Provisional Application for United States Patent

TITLE: FILTRATION APPARATUS AND METHOD

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BRIEF DESCRIPTION OF THE DRAWINGS

[0001] In the drawings, which are not necessarily drawn to scale, like numerals can describe similar components in different views. Like numerals having different letter suffixes can represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

[0002] FIG. 1 is a cross-sectional view of one embodiment of the invention.

[0003] FIG. 2 is a cross-sectional view of another embodiment of the invention.

[0004] FIG. 3 is a cross-sectional view of another embodiment of the invention.

[0005] FIG. 4 is a cross-sectional view of another embodiment of the invention.

[0006] FIG. 5 is a cross-sectional view of another embodiment of the invention.

[0007] FIG. 6 is a cross-sectional view of another embodiment of the invention.

[0008] FIG. 7 is a cross-sectional view of another embodiment of the invention.

[0009] FIG. 8 is a cross-sectional view of one embodiment of the invention and a schematic representation of the interaction of said embodiment with objects of interest.

DETAILED DESCRIPTION OF THE DRAWINGS

[00010] The term “medium” used herein describes any material which is capable of containing, carrying, transporting, or transferring an object of interest. A medium can be a plasma, a gas, a liquid, a solid, or a vacuum, for example. By default, and unless specified, a medium refers to the collection of all objects which interact with a specified apparatus.

[00011] The term “object” used herein describes any component of a medium. An object can be described as a particle, such as a dust particle, a soot particle, an ice particle, a water droplet, a water molecule, a large molecule, a small molecule, or an atom. Other examples of objects are subatomic particles such as electrons, neutrons, or protons. An object can also be described as a wave, such as an acoustic wave, a seismic wave, an ocean wave, a gravity wave, a photon, or a phonon. The invention applies to any medium which can be considered to comprise distinct objects. An object can have a property of interest, as well as a defining property, which can be used to distinguish an object from other objects of the medium.

[00012] One can define a “dynamic boundary condition” as a simplified scenario in which the properties of the medium at a first reservoir and a second reservoir are identical and uniform in time and space.

[00013] One can define a “static boundary condition” as a simplified scenario in which a first and second reservoir are finite in size and isolated from each other and any other reservoirs apart from an embodiment of the invention, such as a filtering apparatus, allowing the exchange of OI between the first and second reservoirs. In the static boundary condition, the macroscopic properties of interest of the medium in the first and second reservoirs have reached a steady state value, i.e. a value that is substantially constant in time and space, i.e. substantially uniform throughout a reservoir. Such macroscopic properties can refer to the pressure, temperature, or density of a medium, for example.

[00014] A "default boundary condition" for an example filtering apparatus can refer to a model scenario in which the properties of the medium at a first reservoir and a second reservoir are identical and uniform in time and space.

[00015] A "baseline scenario" can refer to a scenario in which an example embodiment comprising a filtering apparatus is replaced by a "baseline apparatus” comprising a solid, impermeable, possibly reflective, flat filtering apparatus, and subjected to default boundary conditions.

[00016] A "baseline probability" can refer to the probability for any object which interacts with a baseline apparatus to be located at a specified side of the baseline apparatus after the interaction is completed in a baseline scenario. For example, the baseline probability can be 50% for any side of the baseline apparatus.

[00017] The “characteristic width” of a focusing apparatus is the extent of a focusing apparatus in a direction perpendicular to a local flow of objects of interest which interact with the focusing apparatus.

[00018] The “characteristic length” of a focusing apparatus is the average displacement of objects of interest throughout an interaction with a focusing apparatus within a filtering apparatus.

[00019] The “characteristic dimension” of a focusing apparatus is the average distance travelled by objects of interest throughout an interaction with a focusing or deflection apparatus. In general, the characteristic dimension is a dimension which is relevant to the way in which the filtering apparatus interacts with objects of interest.

[00020] FIG. 1 is a cross-sectional view of one embodiment of the invention. Some features of the apparatus shown in FIG. 1, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, and will therefore not be described in the same detail in the context of FIG. 1, and vice versa.

[00021] There is a first reservoir 1100, in which the medium comprises objects of interest, or "OI", which are schematically represented by individual particles, such as the schematic representation of OI 1112. OI are assumed to be spherical in shape in this simplified embodiment. In FIG. 1, for simplicity, the medium can be considered to be an ideal gas comprising monatomic molecules. In other embodiments the medium can consist of other types of objects, such as water molecules. In other embodiments, OI need not be spherical, but can take any shape. For example, OI can be a diatomic molecule, or a polyatomic molecule, or an aerosol particle like a dust particle or pollen, which can take a wide variety of shapes. A medium can also comprise several different types of objects, such as sodium and chlorine ions found in salt water, or electrons in a conductor. An OI can also be a subatomic particle such as an electron, positron, or photon. An OI can also be a virtual particle, or virtual object, such as a virtual photon, a virtual electron, virtual quarks, or a virtual positron, as describe by quantum field theory. These virtual particles give rise to the zero point energy and associated effects, such as the Casimir effect. Note that the mean free path of virtual particles can be on the order of tens of nanometers. Note that virtual particles also exist in a vacuum.

[00022] The filtering plate 1101 comprises a bulk material 1102, which comprises a first surface 1103. Bulk material 1102 can be made of any suitable material, such as metal, composite, or ceramic. In some embodiments, bulk material 1102 can also be described as a fabric. Bulk material 1102 can comprise graphene in some embodiments. Bulk material 1102 is configured to be perfectly reflective to OI in this embodiment. In other embodiments, bulk material 1102 can have a reflectivity which is greater than zero and less than one. Note that the reflections can be specular or diffuse in this embodiment and embodiments of this type. In the depicted scenario, the reflections of OI from the surface 1103 of bulk material 1102 are specular.

[00023] In this embodiment surface 1103 is planar and comprises segments of two dimensional surfaces, such as surface 1105 and surface 1106. Surface 1106 is two dimensional and parallel to the YZ-plane. Surface 1103 can be considered to be generated by the extrusion of bulk material 1102 in the positive or negative Z-direction. In other embodiments, such as the embodiment depicted in FIG. 7, the surface 1103 can also be cylindrical or circular in three-dimensional form when viewed in the X-direction in FIG. 1. In other embodiments, surface 1103 can also be elliptical, square, or rectangular in form when viewed in the X-direction in FIG. 1. In other embodiments, surface 1103 can be in any three dimensional form, provided the principles of operation are maintained.

[00024] Surface 1103 comprises several identically configured segments, such as segment 1104 or segment 1107. Each segment can be considered to be a focusing apparatus, or a deflection apparatus, which is configured to deflect or redirect objects of interest which interact with surface 1103 in a desired direction. In embodiment 1101, each segment comprises a first surface, such as first surface 1105 or first surface 1108, and a second surface, such as second surface 1106, or second surface 1109. In FIG. 1, the first surface 1105 is inclined at an angle, such that the surface normal is directed in the positive X-direction and in a plane parallel to the XY-plane. The angle between the surface normal and the Y-axis is denoted the "inclination angle". The inclination angle can range from a value greater than zero degrees to a value smaller than ninety degrees. The extent of a segment, such as segment 1104 or segment 1107 along the X-axis, which in this case is also equal to the extent of the first surface along the X-axis, is denoted the "width of a segment". The "depth of a segment" is the extent of a segment along the Y-axis, which in this case is also equal to the extent of the first surface along the Y-axis, or the extent of a second surface, such as second surface 1106 or second surface 1109, along the Y-axis. In this embodiment, the second surfaces, such as second surface 1106, is planar in shape and parallel to the YZ-plane.

[00025] Examples of interactions between OI and the bulk material 1102 are shown in FIG. 1, as exemplified by trajectory 1113 of OI 1112, trajectory 1111 of OI 1110, or trajectory 1115 of OI 1114. As a result of the aforementioned inclination angle of the first surfaces, such as first surface 1105 or first surface 1108, the motion of OI after colliding with the first surfaces is preferentially in the positive X-direction.

