July 17, 1962 G. GERARD ET AL 3,044,113

SUPER-HIGH PRESSURE APPARATUS

Filed Jan. 8, 1959 3 Sheets-Sheet 1

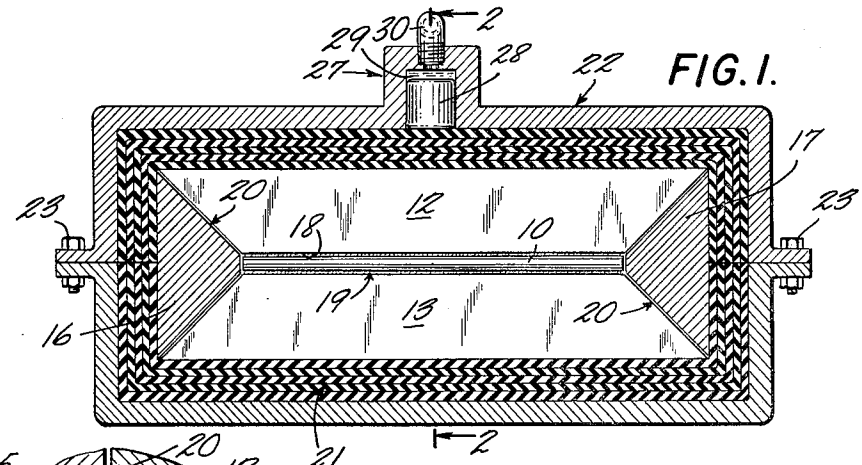


FIG. 1.

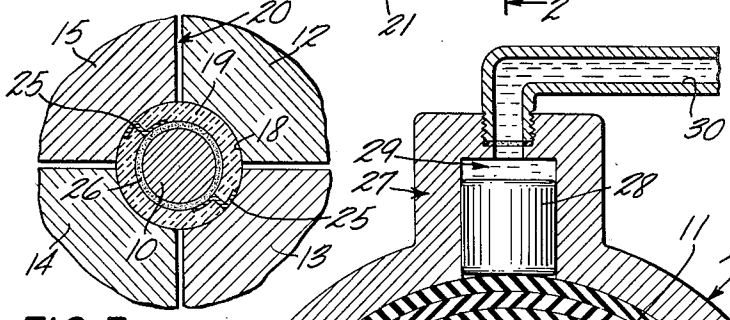


FIG. 3.

FIG. 2.

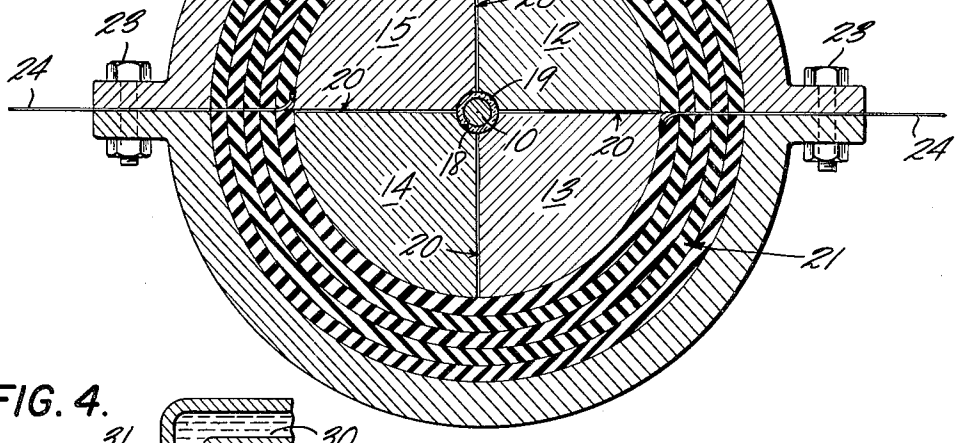
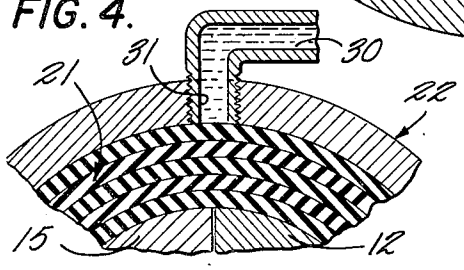


FIG. 4.



