

ION ATTENUATION DEVICE

5 CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from and the benefit of United Kingdom patent application No. 2317200.0 filed on 9 November 2023, the entire contents of which are incorporated herein by reference.

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FIELD OF THE INVENTION

The present invention relates generally to the field of mass spectrometry and/or ion mobility spectrometry. More specifically, the present invention relates to attenuating ions.

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BACKGROUND

It is known to attenuate ions in a mass spectrometer, for example, in order to prevent high ion currents from saturating an ion detector or mass analyser.

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It is desired to provide an improved technique of attenuating ions.

SUMMARY

According to a first aspect, the present invention provides a mass and/or mobility spectrometer comprising: an ion attenuation device comprising an ion guide and an ion attenuator arranged within the ion guide, wherein the ion attenuator is configured to repeatedly switch between a high attenuation mode in which it attenuates ions at a first rate and a low attenuation mode in which it attenuates ions at a lower rate; wherein the spectrometer is configured to maintain the ion attenuation device at a pressure such that different groups of ions that are transmitted by the ion attenuator in different respective low attenuation modes merge with each other downstream of the ion attenuator.

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The groups of ions may merge with each other within the ion guide, downstream of the ion attenuator. The ions may therefore exit the ion attenuation device as a substantially continuous ion beam.

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At least a portion of the ion attenuation device that is downstream of the ion attenuator may be arranged at a pressure of $\geq 10^{-3}$ mbar. The whole length of the ion attenuation device may be maintained at such a pressure. In other words, the portion of the ion attenuation device at which the ion attenuator is located, and optionally also the portion that is upstream, may be maintained at a pressure of $\geq 10^{-3}$ mbar.

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The provision of the ion attenuator within the relatively high pressure ion guide enables the ion attenuation device to merge the groups of ions that are transmitted in the low attenuation modes, and hence reduce the maximum ion current that is transmitted from the exit of the ion attenuation device, without having to transfer the attenuated ions into a

separate high pressure region located downstream of the ion attenuation device. Rather, according to the embodiments of the present invention, the ions remain radially confined within the ion guide before and after attenuation. This also avoids the requirement to align separate ion guides arranged on either side of the ion attenuator.

5 The spectrometer may comprise electronic circuitry that is configured to control the ion attenuator so as to automatically and repeatedly switch between the high and low attenuation modes, e.g. during a single experimental run. For example, the ion attenuator may repeatedly switch back and forth between the high and low attenuation modes at a rate of between 10 Hz and 10 kHz.

10 Ions may be completely attenuated during the high attenuation mode, i.e. such that no ions are transmitted by the ion attenuator.

Ions may substantially not be attenuated by the ion attenuator during the low attenuation mode.

15 The ion guide may comprise a plurality of electrodes configured to guide ions along an axis, wherein the electrodes are arranged in a plurality of axial segments that are spaced apart along the axis of the ion guide, and wherein the ion attenuator is arranged axially between two of the axial segments of the ion guide.

A plurality of the axial segments of the ion guide may be located upstream and/or downstream of the ion attenuator.

20 The ion guide comprises one or more voltage supply for applying one or more voltage to the electrodes, such as one or more RF voltage, in order to radially confine ions within the ion guide.

25 The ion guide may comprise one or more voltage supply for applying different voltages, such as DC voltages, to electrodes in different ones of the axial segments for urging ions downstream through the ion guide.

30 The one or more voltage supplies may be configured to apply different DC voltages to electrodes in different axial segments over a first length of the ion guide that is located upstream of the ion attenuator so as to generate a first DC gradient over the first length, and to apply different DC voltages to electrodes in different axial segments over a second length of the ion guide located downstream of the ion attenuator so as to generate a second DC gradient over the second length. The first and second DC gradients may be the same or they may be different. The voltage applied to the electrode in the axial segment that is at the downstream end of the first length and the voltage applied to the electrode in the axial segment at the upstream end of the second length may create a potential difference between them that creates electric field penetration into the ion attenuator that drives ions downstream through the ion attenuator. The axial electric field strength (along the central axis) within the ion attenuator may be the same as, or different to, the axial electric field strength (along the central axis) of the first and/or second lengths of the ion guide.

40 Additionally, or alternatively, one or more DC voltage may be successively applied to successive electrodes of the ion guide such that one or more DC potential is repeatedly travelled along the ion guide so as to urge the ions downstream through the ion guide.

All of the electrodes of the ion guide may be arranged in a single vacuum chamber of the spectrometer.

A differential pumping aperture may not be provided within or around the ion guide.