[00026] Note that the type of interaction between the OI and the filtering plate 1101 is a function of the inclination angle and the width of a segment, amongst other parameters such as parameters pertaining to the mean free path of objects of interest in the surrounding medium. For a certain value of such parameters, the OI which approach the surface 1103 can, on average, experience a net deflection in the positive X-direction in some embodiments. In a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the positive X-direction. An "initial velocity" is the velocity of an OI immediately prior to interacting with apparatus 1101, i.e. prior to colliding with surface 1103, e.g. with a first surface 1105 or a second surface 1106. A "final velocity" is the velocity of an OI immediately after interacting with apparatus 1101, i.e. after colliding with surface 1103, e.g. with a first surface 1105 or a second surface 1106. Due to the geometry of the surface 1103, the average initial velocity vector of OI can be different to the average final velocity vector of OI. For example, in a hypothetical scenario, such as a scenario in which there is a static boundary condition, the average initial velocity can be directed in the negative Y-direction and parallel to the Y-axis, while the average final velocity can be directed in the positive X- and Y-direction. The non-zero component in the positive X-direction can lead to a net diffusion of OI in the positive X-direction. In other embodiments, or other applications, the average component of the final velocity in the positive X-direction can be larger than the average component of the initial velocity in the positive X-direction, where the average is calculated over all OI which interact with the filtering apparatus 1101.

[00027] The inclination angle can be 50 degrees in some embodiments. The inclination angle can be 45 degrees in some embodiments. The inclination angle can be 30 degrees in some embodiments. The inclination angle can be 15 degrees in some embodiments. The inclination angle can be 10 degrees in some embodiments. The inclination angle can be 5 degrees in some embodiments. Note that in some embodiments, or some methods of operation, the bulk flow of OI which is induced by the interaction of OI with the filtering apparatus 1101 can be in the negative X-direction instead of in the positive X-direction.

[00028] As a result of a bulk flow induced by the interaction of OI with the surface 1103 of bulk material 1102 of filtering apparatus 1101 in the positive X-direction, there is a net force on filtering apparatus 1101 in the negative X-direction. This force can be employed to do mechanical work, for example. The mechanical work can in turn be converted into electrical work by an electrical generator, for instance. The energy for this work is provided by the thermal energy of OI in the first reservoir 1100. Thus a filtering apparatus 1101 can be employed to convert thermal energy into useful work.

[00029] The characteristic dimension of the embodiment shown in FIG. 1 can be considered to be the larger of the two numbers describing the width of a segment and the depth of a segment, for example.

[00030] FIG. 2 is a cross-sectional view of one embodiment of the invention. Some features of the apparatus shown in FIG. 2, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, and will therefore not be described in the same detail in the context of FIG. 2, and vice versa.

[00031] There is a first reservoir 1140, in which the medium comprises objects of interest, or "OI", which are schematically represented by individual particles, such as the schematic representation of OI 1150.

[00032] The filtering plate 1141 comprises a bulk material 1142, which comprises a first surface 1143. Bulk material 1142 can be made of any suitable material, such as metal, composite, or ceramic. In some embodiments, bulk material 1142 can also be described as a fabric.

[00033] In this embodiment surface 1143 comprises segments of surfaces, such as surface 1145 and surface 1146. Surface 1145 is concave in shape, as shown. Surface 1146 is two dimensional and parallel to the YZ-plane in this embodiment. Surface 1143 can be considered to be generated by the extrusion of bulk material 1142 in the positive or negative Z-direction. In other embodiments, the surface 1143 can also be cylindrical or circular in three-dimensional form when viewed in the X-direction. In other embodiments, surface 1143 can also be elliptical, square, or rectangular in form when viewed in the X-direction. In other embodiments, surface 1143 can be in any three dimensional form, provided the principles of operation are maintained.

[00034] Surface 1143 comprises several identically configured segments, such as segment 1144 or segment 1147. Each segment can be considered to be a focusing apparatus, or a deflection apparatus, which is configured to deflect or redirect objects of interest which interact with surface 1143 in a desired direction. In embodiment 1141, each segment comprises a first surface, such as first surface 1145 or first surface 1148, and a second surface, such as second surface 1146, or second surface 1149. In FIG. 2, the first surface 1145 is inclined at an angle, such that the surface normal is directed in the positive X-direction and in a plane parallel to the XY-plane. The aveage angle between the surface normal and the Y-axis is denoted the "inclination angle". The inclination angle can range from a value greater than zero degrees to a value smaller than ninety degrees. The extent of a segment, such as segment 1144 or segment 1147 along the X-axis, which in this case is also equal to the extent of the first surface along the X-axis, is denoted the "width of a segment". The "depth of a segment" is the extent of a segment along the Y-axis, which in this case is also equal to the extent of the first surface along the Y-axis. In this embodiment, the second surfaces, such as second surface 1146, is planar in shape and parallel to the YZ-plane.

[00035] Examples of interactions between OI and the bulk material 1142 are shown in FIG. 2, as exemplified by trajectory 1153 of OI 1152, or trajectory 1151 of OI 1150. As a result of the aforementioned inclination angle of the first surfaces, such as first surface 1145 or first surface 1148, the motion of OI after colliding with the first surfaces is preferentially in the positive X-direction.

[00036] Note that the type of interaction between the OI and the filtering plate 1141 is a function of the inclination angle and the width of a segment, amongst other parameters such as parameters pertaining to the mean free path of objects of interest in the surrounding medium and the shape of the first and second surfaces, such as first surface 1145 and the second surface 1146. For a certain value of such parameters, the OI which approach the surface 1143 can, on average, experience a net deflection in the positive X-direction in some embodiments. In a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the positive X-direction, for example. Due to the geometry of the surface 1143, the average initial velocity vector of OI can be different to the average final velocity vector of OI. For example, in a hypothetical scenario, such as a scenario in which there is a net motion of the filtering apparatus 1141 relative to the medium in reservoir 1140 in the negative X-direction, the average initial velocity vector of OI can be directed in the positive X-direction and in the negative Y-direction, as shown in FIG. 2. The average final velocity can be directed in the positive X- and Y-direction, where the component in the positive X-direction of the average final velocity is larger than the component in the positive X-direction of the average initial velocity. The non-zero net component in the positive X-direction can lead to a net diffusion or a net acceleration of OI in the positive X-direction.

[00037] The inclination angle can be 50 degrees in some embodiments. The inclination angle can be 45 degrees in some embodiments. The inclination angle can be 30 degrees in some embodiments. The inclination angle can be 15 degrees in some embodiments. The inclination angle can be 10 degrees in some embodiments. The inclination angle can be 5 degrees in some embodiments. Note that in some embodiments, or some methods of operation, the bulk flow of OI which is induced by the interaction of OI with the filtering apparatus 1141 can be in the negative X-direction instead of in the positive X-direction.

[00038] As a result of a bulk flow induced by the interaction of OI with the surface 1143 of bulk material 1142 of filtering apparatus 1141 in the positive X-direction, there is a net force on filtering apparatus 1141 in the negative X-direction. This force can be employed to do mechanical work, for example. The mechanical work can in turn be converted into electrical work by an electrical generator, for instance. The energy for this work is provided by the thermal energy of OI in the first reservoir 1140. Thus a filtering apparatus 1141 can be employed to convert thermal energy into useful work.

[00039] The characteristic dimension of the embodiment shown in FIG. 2 can be considered to be the larger of the two numbers describing the width of a segment and the depth of a segment, for example.

[00040] FIG. 3 is a cross-sectional view of one embodiment of the invention. Some features of the apparatus shown in FIG. 3, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, and will therefore not be described in the same detail in the context of FIG. 3, and vice versa.

[00041] There is a first reservoir 1180, in which the medium comprises objects of interest, or “OI”.

[00042] The filtering plate 1181 comprises a bulk material 1182, which comprises a first surface 1183. Bulk material 1182 can be made of any suitable material, such as metal, composite, or ceramic. In some embodiments, bulk material 1182 can also be described as a fabric.

[00043] In this embodiment surface 1183 comprises segments of surfaces, such as surfaces 1185, 1186, 1190, and 1191. Surfaces 1185, 1186, 1190, and 1191 are planar in shape, i.e. two dimensional, in this embodiment. Surface 1183 comprises a top surface, which is parallel to the XZ-plane and planar. Surface 1183 can be considered to be generated by the extrusion of bulk material 1182 in the positive or negative Z-direction in this embodiment. In other embodiments, the surface 1183 can also be cylindrical or circular in three-dimensional form when viewed in the X-direction. In other embodiments, surface 1183 can also be elliptical, square, or rectangular in form when viewed in the X-direction. In other embodiments, surface 1183 can be in any three dimensional form, provided the principles of operation are maintained.

