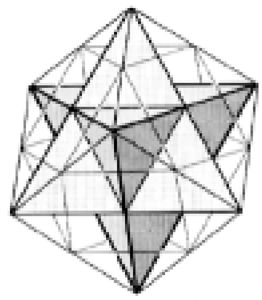

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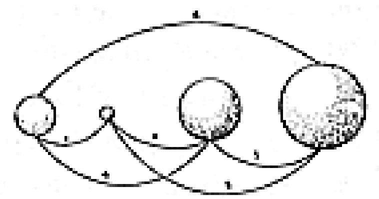

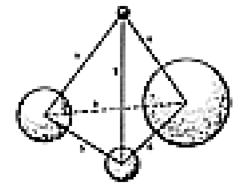

700.00 **Tensegrity**

700.01 Definition: Tensegrity

700.011 The word *tensegrity* is an invention: it is a contraction of *tensional integrity.* Tensegrity describes a structural-relationship principle in which structural shape is guaranteed by the finitely closed, comprehensively continuous, tensional behaviors of the system and not by the discontinuous and exclusively local compressional member behaviors. Tensegrity provides the ability to yield increasingly without ultimately breaking or coming asunder.

700.02 The integrity of the whole structure is invested in the finitely closed, tensional-embracement network, and the compressions are local islands. Elongated compression tends to deflect and fail. Compressions are disintegrable because they are not atomically solid and can permit energy penetration between their invisibly amassed separate energy entities. As a compression member tends to buckle, the buckling point becomes a leverage fulcrum and the remainder of the compression member above acts as a lever arm, so that it becomes increasingly effective in accelerating the failure by crushing of its first buckled-in side. The leverage-accelerated penetration brings about precessional dispersal at 90 degrees.

700.03 Tension structures arranged by man depend upon his purest initial volition of interpretation of pure principle. Tension is omnidirectionally coherent. Tensegrity is an inherently nonredundant confluence of optimum structural-effort effectiveness factors.

700.04 All structures, properly understood, from the solar system to the atom, are tensegrity structures. Universe is omnitensional integrity.

701.00 **Pneumatic Structures**

701.01 Tensegrity structures are pure pneumatic structures and can accomplish visibly differentiated tension-compression interfunctioning in the same manner that it is accomplished by pneumatic structures, at the subvisible level of energy events.

701.02 When we use the six-strut tetrahedron tensegrity with tensegrity octahedra in triple bond, we get an omnidirectional symmetry tensegrity that is as symmetrically compressible, expandable, and local-load-distributing as are gas-filled auto tires.

702.00 Geodesics

702.01 We have a mathematical phenomenon known as a geodesic. A geodesic is the most economical relationship between any two events. It is a special case of geodesics which finds that a seemingly straight line is the shortest distance between two points in a plane. Geodesic lines are also the shortest surface distances between two points on the outside of a sphere. Spherical great circles are geodesics.

703.00 Geodesic-Tensegrity Molecular Kinetics of Pneumatic Systems

703.01 Geodesic domes can be either symmetrically spherical, like a billiard ball, or asymmetrically spherical, like pears, caterpillars, or elephants.

703.02 I prefer to stay with compound curvature because it is structurally stronger than either flat surfaces or simple cylindrical curvature or conical curvature. The new compound-curvature geodesic structures will employ the tensegrity principles. The comparative strength, performance, and weight tables show clearly that the geodesic- dome geometry is the most efficient of all compound-curvatured, omnitriangulated, domical structuring systems.

703.03 All geodesic domes are tensegrity structures whether or not the tension-compression differentiations are visible to the observer. Tensegrity geodesic spheres do what they do because they have the properties of hydraulically or pneumatically inflated structures. Pneumatic structures, such as footballs, provide a firm shape when inflated because the atmospheric molecules inside are impinging outward against the skin, stretching it into accommodating roundness. When more molecules are introduced into enclosures by the air pump, their overcrowding increases the pressure. All the molecules of gas have inherent geometrical domains of activity. The pressurized crowding is dynamic and not static.

703.04 A fleet of ships maneuvering under power needs more room than do the ships of the same fleet when docked side by side. The higher the speed of the individual ships, the greater the sea room required. This means that the enclosed and pressurized molecules in pneumatic structural systems are accelerated in outward-bound paths by the addition of more molecules by the pump and, without additional room, each must move faster to get out of the way of others.

703.05 The pressurized internal liquid or gaseous molecules try to escape from their confining enclosure. The outward-bound molecules impact evenly upon all the inside surface of the enclosure—for instance, upon all of the football's flexible inside skin when it is kicked in one spot from outside. Their many outward-bound impactings force the skin outwardly and firmly in all directions, and the faster they move, the more powerful the impact. This molecular acceleration is misidentified as pressures and firmness of the pneumatic complex. This molecular acceleration distributes the force loads evenly. The outward forces are met by the comprehensive embracement of all the tensile envelope's combined local strengths. All locally impacting external loads, such as the kick given to a point on the football's exterior, are distributed by all the enclosed atmospheric molecules to all of the skin in the innocuously low magnitudes.

703.06 The ability to determine quite accurately what the local loadings of any given pneumatic structure will be under varying conditions and forces is well known and is about as far as the pneumatic sciences have gone in explaining inflated structures. The comfortably equationed state of their art is adequate to their automobile-or-airplane-tire-, balloon-, or submarine-designing needs.

703.07 It is, however, possible to find out experimentally a great deal more about the behavior of those invisible, captive, atmospheric molecules and to arrive at a greater geo-mathematical understanding of the structural relationships between pneumatically inflated bags or vessels and geodesic tensegrity spheres and domes. It is thus possible also to design tensile structures that meet discretely, ergo nonredundantly, the patterns of outwardly impinging forces. It also becomes possible, for the first time, for structural engineers to analyze geodesic domes in a realistic and safe manner. Up to this time, the whole engineering profession has been analyzing geodesics on a strictly *continuous- compression,* crystalline, non-load-distributing, "post-and-lintel" basis. For this reason, the big geodesic domes thus far erected have been way overbuilt by many times their logically desirable two-to-one safety factor.

703.08 While the building business uses safety factors of four, five, or six-to-one, aircraft-building employs only two-to-one or even less because it knows what it is doing. The greater the ignorance in the art, the greater the safety factor that must be applied. And the greater the safety factor, the greater the redundancy and the less the freedom of load distribution.