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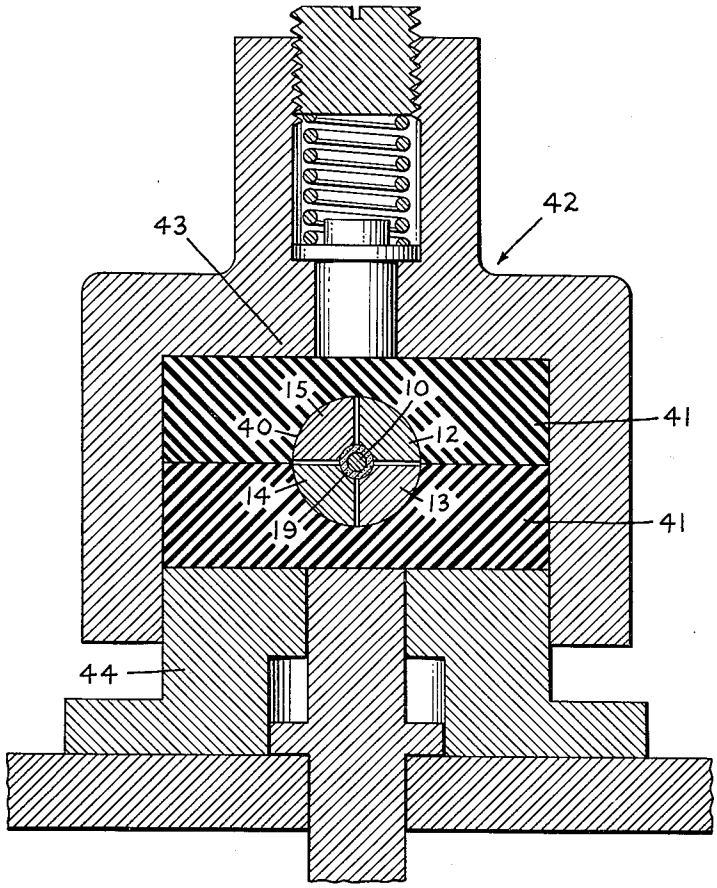
July 17, 1962 G. GERARD ET AL 3,044,113

SUPER-HIGH PRESSURE APPARATUS

Filed Jan. 8, 1959 3 Sheets-Sheet 2

FIG. 5



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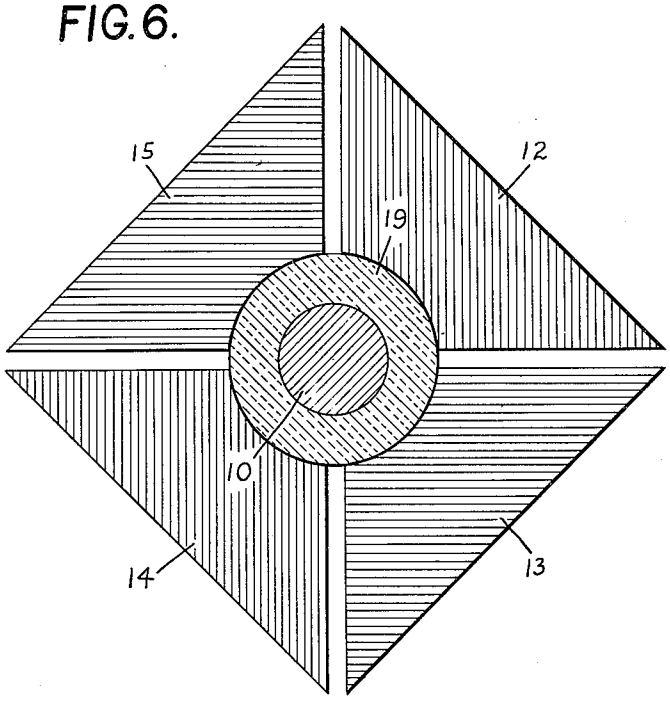
SUPER-HIGH PRESSURE APPARATUS

Filed Jan. 8, 1959 3 Sheets-Sheet 3

FIG. 6.



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United States Patent Office 3,044,113 Patented July 17, 1962

3,044,113

SUPER-HIGH PRESSURE APPARATUS

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Filed Jan. 8, 1959, Ser. No. 785,690
13 Claims. (Cl. 18—5)

This invention relates to super-high pressure apparatus and, more particularly, to a new and improved apparatus for applying higher pressures than have heretofore been attainable to objects of any size or shape.