[00044] Surface 1183 comprises several identically configured segments, such as segment 1184 or segment 1188, or segment 1189. Each segment can also be described as a slot. Each segment can be considered to be a focusing apparatus, or a deflection apparatus, which is configured to deflect or redirect objects of interest which interact with the segment in a desired direction. In embodiment 1181, each segment comprises a first surface, such as first surface 1185 or first surface 1190, and a second surface, such as second surface 1186, or second surface 1191. In FIG. 3, the first surface 1185 is inclined at an angle, such that the surface normal is directed in the positive X-direction and a negative Y-direction, and such that the surface normal lies in a plane parallel to the XY-plane. The average angle between the surface normal of a first surface and the Y-axis is denoted the “first inclination angle”, which is greater than ninety degrees in this embodiment for surface 1185 or surface 1190. The first inclination angle can range from a value greater than ninety degrees to a value smaller than 180 degrees. In FIG. 3, the second surface 1186 is inclined at an angle, such that the surface normal is directed in the negative X-direction and a positive Y-direction, and such that the surface normal lies in a plane parallel to the XY-plane. The average angle between the surface normal of a second surface and the Y-axis is denoted the “second inclination angle”, which is smaller than ninety degrees in this embodiment for surface 1186 or surface 1191. The second inclination angle can range from a value greater than zero degrees to a value smaller than ninety degrees. The angle between a first surface and a second surface is denoted the “internal angle” 1205. The internal angle can be a value larger than zero and smaller than 180 degrees. In the depicted embodiment, the internal angle is larger than zero and smaller than 45 degrees. In the depicted embodiments, the internal angle is approximately 15 degrees.

[00045] The extent of a segment, such as segment 1184 or segment 1189 along the X-axis, which in this case is also equal to the extent of the second surface along the X-axis, is denoted the “width of a segment”. The “depth of a segment” is the extent of a segment along the Y-axis, which in this case is also equal to the extent of the second surface along the Y-axis.

[00046] As a result of the aforementioned inclination angle of the first and second surfaces, such as first surface 1185 or first surface 1190, the motion of OI after colliding with the first or and second surfaces is preferentially in the positive X-direction. In this manner, OI can be deflected or redirected into the positive X-direction as a result of their interaction with the first and second surfaces.

[00047] Note that the type of interaction between the OI and the filtering plate 1181 is a function of the first and second inclination angle and the width of a segment, amongst other parameters such as parameters pertaining to the mean free path of objects of interest in the surrounding medium and the shape of the first and second surfaces, such as first surface 1185 and the second surface 1186. For a certain value of such parameters, the OI which approach the surface 1183 can, on average, experience a net deflection in the positive X-direction in some embodiments. In a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the positive X-direction, for example. Due to the geometry of the surface 1183, the average initial velocity vector of OI can be different to the average final velocity vector of OI. For example, in a hypothetical scenario, such as a scenario in which there is a net motion of the filtering apparatus 1181 relative to the medium in reservoir 1180 in the negative X-direction, the average initial velocity vector of OI can be directed in the positive X-direction and in the negative Y-direction. The average final velocity can be directed in the positive X- and Y-direction, where the component in the positive X-direction of the average final velocity is larger than the component in the positive X-direction of the average initial velocity. The non-zero net component in the positive X-direction can lead to a net diffusion or a net acceleration of OI in the positive X-direction.

[00048] As a result of a bulk flow induced by the interaction of OI with the surface 1183 of bulk material 1182 of filtering apparatus 1181 in the positive X-direction, there is a net force on filtering apparatus 1181 in the negative X-direction. This force can be employed to do mechanical work, for example. The mechanical work can in turn be converted into electrical work by an electrical generator, for instance. The energy for this work is provided by the thermal energy of OI in the first reservoir 1180. Thus a filtering apparatus 1181 can be employed to convert thermal energy into useful work.

[00049] The characteristic dimension of the embodiment shown in FIG. 3 can be considered to be the larger of the two numbers describing the width of a segment and the depth of a segment, for example. In accordance with some embodiments of the invention, the characteristic dimension is smaller than 1000 times the mean free path of OI in an adjacent reservoir.

[00050] FIG. 4 is a cross-sectional view of one embodiment of the invention. Some features of the apparatus shown in FIG. 4, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, and will therefore not be described in the same detail in the context of FIG. 4, and vice versa.

[00051] There is a first reservoir 1230, in which the medium comprises objects of interest, or "OI".

[00052] The filtering plate 1231 comprises a bulk material 1232, which comprises a first surface 1233. Bulk material 1232 can be made of any suitable material, such as metal, composite, or ceramic. In some embodiments, bulk material 1232 can also be described as a fabric.

[00053] In this embodiment surface 1233 comprises segments of surfaces, such as surfaces 1235, 1236, 1237, 1239, 1240, and 1241. Surface 1233 can be considered to be generated by the extrusion of bulk material 1232 in the positive or negative Z-direction in this embodiment. In other embodiments, the surface 1233 can also be cylindrical or circular in three-dimensional form when viewed in the X-direction. In other embodiments, surface 1233 can also be elliptical, square, or rectangular in form when viewed in the X-direction. In other embodiments, surface 1233 can be in any three dimensional form, provided the principles of operation are maintained.

[00054] Surface 1233 comprises several identically configured segments, such as segment 1234, which comprises surfaces 1235, 1236, and 1237, or segment 1238, which comprises surfaces 1239, 1240, and 1241. Each segment can also be described as a slot. Each segment can be considered to be a focusing apparatus, or a deflection apparatus, which is configured to deflect or redirect objects of interest which interact with the segment in a desired direction. In embodiment 1231, each segment comprises a first surface, such as first surface 1235 or first surface 1239, and a second surface, such as second surface 1236, or second surface 1240, as well as a third surface, such as third surface 1237, or third surface 1241.

[00055] The first surface, such as first surface 1235 is convex in shape in this embodiment. The second surface, such as second surface 1236 is concave in shape in this embodiment. The third surface, such as third surface 1237 is concave in shape in this embodiment. The third surface is configured to focus a portion of trajectories of OI onto the first surface, which is configured to defocus and redirect the trajectories of OI into the positive X-direction. The second surface is configured to focus and redirect the trajectories of OI into the positive X-direction. In other embodiments, concave surfaces can be planar or convex, and convex surfaces can be planar or concave, provided that the general principles of operation, i.e. the redirection of trajectories of OI into the positive X-direction, are maintained.

[00056] In FIG. 4, the first surface, such as first surfaces 1235, is inclined at an angle, such that the surface normal is directed substantially in the positive X-direction, and such that the surface normal lies in a plane parallel to the XY-plane. In other embodiments, the surface normal need not lie in a plane parallel to the XY-plane. The average angle between the surface normal of a first surface and the Y-axis is denoted the "first inclination angle", which is approximately ninety degrees in this embodiment for surface 1235 or surface 1239. The first inclination angle can range from a value greater than zero degrees to a value smaller than approximately 135 degrees.

[00057] In FIG. 4, the second surface 1236 is inclined at an angle, such that the surface normal is directed in the positive X-direction and a positive Y-direction, and such that the surface normal lies in a plane parallel to the XY-plane. In other embodiments, the surface normal need not lie in a plane parallel to the XY-plane. The average angle between the surface normal of a second surface and the Y-axis is denoted the "second inclination angle", which is smaller than ninety degrees in this embodiment for surface 1186 or surface 1191. The second inclination angle can range from a value greater than zero degrees to a value smaller than ninety degrees.

[00058] In FIG. 4, the third surface 1237 is inclined at an angle, such that the surface normal is directed in the negative X-direction and a positive Y-direction, and such that the surface normal lies in a plane parallel to the XY-plane. In other embodiments, the surface normal need not lie in a plane parallel to the XY-plane. For example, the third surface can be concave when viewed in the negative Y-direction in order to enhance the focusing effect onto the first surface in the XZ-plane. The average angle between the surface normal of a third surface and the Y-axis is denoted the "third inclination angle", which is smaller than ninety degrees in this embodiment for surface 1237 or surface 1241. The third inclination angle can range from a value greater than zero degrees to a value smaller than ninety degrees.