703.09 First we recall, as has long been known experimentally, that every action has a reaction. For a molecule of gas to be impelled in one direction, it must "shove off from," or be impelled by, another molecule accelerated in an opposite direction. Both of the oppositely paired and impelled action and reaction molecules inside the pneumatically expanded domes will impinge respectively upon two chordally opposed points on the inside of the skin. The middle point of a circular chord is always nearer the center of the circle than are its two ends. For this reason, chords (of arcs of spheres) impinge outwardly against the skin in an acutely glancing angular pattern.

703.10 When two molecules accelerate opposingly from one another at the center of the sphere, their outward trajectories describe a straight line that coincides with the diameter of a sphere. They therefore impinge on the skin perpendicularly, i.e., at 180 degrees, and bounce right back to the sphere center. It is experimentally evidenced that all but two of the myriad molecules of the captive gas do not emanate opposingly from one another at the center of the sphere, for only one pair can occupy one point of tangent bounce-off between any two molecules. If other molecules could occupy the nucleus position simultaneously, they would have to do so implosively by symmetrical self-compression, allowing the sphere to collapse, immediately after which they would all explode simultaneously. No such pulsating implosion-explosion, collapse-and-expand behavior by any pneumatic balls has been witnessed experimentally.

703.11 Molecules of gas accelerating away from one another and trying to proceed in straight trajectories must follow both the shortest-distance geodesic law as well as the angular-reflectance law; they will carom around inside a sphere only in circular paths describing the greatest diameter possible, therefore always in great-circle or geodesic paths.

703.12 For the same reasons, molecules cannot be "stacked up" inside the sphere in parallel or lesser-circle latitude planes. We also found earlier that the molecules could not be exploding simultaneously in all directions from the center of the sphere. If thin, colored vapor streaks are introduced into a transparently skinned, pneumatically pressurized sphere, then only at first superficial observation do the smoke-disclosed molecular motions seem to be demonstrating chaotically random patterns. This is not the case, however, for everything in Universe is in motion and everything in motion is always traveling in the direction of least resistance, wherefore the great circle's inherent polar symmetries of interaction *must impose polar order*—an order that is hidden from the observer only by its articulative velocities, which transcend the human's optically tunable, "velocity-of- motions" spectrum range of apprehending and therefore appear only as clouds of random disorder. Brouwer's theorem shows that when x number of points are stirred randomly on a plane, it can be proved mathematically—when the stirring is stopped—that one of the points was always at the center of the total stirring, and was therefore never disturbed in respect to all the others. It is also demonstrable that any plane surface suitable for stirring things upon, must be part of a system that has an obverse surface polarly opposite to that used for the stirring, and that it too must have its center of stirring; and the two produce poles in any bestirred complex system.

703.13 Every great circle always intercepts any other great circle twice, the interception points always being 180-degree polar opposites. When two force vectors operating in great-circle paths inside a sphere impinge on each other at any happenstance angle, that angle has no amplitude stability. But when a third force vector operating in a great-circle path crosses the other two spherical great circles, a great-circle-edged triangle is formed with its inherently regenerated 180-degree mirror-image polar opposite triangle. With a myriad of successive inside surface caromings and angular intervector impingements, the dynamic symmetry imposed by a sphere tends to equalize the angular interrelationship of all those triangle-forming sets of three great circles which shuntings automatically tend averagingly to reproduce symmetrical systems of omnisimilar spherical triangles always exactly reproduced in their opposite hemispheres, quarterspheres, and octaspheres. This means that if there were only three great circles, they would tend swiftly to interstabilize comprehensively as the spherical octahedron all of whose surface angles and arcs (central angles) average as 90 degrees.

703.14 A vast number of molecules of gas interacting in great circles inside of a sphere will produce a number of great-circle triangles. The velocity of their accomplishment of this structural system of total intertriangulation averaging will seem to be "instantaneous" to the human observer. The triangles, being dynamically resilient, mutably intertransform one another, imposing an averaging of the random-force vectors of the entire system, resulting in angular self-interstabilizing as a pattern of omnispherical symmetry. The aggregate of all the inter-great-circlings resolve themselves typically into a regular pattern of 12 pentagons and 20 triangles; or sometimes more complexedly, into 12 pentagons, 30 hexagons, and 80 triangles described by 240 great-circle chords.

703.15 This is the pattern of the geodesic tensegrity sphere. The numbers of hexagons and triangles and chords can be multiplied in regular arithmetical-geometrical series, but the 12 pentagons, and only 12, will persist as constants; also, the number of triangles will occur in multiples of 20; also, the number of edges will always be multiples of six.

703.16 In the geodesic tensegrity sphere, each of the entirely independent, compressional chord struts represents two oppositely directioned and force-paired molecules. The tensegrity compressional chords do not touch one another. They operate independently, trying to escape outwardly from the sphere, but are held in by the spherical-tensional integrity's closed network system of great-circle connectors, which alone complete the great-circle paths between the ends of the entirely separate, nonintercontacting compressional chords.

704.00 **Universal Joints**

704.01 The 12-spoke wire wheel exactly opposes all tension, compression, torque, or turbining tendencies amongst its members. Universal joints of two axes or three axes of freedom are analogous to the wire wheel as a basic 12-degrees-of-freedom accommodating, controlling, and employing system whose effectiveness relies upon their discrete mechanical and structural differentiation and disposition of all tension and compression forces. All of these may be considered to be basic tensegrity systems. (See illustration 640.41B.)

704.02 The shafted axis of the two-axis universal joint tends to make it appear as a single-axis system. But it constitutes in actuality an octahedral tensegrity, with its yoke planes symmetrically oriented at 90 degrees to one another. The two-axis tensegrity has been long known and is often successfully employed by mechanics as a flexible-membrane coupling sandwiched between two diametrically opposed yoke-ended shafts, precessionally oriented to one another in a 90-degree star pattern. This only tensionally interlinked, i.e., universally jointed, drive shafting has for centuries been demonstrating the discontinuous compression and only tensionally continuous multiaxial, multidimensional symmetry of tensegrity structuring and energetic work transmission from here to there.