Generally, the structural requirements of many newly developed forms of apparatus, such as jet and rocket engine systems, often exceed the physical charatceristics such as fatigue life, yield strength, and modulus of rigidity of the materials now available. Little improvement of these characteristics is to be expected by further refinements in the materials or in heat treating procedures. On the other hand, the application of extreme pressures to such materials now appears to be an effective way of improving their physical characteristics as by inducing phase changes and promoting the alloying of materials that cannot be alloyed at normal pressures.

Heretofore, however, apparatus for subjecting objects to extremely high pressures has been limited as to the size and shape of the objects and has required massive support structures. Also, the presently available apparatus is subject to hydraulic cylinder leakages, cylinder expansion and similar well known problems of high pressure apparatus.

Accordingly, it is an object of this invention to provide new and improved high pressure apparatus capable of applying pressures in the range of 20,000 to 200,000 atmospheres and in excess of 200,00 atmospheres.

Another object of the invention is to provide apparatus of the above character capable of applying extreme pressures to objects of any size or shape.

A further object of the invention is to provide apparatus of the above character having relatively simple and inexpensive structures.

These and other objects of the invention are attained by encasing an object to be subjected to extreme pressure in a viscous pressure-transmitting medium and enclosing it in a pressure-multiplying device comprising a plurality of wedge-shaped segments converging toward the object. The pressure-multiplying device is surrounded by a resilient pressure-transmitting medium in contact with the larger ends of all the segments, while a housing capable of withstanding conventional high pressures encloses the resilient medium and includes a device for applying high pressure to the resilient medium.

Further objects and advantages of the invention will be apparent from a reading of the following description in conjunction with the accompanying drawings in which:

FIG. 1 is a view in longitudinal section through a representative form of super-high pressure apparatus arranged according to the invention;

FIG. 2 is a cross-sectional view of the apparatus of FIG. 1 taken on the lines 2—2 and looking in the direction of the arrows;

FIG. 3 is a magnified sectional fragmentary view showing the central portion of the apparatus of FIG. 2;

FIG. 4 is a fragmentary view showing a modified form of the apparatus of FIG. 1;

FIG. 5 is a view in front elevation and cross-section of another modified form of the invention; and

FIG. 6 is a view in cross-section of the member **11** shown in FIG. 2 when modified to be of exterior cubic shape.

In the typical embodiment of the invention shown by way of example in the drawings and described hereinafter, the high pressure apparatus is arranged to subject

a longitudinal work piece, such as a shaft **10**, to pressures up to 200,000 atmospheres or more. It will be understood, however, that the object to which extreme pressures are applied may be of any desired shape and that there is no limitation on the size of the object since the apparatus may be arranged with any appropriate configuration and capacity.

In order to exert super-high pressures, the apparatus of FIGS. 1 and 2 includes a cylindrical pressure-multiplying member **11** comprising six wedge-shaped segments **12–17** having inner surfaces forming a cavity **18** conforming generally to the outer shape of the shaft **10**, the end segments **16** and **17** being conical in form. These segments are made of any suitable material such as tungsten carbide, for example, which is capable of withstanding the extreme pressures under consideration without substantial deformation or disintegration. It will be understood that any number of pressure-multiplying segments can be used in apparatus according to the invention and their shape may vary according to the configuration of the work piece **10** and the member **11**. For example, if the work piece is of compact shape, the member **11** may be a sphere, cube or tetrahedron and may be divided into four, six or eight identical wedge-shaped segments, FIG. 6 showing the member **11** when comprised, as described, of six identical anvils assembled together to render member **11** of cubic exterior shape. Furthermore, the shape of the cavity **18** need not conform to the contour of the work piece **10**, since the cavity is filled with a pressure-transmitting medium as described below. Thus, for objects of complex shape, such as turbine blades, for example, the cavity may have the nearest simple geometrical shape capable of enclosing the object.

Within the cavity **18**, the shaft **10** is encased in a pressure-transmitting shell **19** composed of any material which is semi-plastic or highly viscous but substantially maintains its shape at the extreme pressures to be generated. Preferably, because of its ease of machining and its electrical and heat insulation properties, the material utilized in the invention is a pyrophyllite, such as Tennessee Grade A lava. Each of the segments **12–17** has its inner face in contact with the shell **19** and the dimensions of all the segments are chosen so that, with their inner faces in contact with the shell, there is a narrow gap **20** between each adjacent pair of segments.