[00059] The extent of a segment, such as segment 1234 or segment 1238 along the X-axis, is denoted the "width of a segment", which is equal to the extent of the combined surface of the first, second, and third surfaces along the X-axis. The "depth of a segment" is the extent of a segment along the Y-axis, which in this case is equal to the extent of the third surface along the Y-axis, or the extent of the combined first and second surface along the Y-axis.

[00060] Examples of interactions between OI and the bulk material 1232 are shown in FIG. 4, as exemplified by trajectory 1243 of OI 1242, or trajectory 1245 of OI 1244, or trajectory 1247 of

OI 1246. As a result of the aforementioned configuration of the first, second, and third surfaces in a segment, the motion of OI after colliding with the first, second, or third surfaces is preferentially in the positive X-direction. In this manner, OI can be deflected or redirected into the positive X-direction as a result of their interaction with the first, second, or third surfaces.

[00061] Note that the type of interaction between the OI and the filtering plate 1231 is a function of the first, second, and third inclination angle, the shape of the first, second, and third surfaces, and the width and depth of a segment, amongst other parameters such as parameters pertaining to the mean free path of objects of interest in the surrounding medium. For a certain value of such parameters, the OI which approach the surface 1233 can, on average, experience a net deflection in the positive X-direction in some embodiments. In a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the positive X-direction, for example. Due to the geometry of the surface 1233, the average initial velocity vector of OI can be different to the average final velocity vector of OI. For example, in a hypothetical scenario, such as a scenario in which there is a net motion of the filtering apparatus 1231 relative to the medium in reservoir 1230 in the negative X-direction, the average initial velocity vector of OI can be directed in the positive X-direction and in the negative Y-direction. The average final velocity can be directed in the positive X- and Y-direction, where the component in the positive X-direction of the average final velocity is larger than the component in the positive X-direction of the average initial velocity. The non-zero net component in the positive X-direction can lead to a net diffusion or a net acceleration of OI in the positive X-direction.

[00062] As a result of a bulk flow induced by the interaction of OI with the surface 1233 of bulk material 1232 of filtering apparatus 1231 in the positive X-direction, there is a net force on filtering apparatus 1231 in the negative X-direction. This force can be employed to do mechanical work, for example. The mechanical work can in turn be converted into electrical work by an electrical generator, for instance. The energy for this work is provided by the thermal energy of OI in the first reservoir 1230. Thus a filtering apparatus 1231 can be employed to convert thermal energy into useful work.

[00063] The characteristic dimension of the embodiment shown in FIG. 4 can be considered to be the larger of the two numbers describing the width of a segment and the depth of a segment, for example. In accordance with some embodiments of the invention, the characteristic dimension is smaller than 1000 times the mean free path of OI in an adjacent reservoir.

[00064] FIG. 5 is a cross-sectional view of one embodiment of the invention. Some features of the apparatus shown in FIG. 5, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, and will therefore not be described in the same detail in the context of FIG. 5, and vice versa.

[00065] There is a first reservoir 1270, in which the medium comprises objects of interest, or "OI".

[00066] The filtering plate 1271 comprises a bulk material 1272, which comprises a first surface 1273. Bulk material 1272 can be made of any suitable material, such as metal, composite, or ceramic. In some embodiments, bulk material 1272 can also be described as a fabric.

[00067] Surface 1273 comprises several identically configured channel systems, with each channel system comprising a plurality of channels, such as channel 1274, channel 1285, or channel 1290. Each channel comprises a first opening, such as first opening 1275 of channel 1274, first opening 1286 of channel 1285, or first opening 1291 of channel 1290, and a second opening, such as second opening 1278 of channels 1274, 1285, or 1290. Each channel also comprises an interior surface, such as interior surface 1276, or interior surface 1292.

[00068] Each channel system can be considered to be a focusing apparatus, or a deflection apparatus, which is configured to deflect or redirect objects of interest which interact with the channel system in a desired direction. As shown in FIG. 5, several channels of a channel system merge into a single channel 1247 within the channel system. Note that a channel system can comprise more than 4 channels merging into a single channel. For instance, a channel system can comprise several more channels offset relative to each other in the XZ-plane, where each channel merges into a single channel 1247. For instance 20 channels can merge into a single channel. In another example, 30 channels can merge into a single channel. The single channel into which several channels merge, such as channel 1274, is denoted the "main channel". The geometry or shape of each channel is configured to focus a portion of trajectories of OI into the main channel.

[00069] The extent of a channel system along the X-axis, is denoted the "width of a channel system", which is equal to the extent of the channel 1274 along the X-axis. The "depth of a channel system" is the extent of a channel system along the Y-axis, which in this case is equal to the extent of channel 1274 along the Y-axis.

[00070] Examples of interactions between OI and the bulk material 1272 are shown in FIG. 5, as exemplified by trajectory 1298 of OI 1297, or trajectory 1304 of OI 1203, for example. As a result of the aforementioned configuration of the channels in a channel system, the motion of OI after interacting with a channel system is preferentially in the positive X-direction. In this manner, OI can be deflected or redirected into the positive X-direction as a result of their interaction with the channels in a channel system.

[00071] Note that the type of interaction between the OI and the filtering plate 1271 is a function of the shape of the channels in a channel system, as well as the width and depth of a channel system, amongst other parameters such as parameters pertaining to the mean free path of objects of interest in the surrounding medium. For a certain value of such parameters, the OI which approach the surface 1273 can, on average, experience a net deflection in the positive X-direction in some embodiments. In a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the positive X-direction, for example. Due to the geometry of the channel system, the average initial velocity vector of OI can be different to the average final velocity vector of OI. For example, in a hypothetical scenario, such as a scenario in which there is a net motion of the filtering apparatus 1271 relative to the medium in reservoir 1270 in the negative X-direction, the average initial velocity vector of OI can be directed in the positive X-direction and in the negative Y-direction. The average final velocity can be directed in the positive X- and Y-direction, where the component in the positive X-direction of the average final velocity is larger than the component in the positive X-direction of the average initial velocity. The non-zero net component in the positive X-direction can lead to a net diffusion or a net acceleration of OI in the positive X-direction.
[00072] As a result of a bulk flow induced by the interaction of OI with the surface 1273 of bulk material 1272 of filtering apparatus 1271 in the positive X-direction, there is a net force on filtering apparatus 1271 in the negative X-direction. This force can be employed to do mechanical work, for example. The mechanical work can in turn be converted into electrical work by an electrical generator, for instance. The energy for this work is provided by the thermal energy of OI in the first reservoir 1270. Thus a filtering apparatus 1271 can be employed to convert thermal energy into useful work.
[00073] The characteristic dimension of the embodiment shown in FIG. 5 can be considered to be the larger of the two numbers describing the width of a channel system and the depth of a channel system, for example. The characteristic dimension of the embodiment shown in FIG. 5 can also be considered to be the length of the main channel, such as channel 1274, of a channel system. In accordance with some embodiments of the invention, the characteristic dimension is smaller than 1000 times the mean free path of OI in an adjacent reservoir.
[00074] FIG. 6 is a cross-sectional view of one embodiment of the invention. Some features of the apparatus shown in FIG. 6, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, and will therefore not be described in the same detail in the context of FIG. 6, and vice versa.

[00075] There is a first reservoir 1330 and a second reservoir 1331 in which the medium comprises objects of interest, or “OI”.

[00076] The filtering plate 1332 comprises a bulk material 1335, which comprises a first surface 1333 and a second surface 1334. Bulk material 1335 can be made of any suitable material, such as metal, composite, or ceramic. In some embodiments, bulk material 1335 can also be described as a fabric.

[00077] The filtering plate 1332 also comprises several channels or channel systems, such as channel 1336, 1351, 1352, or channel 1353. Each channel comprises a first opening, such as first opening 1337, and a second opening, such as second opening 1338. Each channel comprises several segments, such as segment 1339, or segment 1343, or segment 1347, or segment 1349 in channel system 1336. Each channel segment comprises a first interior surface, such as first interior surface 1340 of segment 1339, or first interior surface 1344 of segment 1343. Each channel segment comprises a second interior surface, such as second interior surface 1341 of segment 1339, or second interior surface 1345 of segment 1343. Each segment also comprises a first opening, such as first opening 1337 of segment 1339, and a second opening, such as second opening 1342 of segment 1339. The second opening 1342 of segment 1339 is identical to the first opening 1342 of segment 1343. Each segment is axially symmetric, such that first surfaces, such as first surface 1340, is in the shape of a tapered cylinder or cone, and such that the second surfaces, such as second surface 1341 is in the shape of a planar annular circle. The cross-sectional area of a channel, such as channel 1336 or channel 1352, is circular in shape when viewed in the negative Y-direction. In other embodiments the cross-sectional geometry of a channel when viewed in the negative Y-direction can be square, rectangular, polygonal, or elliptical, for example.

