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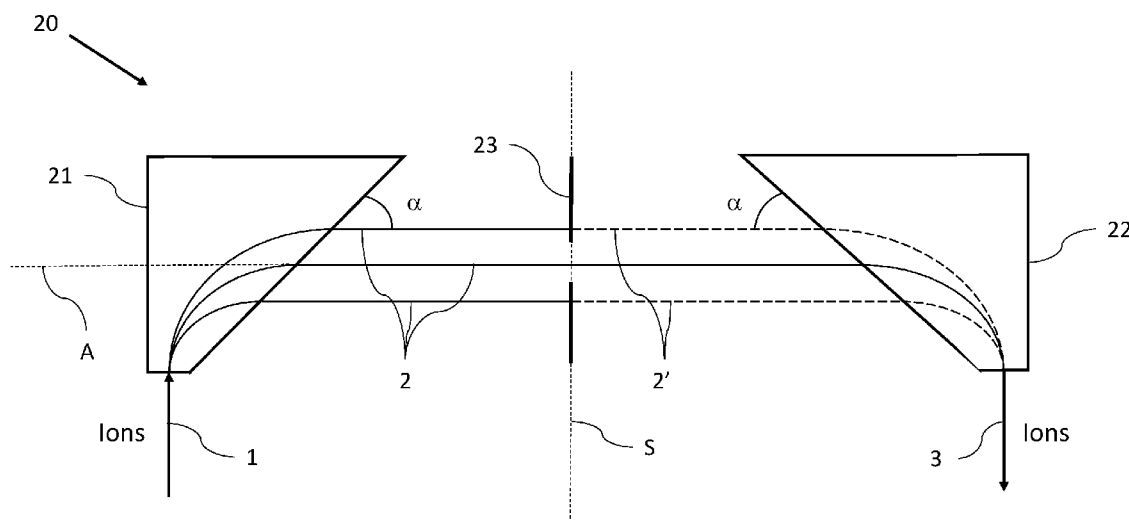


Fig. 2

(57) Abstract: A mass spectrometer comprises an ion source, a static mass pre-filter downstream of the ion source, a collision cell downstream of the static mass pre-filter, at least one mass analyzer downstream of the collision cell, and at least one ion detector downstream of the at least one mass analyzer. The static mass pre-filter (20) comprises a first magnetic sector unit (21) for separating ions into partial ions beams (2), a second magnetic sector unit (22) for merging the partial ion beams, and a slit (23) arranged between the first magnetic sector unit and the second magnetic sector unit for selectively passing partial ion beams (2). The partial ion beams (2) may be symmetric relative to a plane (S) perpendicular to the partial ion beams.

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MASS SPECTROMETERS COMPRISING A STATIC MASS PRE-FILTER

Field of the invention

The present invention relates to mass spectrometers. More in particular, the invention relates to mass spectrometers comprising at least one pre-filter to filter ions before they enter a further component of the mass spectrometer, such as a collision cell.

Background of the invention

US 2018/308674 A1 (Schwieters et al.) describes a mass spectrometer comprising an ion source, a mass filter, a collision cell, and a sector field mass analyzer. The mass filter upstream of the collision cell, which may be referred to as mass pre-filter, is a quadrupole mass filter, which requires a varying field to filter ions according to their m/z ratio. Although such dynamic mass filters function well, the resulting different trajectories of ions having different m/z ratios, and thus the different travel times of the ions, may in some instances cause isotope discrimination.

US 2022/223401 A1 (Schwieters et al.) describes an isotope ratio mass spectrometer comprising an ion source, a static field mass filter, a collision/reaction cell, and a sector field mass analyser for spatially separating ions from the reaction cell according to their mass-charge ratio (m/z ratio). A detector platform is configured for detecting a plurality of different ion species separated by the sector field mass analyser. The static field mass filter acts as a pre-filter to filter ions from the ion source before they enter the reaction cell.

The static field mass filter of US 2022/223401 A1 comprises a first Wien filter that deflects ions away from a longitudinal symmetry axis of the mass spectrometer in accordance with the ions' m/z ratio, and a second Wien filter that deflects ions back towards the longitudinal symmetry axis in accordance with the ions' m/z ratio. An inverting lens is positioned along the longitudinal axis between the Wien filters to invert the direction of deflection of the ions from the first Wien filter. The deflected ions return to substantially the same trajectories, independent of the m/z ratios, thus allowing a high-resolution isotope analysis, for example.

Summary of the invention

The present invention provides a mass spectrometer comprising an ion source, a static mass pre-filter downstream of the ion source, a collision/reaction cell downstream of the mass pre-filter, at least one mass analyzer downstream of the collision/reaction cell, and at least one ion detector

downstream of the at least one mass filter. The mass pre-filter can comprise a first magnetic sector unit for separating ions into partial ion beams, a second magnetic sector unit for merging the partial ion beams, and a slit arranged between the first magnetic sector unit and the second magnetic sector unit for selectively passing partial ion beams. At least the selected partial ion beams can be symmetric. The first magnetic sector unit can be configured for separating ions into parallel, diverging, or converging partial ion beams.

The mass pre-filter may comprise an ion lens assembly arranged between the first magnetic sector unit and the second magnetic sector unit, which ion lens assembly may comprise an inversion lens and/or other ion lenses. The ion lens assembly may comprise a first lens or pair of lenses upstream of the slit and a second lens or pair of lenses downstream of the slit (or slit mechanism), or a single lens or pair of lenses of one side of the slit only. Instead of a single slit, multiple slits and/or diaphragms may be provided. The single or multiple slits and/or diaphragms may be movable. The slits (or slit mechanisms) or diaphragms may be arranged perpendicular to an axis of the arrangement of magnetic sector units but may also be slanted relative to such an axis.

The first pair of lenses may comprise a first zoom lens for converting the parallel ion beams into diverging ions beams and a correction lens for converting the diverging ions beams into parallel ions beams. The second pair of lenses may comprise a first correction lens for converting the parallel ion beams into converging ions beams and a zoom lens for converting the converging ions beams into parallel ions beams.

The ion lens assembly may comprise an inversion lens, for example a single inversion lens which is preferably arranged upstream of the slit. Alternatively, the ion lens assembly may comprise a pair of inversion lenses, preferably arranged on either side of the slit. In an embodiment, the ion lens assembly may comprise an inversion lens and a pair of zoom lenses, the zoom lenses being arranged on either side of the inversion lens, the inversion lens preferably being arranged downstream of the slit.

The ion source may comprise an inductively coupled plasma (ICP) ion source, for example. However, other ion sources may also be used, such as glow discharge sources, photo-ionization sources, and other ion sources.

The collision/reaction cell (which may also be referred to as collision cell or reaction cell) can include at least one gas inlet for supplying at least one collision gas and/or reaction gas, so as to facilitate removal of isobaric interferences, such as by inducing charge transfer reactions, and/or mass shift reactions, and/or fragmentation of molecular species, and/or reducing the absolute kinetic energy and/or reducing the energy spread of ions in the ion beam. The mass pre-filter may also be used in mass spectrometers without a collision/reaction cell.

The at least one mass filter downstream of the collision cell preferably comprises a sector field mass analyser. The at least one mass filter may be a double focusing mass analyser arrangement, for example comprising an electrostatic sector downstream of the collision cell followed by a magnetic sector downstream of the electrostatic sector.

The mass spectrometer may be an isotope ratio mass spectrometer, that is, a mass spectrometer arranged for isotope ratio measurements. The at least one ion detector can be a multicollector, for example comprising a plurality of ion detectors for detecting a plurality of different ion species in parallel.

The mass spectrometer according to any of the preceding claims, wherein the partial ion beams are mirror symmetric relative to a plane perpendicular to at least one partial ion beam. That is, the components of the mass spectrometer are arranged in such a way that the partial ion beams exhibit mirror or reflective symmetry relative to a plane which is substantially perpendicular to a partial ion beam. In the case of parallel partial ion beams, this plane of symmetry may be substantially perpendicular to all partial ion beams. In the case of diverging partial ion beams, the plane of symmetry may be perpendicular to a central partial ion beam. Additionally, or alternatively, the plane of symmetry may be substantially perpendicular to an axis of symmetry of the partial ion beams and/or the magnetic sector units. The plane of symmetry may coincide with a slit mechanism or diaphragm, or may be parallel to at least one slit mechanism or diaphragm.

The partial ion beams may be mirror symmetric relative to a plane coinciding with at least one partial ion beam. That is, a plane of mirror symmetry may coincide with a partial ion beam, for example a central partial ion beam, and/or an axis of symmetry of the partial ion beams and/or the magnetic sector units. In some embodiments, the partial ion beams may be mirror symmetric relative to two, preferably perpendicular, planes of symmetry.