Inasmuch as the degree of pressure-multiplication achieved by the wedge-shaped segments **12–17** is dependent on the relative areas of their outer and inner surfaces, the outer diameter and length of the member **11** are selected relative to the diameter and length of the cavity **18** in accordance with the desired super-high pressure to be obtained in the cavity and the pressure to be applied to the apparatus at the outside of the member **11**. Thus, for example, if a pressure-multiplication of 100 is desired and the cavity is approximately 1 inch in diameter, the member **11** need only be approximately 10 inches in diameter. This relation holds for cavities of uniform cross-section regardless of the length of the cavity. For irregularly shaped cavities, however, the relative areas of each segment must be selected so that all the segments have the same pressure-multiplication factor. Again in this case, a narrow gap **20** must be included between the adjacent faces of the segments.

Surrounding the pressure-multiplying member **11** is a layer **21** of pressure-transmitting material, the entire assembly being enclosed in a close fitting metal housing **22** of high strength. If desired, the layer **21** and the housing **22** may each be made in two parts which are separably joined as by bolts **23** or other suitable means to provide easy access to the member **11**. In order to heat the work piece **10** while applying pressure, two electrical con-

ductors 24 are carried in through the housing 22 and the layer 21 and are joined to opposite segments 13 and 15 of the member 11. Also, as shown in FIG. 3, two conductive electrodes 25 are mounted in the shell 19 to carry current to the interior of the shell and are oriented to contact the segments 13 and 15, respectively. A resistive graphite layer 26 surrounds the shaft 10 within the shell and has its outer surface in contact with the two electrodes 25 at diametrically opposite positions to generate heat when power is applied to the conductors 24. When the work piece is to be heated in this manner, the viscous pressure-transmitting material should provide good electrical and heat insulation and the lava referred to above serves this purpose well. In addition, thermocouple leads (not shown) may also be connected through the shell 19 and through two other segments 12 and 14 in a similar manner to measure the temperature of the work piece.

In order to apply pressure to the layer 21, the housing 22 includes a cylinder 27 communicating with the interior of the housing and a piston 28 is slidably mounted therein. At its outer end, the cylinder 27 has a cavity 29 to receive hydraulic fluid which is joined to a conventional hydraulic system (not shown) providing pressures of 2,000 atmospheres and up, for example, in any well-known manner through a conduit 30. The pressure-transmitting medium 21, which is preferably formed of successive layers of rubber as in conventional rubber pad presses, should be firm enough to prevent extrusion into the gap 20 under pressure, but also sufficiently resilient to provide equal pressure over the entire outer surface of the member 11 in response to operation of the piston 28. For this purpose, the inner layers of rubber adjacent the member 11 may be substantially firm and the outer layers more flexible.

In operation, conventional high pressure is applied to this embodiment of the invention through the conduit 30 and the piston 28. This pressure should be a fraction of the desired super-high pressure commensurate with the multiplying factor of the member 11. Thus, to apply pressures in the range of 300,000 atmospheres to the shaft 10 with a pressure multiplication of 100 as described above, the pressure applied to the piston 28 should be about 3,000 atmospheres. As the piston 28 is driven into the rubber layer 21, the pressure of the fluid in the cavity 29 is applied to the entire outer surface of the member 11 because of the pressure equalization throughout the pressure-transmitting medium 21. The resulting force on the outer surface of the member is transmitted through the segments 12–17 to the much smaller inner surface at the cavity 18, generating the desired super-high pressure at the outer surface of the shell 19.

Inasmuch as the pyrophyllite material of the shell 19 becomes semi-plastic or highly viscous at pressures above about 50,000 atmospheres, the material constitutes a pressure-transmitting medium at these pressures and applies the extreme pressure from the inner surfaces of the segments to the entire outer surface of the work piece 10. Also, the semi-plastic material acts as a seal by filling in the gaps 20 between the segments in the vicinity of the shell 19. If the work piece is to be heated during compression, electrical current passed through the conductors 24, the segments 13 and 15, the electrodes 25 to heat the graphite layer 19.