5 All of the axial segments of the ion guide may be electrically connected via a resistor chain for applying voltages to the electrodes in the axial segments for urging ions downstream through the ion guide.

Ion guide electrodes along the entire length of the ion guide may be directly connected to the same support member.

10 Substantially all of the electrodes of the ion guide and the ion attenuator may be sandwiched between two printed circuit boards (PCBs) such that the electrodes of the ion guide and the ion attenuator are mechanically and electrically connected to the PCBs.

The ion guide may be an axially segmented quadrupole ion guide that is formed from four rows of electrodes, wherein two of the rows of electrodes are electrically connected to a first of the PCBs and two different rows of electrodes are electrically connected to a second of the PCBs.

15 It is alternatively contemplated that substantially all of the electrodes of the ion guide and the ion attenuator may be mechanically and electrically connected to a single PCB.

The electrodes of the ion attenuator may replace a single axial segment of the axially segmented ion guide. Accordingly, the ion guide may comprise a plurality of electrodes configured to guide ions along an axis, wherein the electrodes are arranged in a plurality of axial segments that are spaced apart along the axis of the ion guide and each have the same width in the axial direction; wherein any given one of these axial segments is axially spaced from each of its adjacent axial segments by the same spacing, except for the space between the axial segments in which the ion attenuator is located; and wherein all of the electrodes of the ion attenuator are arranged within an axial space that is substantially the same, or smaller, than the width of one of the axial segments of the ion guide.

20 The ion attenuator may comprise at least one electrode arranged within the ion guide and a voltage supply arranged and configured to apply a voltage to the electrode in the high attenuation mode so as to reflect, deflect or defocus ions passing through the ion attenuator such that they are attenuated at said first rate, and to apply a different voltage to the electrode in the low attenuation mode so as to reflect, deflect or defocus ions passing through the ion attenuator to a lesser extent such that they are attenuated at said lower rate.

35 As described above, ions may substantially not be attenuated by the ion attenuator during the low attenuation mode and/or ions may be substantially fully attenuated during the high attenuation mode such that no ions are transmitted by the ion attenuator.

40 The ion attenuator may comprise an upstream electrode and a downstream electrode that is arranged downstream of the upstream electrode, wherein the ion attenuator is configured to apply a voltage to the downstream electrode in the high

attenuation mode so as to reflect ions passing through the ion attenuator such that they strike the upstream electrode.

The ion attenuator may be configured such that the reflected ions strike a downstream surface of the upstream electrode which is, optionally, substantially orthogonal to the axis through the ion guide.

Reflecting the ions onto the downstream surface of the upstream electrode avoids these ions hitting other regions and causing surface charging at locations where this would adversely affect the passage of ions through the ion attenuation device in the low attenuation mode.

The spectrometer may comprise one or more further ion attenuators within the ion guide, wherein each of the one or more further ion attenuators is configured to repeatedly switch between a high attenuation mode in which it attenuates ions at a first rate and a low attenuation mode in which it attenuates ions at a lower rate.

Each of the one or more further ion attenuators may have corresponding features to the ion attenuator described above.

The pressure, and the ion attenuators, in the ion attenuation device may be arranged such that the groups of ions that are transmitted by each of the ion attenuators in the low attenuation modes merge with each other before these ions reach the subsequent ion attenuator in the downstream direction.

The final ion attenuator in the ion attenuation device is preferably arranged such that the groups of ions transmitted by it in the low attenuation modes merge with each other before the ions reach the exit of the ion attenuation device.

The spectrometer may comprise a first vacuum chamber configured to be maintained at a first pressure and a second vacuum chamber configured to be maintained at a lower pressure, wherein the ion attenuation device is located within the second vacuum chamber with its entrance end mounted to a differential pumping aperture between the first and second vacuum chambers so as to form a gas tight seal around its entrance, and wherein the circumference of the ion attenuation device is sealed in a gas tight manner over at least a portion of its length starting from its entrance end.

Such an arrangement enables the gas pressure within said at least a portion of the ion attenuation device to be maintained higher than the pressure in the rest of the second vacuum chamber, since gas flows from the higher pressure first vacuum chamber into the sealed portion of the ion attenuation device.

The spectrometer may comprise a charge detection mass spectrometry ion analyser, or a time of flight mass analyser, arranged to receive and analyse ions transmitted by the ion attenuation device, or to receive and analyse ions derived therefrom.

The time of flight mass analyser may be a multi-reflecting time of flight mass analyser having at least two ion mirrors that reflect ions multiple times as they travel to a detector that determines the mass to charge ratios of the ions based on their flight time through the mass analyser.