The partial ion beams may be substantially symmetric for at least a selected range of mass-to-charge ratios. That is, the symmetry may hold for only a range of m/z ratios, the partial ion beams outside the range not being symmetric. The selected range of m/z ratios may be a range of interest. The selected range of mass-to-charge ratios may for example comprise at least all isotopes of an element of which ions are to be detected.

The present invention further provides a static mass pre-filter for use in a mass spectrometer, the static mass pre-filter comprising a first magnetic sector unit for separating ions into partial ion beams, a second magnetic sector unit for merging partial ion beams, and a slit arranged between the first magnetic sector unit and the second magnetic sector unit for selectively passing partial ion beams, the magnetic sector units being arranged for producing symmetric selected partial ion beams. The partial ion beams may be mirror symmetric relative to a plane of symmetry, which plane may be perpendicular to at least one partial ion beam.

The present invention also provides a method of mass spectrometry, comprising:

- generating a beam of ions from a sample,
- mass pre-filtering ions from the beam in accordance with their mass to charge ratio,
- inducing a mass shift of the pre-filtered ions using a reaction cell,
- spatially separating mass-shifted ions in accordance with their mass to charge ratios, and
- detecting spatially separated ions.

The pre-mass filtering comprises using a first magnetic sector unit for separating ions into partial ions beams, using a second magnetic sector unit for merging partial ion beams, and using a slit arranged between the first magnetic sector unit and the second magnetic sector unit for selectively passing partial ion beams.

A step following the pre-mass filtering and preceding the spatially separating selected ions is passing the mass filtered ions through a collision cell, which contains a collision or reaction gas. Passing the mass filtered ions through the collision cell can remove isobaric mass spectral interferences, through various mechanisms, such as charge transfer reactions, fragmentation of molecular species and/or mass shift reactions in the cell. Such techniques are described in US 2018/308674 A1 (Schwieters et al.), the entire contents of which are herewith incorporated by reference in this document.

Brief description of the drawings

Fig. 1 schematically shows, in a perspective view, a mass spectrometer provided with a pre-filter according to the prior art.

Fig. 2 schematically shows a first embodiment of a pre-filter according to the present invention.

Fig. 3 schematically shows a second embodiment of a pre-filter according to the present invention.

Fig. 4 schematically shows a third embodiment of a pre-filter according to the present invention.

Fig. 5 schematically shows a fourth embodiment of a pre-filter according to the present invention.

Fig. 6 schematically shows a fifth embodiment of a pre-filter according to the present invention.

Fig. 7 schematically shows a sixth embodiment of a pre-filter according to the present invention.

Fig. 8 schematically shows a seventh embodiment of a pre-filter according to the present invention.

Fig. 9 schematically shows an eighth embodiment of a pre-filter according to the present invention.

Fig. 10 schematically shows a first exemplary embodiment of a mass spectrometer provided with a pre-filter.

Fig. 11 schematically shows a second exemplary embodiment of a mass spectrometer provided with a pre-filter.

Description of embodiments

This invention provides a novel static mass filter and a novel mass spectrometer provided with a static mass filter used as a pre-filter. US 2022/223401 A1, which is herewith incorporated by reference in this document, describes a mass spectrometer provided with a static mass filter used as a mass pre-filter. The known static mass filter comprises two Wien filters and an inversion lens. Embodiments of the static mass filters of this invention may be provided using conventional components, such as magnetic sector units. In addition, embodiments of the static field mass filters of this invention may be provided without an inversion lens.

Fig. 1 shows a mass spectrometer as described in US 2022/223401 A1. The isotope ratio mass spectrometer (IRMS) 100 of Figure 1 includes an ion source 10, a static mass filter (or static mass pre-filter) 20, a collision cell 30, an accelerator 40, an electrostatic sector unit 50, a focusing lens 60, a magnetic sector unit 70, dispersion optics 80 and a detector platform 90.

The exemplary ion source 10 includes a triaxial ICP torch 11, an assembly 12 consisting of a sampler cone, one or more skimmer cones, an extraction lens and/or a further skimmer cone, and another ion optical device 13. This ion source arrangement results in a collimated ion beam.

Downstream of the ion source 10 is positioned a static field mass filter 20 which will be described in further detail below. The static field mass filter 20 maintains constant electric and magnetic fields, so that transmission of ions through the static field mass filter has a flat response across the selected m/z (mass per elementary charge) range. A quadrupole mass filter, which may be used in this position instead, does not provide such a flat response. In a quadrupole mass filter, the electromagnetic fields change with time according to the applied frequency, which results in a zig zag trajectory of the ions.

The prior art static field mass filter 20 of Figure 1 does not introduce a lateral mass discrimination (as would happen in, for example, a magnetic sector analyser) so that the ion beam exiting the static field mass filter 20 can be focused onto the relatively small (ca. 2mm) entrance aperture of a collision cell 30, across the width of the mass window selected for transmission by the static field mass filter 20.

Following the collision cell 30, ions are accelerated by an accelerator 40 and focused into the ion optics of a double focusing high resolution multicollector mass spectrometer for simultaneous detection of different isotopes (of a sample and/or a standard). Further, the double focusing high resolution multicollector mass spectrometer includes an electrostatic sector 50 and a magnetostatic sector 70, separated by a focusing lens 60. Downstream of the high resolution multicollector mass spectrometer, the arrangement of Figure 1 contains dispersion optics 80 and finally a detector platform 90 again. A suitable detector platform is described in GB 2541391 A (Deerberg et al.), for example.

The static field mass filter 20 in Figure 1 is constituted by a double Wien filter. Wien filters employ an arrangement of crossed electrostatic and magnetostatic fields. Ions passing through this arrangement are subject to the magnetic Lorentz force and the electric field strength. In accordance with the present invention, however, other types of pre-filters can be used instead of Wien filters.

It is noted that in the present document, the terms mass pre-filter, pre-mass filter and pre-filter will be used interchangeably. The pre-filters of the present invention are preferably static field mass filters which have static electric and/or magnetic fields, as opposed to multipole (e.g., quadrupole) mass filters, which typically have non-static (i.e., high frequency) electric fields.

A first embodiment of a static field mass filter according to the present invention, configured for use as a pre-filter in a mass spectrometer, such as an isotope ratio mass spectrometer (IRMS), is schematically shown in Fig. 2. The mass pre-filter 20 comprises a first magnetic sector unit 21, a second magnetic sector unit 22 and a slit or diaphragm unit 23 arranged between the magnetic sector units 21 & 22. The first magnetic sector unit 21 is configured for separating the incoming ion beam 1 according to the m/z ratios of the ions, thus producing multiple partial ion beams. In the embodiment shown, the incoming ion beam 1 is deflected over an angle of 90° by the magnetic field inside the first magnetic sector unit 21 and the resulting partial ions beams 2 are substantially parallel. This can be achieved by the incoming ion beam 1 being arranged substantially perpendicular to the entry surface of the first magnetic sector unit 21 and having a 45° angle α relative to the exit surface. The second magnetic sector unit 22 mirrors the 90° deflection action of the first magnetic sector unit 21 (45° angle α of the ion beam 2 relative to the entry surface and perpendicular exit surface) and brings the partial ion beams 2 back together, thus forming the outgoing or merged ion beam 3, which is now directed at an angle of 180° relative to the incoming or original ion beam 1.

The diaphragm or slit structure 23 (which may also be referred to as slit unit, slit mechanism or slit) allows to selectively pass partial ion beams 2, namely, to select a mass window of ions to pass. The diaphragm or slit structure 23 may be positioned at the plane of symmetry between the magnetic sector units 21 & 22, as shown. The diaphragm or slit structure 23 comprises a plate or other structure provided with an opening, the actual slit. The opening may be round, rectangular, polygonal or have another suitable shape. The width of the opening may be variable to allow the selection of more or less partial ions beams. Additionally, or alternatively, the location of the opening may be variable relative to the partial ion beams 2 so as to be able to select one or more of these partial ion beams. Thus, in the embodiment of Fig. 2, the opening of the slit 23 may be higher or lower than shown. In some embodiments, a structure comprising more than one opening may be provided to pass multiple partial ion beams simultaneously. Instead of a single slit, two, three or more slit structures and/or diaphragms 23 may be used. Conversely, a single structure may comprise two, three or more openings. The mass window of the partial ion beam can be selected by the position and size of the opening of the diaphragm or slit structure 23.