In the embodiment of the invention shown in FIG. 3, the pressure of the hydraulic system is applied through the conduit 30 and an aperture 31 into the housing 22 directly to the outside of the pressure-transmitting layer 21. In this instance, the pressure-transmitting medium should provide a fluid-tight enclosure about the member 11 to prevent any hydraulic fluid from passing into the gaps 20. Inasmuch as this embodiment has no piston stroke limitation and any necessary quantity of fluid may be forced into the housing, it is not necessary to provide a close fit between the rubber layer 21 and the housing 22.

Although the invention has been described herein with reference to specific embodiments, many modifications and variations therein will readily occur to those skilled in the art. For example, any suitable means may be utilized for applying pressure uniformly to the outside surface of the member 11. Thus, the member may be inserted in an appropriately formed cavity 40 in the rubber pad 41 of a conventional rubber pad press 42 of the type, for example, which is shown in FIG. 5 of U.S. Patent No. 2,375,599, issued May 8, 1945, to Lewis E. Walton. Thereafter, pressure is exerted by driving the platens 43, 44 of the press together. At this point, reference is made to our copending application, Serial No. 732,311 filed May 1, 1958. Accordingly, all such variations and modifications are included within the intended scope of the invention as defined by the following claims.

We claim:

1. Apparatus for applying extreme pressure to a body of material comprising, means forming and bounding a pressure-containing enclosure, pressure-multiplying means within the enclosure in separated relation from said enclosure bounding means and comprising a plurality of pressure multiplying units movable relative to and towards each other and having inner surfaces of relatively small area cooperative to form a cavity to receive said body and outer surfaces of relatively large area, pressure-transmitting means confined by said bounding means within said enclosure so as to be circumjacent the pressure-multiplying means and so as to be in pressure communicating relation both with said bounding means and with the unit surfaces of relatively large area, and means for applying pressure to said pressure-transmitting means to develop therein a pressure communicated therefrom to said last named surfaces to produce a movement of said units relative to and towards each other.

2. Apparatus for applying extreme pressure to a body of material comprising, means forming and bounding a pressure-containing enclosure, pressure-multiplying means within the enclosure in separated relation from said enclosure bounding means and comprising a plurality of pressure-multiplying units having inner surfaces of relatively small area cooperative to form a cavity to receive said body and outer surfaces of relatively large area, the adjacent units being separated by small gaps, resilient pressure-transmitting means confined by said bounding means within said enclosure so as to envelop the pressure-multiplying means and so as to be in pressure communicating relation both with said bounding means and with the unit surfaces of relatively large area, said pressure transmitting means being resistant to extrusion into the gaps under pressure, and means for applying pressure to the resilient pressure-transmitting means to develop throughout the volume thereof a pressure communicated to said last named surfaces to produce a simultaneous inward driving of said units.

3. Apparatus for applying extreme pressure to an object comprising an enclosure, pressure-multiplying means within the enclosure comprising a plurality of wedge-shaped segments converging toward the object, viscous pressure-transmitting means surrounding the object and substantially enclosed by the segments, resilient pressure-transmitting means surrounding the pressure-multiplying means and forming a fluid-tight seal thereabout, and means for introducing hydraulic fluid under pressure into the enclosure.

4. Super high pressure apparatus for compressing an object encased by pressure transmitting material comprising, an array of at least four pressure-multiplying units each having a rear end, a smaller front end and a front face at its smaller end, and each such unit further having a taper converging towards and terminating at its front face, said units being disposed in three dimensions to define by such faces of all said units a central cavity adapted to contain said encased object and said units being each rendered inwardly movable relative to the others by gaps

of which one is between each unit and each of other units adjacent thereto, said array of units being operably disposed between platens of a press which are drivable together, and unit-displacing means providing a wall portion behind and abutting the rear end of each of a plurality of said units to operably make pressure contact therewith, said unit-displacing means being adapted in cooperation with such platens at a time when the latter are driven towards each other and said object is so contained to subject it to simultaneous pressures from all the units of said array by producing between each one and the others of the unit of said array a closing relative movement creating a pressure engagement between the front face of each such unit and an opposite area of the pressure transmitting material encasing the object.