705.00 **Simple Curvature: The Barrel**

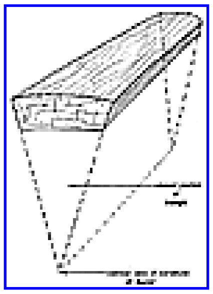
Fig. 705.01

705.01 The barrel represents an advanced phase of the Roman arch principle of stability accomplished by simple (approximately) single-axis curvature. A barrel is comprised of a complete ring around one axis of a number of parallel staves. A cross section cut through the barrel perpendicular to its single axis of curvature shows each of the stave's sections looking like keystones in an arch. Each stave is a truncated section of a triangle whose interior cutaway apex would be at the center of the barrel. The staves employ only the outer trapezoidal wedge-shaped cross section, dispensing with the unnecessary inner part of the triangle. The stave's cross section is wedge-shaped because the outer edge of the stave is longer than the inner edge of the stave. Because the stave's outer-circle chord is longer than its inner-circle chord, it cannot fall inwardly between the other staves and it cannot fall outwardly from close-packed association with the other staves because they are all bound inwardly together by the finitely closed barrel "hoops" of steel.

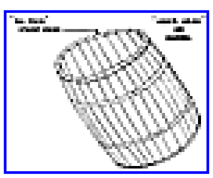
Fig. 705.02

705.02 All these barrel staves are lined in parallel to one another and are bound cylindrically. They constitute a finite, closed cylinder held together in compression by finitely encompassing tension bands, or hoops, which are parallel to one another and at 90 degrees to the axis of the staves. The staves cannot move outwardly due to the finiteness of the straps closing back upon themselves; they cannot fall inwardly on each other because their external chords are bigger than their internal chords. The tendency of internally loaded cylinders and vertically compressed columns to curve outwardly at their midgirth in their vertical profile is favored by designing and making the barrel staves of greater cross section at their midbarrel portions and the finite, closed-circle bands of lesser diameter near the ends than at the middle. The curving lines of compression thrust back against themselves, while the tension lines tend to pull true and form a finite closure, pressing the short, true chord sections of the staves tightly against one another in

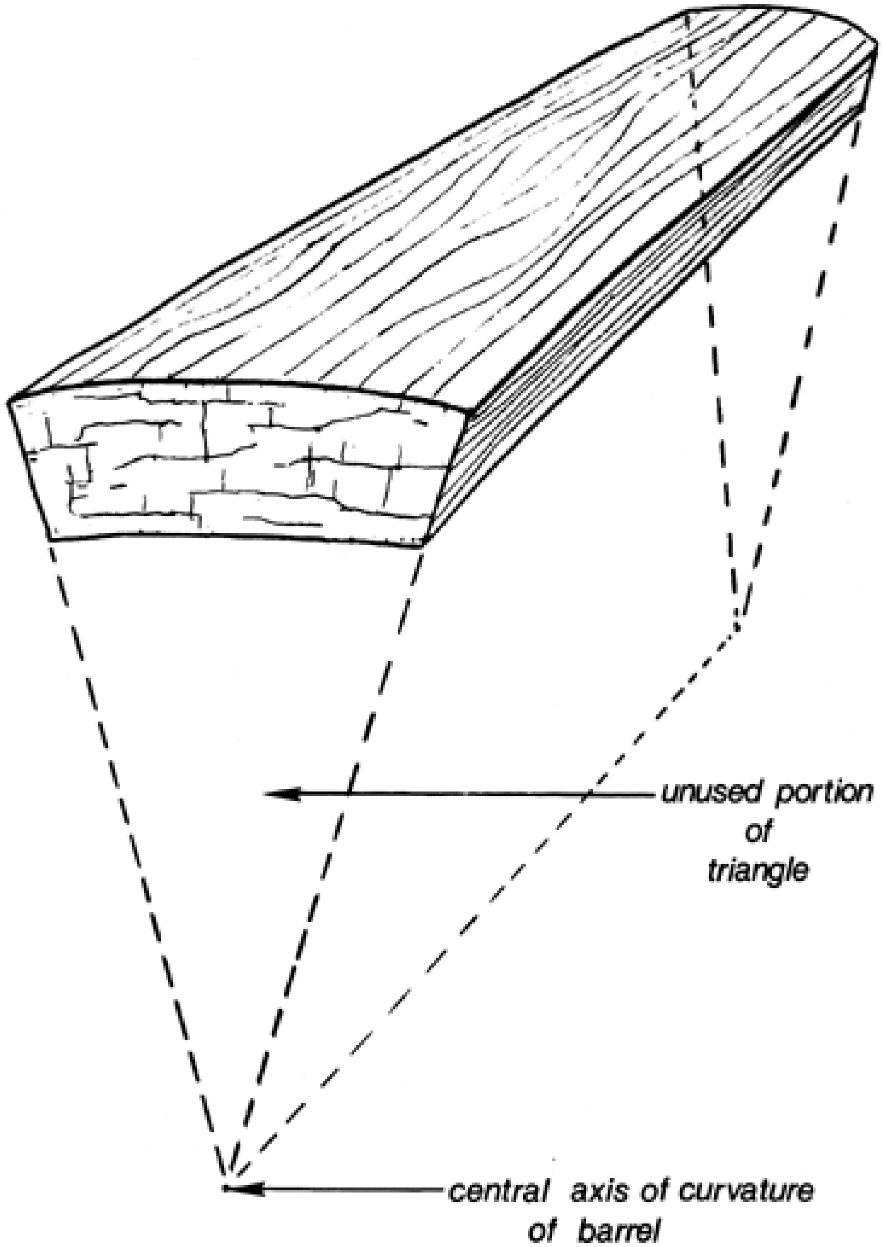
unused portion
of
triangle
central axis of curvature
of barrel

Fig. 705.01

Fig. 705.02

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a complete circular arch; thus the staves may be flexed, when the barrel is internally filled, without tendency to failure.

705.03 Thus the barrel, when in good material condition, usually proves to be structurally stable and able to withstand the impact of dropping, especially when internally loaded, because the internal load tends to distribute any local shock load to all the enclosing barrel's internal surface and thence to the finitely closed, steel circle bands. Barrels constitute closed circuits of continuous tension finitely restraining discontinuous, though contiguously islanded, staves of compression in dynamic stability. Whether pressure is exerted upon its structure from outside or inside the barrel, the result is always an outward thrust of the staves against the tension members, whose finite closure and cross-sectional strength ultimately absorb all the working or random loads. The vertical forces of gravity in the primary working stresses of internally loaded, simple-curvature structures—such as those of the cylinder, barrel, tree trunk, or Greek column—are translated precessionally into horizontally outward buckling and torque stresses. When, however, such cylinders are not internally loaded and are turned over on their side with their axes horizontal, the stresses are precessed horizontally, outward from the cylinder ends toward the infinite poles of cylindrically paralleled stave lines. Under these conditions, the outer hoops' girth does not aid the structural interstabilization, and the forces of gravity acting vertically against the horizontally paralleled staves develop a lever arm of the topmost staves against the opposite outer staves of the barrel, tending to thrust open the sidemost staves from one another and thus allowing the integrity of the arch to be disintegrated, allowing infinity to enter and disintegrate the system.