The arrangement of the magnetic sector units 21 and 22 provides a central axis A of the partial ion beams 2. This central axis A may coincide with or be parallel to a central partial ion beam 2. In the embodiment shown, the partial ion beams are mirror symmetric relative to a plane of symmetry S,

which in this embodiment coincides with the slit structure 23. The plane of symmetry S is, in the embodiment shown, perpendicular to the central axis A. This symmetry allows the (selected) partial ion beams 2 to be substantially fully merged into the outgoing ion beam 3. This in turn allows high-resolution isotope measurements, as the ion trajectories of the different m/z ratios are well-defined and isotope discrimination can be avoided. The central axis A provides another plane of mirror symmetry for at least part of the partial ion beams 2 between the magnetic sector units 21 and 22. It can thus be seen that the geometry of the static mass pre-filter has specific properties.

Thus, Fig. 2 shows a static mass pre-filter for use in a mass spectrometer, the static mass pre-filter comprising a first magnetic sector unit for separating ions, a second magnetic sector unit for merging separated ions, and a slit arranged between the first magnetic sector unit and the second magnetic sector unit for passing selected ions. In particular, the first magnetic sector unit is configured for separating ions into substantially parallel ion beams. However, in some embodiments the first magnetic sector unit is configured for separating ions into diverging ion beams, as will be discussed later with reference to Fig. 4. In the embodiment of Fig. 2, each magnetic sector unit 21, 22 deflects the (partial) ion beams over an angle of 90° . In some embodiments, other angles can be used, for example 45° , 60° or 80° . In those embodiments, the partial ions beams emerging from the first magnetic sector unit 21 will typically not be parallel.

It will be clear that the mass pre-filter of the present invention provides a good alternative to the known double Wien filter while using commonly available components. The magnetic sector units 21 and 22 may be commercially available and have a relatively simple structure. As is well known, magnetic sector units use a magnetic field to spatially separate moving ions. Thus, the incoming ion beam 1 is split up into partial ion beams 2, each partial ion beam consisting of ions having a certain mass/charge (m/z) ratio. The spatial separation allows some partial ion beams 2 to be selectively passed using the slit 23, while other partial ion beams 2' are blocked. The magnetic sector units 21 and 22 are static units, that is, they use static magnetic (and optionally electric) fields, as opposed to the dynamic (typically RF) fields of quadrupole filters. For this reason, the mass pre-filter of the present invention may be referred to as a static mass pre-filter or a static field mass pre-filter.

The mass pre-filter may comprise an ion lens assembly arranged between the first magnetic sector unit 21 and the second magnetic sector unit 22. An exemplary embodiment is shown in Fig. 3, in which the magnetic sectors units 21, 22 and the slit structure 23 are similar or identical to those of Fig. 2. The ion lens assembly comprises a pair of zoom lenses 24, 25 and a pair of correction lenses

26, 27. The first zoom lens 24 converts the substantially partial beams 2 into diverging beams (apart from the partial beam located on the central or optical axis A) so as to increase the spacing between the partial beams, i.e. the mass dispersion, and thus increase resolution of the mass window selection. The (optional) first correction lens 26 converts the diverging partial beams into substantially parallel partial beams so that the partial beams pass through the slit 23 in parallel (as will be shown later, this is not essential). A second correction lens 27 converts the parallel partial beams 2 into converging partial beams, so that the second zoom lens 25 outputs a set of substantially parallel partial beams again.

The ion lenses may be commercially available ion lenses using voltages to generate suitable electric fields. These electric fields are typically static electric fields.

Another ion lens assembly is shown in Fig. 4. In this embodiment, the first magnetic sector unit 21 is configured to produce diverging partial ion beams 2. This can be achieved, for example, by using a magnetic sector that provides a rectangular shaped magnetic field. An inversion lens 28 may convert the diverging set of partial ion beams into a converging set of partial ion beams, while the second magnetic sector unit 22 can be arranged to convert the converging set of partial ion beams into a single ion beam.

In the embodiment of Fig. 4, there is also a plane S of mirror symmetry of the partial ion beams 2 and of the incoming and outgoing beams 1 and 2. In this embodiment, the plane S intersects the inversion lens 28, as the slit structure 23 is spaced apart from the plane S due to the presence of the inversion lens 28.

Embodiments can be provided in which the first magnetic sector unit 21 can be arranged to produce converging partial ion beams 2. In such embodiments, the inversion lens may convert a converging set of partial ion beams into a diverging set of partial ion beams, while the second magnetic sector unit 22 can be arranged to convert a diverging set of partial ion beams into a single ion beam.

The embodiment of Fig. 5 is similar to the one of Fig. 4 in that the first magnetic sector unit 21 is arranged to produce diverging partial ion beams 2. Due to a first inversion lens 28, however, the partial beams 2 impinge upon the slit structure in parallel. A second inversion lens 29 converts the parallel partial ion beams into converging partial ion beams. As with other embodiments, the converging action of the second inversion lens 29 is only required when off-axis partial ion beams

are passed through the slit, as partial ion beams substantially coinciding with the ion optical axis will typically not be affected by the ion lenses. The slit structure 23 can be positioned at the plane of symmetry between the magnetic sectors 21, 22 and the first and second inversion lenses 28, 29 can be positioned symmetrically about the plane of symmetry.

In the embodiment of Fig. 6, the angle between the incoming ion beam 1 and the exiting ion beam 3 is not 180° , as in the previous embodiments, but less than 180° . In the example shown, the angle is approximately 80° , but this angle can also be approximately 90° . It can thus be seen that the angle between the incoming ion beam and the exiting ion beam can depend on the geometry of the mass pre-filter. In particular, the magnetic sector units 21 & 22 of Fig. 6 each deflect the ions over less than 90° , for example approximately 45° or approximately 30° . As can be seen, the angle α at which the partial ion beams 2 exit the first magnetic sector unit 21 is less than 45° , in the present example approximately 30° for the center partial beam. Similarly, the angle at which the partial ion beams 2 enter the second magnetic sector unit 22 is the same angle α of less than 45° , in the present example approximately 30° for the center partial beam.

A further embodiment is shown in Fig. 7, where the first magnetic sector unit 21 is arranged for producing diverging partial ion beams 2, which are made more divergent by a first zoom lens 24. An inversion lens 28 inverts (that is, converts from diverging into converging) the partial ion beams 2, while a second zoom lens 25 decreases the convergence of the partial ion beams, so that the second magnetic sector unit 22 can bring the filtered partial ion beams together in a single output ion beam.

In the embodiment shown in Fig. 7, the slit structure 23 is arranged between the first zoom lens 24 and the inversion lens 28. In alternative embodiments, the slit structure 23 could be arranged between the inversion lens 28 and the second zoom lens 25, for example.

A generic embodiment is illustrated in Fig. 8, where the first ion dispersion unit 21 need not be a magnetic sector unit but could be an electric sector unit, for example. Similarly, the second ion dispersion unit 22 need not be a magnetic sector unit but also could be an electric sector unit, for example. As the first ion dispersion unit 21 is arranged for producing a diverging set of partial ion beams, an inversion lens 28 is used. The inversion lens 28 can be positioned at the plane of symmetry, mid-way between the first and second ion dispersion units 21, 22. In the embodiment shown, the inversion lens 28 is arranged downstream of the slit structure 23, but in other

embodiments the slit structure may be positioned upstream. In either case, the slit structure will be arranged near, but typically spaced apart from, the inversion lens.

A similar embodiment comprising zoom lenses 24 and 25 is schematically shown in Fig. 9.

Other embodiments of the pre-filter of the present invention can be envisaged, for example embodiments utilizing an ion deflection of up to (or even exceeding) 360° , similar to an omega filter in electron microscopy applications. Such an embodiment can be used to filter a mass window from an ion beam and may comprise a magnetic prism sector with two electrostatic sectors. Between these two electrostatic sectors there is a slit to cut the mass window. The arrangement may be mirrored along the plane which is defined by the slit plate.

A first embodiment of a mass spectrometer comprising a static field pre-filter according to the present invention is schematically shown in Fig. 10. The mass spectrometer 100 of Fig. 10 is shown to comprise an ion source 10, a pre-filter 20, a collision cell 30, a magnetic sector 70 mass analyser and a detector platform 90. The ion source 10 can be a plasma ion source, such as an inductively coupled plasma (ICP) ion source. In some embodiments, a different type of ion source can be used. The pre-filter 20 can be a static field mass filter as described above. The collision cell 30, which in use contains a suitable gas, can be configured for removing isobaric interferences, such as by charge transfer reactions, fragmentation of molecular species, and/or inducing mass shift reactions, in particular mass shift reactions to higher mass as described in GB 2546060 A, as mentioned above. In some embodiments, the magnetic sector 70 may be replaced or complemented by another type of mass analyzer, such as a multipole mass filter, in particular a quadrupole mass analyser, or a time-of-flight mass analyser for example. The detector platform 90 can be a single collector for sequential ion detection or more commonly is a multicollector for simultaneous detection of ions having different masses, e.g., different isotopes, especially useful for accurate isotope ratio measurements.