The charge detection mass spectrometry ion analyser or the time of flight mass analyser may be arranged at a pressure of $\leq 10^{-8}$ mbar or 10^{-9} mbar.

The entire ion path between the downstream end of the ion attenuation device and the charge detection mass spectrometry ion analyser or time of flight mass analyser may be a pressure that is equal or lower than the lowest pressure inside the ion attenuation device.

5 The ion attenuation device described herein is novel in its own right. As such, from a second aspect the present invention provides an ion attenuation device comprising an ion guide and an ion attenuator arranged within the ion guide, wherein the ion attenuator is configured to repeatedly switch between a high attenuation mode in which it attenuates ions at a first rate and a low attenuation mode in which it attenuates ions at a lower rate.

10 The ion attenuation device may be configured to be maintained at a pressure such that different groups of ions that are transmitted by the ion attenuator in different respective low attenuation modes merge with each other downstream of the ion attenuator.

 The ion attenuation device may have any of the features described herein, such as those described in relation to the first aspect of the invention without being limited to the other features of the spectrometer.

15 The present invention also provides a method of attenuating ions using the ion attenuation device described herein.

 Accordingly, the present invention provides a method of mass and/or mobility spectrometer comprising: providing a spectrometer or ion attenuation device as described
20 herein; supplying ions into an upstream end of the ion attenuation device; repeatedly switching the ion attenuator between the high attenuation mode in which it attenuates ions at the first rate and the low attenuation mode in which it attenuates ions at the lower rate; and wherein the ion attenuation device is maintained at a pressure such that different groups of ions that are transmitted by the ion attenuator in different respective low
25 attenuation modes merge with each other downstream of the ion attenuator.

 The ions that are supplied to the ion attenuation device are guided to the ion attenuator by the ion guide, and the ions that are transmitted by the ion attenuator are guided to the downstream end of the ion attenuation device by the ion guide.

 The method may comprise mass and/or ion mobility analysing ions transmitted by
30 the ion attenuation device, or ions derived therefrom, using a mass analyser or ion mobility analyser.

 For example, the ions may be analysed using a charge detection mass spectrometry ion analyser, or a time of flight mass analyser.

35 BRIEF DESCRIPTION OF THE DRAWINGS

 Various embodiments of the present invention will now be described, by way of example only, and with reference to the accompanying drawings in which:

 Figs. 1A-1E shows different views of an ion attenuation device according to an
40 embodiment of the present invention, whereas Fig. 1F shows the ion attenuator electrodes;

 Fig. 2 shows a view of an ion attenuation device according to an embodiment of the present invention having two ion attenuators within the ion guide; and

Fig. 3 shows an embodiment of a mass spectrometer according to an embodiment of the present invention.

DETAILED DESCRIPTION

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Embodiments of the present invention relate to an ion attenuation device for attenuating an ion beam passing therethrough. The device may be used, for example, to avoid saturation or extend the dynamic range of a downstream mass analyser or other detector.

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Figs. 1A-1B show different perspective views of an ion attenuation device 1 according to an embodiment of the present invention. Fig. 1C shows a cross-sectional view of the ion attenuation device when viewed from one side. The ion attenuation device comprises an upstream end 2 for receiving ions, a downstream end 4 from which ions exit, and an ion guide 6 arranged therebetween for guiding ions along an axis. The ion attenuation device may also have a conical entrance lens 8 at its upstream end, arranged upstream of the ion guide 6. As will be described in more detail below, a pulsed ion attenuator 10 is arranged within the ion guide 6 for attenuating ions passing through the ion guide. In the embodiment shown, the ion guide and pulsed ion attenuator are sandwiched between two printed circuit boards (PCBs) 12, 14 such that the electrodes of the ion guide and pulsed ion attenuator are electrically connected to the PCBs. This enables the PCBs to apply the required voltages to the electrodes and also to mechanically constrain the electrodes of the ion guide and pulsed ion attenuator in their desired locations. The PCBs may be maintained at fixed positions relative to each other by fixture rods 16. However, it will be appreciated that the use of PCBs is not essential and that the ion guide and pulsed ion attenuator may be supplied with voltages and mechanically mounted relative to each other using other means.

