions can be derived from calibrated mobility spectra.

[0022] The ion current may be measured and separated according to mass by a mass analyzer, in the form of a series of mass spectra as a function of the height of the voltage $V=(U_4-U_2)$ at the apertured diaphragms, using, for example, a time-of-flight mass spectrometer with orthogonal ion injection. Individual ion current curves for ions of individual mass ranges may then be derived from the series of mass spectra. Differentiating the individual ion current curves provides ion mobility spectra for individual mass ranges. The mass ranges can cover ions of several masses, such as the masses of an isotopic group, or ions of a single mass.