[00078] In FIG. 6, the first interior surface 1340 is inclined at an angle, such that the surface normal has a component in the negative Y-direction. Recall that the first interior surface 1340 is axially symmetric about a central axis parallel to the Y-axis in this embodiment. The average angle between the surface normal of a first interior surface and the Y-axis is denoted the “first inclination angle”, which is greater than ninety degrees in this embodiment for first interior surface 1340 or first interior surface 1344. The first inclination angle can range from a value greater than ninety degrees to a value smaller than 180 degrees. The first inclination angle can be 120 degrees, for example. The first inclination angle can be 105 degrees, for example. The first inclination angle can be 150 degrees, for example.

[00079] In FIG. 6, the second interior surface 1341 is configured such that the surface normal is directed in the positive Y-direction. The average angle between the surface normal of a second interior surface and the Y-axis is denoted the "second inclination angle", which is zero degrees in this embodiment for surface 1341 or surface 1345. The second inclination angle can range from a value greater than or equal to zero degrees to a value smaller than ninety degrees. The second inclination angle can be zero degrees, for example. The second inclination angle can be 10 degrees, for example.

[00080] The extent of the first interior surface along the Y-axis is denoted the "first extent", and the extent of the second interior surface along the Y-axis is denoted the "second extent". In typical embodiments, the first extent is larger in magnitude than the second extent.

[00081] The extent of a channel segment along the X-axis, is denoted the "width of a channel segment". The "depth of a channel segment" is the extent of a channel segment along the Y-axis.

[00082] The first interior surface can be considered to focus or preferentially transmit OI through the second opening of a channel segment, such as second opening 1342, compared to through the first opening of a channel segment, such as first opening 1337. As a result of the aforementioned geometry and a sufficiently small size of the channels, the motion of OI after interacting with a channel is preferentially in the negative Y-direction. In this manner, OI can be deflected or redirected into the negative Y-direction as a result of their interaction with the channel segments. OI thus preferentially diffuse through a channel in the negative Y-direction from the first reservoir 1330 into the second reservoir 1331 as opposed to in the positive Y-direction from the second reservoir 1331 into the first reservoir 1330.

[00083] The focusing effect is described in more detail in the context of FIG. 8. The configuration of a channel segment of the embodiment shown in FIG. 6 can be considered to be similar to the configuration of a single channel of the embodiment shown in FIG. 8. The embodiments shown in FIG. 6 can be considered to be an arrangement of several embodiments shown in FIG. 8 arranged in series, where the second opening 2042 of one channel overlaps with the first opening 2041 of a second channel, and where each channel in FIG. 8 forms a channel segment in FIG. 6.

[00084] In other embodiments the diameter of the cross-section of the first interior surface viewed along the Y-axis can increase at a decreasing rate in the negative Y-direction, resulting in a concave first interior surface. This can enhance the focusing effect of OI in the negative Y-direction. Also within the scope of the invention are embodiments in which the diameter of the cross-section of the first interior surface viewed along the Y-axis increase at an increasing rate in the negative Y-direction, resulting in a convex first interior surface.

[00085] Note that the type of interaction between the OI and the filtering plate 1332 is a function of the shape of the channels, as well as the width and depth of a channel, amongst other parameters such as parameters pertaining to the mean free path of objects of interest in the surrounding medium. For a certain value of such parameters, the OI which approach the surface 1333 or surface 1334 can, on average, experience a net deflection in the negative Y-direction in some embodiments.

[00086] The "first transmissivity" is the probability of an OI diffusing into the second reservoir 1331 after entering a channel from the first reservoir 1330. The "second transmissivity" is the probability of an OI diffusing into the first reservoir 1330 after entering a channel from the second reservoir 1331. Due to the geometry and sufficiently small size of the channel segments, the first transmissivity is larger than the second transmissivity.

[00087] In a static boundary condition, this can lead to an increase in the concentration of OI in the second reservoir 1331 compared to the first reservoir 1330. The filter plate 1332 can thus be employed in pumping applications.

[00088] In a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the negative Y-direction, for example. Due to the geometry of the channel, the average initial velocity vector of OI can be different to the average final velocity vector of OI. For example, in a hypothetical scenario, such as a scenario in which there is a net motion of the filtering apparatus 1332 relative to the medium in reservoir 1330 in the positive Y-direction, the average initial net velocity vector of OI can be directed in the negative Y-direction. The average final velocity can be directed in the negative Y-direction, where the component in the negative Y-direction of the average final velocity is larger than the component in the negative Y-direction of the average initial velocity. The non-zero net component in the negative Y-direction can lead to a net diffusion or a net acceleration of OI in the negative Y-direction.

[00089] As a result of a bulk flow induced by the interaction of OI with the surfaces of filtering apparatus 1332 in the negative Y-direction, there is a net force on filtering apparatus 1332 in the positive Y-direction. This force can be employed to do mechanical work, for example. The mechanical work can in turn be converted into electrical work by an electrical generator, for instance. The energy for this work is provided by the thermal energy of OI in the first reservoir 1330 or the second reservoir 1331. Thus a filtering apparatus 1332 can be employed to convert thermal energy into useful work.

[00090] The characteristic dimension of the embodiment shown in FIG. 6 can be considered to be the larger of the two numbers describing the width of a channel segment and the depth of a channel segment, for example. In accordance with some embodiments of the invention, the characteristic dimension is smaller than 1000 times the mean free path of OI in an adjacent reservoir.

[00091] The embodiment shown in FIG. 6 can be considered to be similar to the embodiment shown in FIG. 1, where the surface 1103 can also be cylindrical or circular in three-dimensional form, and where both the width of a channel segment and the depth of a channel segment are smaller than 1000 times the mean free path of OI in an adjacent reservoir.

[00092] FIG. 7 is a cross-sectional view of one embodiment of the invention. Some features of the apparatus shown in FIG. 7, as well as some of the principles of operation of the apparatus share similarities with the apparatus shown in the other figures, and will therefore not be described in the same detail in the context of FIG. 7, and vice versa.

[00093] There is a first reservoir 1400 and a second reservoir 1401 in which the medium comprises objects of interest, or “OI”.

[00094] The filtering plate 1402 comprises a bulk material 1405, which comprises a first surface 1403 and a second surface 1404. Bulk material 1405 can be made of any suitable material, such as metal, composite, or ceramic. In some embodiments, bulk material 1405 can also be described as a fabric.

[00095] The filtering plate 1402 also comprises several channels or channel systems, such as channel 1406, or channel 1421. Each channel comprises a first opening, such as first opening 1407 or first opening 1422, and a second opening, such as second opening 1408 or second opening 1423. Each channel comprises several segments, such as segment 1409, or segment 1413, or segment 1417, or segment 1419 in channel system 1406. Each channel segment comprises a first interior surface, such as first interior surface 1410 of segment 1409. Each channel segment comprises a second interior surface, such as second interior surface 1411 of segment 1409. Each segment also comprises a first opening, such as first opening 1407 of segment 1409, and a second opening, such as second opening 1412 of segment 1409. The second opening 1412 of segment 1409 is identical to the first opening 1412 of segment 1413. Each segment is axially symmetric, such that first surfaces, such as first surface 1410, is in the shape of a tapered cylinder or cone, and such that the second surfaces, such as second surface 1411 is in the shape of a planar annular circle. The cross-sectional area of a channel, such as channel 1406 or channel 1421, is circular in shape when viewed in the negative Y-direction. In other embodiments the cross-sectional geometry of a channel when viewed in the negative Y-direction can be square, rectangular, polygonal, or elliptical, for example.