5. Apparatus for compressing a body formed of an object encased by pressure-transmitting material comprising, a plurality of rigid pressure-multiplying elements each having a front face at the inner end thereof and a larger rear face at the outer end thereof, said elements being disposed in a plurality of planes to define by the front faces of all said elements a central cavity adapted to contain said body, means defining a single fluid-containing space in pressure-communicating relation with each of said elements, means to pressurize a volume of a fluid disposed within such fluid-containing space, the pressure so developed in said fluid volume being communicated to the larger rear faces of said elements to move them relative to and towards the center of said cavity at a time when said body is so contained so as to subject it to simultaneous pressures from all elements and fluid sealing means obstructing entry between said elements of pressurized fluid from said space.

6. Apparatus for applying extreme pressure to a body of material comprising, means forming and bounding a pressure-containing fluid-tight enclosure, pressure multiplying means comprising a plurality of pressure multiplying units movable relative to and towards each other and having inner surfaces of relatively small area forming a cavity for receiving said body, and having outer surfaces of relatively large area, said pressure multiplying means being disposed in said enclosure in separated relation from said enclosure bounding means, and said enclosure being adapted to contain between said bounding means and pressure multiplying means hydraulic fluid circumjacent said pressure multiplying means and in pressure-communicating relation both with said bounding means and with said outer surfaces of ones of said units, means to develop in such fluid a hydrostatic pressure communicated to said outer surfaces of said ones of said units to move such units relative to and towards each other to compress said body in said cavity, and fluid sealing means obstructing entry between said elements of pressurized fluid from said enclosure.

7. Apparatus for applying extreme pressure to a body of material comprising, means forming and bounding a pressure-containing fluid-tight enclosure, pressure multiplying means comprising a plurality of pressure multiplying units having inner surfaces of relatively small area forming a cavity for receiving said body, and having outer surfaces of relatively large area, said pressure multiplying means being disposed in said enclosure in separated relation from said enclosure bounding means and being characterized by gaps disposed between the units thereof and permitting movement of said units relative to and towards each other, and said enclosure being adapted to contain between said bounding means and pressure multiplying means hydraulic fluid circumjacent said pressure multiplying means and in pressure-communicating relation both with said bounding means and with said outer surfaces of ones of said units, fluid-tight sealing means cooperating with said gaps between said ones of said units to preclude passage of such fluid through such gaps into said cavity, and means to develop in such fluid a hydrostatic pressure communicated to said outer surfaces of said ones of said units to move such units relative to and towards each other.

8. Apparatus for applying extreme pressure to a body of material comprising, means forming and bounding a pressure-containing fluid-tight enclosure, pressure multiplying means comprising a plurality of relatively aligned pressure multiplying units having inner surfaces of relatively small area forming a cavity for receiving said body, and having outer surfaces of relatively large area, said pressure multiplying means being disposed in said enclosure in separated relation from said enclosure bounding means and being characterized by gaps disposed between the units thereof and permitting movement of said units relative to and towards each other and said enclosure being adapted to contain between said bounding means and pressure multiplying means hydraulic fluid circumjacent said pressure multiplying means and in pressure-communicating relation both with said bounding means and with said outer surfaces of ones of said units, means to maintain said units in a predetermined relative alignment thereof and to provide for said gaps between said ones of said units a fluid-tight sealing precluding passage of such fluid through such gaps into said cavity, and means to develop in such fluid a hydrostatic pressure communicated to said outer surfaces of said ones of said units to move such units relative to and toward each other.

9. Super high pressure apparatus for applying extreme pressure to a body comprised of an object encased by material adapted to become viscous and thereby pressure-transmissive under high pressure, said apparatus comprising, means providing a pressure-restraining ring, a plurality of first pressure multiplying units having inner surfaces of relatively small area bordering the circumference of a cavity for receiving said body, and having outer surfaces of relatively large area, said pressure multiplying units being disposed within and centrally of said ring to extend in the radial direction of said ring away from said cavity so as to present said outer surfaces thereof towards said ring, and said units being characterized by gaps between said units permitting radial movement of said units relative to and towards each other, a pair of second pressure multiplying units disposed at opposite ends of said cavity to close off said ends and to each be separated by a gap from each of said first units, said second units each having the same ratio of outer surface area to inner surface area as said first units to thereby provide the same pressure multiplying factor as said first units, and hydraulic pressure-producing means disposed outside said second units and, also, within said ring between said ring and first pressure multiplying units to be in pressure communicating relation both with said ring and with the outer surfaces of said first and second units, said hydraulic means being adapted by applying to the outer surface of each of said first and second units an inwardly directed force proportional to the inner surface area of such unit to produce between said units a relative closing movement contracting the size of said cavity and producing uniform extreme pressure by all said first and second units upon said body when contained in said cavity.