705.04 Each of the barrel's tension hoops represents a separately operating, exclusively tensional circle with its plane parallel to, and remote from, the planes of the other, only separately acting, barrel hoops. The tension bands do not touch one another. The tension bands are only parallel to one another and act only at 90 degrees against the staves, which are also only parallel to one another. Neither the staves nor the tension hoops cross one another in such a manner as to provide intertriangulation and its concomitant structural self-stabilization. In fact, they both let infinity into the system to disintegrate it between the only parallel staves and hoops whose separate parts reach forever separately only toward infinity.

705.05 If we take a blowtorch and bum out one of the wooden staves, the whole barrel collapses because infinity floods in to provide enough space between the staves for their arch to be breached and thus collapse disintegratively. What the blowtorch does is to let infinity—or the nothingness of Universe—into the system to intrude between the discontinuous and previously only contiguously crowded together, exclusively compressional members of the system.

705.06 Barrels and casks, which provided great shipping and storage "container advantage" in the past, secured only by finite closure continuities of the only separately acting tension circles, were inherently very limited in structural efficiency due to the infinitely extendable—ergo, infinitely disassociative—staves as well as by the infinity that intruded disintegratively between the barrel's parallel sets of circular bands or hoops.

Next Section: 706.00

706.00 **Compound Curvature: Spherical Cask**

706.01 Engineers and mathematicians both appear presently to be unfamiliar with practical means for discretely analyzing and employing the three-way grids of finitely closed, great-circle triangulations despite the fact that their triangular integrities constitute nature's most powerful and frequently employed structural systems. You can inform yourself experimentally regarding the relative structural effectiveness of flat, simple- cylinder, and compoundly curved sheet material by taking a flat piece of paper, standing it on its edges, and loading that top edge; you will note that it has no structural strength whatsoever—it just crumples. But if we roll-form the same piece of paper into a cylinder, which is what is called simple curvature, we can use the cylinder as a column in which all the compressionally functioning lines are parallel to each other and interact with the closed-circle tensional strength of the paper cylinder's outside surface like the staves and hoops of a barrel.

706.02 But only if we achieve a three-way interaction of great circles can we arrive at the extraordinary stability afforded by the omnitensionally integrated, triangular interstabilization of compound curvature. This we do experimentally with the same sheet of paper, which we now form into a conical shape. Standing the cone on its finitely closed circular base and loading its apex, we find it to be more stable and structurally effective for supporting a concentrated top loading than was either the first sheet or the simply curved cylinder. The top load now thrusts downwardly and outwardly toward the finitely closed, tensionally strong base perimeter, which becomes even stronger if the cone is foldingly converted into a tetrahedron whose insideness concavity and outsideness convexity and omnifinite tensional embracement constitute the prime manifestation of so-called "compound curvature."

706.03 In contrast to our simply curved, cylindrical barrel construction, let us now make a wooden geodesic sphere in which all of the triangular facets are external faces of internally truncated tetrahedra whose interior apexes, had they not been snubly truncated, would each have reached the center of the sphere. Each of the outwardly triangular, internally truncated, tetrahedral cork's edges is covered by finitely closed great-circle tension straps. The steel tension straps are not parallel to each other but are omnitriangularly interconnected to form a spherical barrel. Every great circle of a spherical cask crosses all other great circles of that sphere twice. Any two such—only polarly interconnected—great circles can hinge upon each other like a pair of shears. They are angularly unstable until a third great circle that does not run through the same crossings of the other two inherently crosses both of the first two great circles and, in effect, taking hold of the lever ends of the other two great circles, with the least effort accomplishes stabilization of the oppositely converging angle.

706.04 So we now have an omnitriangulated geodesic sphere of triangulated wooden plugs, or hard wooden corks fashioned of the same barrel stave oak, each one surrounded by and pressed tightly against three other such triangular hardwood corks; each has its exterior triangular facets edged by three great circles whose lengths are greater than the respectively corresponding wooden cork triangle's interior chords so that none of the wooden corks can fall inwardly. The finitely closed great-circle straps are fastened to each other as they cross one another; thus stably interpositioned by triangulation, they cannot slip off the sphere; and none of the wooden triangular corks can fall in on one another, having greater outer edge lengths than those of their inner edges. The whole sphere and its spherical aggregates of omnitriangularly corked surface components are held tightly together in an omnitriangulated comprehensive harness. All of the great circles are intertriangulated in the most comfortable, ergo most economical, interpositions possible.

706.05 If we now take a blowtorch and bum out entirely one of the triangular, truncated wooden corks—just as we burned out one of the barrel's wooden staves—unlike the barrel, our sphere will not collapse. It will not collapse as did the regular barrel when one stave was burnt out. Why does it not collapse? Because the three- way triangular gridding is finitely closed back on itself. Infinity is not let into the system except through the finitely-perimetered triangular hole. The burning out of the triangular, truncated tetrahedron, hardwood cork leaves only a finite triangular opening; and a triangular opening is inherently a stable opening. We can go on to bum out three more of the triangular, truncated wooden corks whose points are adjacent to each other, and while it makes a larger opening, it remains a triangular opening and will still be entirely framed with closed and intertriangulated great circles; hence it will not collapse. In fact, we find that we can bum out very large areas of the geodesic sphere without its collapsing. This three-way finite crossing of most economical great circles provides a powerful realization of the fundamentals of compound curvature. Compound curvature is inherently self- triangulating and concave-convexing the interaction of those triangles around the exterior vertexes.

706.10 **Sphericity:** Compound curvature, or sphericity, gives the greatest strength with the least material. It is no aesthetic accident that nature encased our brains and regenerative organs in compoundly curvilinear structures. There are no cubical heads, eggs, nuts, or planets.