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The ion attenuation device is to be mounted into a vacuum chamber of a mass and/or mobility spectrometer. As such, the ion attenuation device may have mounting components at one or both ends for mounting the ion attenuation device in the vacuum chamber. For example, the ion attenuation device may have the illustrated mounting flange 18 at the upstream end and/or a mounting block 20 at the downstream end. These mounting components may be made from an electrical insulator, such as PEEK. At least the mounting component at the upstream end may be configured to mount the upstream end of the ion attenuation device to an aperture in a wall of the vacuum housing. As such, the mounting component may include a seal, such as O-ring seal 22, for providing a gas tight seal between the aperture and the ion attenuation device. However, it is contemplated that the mounting flange 18 may not be provided and that the ion attenuation device may simply be arranged within the vacuum chamber of the mass and/or mobility spectrometer such that the inlet aperture of the ion attenuation device is arranged at or within the entrance aperture to the vacuum chamber and the exit aperture of the ion attenuation device is arranged at or within the downstream exit aperture to the vacuum chamber.

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Fig. 1D shows a view when the PCBs 12, 14 are separated from each other such that the electrodes of the ion guide 6 and the electrodes of the ion attenuator 10 can be seen. In the depicted embodiment, the ion guide is an axially segmented quadrupole ion guide that is formed from four rows of electrodes. Two of the rows of electrodes may be electrically connected to and mounted directly on a first of the PCBs 12 and the other two rows of electrodes may be electrically connected to and mounted directly on the second of the PCBs 14. Each electrode of the ion guide may be formed from a bent metal plate, although it will be appreciated that other forms of electrode may be used. When the ion attenuation device is constructed, the PCBs are arranged parallel to and facing each other (as shown in Figs. 1A-1B) such that the four rows of electrodes are aligned so as to form the ion guide. An RF voltage supply is provided for applying RF voltages to the electrodes of the ion guide, via the PCBs, in the usual manner so as to generate an electric field that radially confines the ions within the ion guide. For example, one phase of an RF voltage may be applied to the electrodes in the upper row of electrodes that is arranged on the first PCB, and also to the electrodes in the lower row of electrodes that is arranged on the second PCB. The opposite phase of the RF voltage may be applied to the electrodes in the lower row of electrodes that is arranged on the first PCB, and also to the electrodes in the upper row of electrodes that is arranged on the second PCB.

DC voltage supplies may also be provided for applying DC voltages to the electrodes of the ion guide, via the PCBs, so as to generate an axial electric field that urges ions downstream through the ion guide. More specifically, the voltage supplies may be configured such that different DC voltages are applied to electrodes that are arranged at different axial positions along the ion guide, so as to urge the ions downstream.

The ion attenuator 10 may comprise at least one electrode that is arranged within the ion guide 6. The ion attenuator may comprise a first electrode 10a that is arranged the first PCB 12 at a location that is axially between two axial segments of the ion guide. The ion attenuator may also comprise at least a second electrode 10b, and preferably also a third electrode 10c, arranged on the second PCB 14 at a location between two axial segments of the ion guide 6. As will be discussed further below, DC voltage supplies may also be provided for applying DC voltages to the electrodes of the ion attenuator, via the PCBs, in order to attenuate the ions passing through the ion guide.

Fig. 1E shows a cross-sectional view through the portion of the ion attenuation device in Figs. 1A-D that includes the ion attenuator 10, whereas Fig. 1F shows a perspective view of the electrodes of the ion attenuator in isolation. As described above, the first electrode 10a of the ion attenuator is arranged axially between axial segments of the ion guide 6 that are arranged on the first PCB 12, and the second and third electrodes 10b, 10c of the ion attenuator are arranged axially between axial segments of the ion guide 6 that are arranged on the second PCB 14. The first electrode 10a is arranged opposite to the second and third electrodes 10b, 10c.

As best shown in Fig. 1F, the first electrode 10a cooperates with each of the second and third electrodes 10b, 10c so as to define an aperture 24 therebetween for the ions to pass through. The first electrode 10a may be thicker, in the axial direction, than

each of the second and third electrodes 10b, 10c. For example, the first electrode 10a may have a thickness of 4mm, whereas each of the second and third electrodes 10b, 10c may each have a thickness of 1.5 mm. The second and third electrodes 10b, 10c may be arranged between the upstream and downstream sides of first electrode 10a.

5 The electrodes of the ion attenuator 10 may replace a single axial segment of an axially segmented ion guide 6 that is uniformly segmented in the axial direction. For example, the ion guide may be formed from a plurality of axial segments located at different axial positions along the ion guide, where these axial segments have the same width in the axial direction. Any given one of these axial segments may be axially spaced
10 from each of its adjacent axial segment by the same spacing, except for the spacing between the pair of axial segments that are located directly adjacent to the ion attenuator. All of the electrodes of the ion attenuator may be arranged within an axial space that is substantially the same, or smaller, than the width of one of the axial segments of the ion guide. However, in less preferred embodiments, the axial space in which the electrodes of
15 the ion attenuator are arranged may be larger than the width of each other axial segment of the ion guide.