10. Super high pressure apparatus for applying extreme pressure to a body comprised of an object encased by material adapted to become viscous and thereby pressure transmissive under high pressure, said apparatus comprising, four simultaneously inwardly movable first pressure multiplying members each having an outer face, a smaller inner face, a center line of action, and an outward to inward diminishing taper, said four members being disposed with their center lines of action equiangularly spaced in a common plane around a central axis normal to said plane, and with their inner faces disposed towards and spaced from said axis to border four sides of a central cavity adapted to receive said body and defined by said inner faces so as, in said plane, to be of the same dimension in each of two mutually perpen-

dicular directions, and each of said four members being separated by respective gaps from the ones adjacent thereto to permit simultaneous inward movement of said members, the taper of each of said members imparting thereto within the extent of the taper a trapezoidal cross section both in said common plane and in an axially extending plane bisecting such member and containing the center line of action thereof, two simultaneously inwardly movable second pressure multiplying members each having an outer face and a smaller inner face and respectively disposed on opposite sides of said plane to each be separated by a gap from each of said first four members, said two second members having their center lines of action coincident with said axis and being tapered to have within the extent of the taper a trapezoidal cross section in each of the bisecting planes for said first members, and the inner faces of said two second members bordering opposite ends of said cavity, said second members having the same ratio of outer face area to inner face area as said first members to thereby provide the same pressure multiplication factor as said first members and means adapted by applying to the outer face of each of said first and second members an inwardly directed force proportional to the area of the inner face thereof to drive all six members simultaneously inward so as to apply uniform extreme pressure by the front faces of all of said first and second members to said body when contained in said cavity.

11. Apparatus as in claim 10 in which all six of said pressure multiplying members are substantially identical.

12. Super high pressure apparatus for exerting extreme pressure on a body comprised of an object to be compressed and a casing of pressure-transmitting material surrounding said object, said apparatus comprising, a plurality of pressure multiplying elements each having a smaller front face than rear face, said elements being disposed around a principal axis of a central cavity for receiving said body to each be rendered inwardly movable relative to the others by being separated by a gap from each of adjacent elements on either side thereof, and to define by the front faces of all said elements a surface which circumferentially bounds said cavity, and which is elongated such that its axial extent exceeds its extent in a plane normal to said axis, the front and rear faces of said elements being also axially elongated in correspondence with the elongation of said surface, hydraulic pressure-generating means disposed outwardly of the rear face of each of said elements, a housing shell surrounding said elements and pressure generating means to provide a pressure absorbing girdle for outwardly directed pressure generated by said means, and pressure transmitting means disposed between said generating means and each of said elements to be in contact with the rear face of each thereof over an axially elongated region at least substantially coextensive with such face, and to transmit from said generating means through such region of contact to such face a pressure which is inwardly directed and is equalized over said region, said transmitted pressure being adapted by moving said elements relative to and towards the center of said cavity to compress said body, and a pair of end members disposed at the axially opposite ends of such cavity to bear at said ends against said body during compression thereof.

13. Super high pressure apparatus for exerting extreme pressure on a body comprised of an object to be compressed and a casing of pressure-transmitting material surrounding said object, said apparatus comprising, a plurality of first, similar pressure multiplying elements each having a smaller front face than rear face, said elements being disposed around a principal axis of a central cavity for receiving said body to each be rendered inwardly movable relative to the others by being separated by a gap from each of adjacent elements on either side thereof, and to define by the front faces of all said elements a surface which circumferentially bounds said cavity, and which is generatable geometrically by movement of a straight line parallel to said axis around a closed path, a pair of second pressure multiplying elements disposed at opposite ends of said cavity to each be rendered movable relative to said first elements by being separated by a gap from each of said first elements, said second elements being each characterized by the same ratio of rear face area to front face area as said first elements to thereby provide the same pressure multiplication factor as said first elements, but said second elements having a smaller front face area than that of said first elements, and means adapted by applying to the rear face of each of said first and second elements a force proportional to the front face area thereof to move all said elements inwardly relative to each other to thereby exert a uniform extereme pressure by the front faces of all said elements on said body when contained in said cavity.

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