[00096] In FIG. 7, the first interior surface 1410 is inclined at an angle, such that the surface normal has a component in the negative Y-direction. Recall that the first interior surface 1410 is axially symmetric about a central axis parallel to the Y-axis in this embodiment. The average angle between the surface normal of a first interior surface and the Y-axis is denoted the "first inclination angle", which is greater than ninety degrees in this embodiment. The first inclination angle can range from a value greater than ninety degrees to a value smaller than 180 degrees. The first inclination angle can be 120 degrees, for example. The first inclination angle can be 105 degrees, for example. The first inclination angle can be 150 degrees, for example.

[00097] In FIG. 7, the second interior surface 1411 is configured such that the surface normal is directed in the positive Y-direction. The average angle between the surface normal of a second interior surface and the Y-axis is denoted the "second inclination angle", which is zero degrees in this embodiment for surface 1411. The second inclination angle can range from a value greater than or equal to zero degrees to a value smaller than ninety degrees. The second inclination angle can be zero degrees, for example. The second inclination angle can be 10 degrees, for example.

[00098] The extent of the first interior surface along the Y-axis is denoted the "first extent", and the extent of the second interior surface along the Y-axis is denoted the "second extent". In typical embodiments, the first extent is larger in magnitude than the second extent.

[00099] The extent of a channel segment along the X-axis, is denoted the "width of a channel segment". The "depth of a channel segment" is the extent of a channel segment along the Y-axis. The extent of the first interior surface along the X-direction, or the extent of the second interior surface along the X-direction, is denoted the "thickness of a channel segment". The thickness of a channel segment in the context of FIG. 7 is analogous to the depth of a channel segment in the context of FIG. 1. The depth of a channel segment in the context of FIG. 7 is analogous to the width of a channel segment in the context of FIG. 1.

[000100] The first interior surface can be considered to preferentially direct OI in the negative Y-direction. As a result of the aforementioned geometry and a sufficiently small size of the depth and thickness of a channel segment, the motion of OI after interacting with a channel is preferentially in the negative Y-direction. This is similar to the interaction between OI and the bulk material 1102 in FIG. 1, where the OI which approach the surface 1103 can, on average, experience a net deflection in the positive X-direction in some embodiments. For the embodiment shown in FIG. 7, for a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the negative Y-direction. OI thus preferentially diffuse through a channel in the negative Y-direction from the first reservoir 1400 into the second reservoir 1401 as opposed to in the positive Y-direction from the second reservoir 1401 into the first reservoir 1400.

[000101] In other embodiments the diameter of the cross-section of the first interior surface viewed along the Y-axis can increase at a decreasing rate in the negative Y-direction, resulting in a concave first interior surface. This can enhance the focusing effect of OI in the negative Y-direction, as explained in more detail in the context of FIG. 2. Also within the scope of the invention are embodiments in which the diameter of the cross-section of the first interior surface viewed along the Y-axis increase at an increasing rate in the negative Y-direction, resulting in a convex first interior surface.

[000102] As mentioned, the interior surface of channel 1406 or channel 1421 is configured similarly to the embodiment 1101 shown in FIG. 1. Similarly, in other embodiments, the interior surface of channel 1406 can be configured similarly to the embodiment 1141 shown in FIG. 2. In other embodiments, the interior surface of channel 1406 can be configured similarly to the embodiment 1181 shown in FIG. 3. In other embodiments, the interior surface of channel 1406 can be configured similarly to the embodiment 1231 shown in FIG. 4. In other embodiments, the interior surface of channel 1406 can be configured similarly to the embodiment 1271 shown in FIG. 5. Due to the parallel arrangement of channels it is possible to convert the shear force exerted by OI on the channel walls into an axial force. By specially configuring the geometry of the interior walls of a channel, the lateral forces or shear forces on a channel wall can be combined into an axial thrust force on a plate, such as plate 1402, in the positive Y-direction.

[000103] Note that the type of interaction between the OI and the filtering plate 1402 is a function of the shape of the channels, as well as the width and depth of a channel, amongst other parameters such as parameters pertaining to the mean free path of objects of interest in the surrounding medium. For a certain value of such parameters, the OI which approach the surface 1403 or surface 1404 can, on average, experience a net deflection in the negative Y-direction in some embodiments.

[000104] The “first transmissivity” is the probability of an OI diffusing into the second reservoir 1401 after entering a channel from the first reservoir 1400. The “second transmissivity” is the probability of an OI diffusing into the first reservoir 1400 after entering a channel from the second reservoir 1401. Due to the geometry and sufficiently small size of the channel segments, the first transmissivity is larger than the second transmissivity.

[000105] In a dynamic boundary condition, this can lead to a net diffusion, or a bulk flow, of OI in the negative Y-direction, for example. Due to the geometry of the channel, the average initial velocity vector of OI can be different to the average final velocity vector of OI. For example, in a hypothetical scenario, such as a scenario in which there is a net motion of the filtering apparatus 1402 relative to the medium in reservoir 1400 in the positive Y-direction, the average initial net velocity vector of OI can be directed in the negative Y-direction. The average final velocity can be directed in the negative Y-direction, where the component in the negative Y-direction of the average final velocity is larger than the component in the negative Y-direction of the average initial velocity. The non-zero net component in the negative Y-direction can lead to a net diffusion or a net acceleration of OI in the negative Y-direction.

[000106] As a result of a bulk flow induced by the interaction of OI with the surfaces of filtering apparatus 1402 in the negative Y-direction, there is a net force on filtering apparatus 1402 in the positive Y-direction. This force can be employed to do mechanical work, for example. The mechanical work can in turn be converted into electrical work by an electrical generator, for instance. The energy for this work is provided by the thermal energy of OI in the first reservoir 1400 or the second reservoir 1401. Thus a filtering apparatus 1402 can be employed to convert thermal energy into useful work.

[000107] The characteristic dimension of the embodiment shown in FIG. 6 can be considered to be the larger of the two numbers describing the thickness of a channel segment and the depth of a channel segment, for example. In accordance with some embodiments of the invention, the characteristic dimension is smaller than 1000 times the mean free path of OI in an adjacent reservoir.

[000108] The embodiment shown in FIG. 7 can be considered to be similar to the embodiment shown in FIG. 1, where the surface 1103 can also be cylindrical or circular in three-dimensional form, and where the depth and thickness of a channel segment is smaller than 1000 times the mean free path of OI in an adjacent reservoir.

[000109] Note that the width of a channel segment in FIG. 7 can be larger than 1000 times the mean free path of OI in an adjacent reservoir. The maximum width or length of a channel in the embodiment shown in FIG. 7, such as channel 1406, need not be constrained to a value which is smaller than about 1000 times the mean free path of an object of interest in an adjacent reservoir. This is due to the interior channel walls, such as surfaces 1410 and 1411, of channel 1406 being configured in a similar manner as the surfaces of the embodiment shown in FIG. 1, such as surface 1108 or surface 1109. As such, surfaces 1410 and 1411 can be considered to be distinct focusing apparatuses in the first reservoir 1400, which also extends into channel 1406. In other words, in the limit in which the width of channel 1406 is sufficiently large, the interior surface of channel 1406 can be modeled or considered to interact with the objects of interest within the channel 1406 in a similar manner as the filtering plate 1101 interacts with objects of interest in the first reservoir 1100 in FIG. 1. For instance, the width of channel 1406 can be one million mean free paths of objects of interest in channel 1406 in some embodiments. In another example, the width of channel 1406 can be 10,000 mean free paths of objects of interest in channel 1406 or an adjacent reservoir in some embodiments.

[000110] FIG. 8 is a cross-sectional view of one embodiment of the invention and a schematic representation of the interaction of said embodiment with objects of interest.

[000111] In FIG. 8 the distribution of initial directions, i.e. the distribution of the directions of the initial velocities of OI which interact with the filtering apparatus 900, are uniformly distributed over the range of all angles, i.e. 360 degrees. In the simplified scenario shown in FIG. 8, the distribution of initial directions for OI which enter a channel from the first reservoir 2036 is uniform. This is indicated by the uniformly distributed incident flux 2059 from the first reservoir, where the distribution is uniform over the range of possible directions indicated by the arrows within the contours of the plot of the incident flux 2059. The incident flux 2059 is measured relative to the reference line 2056. For the dynamic boundary condition the properties of the first reservoir 2036 and the second reservoir 2037 are assumed to be instantaneously identical. Accordingly, the distribution of incident flux 2060 of OI from the second reservoir 2037 as a function of the direction of the incident velocity is also uniform over all directions, as indicated by a constant magnitude of flux 2060 relative to reference line 2057.