706.20 **Three-Way Great Circling:** While great circles are the shortest distances around spheres, a *single* great-circle band around a sphere will readily slide off. Every great circle of a sphere must cross other great circles of that sphere twice, with the crossings of any two always 180 degrees apart. Since an infinite number of great circles may run through any two same points on a sphere 180 degrees apart, and since any *two* great-circle bands are automatically self-interpolarizing, two great-circle bands on a sphere can rotate equatorially around their mutual axis and attain congruency, thereafter to act only as one solitary meridian, and therefore also free to slide off the sphere. Not until we have *three* noncommonly polarized, great-circle bands providing omnitriangulation as in a spherical octahedron, do we have the great circles acting structurally to self-interstabilize their respective spherical positionings by finitely intertriangulating fixed points less than 180 degrees apart.

706.21 Since great circles describe the shortest distances between any two spherical points less than 180 degrees apart, they inherently provide the most economical spherical barrel bandings.

706.22 The more minutely the sphere is subtriangulated by great circles, the lesser the local structural-energy requirements and the greater the effectiveness of the mutual- interpositioning integrity. This spontaneous structural self-stabilizing always and only employs the chords of the shortest great-circle arc distances and their respective spherical finiteness tensional integrity.

706.23 When disturbed by energy additions to the system, the triangular plug "corks" can only—and precessionally "prefer"—to be extruded only outwardly from the system, like the resultant of all forces of all the kinetic momentums of gas molecules in a balloon. The omni-outwardly straining forces of all the compressional forces are more than offset by the finitely closed, omni-intertriangulated, great-circle tensions, each of whose interstitial lines, being part of a triangle—or minimum structure—are inherently nonredundant. The resultant of forces of all the omni-intertriangulated great-circle network is always radially, i.e. perpendicularly, inward. The tightening of any one great circle results in an even interdistribution of the greater force of the inward-outward balance of forces.

706.30 **Fail-Safe Advantages:** With each increase of frequency of triangular module subdivisions of the sphere's unitary surface, there is a corresponding increase in the fail-safe advantage of the system's integrity. The failure of a single triangular cork in an omnitriangulated spherical grid leaves a triangular hole, which, as such, is structurally innocuous, whereas the failure of one stave in a simple-curvature barrel admits infinity and causes the whole barrel to collapse. The failure of two adjacent triangular corks in a spherical system leaves a diamond-shaped opening that is structurally stable and innocuous; similarly, the failure of five or six triangles leaves a completely arched, finitely bound, and tensionally closed pent or hex opening that, being circumferentially surrounded by great circles, is structurally innocuous. Failure of a single spherical-tension member likewise leaves an only slightly relaxed, two-way detoured, diamonded relaying of the throughway tensional continuity. Considerable relaxing of the spherical, triangulated-cork barrel system by many local tension failures can occur without freeing the corks to dangerously loosened local rotatability, because the great-circle crossings were interfastened, preventing the tensionally relaxed enlargement of the triangular bonds. The higher the frequency and the deeper the intertrussing, the more fail-safe is this type of spherical structure.

706.31 Structural systems encompassing radial compression and circumferential tension are accomplished uniquely and exclusively through three-way spherical gridding. These radial and circumferential behaviors open a whole new field of structural engineering formulations and an elegance of refinement as the basis for a new tensegrity- enlightened theory of engineering and construction congruent with that of Universe.

707.00 **Spherical and Triangular Unity**

707.01 **Complex Unity and Simplex Unity:** The sphere is maximal complex unity and the triangle is minimal simplex unity. This concept defines both the principles and the limits governing finite solution of all structural and general-systems-theory problems.

707.02 Local isolations of "point" fixes, "planes," and "lines" are in reality only dependent aspects of larger, often cosmically vast or micro-, spheric topological systems. When local isolation of infinitely open-ended planes and linear-edged, seemingly flat, and infinite segments are considered apart from their comprehensive spherical contexts, we are confronted with hopelessly special-cased and indeterminate situations.

707.03 Unfortunately, engineering has committed itself in the past exclusively to these locally infinite and inherently indeterminate systems. As a consequence, engineering frequently has had to rely only on such trial-and-error-evolved data regarding local behaviors as the "rate" of instrumentally measurable deflection changes progressively produced in static-load increases, from which data to evolve curves that theoretically predict "failure" points and other critical information regarding small local systems such as columns, beams, levers, and so forth, taken either individually or collectively and opinionatedly fortified with safely "guesstimated" complex predictions. Not until we evolve and spontaneously cultivate a cosmic comprehension deriving from universal, finite, omnitriangulated, nonredundant structural systems can we enjoy the advantage of powerful physical generalizations concisely describing all structural behaviors.

710.00 **Vertexial Connections**

710.01 When a photograph is made of a plurality of lines crossing through approximately one point, it is seen that there is a blurring or a running together of the lines near the point, creating a weblike shadow between the converging lines—even though the individual lines may have been clearly drawn. This is caused by a refractive bending of the light waves. When the masses of the physically constituted lines converge to critical proximity, the relative impedance of light-wave passage in the neighborhood of the point increases as the second power of the relative proximities as multiplied by a factor of the relative mass density.

710.02 Tensegrity geodesic spherical structures eliminate the heavy sections of compression members in direct contact at their terminals and thus keep the heavy mass of respective compressions beyond critical proximities. As the vertexial connections are entirely tensional, the section mass is reduced to a minimum, and system "frequency" increase provides a cube-root rate of reduction of section in respect to each doubling frequency. In this manner, very large or very small tensegrity geodesic spheroids may be designed with approximate elimination of all microwave interferences without in any way impairing the structural dimensional stability.

710.03 The turbining, tensionally interlaced joints of the tensegrity-geodesic spheroids decrease the starlike vertexial interference patterns.

711.00 Gravity as a Circumferential Force

711.01 **Circumference:** Circumference = π D = C. Wherefore, we can take a rope of a given D length and lay it out circumferentially to make it a circle with its ends almost together, but with a tiny gap between them.

711.02 Then we can open out the same rope to form only a half-circle in which the diameter doubles that of the first circle and the gap is wide open.

711.03 Halfway between the two, the gap is partially open.

711.04 As we open gaps, we make the sphere bigger. The comprehensive tension wants to make it smaller. Struts in the gap prevent it from becoming smaller. Struts make big. Tension makes small. The force of the struts is only outward. The force of the tension network is only inward.

711.10 **Circumferential Advantage over Radial:** Gravity is a spherically circumferential, omniembracingly contractive force. The resultant is radially inward, attempting to make the system get smaller. The *circumferential* mass-interattraction effectiveness has a constant coherent advantage ratio of 12 to 1 over the only *radially* effective mass attraction; ergo, the further inward within the embraced sphere, the greater the leverage advantage of the circumferential network over the internal compaction; ergo, the greater the radial depth within, the greater the pressure.