 In operation, ions are supplied to the upstream end 2 of the ion attenuation device such that they pass into the upstream end of the ion guide 6. RF voltages are applied to the electrodes of the ion guide so as to radially confine the ions. Different DC voltages
20 may also be applied to different electrodes of the ion guide that are located at different axial positions so as to provide an axial electric field that urges the ions downstream through the ion guide. Alternatively, or additionally, one or more DC voltage may be successively applied to successive electrodes of the ion guide such that one or more DC potential is repeatedly travelled along the ion guide so as to urge the ions downstream
25 through the ion guide.

 Voltages, such as DC voltages, are applied to the electrodes of the ion attenuator 10 in a manner such that it repeatedly switches between a high attenuation mode and a low attenuation mode as the ions pass through it. Preferably, RF voltages are not applied to the electrodes of the ion attenuator. In the high attenuation mode, the voltages applied
30 to the electrodes of the ion attenuator cause the ions passing through the ion attenuator to be deflected and lost, such as by causing them to strike an electrode or other surface and be electrically neutralised. For example, the first 10a and third 10c electrodes of the ion attenuator 10 may be maintained at a different voltage to the second electrode 10b such that ions passing downstream through the ion attenuator are reflected by the third
35 electrode 10c onto the second electrode 10b. The ions may be reflected onto the downstream surface of the second electrode 10b (e.g. rather than onto its radially inner surface), which is advantageous as it avoids these ions hitting other regions and causing surface charging at locations where this would adversely affect the passage of ions through the ion attenuation device in the low attenuation mode. It is desirable to neutralise the ions
40 in the high attenuation mode, because otherwise these ions would be radially confined by the ion guide and would then be able to pass downstream through the ion attenuator 10 once it was switched back to the low attenuation mode.

In the low attenuation mode, the voltages applied to the electrodes of the ion attenuator cause the ions passing through the ion attenuator to be deflected and lost at a lower rate than in the high attenuation mode. For example, ions may substantially not be deflected or attenuated by the ion attenuator in the low attenuation mode, but rather may
5 simply pass downstream through the ion attenuator.

Although the pulsed ion attenuator 10 intermittently attenuates the ion beam that has passed into the ion attenuation device, which may be a substantially continuous ion beam, this will not necessarily achieve the desired beam characteristics, such as preventing saturation or improving the dynamic range of a downstream ion analyser or
10 detector. This is because the ion current passing through the ion attenuator during the low attenuation modes will still be relatively high and so the maximum ion current at the exit of the ion attenuation device may not be reduced by the ion attenuator alone. Rather, the ion attenuator intermittently transmits groups (e.g. discrete packets) of relatively high intensity ions in the high transmission modes, which may be problematic for the downstream
15 analyser or detector. In order to avoid this, the ion attenuation device may be maintained at a relatively high pressure so as to cause the ions transmitted by the ion attenuator to collide with background gas molecules within the ion attenuation device and cause the groups of ions (e.g. ion packets) transmitted by the ion attenuator in the high transmission modes to be spatially dispersed in the axial direction and merge with each other as the ions
20 travel downstream through the ion attenuation device. For example, at least the portion of the ion attenuation device arranged downstream of the ion attenuator may be arranged at a pressure of $\geq 10^{-3}$ mbar.

In embodiments in which the ion attenuator transmits discrete ion packets in the high transmission modes (i.e. where the low transmission modes substantially prevent ions
25 being transmitted downstream), the collisions between the ions and the background gas may cause the ion packets to merge with each other to form a substantially continuous ion beam at the exit of the ion attenuation device. The ions packets may therefore be merged within the ion attenuation device, downstream of the ion attenuator, so as to form an ion beam having a relatively low average intensity, i.e. lower than the average intensity of an
30 ion packet immediately downstream of the ion attenuator.

The provision of the ion attenuator within the relatively high pressure ion guide enables the ion attenuation device to reduce the maximum ion current that is transmitted, without having to transfer the attenuated ions into a separate higher pressure region located downstream of the ion attenuator. Rather, according to the embodiments of the
35 present invention, the ions remain radially confined within the ion guide before and after attenuation. This also avoids the requirement to align separate ion guides on either side of the ion attenuator.