In the embodiment of Fig. 10, the mass pre-filter 20 is arranged downstream of the ion source 10, the collision cell 30 is arranged downstream of the mass pre-filter 20, the magnetic sector unit 70 is arranged downstream of the collision cell 30, and the detector platform 90 is arranged downstream of the magnetic sector unit 70. Conversely, the ion source 10 is arranged upstream of the mass pre-filter 20, the mass pre-filter 20 is arranged upstream of the collision cell 30, the collision cell 30 is arranged upstream of the magnetic sector unit 70, and the magnetic sector unit 70 is arranged upstream of the detector platform 90.

A second embodiment of a mass spectrometer comprising a static field pre-filter according to the present invention is schematically shown in Fig. 11. The mass spectrometer 100 of Fig. 11 is shown to comprise an ion source 10, a pre-filter 20, a collision cell 30, an electric sector unit 50, a magnetic sector unit 70 and a detector platform 90. As in Fig. 10, the pre-filter 20 can be a static field mass filter as described above. In some embodiments, the magnetic sector 70 may be replaced or complemented by another type of mass analyzer, such as a multipole mass filter, time of flight analyser etc. The ion source 10, collision cell 30 and detector platform 90 can be the same as in the embodiment shown in Fig. 10.

It will be appreciated that other configurations of mass spectrometer may be used than those shown in Figs. 10 and 11, for example the order of the electric sector and magnetic sector may be reversed.

It will be understood by those skilled in the art that the invention is not limited to the embodiments described above and that many additions and modifications can be made without departing from the scope of the invention as defined in the appending claims.

Claims

1. A mass spectrometer, comprising an ion source, a static mass pre-filter downstream of the ion source, a collision cell downstream of the static mass pre-filter, at least one mass analyzer downstream of the collision cell, and at least one ion detector downstream of the at least one mass analyzer,
characterized in that the static mass pre-filter comprises a first magnetic sector unit for separating ions into partial ions beams, a second magnetic sector unit for merging partial ion beams, and a slit arranged between the first magnetic sector unit and the second magnetic sector unit for selectively passing partial ion beams, and in that the selected partial ion beams are symmetric.
2. The mass spectrometer according to claim 1, wherein the first magnetic sector unit is configured for separating ions into parallel partial ion beams.
3. The mass spectrometer according to claim 1, wherein the first magnetic sector unit is configured for separating ions into diverging partial ion beams.
4. The mass spectrometer according to claim 1, wherein the mass pre-filter comprises an ion lens assembly arranged between the first magnetic sector unit and the second magnetic sector unit.
5. The mass spectrometer according to claims 2 and 4, wherein the ion lens assembly comprises a first pair of lenses upstream of the slit and a second pair of lenses downstream of the slit.
6. The mass spectrometer according to claim 5, wherein the first pair of lenses comprises a first zoom lens for converting the parallel ion beams into diverging ions beams and a correction lens for converting the diverging ions beams into parallel ions beams, and wherein the second pair of lenses comprises a first correction lens for converting the parallel ion beams into converging ions beams and a zoom lens for converting the converging ions beams into parallel ions beams.
7. The mass spectrometer according to claims 3 and 4, wherein the ion lens assembly comprises an inversion lens.

8. The mass spectrometer according to claim 7, wherein the ion lens assembly comprises a single inversion lens which is preferably arranged upstream of the slit.
9. The mass spectrometer according to claim 7, wherein the ion lens assembly comprises a pair of inversion lenses which are preferably arranged on either side of the slit.
10. The mass spectrometer according to claim 7, wherein the ion lens assembly comprises an inversion lens and a pair of zoom lenses, the zoom lenses being arranged on either side of the inversion lens, the inversion lens preferably being arranged downstream of the slit.
11. The mass spectrometer according to any of the preceding claims, wherein the at least one mass analyzer comprises a magnetic sector mass analyzer.
12. The mass spectrometer according to any of the preceding claims, wherein the at least one mass analyzer comprises a multipole mass filter, preferably a quadrupole mass filter.
13. The mass spectrometer according to any of the preceding claims, further comprising an electric sector unit downstream of the collision cell.
14. The mass spectrometer according to any of the preceding claims, wherein the partial ion beams are mirror symmetric relative to a plane perpendicular to at least one partial ion beam.
15. The mass spectrometer according to any of the preceding claims, wherein the partial ion beams are mirror symmetric relative to a plane coinciding with at least one partial ion beam.
16. The mass spectrometer according to any of the preceding claims, wherein the partial ion beams are symmetric for at least a selected range of mass-to-charge ratios.
17. The mass spectrometer according to claim 16, wherein the selected range of mass-to-charge ratios comprises at least all isotopes of an element of which ions are to be detected.

18. The mass spectrometer according to any of the preceding claims, which is an isotope ratio mass spectrometer.
19. A static mass pre-filter for use in a mass spectrometer,
characterized in that the mass pre-filter comprises a first magnetic sector unit for separating ions into partial ion beams, a second magnetic sector unit for merging partial ion beams, and a slit arranged between the first magnetic sector unit and the second magnetic sector unit for selectively passing partial ion beams, and in that the magnetic sector units are arranged for producing symmetric selected partial ion beams.
20. The static mass pre-filter according to claim 19, wherein the first magnetic sector unit is configured for separating ions into parallel ion beams.
21. The static mass pre-filter according to claim 20, wherein the first magnetic sector unit is configured for separating ions into diverging ion beams.
22. The static mass pre-filter according to claim 21, comprising an ion lens assembly arranged between the first magnetic sector unit and the second magnetic sector unit.
23. The static mass pre-filter according to claim 22, wherein the ion lens assembly comprises a first pair of lenses upstream of the slit and a second pair of lenses downstream of the slit.
24. The static mass pre-filter according to claim 23, wherein the first pair of lenses comprises a first zoom lens for converting the parallel ion beams into diverging ions beams and a correction lens for converting the diverging ions beams into parallel ions beams, and wherein the second pair of lenses comprises a first correction lens for converting the parallel ion beams into converging ions beams and a zoom lens for converting the converging ions beams into parallel ions beams.
25. The static mass pre-filter according to claims 21 and 22, wherein the ion lens assembly comprises at least one inversion lens.
26. The static mass pre-filter according to claims 19 to 25, wherein the partial ion beams are mirror symmetric relative to a plane perpendicular to at least one partial ion beam.

27. A kit-of-parts for producing a static mass pre-filter according to any of claims 19 to 26.

28. A method of mass spectrometry, comprising:

- generating a beam of ions from a sample,
- mass pre-filtering ions from the beam in accordance with their mass to charge ratio,
- inducing a mass shift of the pre-filtered ions using a reaction cell,
- spatially separating mass-shifted ions in accordance with their mass to charge ratios, and
- detecting the spatially separated ions,

characterized in that the pre-mass filtering comprises:

- using a first magnetic sector unit for separating ions into partial ions beams,
- using a second magnetic sector unit for merging partial ion beams, and
- using a slit arranged between the first magnetic sector unit and the second magnetic sector unit for selectively passing partial ion beams.