711.20 **Ratio of Tensors:** Locally on a circle, each particle has two sideways tensors for each inward tensor. One great-circle plane section through a circle shows two sideways tensors for one inward vector. But, on the surface of a sphere, each particle has six circumferential tensors for each single inward radial vector. When you double the radius, you double the chord.

711.30 **Struts as Chords in a Spherical Network:** When inserting a strut into a tensegrity sphere, we have to pull the tension lines outward from the system's center, in order to insert the strut between the vertexes of those lines. As we pull outward, the chordal distance of the gap between the spheric tension lines increases.

711.31 If we wish to open the slot in the basketball or football's skin through which its pneumatic bladder is to be inserted, we pull it outwardly and apart to make room inside.

711.32 The most outward chord of any given central angle of a circle is the longest. The omnicircumferential, triangularly stabilized, interconnecting tension lines of the spherical-network system cannot get bigger than its discretely designed dimensions and the ultimate tensile strength of the network's tensors, without bursting its integrity. The comprehensive spherical-tensor network can only relax inwardly. When all in place, the tensegrity-compression struts can only prevent the tension network from closing inward toward the sphere's center, which is its comprehensive proclivity.

711.33 The synergetic force of the struts (that is, their total interrelationship tendency) is not predicted by any one strut taken singly. It is entirely omniradially outward. The force of the strut is not a chordal two-way thrust.

711.34 A fully relaxed spherical tensegrity structure may be crumpled together in a tight bundle without hurting it, just as a net shopping bag can be stuffed into a small space. Thereafter, its drooped, untaut tension members can only yield outward radially to the dimensionally predesigned and prefabricated limits of the omniclosed spheric system, which must be progressively opened to accommodate the progressive interconstruction of the predesigned, prefabricated chordal lengths of the only circumferentially arrayed compression struts.

711.35 The compression struts are islanded from one another, that is, in each case, neither of the separate compression strut's ends touches any part of any other compression strut in the spheric system. As struts are inserted into the spheric-tension network, the whole spheric system is seen to be expanding omnioutwardly, as do pneumatic balloons when air is progressively introduced into their previously crumpled skins.

711.36 The comprehensive, finitely closed tension network's integrity is always pulling the islanded compression struts inward; it is never pushing them, nor are they pushing it, any more than a rock lying on Earth's crust thrusts horizontally sidewise. The rock is held where it is by the comprehensively contractive Earth's inter-mass-attraction (gravitational) field, or network. But the more rocks we add, the bigger the sphere held comprehensively together by the omnitensively cohering, gravitational consequences of the omni-interattractive mass aggregate.

712.00 **Clothesline**

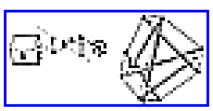


Fig. 712.01

712.01 Surprising behaviors are found in tensegrity structures. The illustration shows a house and a tree and a clothesline. The line hangs low between the house and the tree. To raise the line so that the clothes to be dried will not sweep the ground, the line is elevated by a pole that has one end thrust against the ground and the other end pushed outwardly against the line. The line tightens with the pole's outer end at the vertex of an angle stretched into the line. The line's angle shows that the line is yielding in the direction away from the thrusting pole.

712.02 As the clothesline tightens and bends, it always yields *away* from the pushing strut. In spherical tensegrity structures the islanded compression struts *pull* the tension lines to *angle toward* the strut ends.

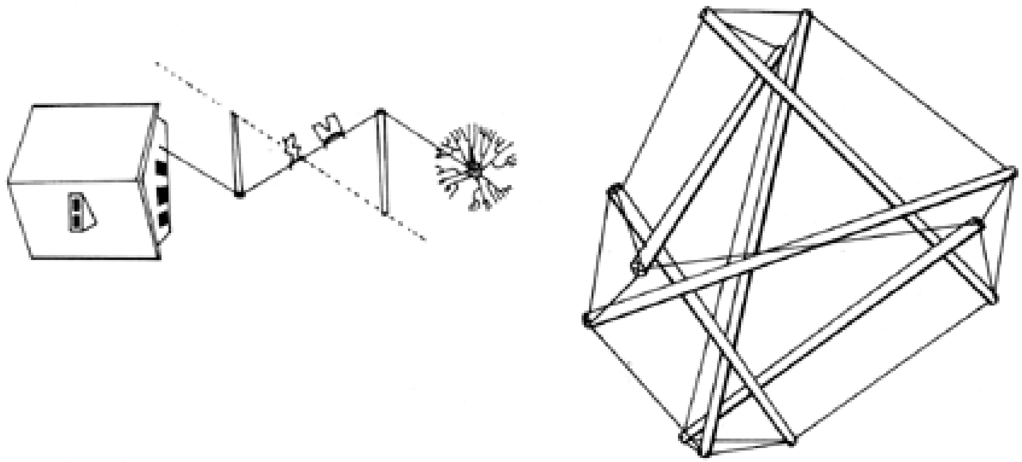


Fig. 712.01 Tensegrity Behavior.

712.03 When we release a compression member from a tensegrity sphere, one end does not thrust *by* the tension member to which it was fastened in a circumferential direction. It was not fastened in *thrust* or *sheer*. It was not pushing circumferentially. It was resisting being compressed, and like a cork in a bottle, it was employing its frictional contact with the tension net at both its ends to *resist* its only tendency, which was to exit radially outward from the system's center.

713.00 **Discontinuous Compression**

713.01 **Subvisible Discontinuity:** In the Babylonian, Egyptian, and Ionian eras of ways of looking at, thinking about, and formulating, there evolved a concept of a "first family" of geometrical "solids," in which each member was characterized by all of its faces being identical and all of its edges being one length only. Humans were then unaware of what physics was only much later to discover experimentally: that nature discloses no evidence of a continuum. Experiment discloses only aggregates of separate, finitely closed events. Ergo, there are no solids.

713.02 Their optical illusion and stubbornly conditioned reflexes have since motivated one generation after another to go on teaching and accepting the misconception of geometric "solids," "planes," and "straight lines," where physics has discovered only wavilinear trajectories of high-frequency, yes-no event pulsations. With the misconception of straight lines came the misconception of the many lines going through the same point at the same time. Wherefore the 12 edges that define the cube were assumed to be absolute straight lines, and therefore sets of them ran simultaneously into the thus absolutely determined eight corner "points" of the cube.