In the embodiment shown in Figs. 1A-1D, the ion attenuator 10 is located between the first axial segment of the ion guide 6 that defines the upstream end of the ion guide and
40 the second axial segment of the ion guide. However, it is contemplated that the ion attenuator may be arranged at a different position within the ion guide. For example, the

ion attenuator may be arranged such that a plurality of axial segments of the ion guide are located upstream and/or downstream of the ion attenuator.

Additionally, or alternatively, it is contemplated that two or more ion attenuators 10 may be arranged within the ion guide 6. This may be used to attenuate the ion beam to a relatively high level. For instance, a single ion attenuator may attenuate the ions such that approximately 1% of the ion beam is transmitted, whereas two ion attenuators may attenuate the ions such that approximately 0.01% of the ion beam is transmitted. The use of multiple ion attenuators within the ion guide is particularly advantageous in applications in which it is desired to transmit ions at a very low rate, such as in charge detection mass spectrometry in which it may be desired to transmit only a single ion or several ions at any one time. In the embodiments having multiple ion attenuators, a plurality of axial segments of the ion guide may be arranged between the attenuators and/or downstream of the final ion attenuator. The attenuators are desirably arranged such that the groups of ions (e.g. discrete ion packets) transmitted by each ion attenuator in the low attenuation modes merge with each other before the ions reach the next ion attenuator. The final attenuator is preferably also arranged such that the groups of ions (e.g. discrete ion packets) transmitted by it in the low attenuation modes merge with each other before the ions reach the exit of the ion attenuation device.

Fig. 2 shows a view of an example in which two ion attenuators 10, 11 are located within the ion guide 6. This embodiment corresponds to that shown in Fig. 1D, except that a second ion attenuator 11 is located within the ion guide downstream of the first ion attenuator 10. It will be appreciated that the first ion attenuators 10 and/or the second ion attenuator 11 may be located within the ion guide at axial positions that are different to those that are shown. Also, or alternatively, the first and second ion attenuators may have the same electrode structures and operate in the same manner so as to attenuate ions, or may have different electrode structures and operate in different manners so as to attenuate ions.

Fig. 3 shows an embodiment of a mass spectrometer according to the present invention. The spectrometer comprises an ion source 30 and a first ion guide 31 arranged in a first vacuum chamber 32. The first ion guide may be in the form of an ion tunnel ion guide having an ion funnel at its downstream end, although other forms of ion guide may be used instead or as well. The first vacuum chamber may be maintained at a pressure or, for example, 5 mbar. It is contemplated that alternatively the ion source may be an atmospheric pressure ion source arranged upstream of the first vacuum chamber. An ion attenuation device 1 of the type as described herein above is provided in a second vacuum chamber 33 that is maintained at a lower pressure than the first vacuum chamber, such as at 10^{-5} mbar.

As described above, the ion attenuation device comprises an ion attenuator 10 within an ion guide 6. The upstream end of the ion attenuation device may be mounted to the differential pumping aperture 34 between the first and second vacuum chambers so as to form a gas tight seal between the ion attenuation device and the wall between the two vacuum chambers. The circumference of the ion attenuation device may be sealed in a

gas tight manner for at least a portion of its length starting from the upstream end. As such, the gas pressure within said at least a portion of the ion attenuation device may be maintained higher than the pressure in the rest of the second vacuum chamber, since gas flows from the higher pressure first vacuum chamber into the ion attenuation device.

5 However, it is contemplated that the ion attenuation device is not sealed to the differential pumping aperture and that it may not be sealed around its circumference.

An ion analyser 35 such as a mass analyser is provided in a final vacuum chamber 36. If the ion analyser requires a very low pressure to be able to operate efficiently, then one or more additional vacuum chambers may be provided between the second vacuum chamber and the final vacuum chamber so as to enable the final vacuum chamber to be pumped down to the desired pressure. For example, the ion analyser 35 may be a charge detection mass analyser or a time of flight mass analyser such as a multi-reflecting time of flight mass analyser. Such mass analysers may be maintained at a pressure of $\leq 10^{-8}$ mbar or 10^{-9} mbar. In the depicted embodiment third and fourth vacuum chambers 37, 38 are provided between the second vacuum chamber and the final vacuum chamber. Each of the third and fourth vacuum chambers has an ion guide therein for guiding ions through it to the next vacuum chamber. Additional, non-illustrated, ion-optics may be provided as well, such as DC lenses. By way of example, the third vacuum chamber may be maintained at a pressure of approximately 10^{-5} mbar and the fourth vacuum chamber may be maintained at a pressure of approximately 10^{-7} mbar. The ion guide 39 in the third and/or the ion guide 40 in the fourth vacuum chamber may have an axial DC electric field maintained across it so as to urge ions therethrough in the downstream direction. This may be achieved, for example, by the ion guide in the third and/or fourth vacuum chamber being an axially segmented ion guide having a voltage supply that applies different DC voltages to different axial segments. As the pressure reduces there may be less necessity apply an axial DC electric field across the ion guide and as such the ion guide in the fourth vacuum chamber may not provide this feature, i.e. it may not be axially segmented.