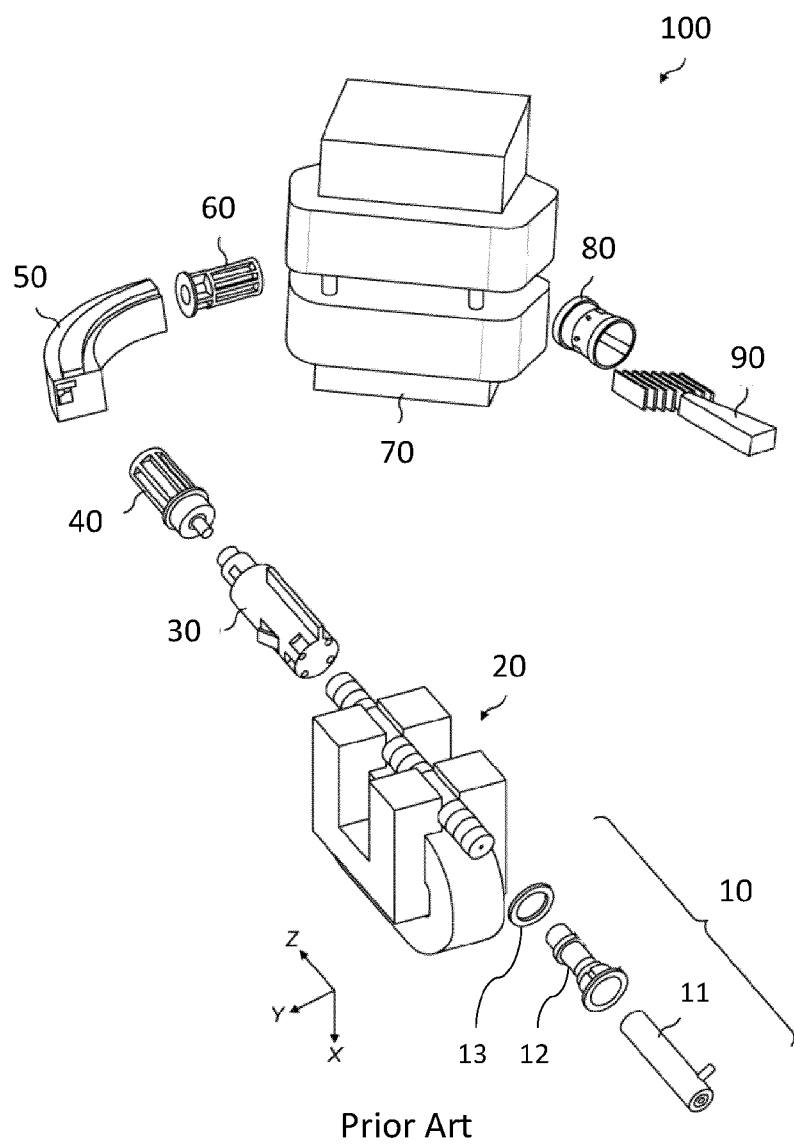


Fig. 1

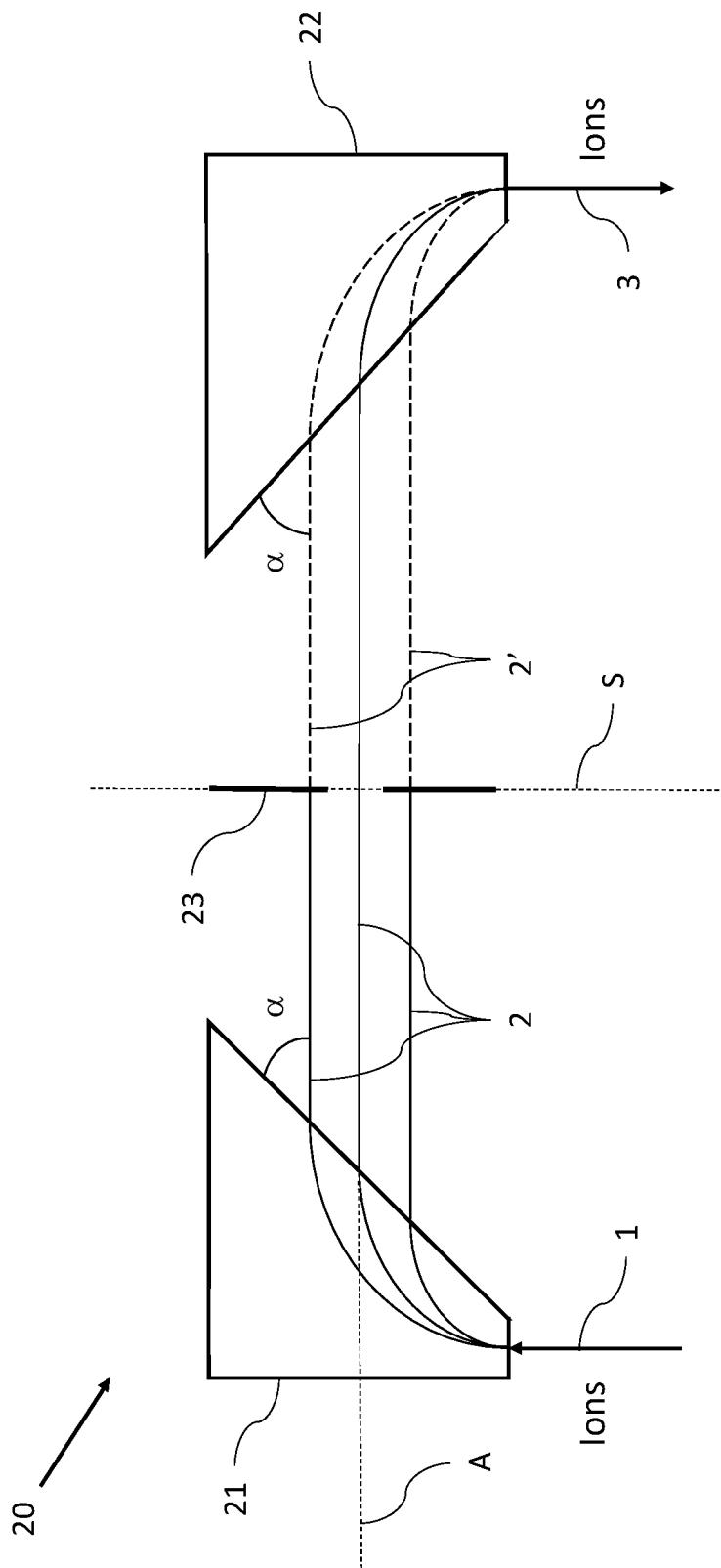


Fig. 2

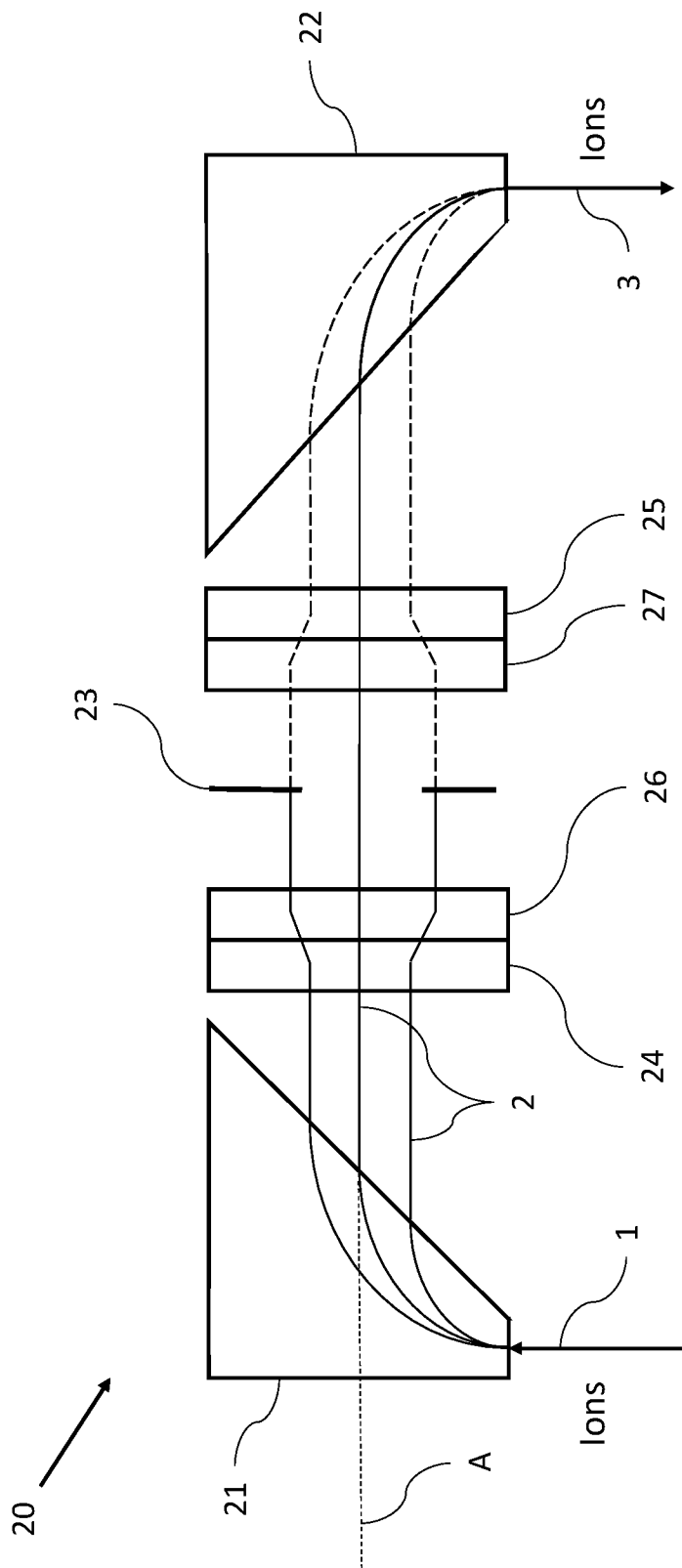


Fig. 3

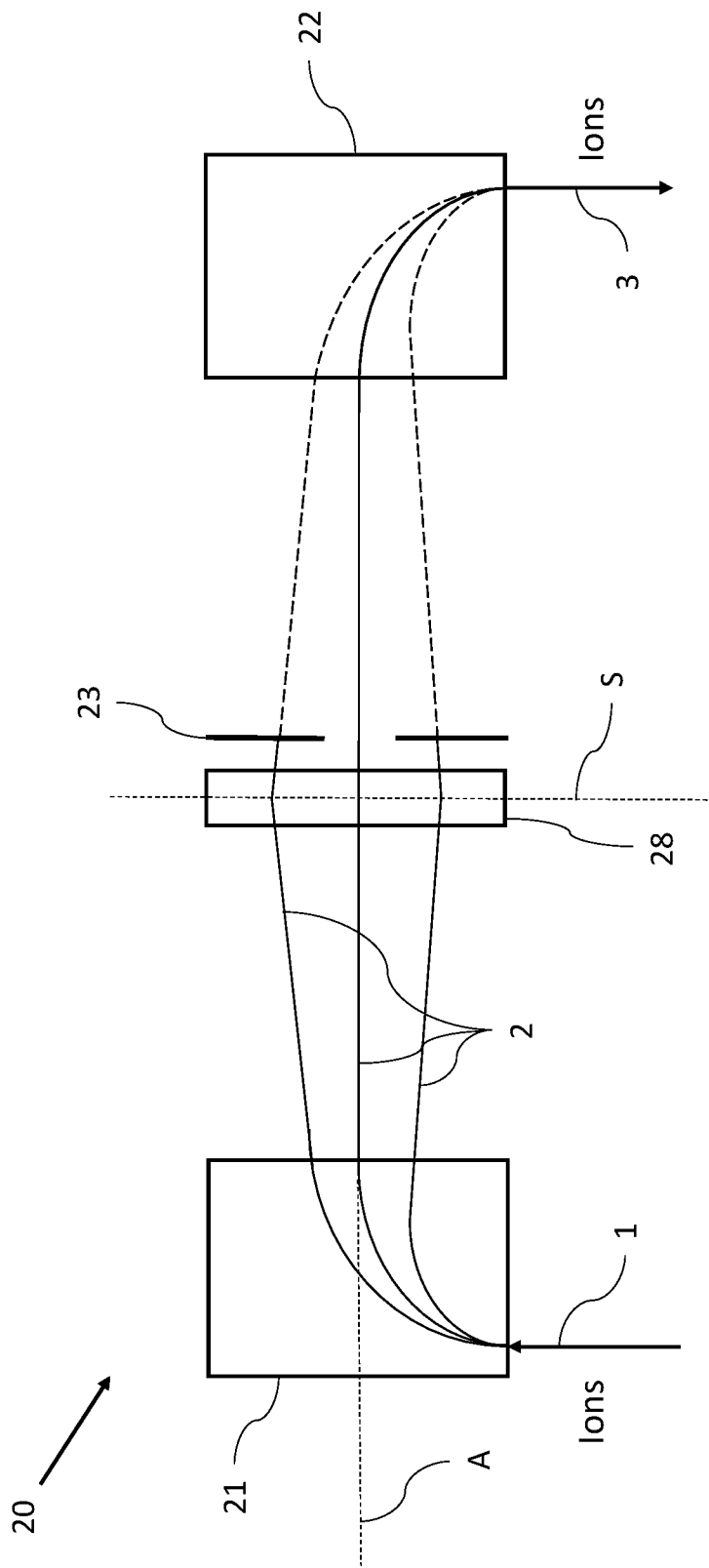


Fig. 4

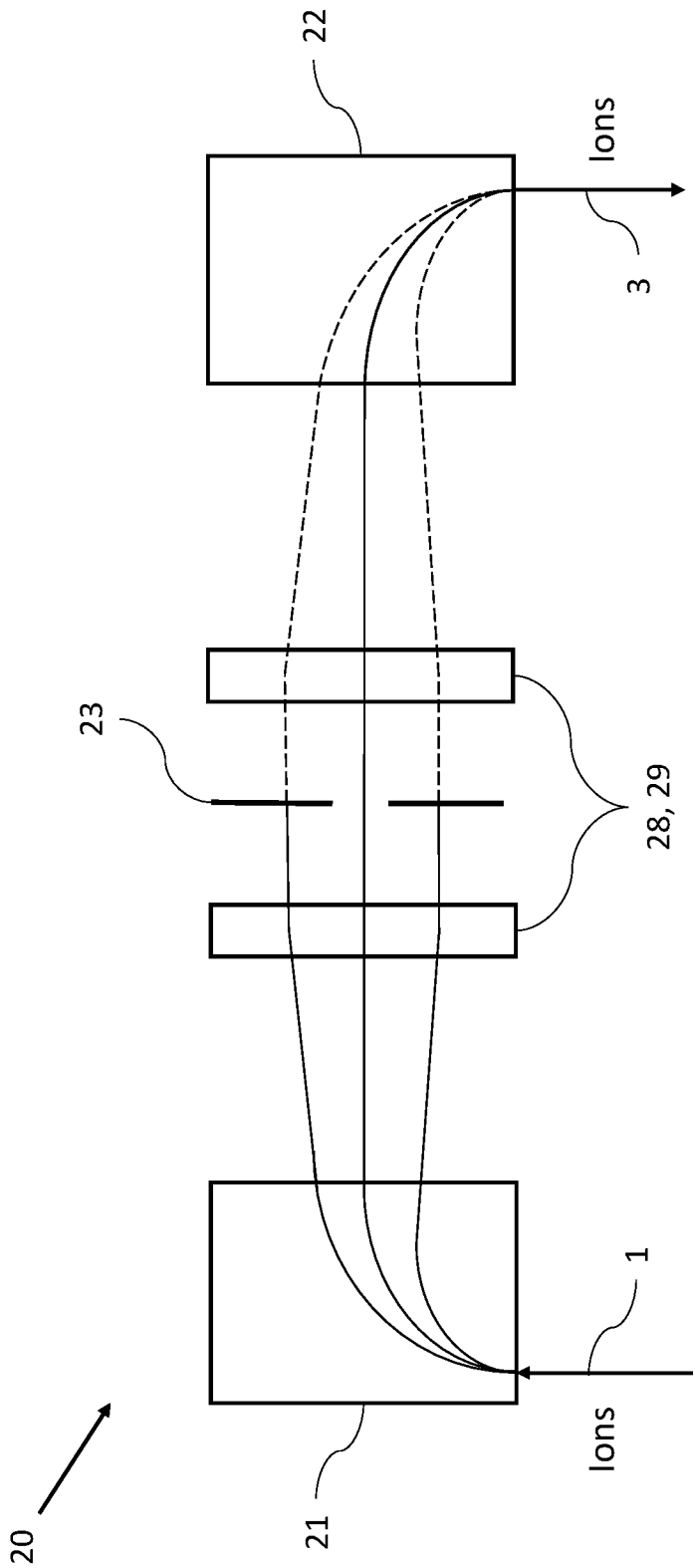


Fig. 5

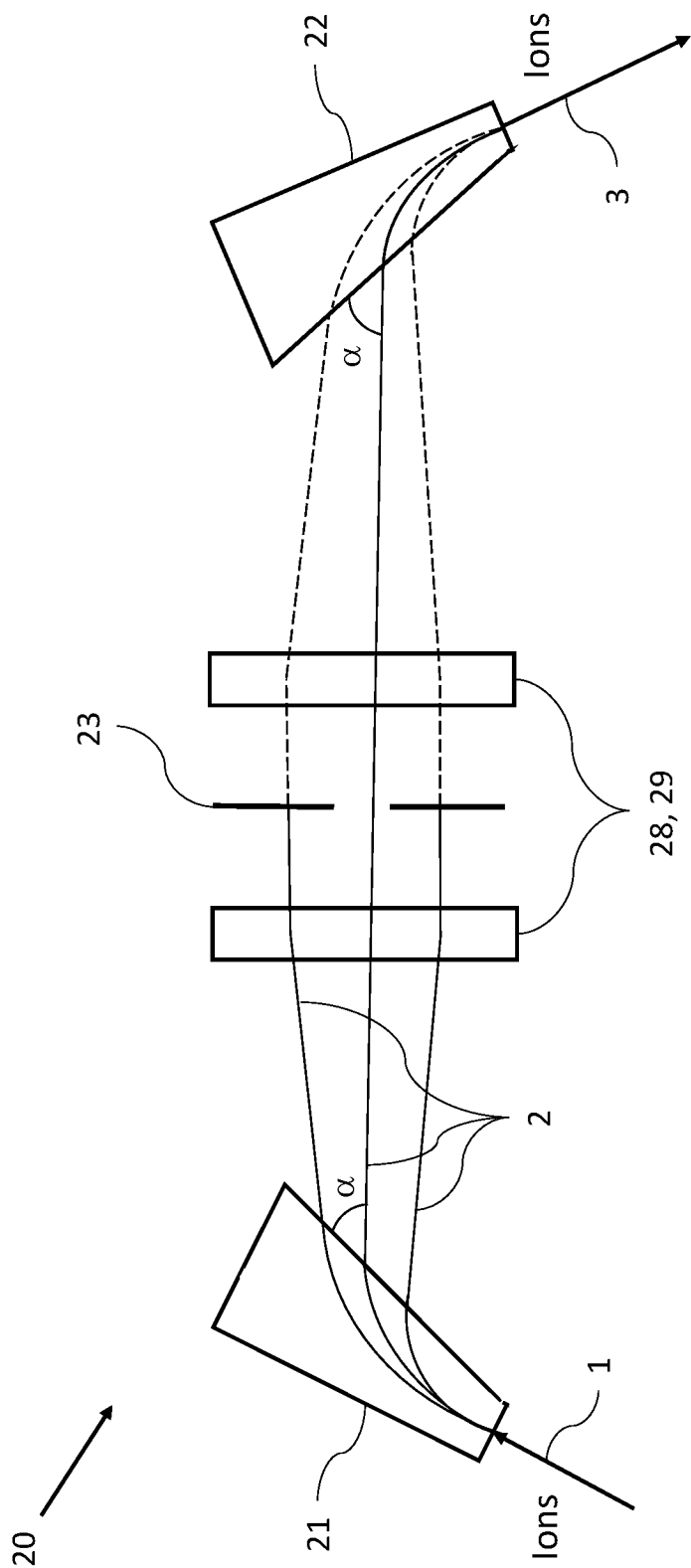


Fig. 6

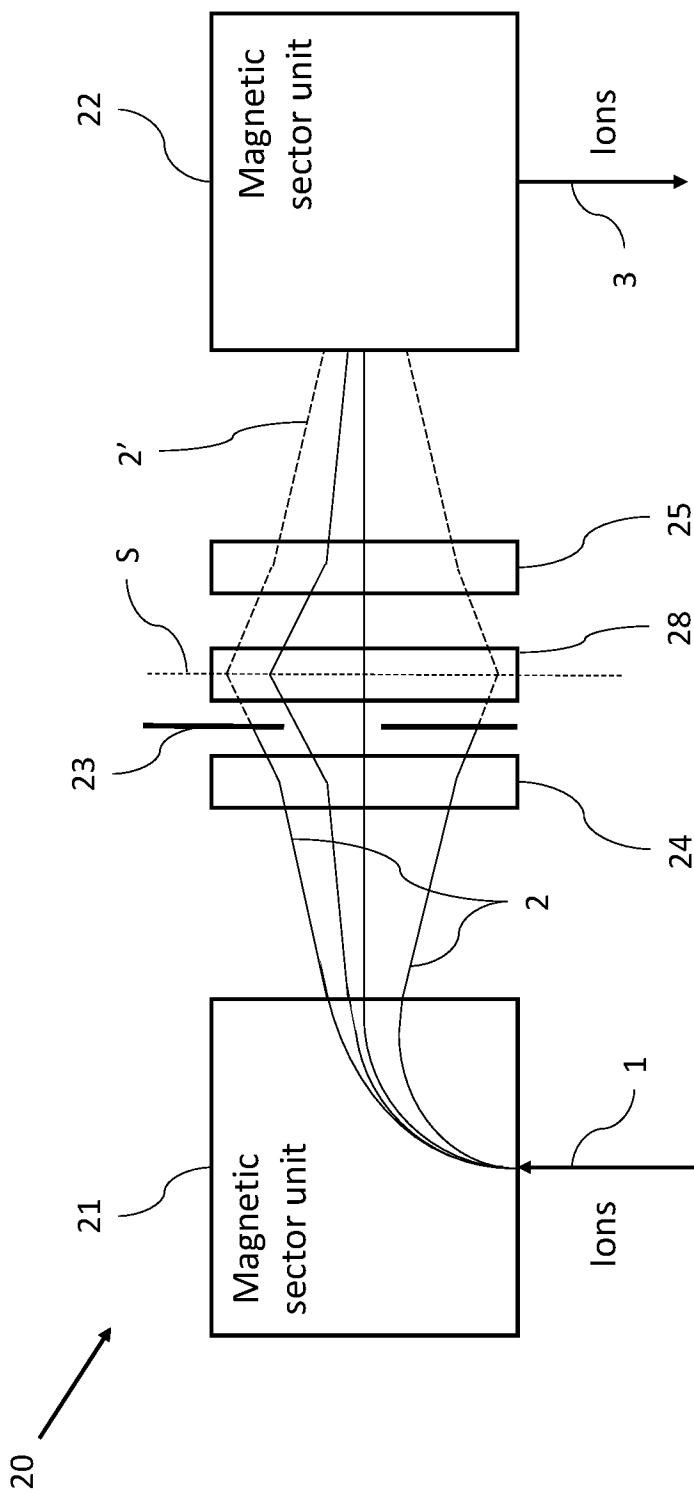


Fig. 7

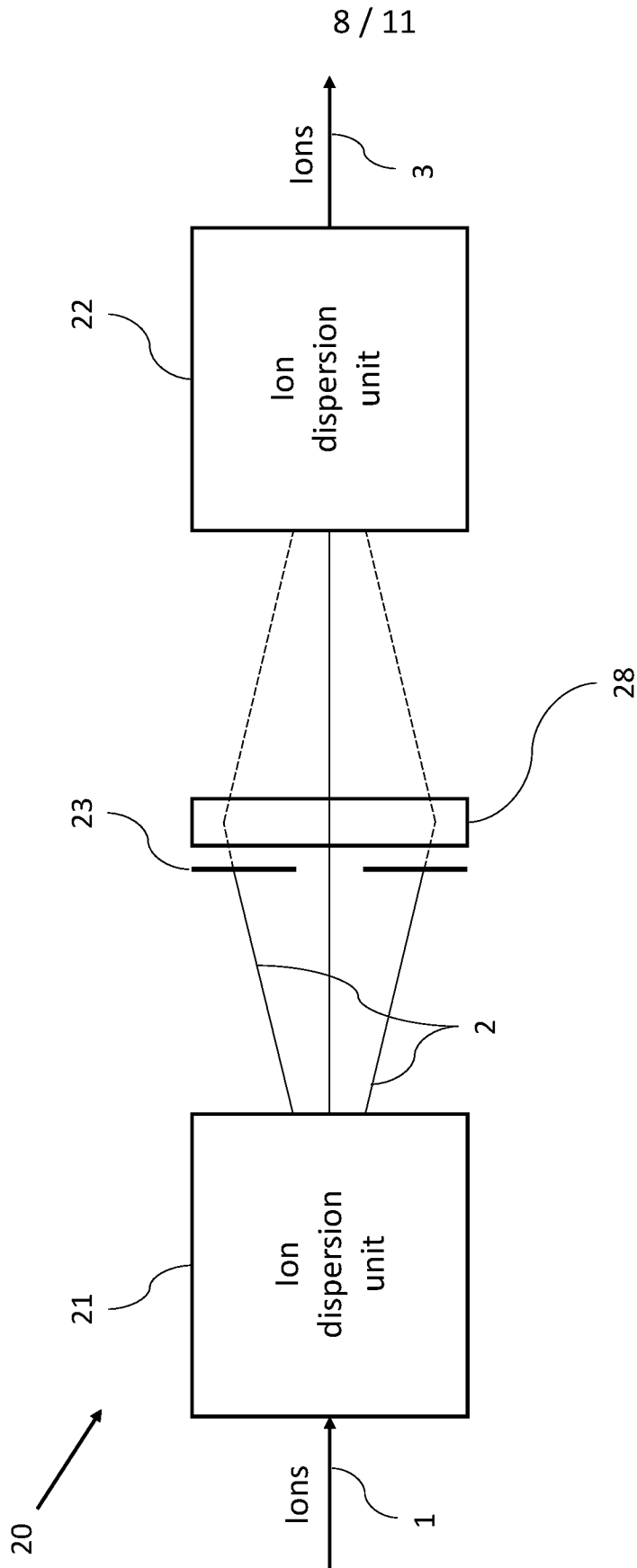