713.03 Humans were accustomed to the idea that edges come together at one certain point. But we now know operationally that if we look at any of the edges of any item microscopically, there is no such absolute line, and instead there is seen to be an aggregate of atomic events whose appearance as an aggregate is analogous to the roughly rounding, wavilinear profiled, shoulder "edge" of a rock cliff, sand, or earth bluff standing high above the beach of the shore lying below, whose bluff and beach disclose the gradual erosion of the higher land by the sea.

713.04 The corners of the solids are also just like the corners of an ocean-side bluff that happens to have its coastwise direction changed at 90 degrees by large geological events of nature such as an earthquake fault. Such an easterly coastline's bluff casts dark shadows as the Earth rotates; seen from airplanes at great altitudes, long sections of that black coastal shadow may appear illusionarily as "straight."

713.05 We can make Platonic figures in nonsolid tensegrity where none of the lines go through any of the same points at the same time, and we realize that the only seemingly continuous, only mass-interattractively cohered, atomic "Milky Way" tensor strands spanning the gaps between the only seemingly "solid," omni-islanded, vectorially compressioned struts, do altogether permit a systematic, visually informed, and realistically comprehended differentiation between the flexible tensor and inflexible vector energy-event behaviors, all of which are consistent with all the experimental information accruing to the most rigorous scientific discipline.

713.06 The eye can resolve intervals of about 1/100th of an inch or larger. Below that, we do not see the aggregates as points. Thereafter, we see only "solid"-color surfaces. But our color receptivity, which means our only-human-optics-tunable range of electromagnetic radiation frequencies, cannot "bring in," i.e., resonatingly respond to, more than about one-millionth of the now known and only instrumentally tune-in-able overall electromagnetic-wave-frequency range of physical Universe. This is to say that humans can tune in directly to less than one-millionth of physical reality—ergo, cannot "see" basic atomic and molecular-structuring events and behaviors, but our synergetic tensegrity principles of structuring are found instrumentally to be operative to the known limits of both micro- and macro-Universe system relationships as the discontinuous, entropic, radiational, and omnicohering, collecting gravitational syntropics. (See Sec. 302..)

713.07 **Convergence:** While we cannot see the intervals between atomic-event waves, the tensegrity structuring principles inform our consideration of the invisible events. Every time we instrumentally magnify the illusionarily converging geometrical "lines" defining the edges of "solids," we see them only wavilinearly converging toward critical proximity but never coming completely together; instead, twisting around each other, then slivering again, never having gone through the same "points."

713.08 When we first try to differentiate tension and compression in consciously attempting to think about the behavior of structures in various locals of Universe, it becomes apparent that both macro-Universe and micro Universe are only tensionally cohered phenomena. They both obviously manifest discontinuous compression islands. It is evidenced, in cosmically structured systems, both macro and micro, that compression members never touch one another. Earth does not roll "ball bearing" around on the surface of Mars; nor does the Moon roll on Earth, and so forth. This structural scheme of islanded spheres of compression, which are only mass-attractively cohered, also characterizes the atomic nucleus's structural integrities. Tensegrity discoveries introduce new and very different kinds of structural principles which seem to be those governing all structuring of Universe, both macrocosmic and microcosmic.

713.20 **Compression Members**

713.21 **Behavior of Compression Members in Spherical Tensegrity Structures:** In spherical tensegrity constructions, whenever a tension line interacts with a compression strut, the line does *not* yield in a circumferential direction away from the strut. The islanded compression member, combining its two ends' oppositely outward thrust, *pulls* on the omni-integrated tension network only acting as a radially outward force in respect to the sphere's center.

713.22 When we remove a compression member from a tensegrity sphere of more than three struts, the compression member of the original triangular group, when released on one end, does not *shove by* the tension member to which it was fastened. It is not fastened in *shove* or *sheer*. It pulls outwardly of the spherical system, away from the tension members at both of its ends simultaneously; when released, it pops only outwardly from the sphere's center.

713.23 When inserting a strut into a tensegrity sphere, you are pulling the tensional network only outwardly of the system in order to allow the strut to get *into* the system, that is, toward the structure's center. The strut pulls only outward on the two adjacent tension members to which it is fixed, trying to escape only radially outwardly from the system's center.

Next Section: 714.00

714.00 **Interstabilization of Local Stiffeners**

714.01 **Local, Discontinuous, Compressional Strut Waves Interstabilizing Two Concentric, Differentially Radiused Tensegrity Spheres:** Highly stable, nonredundant, rigidly trussed, differently radiused, concentric spherical tensegrity structures of hexagonal-pentagonal, inner *or* outer (but not both) surface dimples, symmetrically interspersing their omnitriangularly interlinked, spherically closed systems, may be constructed with swaged crossings of high-tensile-steel-cabled, spherical nets and locally islanded compressional struts occurring discontinuously as inbound-outbound, triangularly intertrussing, locally islanded compressional struts. The struts may then be either hydraulically actuated to elongate them to designed dimensions, or may be locally jacked in between the comprehensively prefabricated, spherical-system tensional network.

714.02 The local struts are so oriented that they always and only angle inwardly and outwardly between the concentric, differently radiused, comprehensively finite, exterior and interior, tensional spherical nets. The result is an interstabilized dynamic equilibrium of positive and negative waves of action. Such tensegrity sphere structures are limited in size only by the day-to-day limits of industrial production and service-logistics techniques. Large tensegrity spheres can have their lower portions buried in reinforced-concrete as tie- down bases to secure them against hurricane-drag displacement.

715.00 *Locked Kiss*

715.01 As we increase the frequency of triangular-module subdivisions of a tensegrity geodesic sphere, we thus also increase the number of compression struts, which get progressively halved in length, while their volumes and weights shrink eightfold. At the same time, the arc altitude between the smaller arcs and chords of the sphere decreases, while the compression members get closer and closer to the adjacent compression members they cross. Finally, we reach the condition where the space between the struts is the same dimension as the girth radius of the struts. At this point, we can let them kiss- touch; i.e., with the ends of two converging struts contacting the top middle of the strut running diagonally to those two struts and immediately below their ends. We may then lock the three kissing members tensionally together in their kiss, but when we do so, we must remember that they were not pushing one another when they "kissed" and we locked them in that equilibrious, "most comfortable" position of contact coincidence. Tensegrity spheres are not fastened in shear, even though their *locked kiss* gives a superficially "solid" continuity appearance that is only subvisibly discontinuous at the atomic level.