Although the present invention has been described with reference to various embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the scope of the invention as set forth in the accompanying claims.

For example, an embodiment has been described in which the ion attenuator has a relatively thick first electrode 10a arranged opposite second and third electrodes 10b, 10c that are each thinner. Such an arrangement may be used in third mode in which the voltages that are applied to the first, second and third electrodes are selected so as to cause the ions to strike the radially inner surface of the first electrode and undergo surface induced dissociation so as to produce fragment ions. The resulting fragment ions may then be guided downstream through the ion guide.

However, it is contemplated that the ion attenuator(s) disclosed herein may have electrode configurations other than that shown in the drawings. For example, the first electrode 10a may be replaced with two axially spaced electrodes, each of which opposes one of the second and third electrodes 10b, 10c. During the high attenuation mode the third

electrode 10c and the more downstream of these two axially spaced electrodes may be maintained at one or more voltages so as to cause the ions to be reflected back onto the second electrode and/or the more upstream of the two axially spaced electrodes.

5 Additionally, or alternatively, although the ion attenuator in the depicted embodiment has two opposing electrodes at any given axial location so as to form the ion guiding aperture 24 (see Fig. 1F), it is contemplated that the ion attenuator may comprise more than two electrodes arranged circumferentially around the central axis of the ion guide in order to define the ion guiding aperture. For example, four electrodes may be arranged circumferentially around the axis in order to define the ion guiding aperture (at any given
10 axial location). These electrodes may be aligned with the electrodes of the ion guide.

It is contemplated that the ion attenuator(s) described herein may attenuate ions by techniques other than reflecting the ions in the high attenuation modes. For example, in the high attenuation modes the ions may be deflected, such as by being defocussed, in a manner such that the ions continue to travel in a downstream direction (i.e. rather than
15 being reflected) but such that they strike an electrode or other surface so as to cause them not to be onwardly transmitted to the exit of the ion attenuation device. Additionally, or alternatively, in the high attenuation mode one or more voltages may be applied to electrodes of the ion attenuator so as to radially eject ions from the ion attenuation device.

Although the ion guide 6 has been described in the embodiments as being an axially segmented quadrupole having multiple axial segments downstream of the ion
20 attenuator 10, it is contemplated that in less preferred embodiments the ion guide may have a single axial segment downstream of the ion attenuator, and optionally a single axial segment upstream of the ion attenuator. In such embodiments, additional DC electrodes may be arranged to provide the axial electric field for urging ions downstream through the
25 ion guide.

The ion guide 6 of the ion attenuation device may not be a quadrupole ion guide but may instead be a different multipole ion guide or an ion tunnel/funnel ion guide formed from a stack of apertured electrodes, where the ion attenuator is arranged within the stack of electrodes.

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Claims:

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1. A mass and/or mobility spectrometer comprising:
an ion attenuation device comprising an ion guide and an ion attenuator arranged within the ion guide, wherein the ion attenuator is configured to repeatedly switch between a high attenuation mode in which it attenuates ions at a first rate and a low attenuation
10 mode in which it attenuates ions at a lower rate;
wherein the spectrometer is configured to maintain the ion attenuation device at a pressure such that different groups of ions that are transmitted by the ion attenuator in different respective low attenuation modes merge with each other downstream of the ion attenuator.
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2. The spectrometer of claim 1, wherein at least a portion of the ion attenuation device that is downstream of the ion attenuator is arranged at a pressure of $\geq 10^{-3}$ mbar.
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3. The spectrometer of claim 1 or 2, wherein the ion guide comprises a plurality of electrodes configured to guide ions along an axis, wherein the electrodes are arranged in a plurality of axial segments that are spaced apart along the axis of the ion guide, and wherein the ion attenuator is arranged axially between two of the axial segments of the ion guide.
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4. The spectrometer of claim 3, wherein the ion guide comprises one or more voltage supply for applying different voltages, such as DC voltages, to electrodes in different ones of the axial segments for urging ions downstream through the ion guide.
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5. The spectrometer of any preceding claim, wherein all of the electrodes of the ion guide are arranged in a single vacuum chamber of the spectrometer.
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6. The spectrometer of any preceding claim, wherein ion guide electrodes along the entire length of the ion guide are directly connected to the same support member.
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7. The spectrometer of any preceding claim, wherein substantially all of the electrodes of the ion guide and the ion attenuator are sandwiched between two printed circuit boards (PCBs) such that the electrodes of the ion guide and the ion attenuator are mechanically and electrically connected to the PCBs.
8. The spectrometer of claim 7, wherein the ion guide is an axially segmented quadrupole ion guide that is formed from four rows of electrodes, wherein two of the rows of electrodes are electrically connected to a first of the PCBs and two different rows of electrodes are electrically connected to a second of the PCBs.