[000112] Such a distribution of incident flux occurs in a wide variety of applications of embodiments of the invention. For example, in a typical stationary medium, i.e. a medium in which the average velocity of OI is zero, i.e. a medium in which the bulk flow is zero, the distribution of velocities of OI is uniformly distributed over all angles. This applies to atoms or molecules in gases, or electrons in the conduction bands of conductors. A filtering apparatus placed in such a stationary medium will therefore be subject to a uniform distribution of initial directions, i.e. the probability of an OI interacting with a channel or an outside surface of a filtering apparatus having an initial velocity with a specified direction is approximately equal for all directions.

[000113] For the simplified embodiment shown in FIG. 8, all of the OI which enter a channel such as channel 2039 from the first reservoir 2036 and transmitted to the second reservoir. Note that, for simplicity, it is assumed that there are no randomizing scattering events throughout the motion of an OI through the filtering apparatus. In other embodiments there can be scattering events, such as OI to OI collisions or diffuse reflections from the interior surface of a channel, such as interior surface 2047, provided that there can still be a net diffusion for a dynamic boundary condition or a net concentration, pressure, or density difference for a static boundary condition. As an OI diffuses from the first reservoir 2036 to the second reservoir 2037 through channel 2039, an OI can collide with the interior wall 2047 of a channel. Due to the angle of the wall relative to the XZ-plane, the component of the direction of motion of an OI along the Y-direction increases. This effect is shown in FIG. 8 in terms of the example trajectory of an OI, such as trajectory 2053 of OI 2052. As shown, the component of motion or of the velocity of OI 2052 in the negative Y-direction increases in magnitude with each collision with the interior surface 2047. As a result, the initially uniform distribution of velocities in the first reservoir 2036 indicated by flux magnitude 2059 as a function of direction is no longer uniform when the OI arrive in the second reservoir 2037. The initially hemispherical, uniform distribution of directions has been focused into a concentrated beam 2064 of outflow velocities. Due to the high first transmissivity and the geometric properties of the interior surface 2047 of channel 2039 the entire influx 2059, i.e. the influx 2059 integrated over all angles, has been focused into a reduced set of angles, i.e. a concentrated beam 2064.

[000114] Conversely, any influx 2060 from the second reservoir 2037 into channel 2039 with an initial angle which lies within the limited range of said beam 2064 is spread out over the entire range of possible influx angles, resulting in a reduced outflux magnitude 2061, measured relative to the same reference line 2056. Any influx 2060 from the second reservoir into channel 2039 with an initial angle which lies outside the limited range of said beam 2064 is reflected back into the second reservoir 2037, as indicated by the portion 2063 of outflux 2062 which lies outside of beam 2064. Outflux 2062 is also measured relative to reference line 2057. The scenario in which an OI from the second reservoir 2037 is reflected back into the second reservoir 2037 is exemplified by trajectory 2055 of OI 2054.

[000115] As a result, the first transmissivity is larger than the second transmissivity. In some embodiments, the ratio of the first transmissivity to the second transmissivity is sufficiently large, that the ratio of the product of the first transmissivity and the first capture area, i.e. the area of first opening 2041 in the XZ-plane, to the product of the second transmissivity and the second capture area, i.e. the area of the second opening 2042, is greater than one, despite the first capture area being smaller than the second capture area. In some such embodiments, therefore, there is a net diffusion of OI from the first reservoir 2036 to the second reservoir 2037 for a dynamic boundary condition, or a larger concentration, density, or pressure of OI in the second reservoir 2037 relative to the first reservoir 2036 for a static boundary condition.

[000116] For a dynamic boundary condition, there is a net flow 1040 of objects of interest through the filtering apparatus 900, or 1000, from the first reservoir 2036 into the second reservoir 2037. The filtering apparatus 900 comprises a bulk material 2065, a first surface 2046, several channels, such as channel 2039, each channel comprising a first opening 2041 or 1006 and a second opening 2042 or 1008 and an interior surface 2047. In the depicted embodiment, the majority of interactions between the objects of interest and the boundaries of the channel, i.e. the interior surface 2047, can be described as specular reflections. In some such embodiments, more than 50% of said interactions can be described as specular reflections. In some such embodiments, more than 90% of said interactions can be described as specular reflections. In some such embodiments, more than 30% of said interactions can be described as specular reflections.

[000117] Note that the effective aperture of first opening 2041 to the second reservoir 2037 is described by the cross-sectional area of beam 2064 along the length of the beam, which is cone shaped in this example. The effective aperture of first opening 2041 to the first reservoir 2036 is described by the cross-sectional area of outflux 2061, which is almost hemispherical in this example. For the dynamic boundary condition, therefore, the aperture in the second reservoir is smaller than the aperture in the first reservoir, resulting in a net diffusion of OI from the first reservoir to the second reservoir.

[000118] The "width" of a channel is the maximum collisional diameter of a theoretical, spherical object of interest which is able to diffuse through the channel. Note that the width of a channel can be different to the characteristic width of a focusing apparatus, or the characteristic width of a channel segment.

[000119] The average "length" of a channel, or the average length of a channel system, is the length of the line which describes the centroid of a channel between the openings of the channel, where the openings refer to the interface between the channel and a reservoir. A single point on the centroid describes the center of the cross-sectional area of a channel at the location of the point, where the cross-sectional area is measured on a plane perpendicular to the local average direction of diffusion of objects of interest through a channel, i.e. perpendicular to the local axis along the length of the channel. For example, the cross-sectional area of a point within channel 1336 is measured along a plane parallel to the XZ-plane. Since the channels in the depicted channel system have a circular cross-section in general, the centroid of the channels is the line describing the centers of the circles describing the cross-sections of each channel along the length of each channel. Note that the length of a channel can be different to the characteristic length of a focusing apparatus. For example, a channel, such as channel 1336 in FIG. 6, can comprise several individual focusing apparatuses, such as focusing apparatus 1339 or focusing apparatus 1343. The characteristic length of focusing apparatus 1339 can be considered to be the distance between the first opening 1337 and the first internal opening 1342 measured along the Y-axis. In this case, the characteristic dimension can be considered to be approximately equal to the characteristic length of focusing apparatus 1339.

[000120] The length of channel 1336 in FIG. 6 is the distance of separation between the first opening 1337 and the second opening 1338 of channel 1336, where the first opening 1337 describes the interface between channel 1336 and the first reservoir 1330, and the second opening 1338 describes the interface between channel 1336 and the second reservoir 1331. Since channel 1336 is axially symmetric about a central axis, the line which describes the centroid of channel 1336 is straight and parallel to the Y-axis. The length of channel 1336 in this particular embodiment is therefore also equal to the shortest distance between the first opening 1337 and the second opening 1336. Since the first surface 1333 and the second surface 1334 are planar and parallel to the XZ-plane, the length of channel 1336 in this particular embodiment is also equal to the shortest distance between the first surface 1333 and the second surface 1334. The distance between the first surface 1333 and the second surface 1334 can also be referred to as the height of the depicted apparatus, as mentioned.

[000121] In another example, the length of channel 1285 in FIG. 5 is the length of the line which describes the centroid of channel 1285. Since channel 1285 merges with channel 1274, the centroid of channel 1285 merges with the centroid of channel 1274. The length of channel 1285 is therefore the length of the centroid of the channel between the first opening 1286 of channel 1285 and the second opening 1278 of channel 1285, which is also the second opening 1278 of channel 1274. The first opening 1286 of channel 1285 is the interface between channel 1285 and the first reservoir 1270. Similarly, the length of channel 1290 is the length of the centroid of the channel between the first opening 1291 of channel 1290, which is located at the interface between channel 1290 and the first reservoir 1270, and the second opening 1278 of channel 1290, which is located at the interface between channel 1290, which has merged with channel 1274, and the first reservoir 1270. The second opening 1278 of channel 1290 is also the second opening 1278 of channel 1274.