Fig. 8

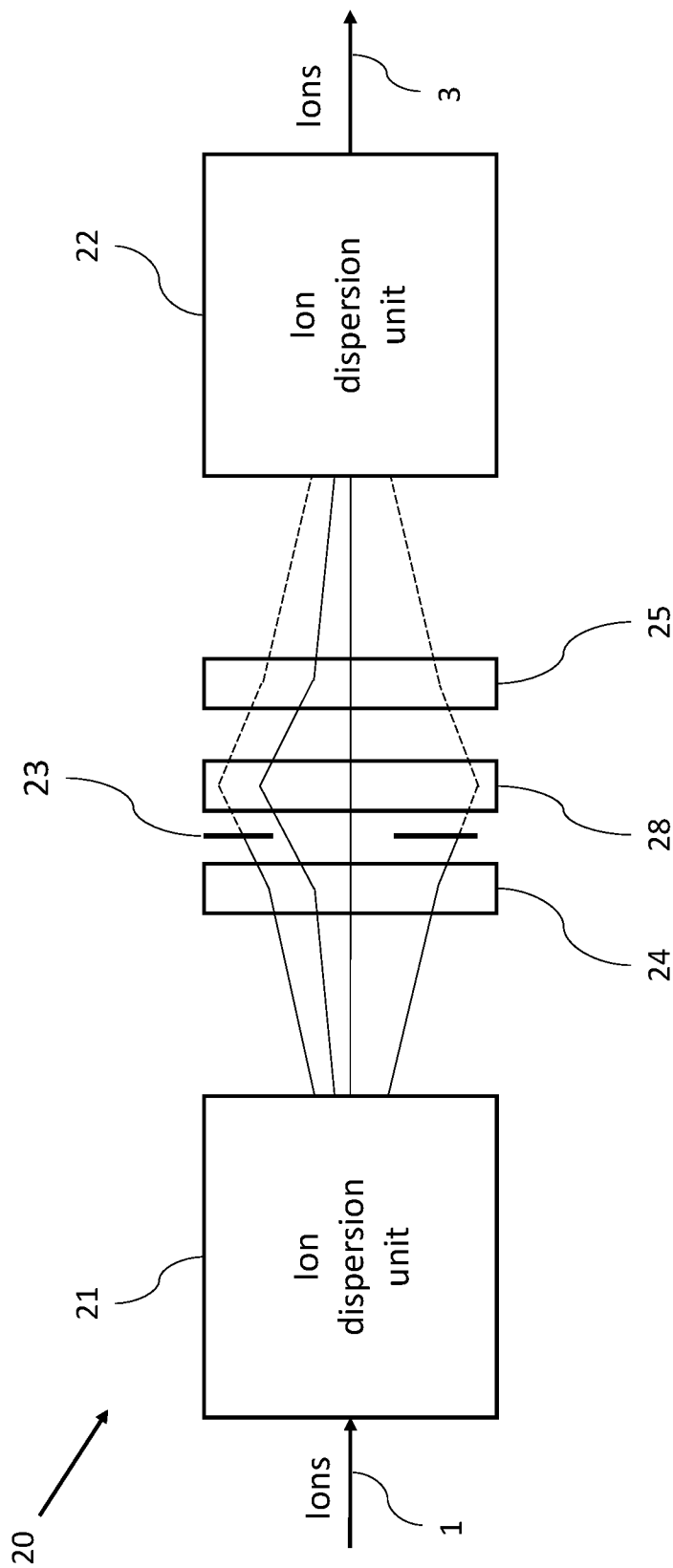


Fig. 9

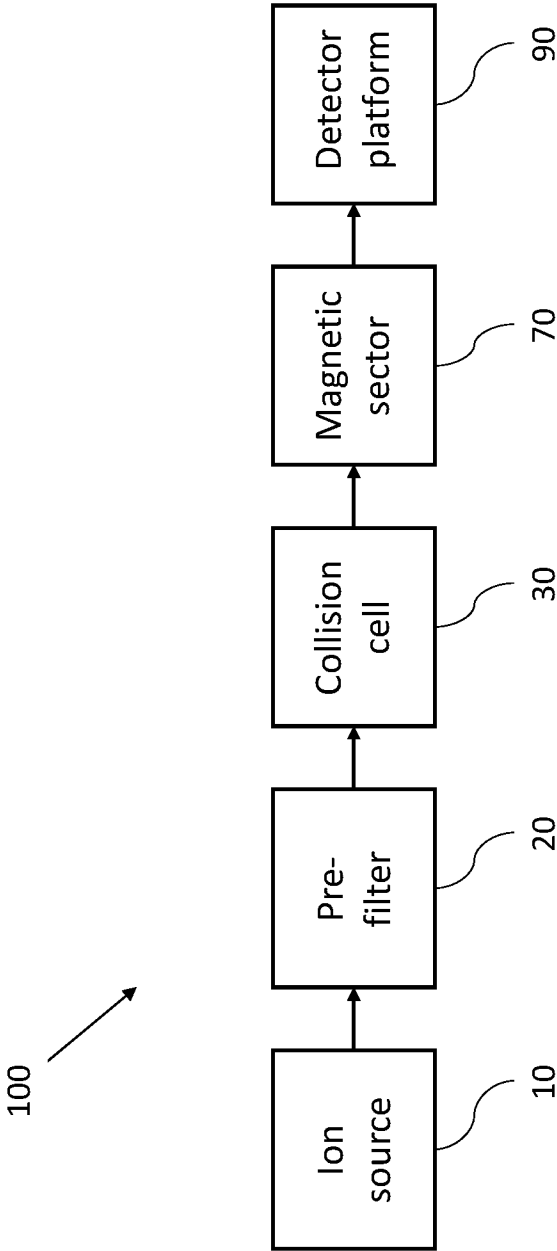


Fig. 10

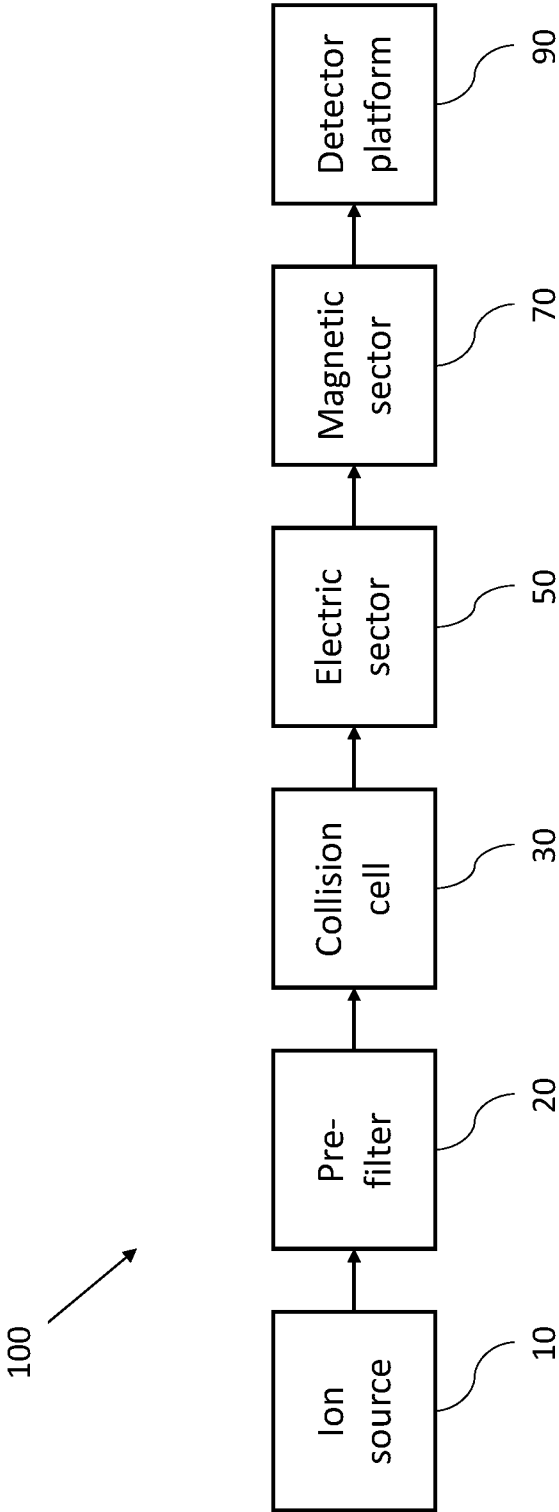


Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/068231

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01J49/00 H01J49/30
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 723 862 A (FORMAN LEON [US]) 3 March 1998 (1998-03-03)	19-27
Y	column 16, line 30 - column 17; figures 1, 7 column 24, line 15 - column 26, line 51; figures 8, 10 -----	1-18,28
Y	US 2016/284526 A1 (KENNY DANIEL JAMES [GB] ET AL) 29 September 2016 (2016-09-29) paragraphs [0225] - [0228]; figure 1 paragraphs [0201] - [0204] -----	1-18,28
Y	US 2022/223401 A1 (SCHWIETERS JOHANNES [DE] ET AL) 14 July 2022 (2022-07-14) cited in the application paragraphs [0071] - [0075]; figure 1 -----	13,17,18



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 September 2024

Date of mailing of the international search report

09/10/2024

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2024/068231

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			WO 2019180045 A1 26-09-2019