9. The spectrometer of any preceding claim, wherein the ion guide comprises a plurality of electrodes configured to guide ions along an axis, wherein the electrodes are arranged in a plurality of axial segments that are spaced apart along the axis of the ion guide and each have the same width in the axial direction; wherein any given one of these axial segments is axially spaced from each of its adjacent axial segments by the same spacing, except for the space between the axial segments in which the ion attenuator is located; and wherein all of the electrodes of the ion attenuator are arranged within an axial space that is substantially the same, or smaller, than the width of one of the axial segments of the ion guide.
10. The spectrometer of any preceding claim, wherein the ion attenuator comprises at least one electrode arranged within the ion guide and a voltage supply arranged and configured to apply a voltage to the electrode in the high attenuation mode so as to reflect, deflect or defocus ions passing through the ion attenuator such that they are attenuated at said first rate, and to apply a different voltage to the electrode in the low attenuation mode so as to reflect, deflect or defocus ions passing through the ion attenuator to a lesser extent such that they are attenuated at said lower rate.
11. The spectrometer of any preceding claim, wherein the ion attenuator comprises an upstream electrode and a downstream electrode that is arranged downstream of the upstream electrode, wherein the ion attenuator is configured to apply a voltage to the downstream electrode in the high attenuation mode so as to reflect ions passing through the ion attenuator such that they strike the upstream electrode.
12. The spectrometer of claim 11, wherein the ion attenuator is configured such that the reflected ions strike a downstream surface of the upstream electrode which is, optionally, substantially orthogonal to the axis through the ion guide.
13. The spectrometer of any preceding claim, comprising one or more further ion attenuators within the ion guide, wherein each of the one or more further ion attenuators is configured to repeatedly switch between a high attenuation mode in which it attenuates ions at a first rate and a low attenuation mode in which it attenuates ions at a lower rate.
14. The spectrometer of claim 13, wherein the pressure, and the ion attenuators, in the ion attenuation device are arranged such that the groups of ions that are transmitted by each of the ion attenuators in the low attenuation modes merge with each other before these ions reach the subsequent ion attenuator in the downstream direction.
15. The spectrometer of any preceding claim, comprising a first vacuum chamber configured to be maintained at a first pressure and a second vacuum chamber configured to be maintained at a lower pressure, wherein the ion attenuation device is located within

the second vacuum chamber with its entrance end mounted to a differential pumping aperture between the first and second vacuum chambers so as to form a gas tight seal around its entrance, and wherein the circumference of the ion attenuation device is sealed in a gas tight manner over at least a portion of its length starting from its entrance end.

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16. The spectrometer of any preceding claim, comprising a charge detection mass spectrometry ion analyser, or a time of flight mass analyser, arranged to receive and analyse ions transmitted by the ion attenuation device, or to receive and analyse ions derived therefrom.

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17. The spectrometer of claim 16, wherein the charge detection mass spectrometry ion analyser or the time of flight mass analyser is arranged at a pressure of $\leq 10^{-8}$ mbar or 10^{-9} mbar.

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18. An ion attenuation device comprising an ion guide and an ion attenuator arranged within the ion guide, wherein the ion attenuator is configured to repeatedly switch between a high attenuation mode in which it attenuates ions at a first rate and a low attenuation mode in which it attenuates ions at a lower rate.

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19. A method of mass and/or mobility spectrometer comprising:
providing a spectrometer or ion attenuation device as claimed in any preceding claim;
supplying ions into an upstream end of the ion attenuation device;
repeatedly switching the ion attenuator between the high attenuation mode in which
it attenuates ions at the first rate and the low attenuation mode in which it attenuates ions
at the lower rate; and
wherein the ion attenuation device is maintained at a pressure such that different groups of ions that are transmitted by the ion attenuator in different respective low attenuation modes merge with each other downstream of the ion attenuator.

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