[000122] In some embodiments the channel system comprising channels 1274, 1285, 1290, and any other channels which merge with channel 1274, can be considered to be a focusing apparatus. In this case, the characteristic length of this channel system, or focusing apparatus, is the average length of all channels associated with the channel system. In other embodiments, a focusing apparatus can be considered to consist of only the junction between two or more channels which merge into a single channel, and adjacent portions of the merging and merged channels. In such embodiments, the characteristic length of a channel can be shorter than the length of a channel.

[000123] For each of the embodiments in FIGS. 1-7 the “characteristic dimension” has been defined. In some example embodiments, the characteristic dimension of a focusing apparatus, or a channel segment, or a surface feature, of a filtering apparatus is smaller than a number several orders of magnitude larger than the smallest mean fee path of objects of interest within an adjacent reservoir, such as first reservoir 1270, or second reservoir 1331. In accordance with some embodiments, the characteristic dimension is smaller than a value three orders of magnitude larger than the smallest mean fee path of objects of interest within an adjacent reservoir. In other words, the ratio of the smallest mean free path of an object of interest in an adjacent reservoir to the characteristic dimension is larger than 0.001 in some embodiments.

[000124] The ratio of the mean free path of an object of interest in a specified reservoir to the characteristic dimension of a focusing apparatus is denoted the "relative length", or "RL". Unless otherwise specified, the medium or the reservoir which provides the mean free path in the calculation of the RL is the medium or reservoir with the smallest mean free path. The mean free path is measured adjacent to the filtering apparatus or to the channel opening. The mean free path is measured exclusively within the medium, i.e. exclusively between collisions of objects of interest with other objects, i.e. objects other than the bulk material of the filtering apparatus or objects other than objects associated with, or employed by, the filtering apparatus. The relative length describes the size of the focusing apparatus relative to the properties of the surrounding medium. In embodiments in which the medium can be described as a fluid, this ratio can be referred to as the Knudsen number.

[000125] For RL which are multiple orders of magnitude smaller than 0.001, the focusing effect of the focusing apparatus can be non-zero, but negligibly small. In other example embodiments of the invention, the RL can be 0.01. The RL can also be 0.1, for example. The RL can be 1 in another example. The RL can be 10 in another example. The RL can also be larger than 10. In general, a larger RL increases the performance of the focusing apparatus or filtration system, but increases the complexity or difficulty of manufacture. An increase in the characteristic dimension relative to the mean free path of objects of interest in an adjacent reservoir can increase the probability of scattering of objects of interest as they travel through the filtering apparatus or interact with the focusing apparatus. This can reduce the focusing or redirection effect of the filtering apparatus on the trajectories of objects of interest, and reduce the performance of the filtering apparatus.

[000126] For example, the mean free path of nitrogen gas at standard temperature and pressure is approximately 60 nanometers. For applications of a filtering apparatus in which the objects of interest are nitrogen atoms, and in which the first, and, if applicable, second reservoirs, are at standard temperature and pressure, the characteristic dimension can be smaller than 60 micrometers in some embodiments. For instance, the characteristic dimension can be about 60 nanometers, where “about” and “approximately” as used herein refer to a value within plus or minus 30% of the stated figure. In another example filtering apparatus, the characteristic dimension can be about 6 micrometers. The characteristic dimension associated with another embodiment can be about 600 nanometers, for example. The characteristic dimension associated with another embodiment can be about 6 micrometers, for example.

[000127] In another example, the mean free path of electrons in the conduction band in copper can be considered to be approximately 40 nanometers. In embodiments of a filtering apparatus in which the objects of interest are electrons, the bulk material, such as bulk material 1405, or bulk material 1102, or bulk material 1182, can comprise an electrical insulator. The bulk material can optionally comprise material with a reflectivity which is greater than zero with respect to electrons. In these and other example embodiments, the bulk material can comprise material with a different refractive index with respect to objects of interest, i.e. electrons in this case, for example. In embodiments of the invention in which the objects of interest are electrons in the conduction band, and in which the medium in the first and second reservoir is copper, the characteristic dimension associated with some embodiments can be less than or equal to 40 micrometers, for example. For instance, the characteristic dimension can be less than or approximately equal to 400 nanometers. The characteristic dimension associated with some embodiments can alternatively be about 40 nanometers, for example. The characteristic dimension of a filtering apparatus or a focusing apparatus can be approximately 4 micrometers, for instance. The characteristic dimension of a filtering apparatus or a focusing apparatus can be approximately 4 nanometers, in another example.

[000128] For embodiments in which the objects of interest behave like waves, such as photons, phonons, acoustic waves, or ocean waves, for example, the mean free path can be very large, possibly even infinitely large. For very large values of mean free path, some objects of interest rarely or never scatter within a medium, such as a first reservoir or a second reservoir. This can be due to the superposition principle, which applies to some wave types. Since the mean free path of some of these objects of interest is larger than the mean free path in the aforementioned examples, the characteristic dimension of the embodiments can be larger as well. This can significantly reduce the complexity associated with the manufacture of a filtering apparatus. A sufficiently large ratio of the mean free path relative to the characteristic dimension of the filtration apparatus should preferably be maintained.

[000129] A medium can be located in a first reservoir, a second reservoir, and/or the interior of a channel, such as the example channel 1274 in FIG. 5, or channel 1336 in FIG. 6, or the interior of a focusing apparatus. The characteristic dimension of a filtering apparatus which is configured to interact with photons can be about ten meters, for example. The characteristic dimension can be about 1 centimeter in another example. The characteristic dimension can be serval nanometers in another example. The focusing portions of the example embodiments shown in the figures function in a manner comparable to optical telescopes or solar concentrators, for instance. In other embodiments, lenses can be used to perform the focusing of the trajectories of objects of interest. The lenses can employ refraction or diffraction, for example. As mentioned, in such embodiments, the objects of interest can be waves or wavelike particles, such as acoustic waves, ocean waves, gravity waves, phonons, photons or electrons. The calculation of the mean free path of photons in the medium surrounding and enveloping the bulk material in a filtering apparatus preferably takes into account photon-object scattering, i.e. collision between photons and other objects in the medium, such as air molecules. This effect can be mitigated by evacuating the portion of the filtering apparatus which is concerned with the focusing of the objects of interest, e.g. the photons, by removing, or reducing the concentration of, other objects of interest, e.g. air molecules, which would otherwise interfere with, and reduce the mean free path of, the objects of interest. For example, the focusing portion of the filtering apparatus, such as the example channel system in FIG. 5, can be located in a vacuum, or a region of reduced density of objects of interest, or any other objects which can unintentionally scatter an object of interest.

[000130] The manner in which a filtration apparatus is manufactured depends on the scale or the characteristic dimension of a filtration apparatus. For example, consider an application example in which the mean free path of objects of interest in a medium is about one millimeter. The characteristic dimension of an example embodiment of a filter system for such an application can be about one centimeter. Structures of this scale can be readily manufactured and mass produced using conventional mechanical manufacturing techniques, such as computer numerical controlled (CNC) mills, selective laser sintering (SLS), photolithography and etching, additive printing processes, and so on.

[000131] Embodiments of a filtering apparatus for which the characteristic dimension is on the order of nanometers can be manufactured with semiconductor manufacturing equipment and procedures. For example, grayscale electron beam or ion beam lithography can be employed to manufacture molds with large arrays of repeating patterns of complex geometry at the nanometer scale. These molds can be employed to imprint the desired surface features on a substrate using nanoimprint lithography. This method can be employed to manufacture embodiments as shown in the examples of FIGS. 1-4, for example. In another example, embodiments can be manufactured using nanometer scale additive manufacturing techniques, such as electron beam induced deposition. These and other manufacturing techniques can benefit from interference effects to manufacture the aforementioned large arrays of complex structures. These methods are known in the field of interference lithography, for example. Such methods can be employed to manufacture embodiments similar to the embodiments shown in FIGS. 5-7, for instance. Subtractive manufacturing techniques such as deep reactive ion etching can be employed to manufacture channels of filtration apparatuses of the type shown in FIGS. 5-7. In the manufacture of some embodiments, subtractive and additive manufacturing techniques can be employed. For instance, individual channel segments, such as channel segment 1339 or channel segment 1343, can be manufactured using subtractive manufacturing techniques, while sequential layers of bulk material, such as the bulk material 1335 can be deposited using additive manufacturing techniques.

[000132] Unless specified or clear from context, the term "or" is equivalent to "and/or" throughout this paper.