716.00 **Complex Continuity and Discontinuity in Tensegrity Structures**

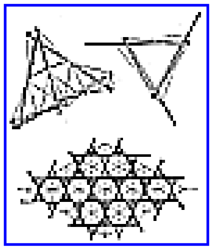


Fig. 716.01

716.01 The terminal junctures of four three-strut tensegrity octahedra are all 180-degree junctures. They appear to be compressionally continuous, while the central coherence of the three struts appears visibly discontinuous. The complex tensegrity presents a visibly deceptive appearance to the unwary observer. The two joined legs of the basic units appear as single units; as such, they appear to be primary elements of the complex tensegrity, whereas we learn from construction that our elements are the three- strut octahedra and that the cohering principle of the simplest elements is tensegrity.

716.02 The fundamental, repeatable unit used to form the spherical tensegrity structures is a flattened form of the basic three-strut tensegrity octahedron.

716.03 The basic 12-frequency tensegrity matrix employs collections of the basic three-strut units joined at dead center between single- and double-bonded discontinuity. The shaded triangles in the illustration represent the sites for each of the three-strut units. This matrix is applied to the spherical triacontrahedron—consequently, the large 12- frequency rhombus (illustration 716.01C) is one-thirtieth of the entire sphere.

716.10 **Convergence**

716.11 Whereas man seems to be blind in employing tensegrity at his level of everyday consciousness, we find that tensegrity structures satisfy our conceptual requirement that we may not have two events passing through the same point at the same time. Vectors converge in tensegrity, but they never actually get together; they only get into critical proximities and twist by each other.

717.00 **Single- and Double-Bonding in Tensegrity Spheres**

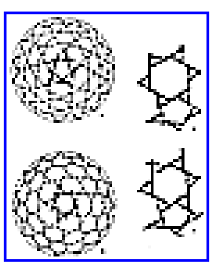


Fig. 717.01

717.01 Basic three-strut tensegrities may be joined in single-bonding or double-bonding to form a complex, 270-strut, isotropic tensegrity geodesic sphere. It can be composited to rotate negatively or positively. A six-frequency triacontrahedron tensegrity is shown in illustration 717.01.

717.02 Complexes of basic three-strut tensegrities are shown with axial alignment of exterior terminals to be joined in single bond as a 90-strut tensegrity.

720.00 Basic Tensegrity Structures

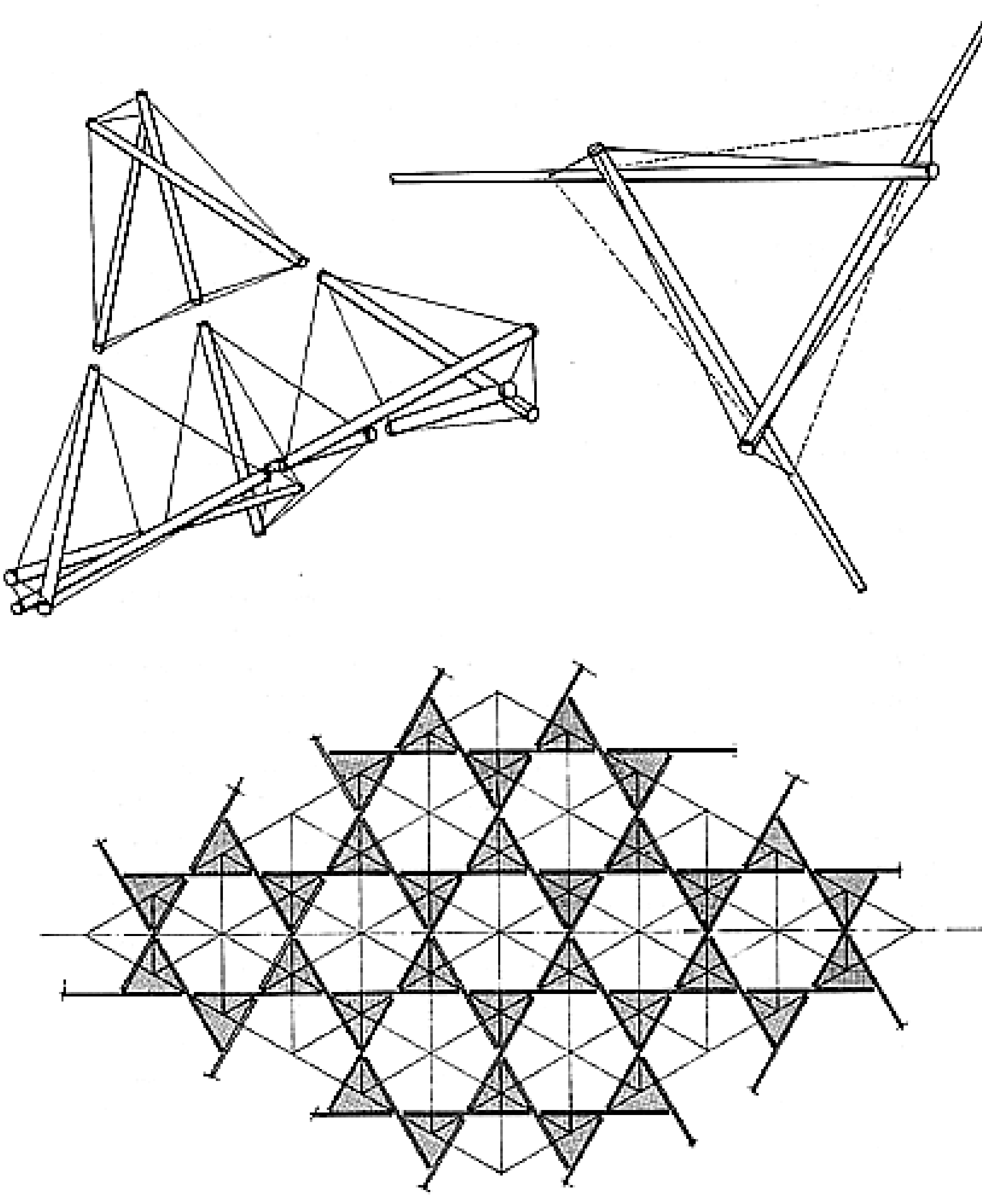


Fig. 716.01

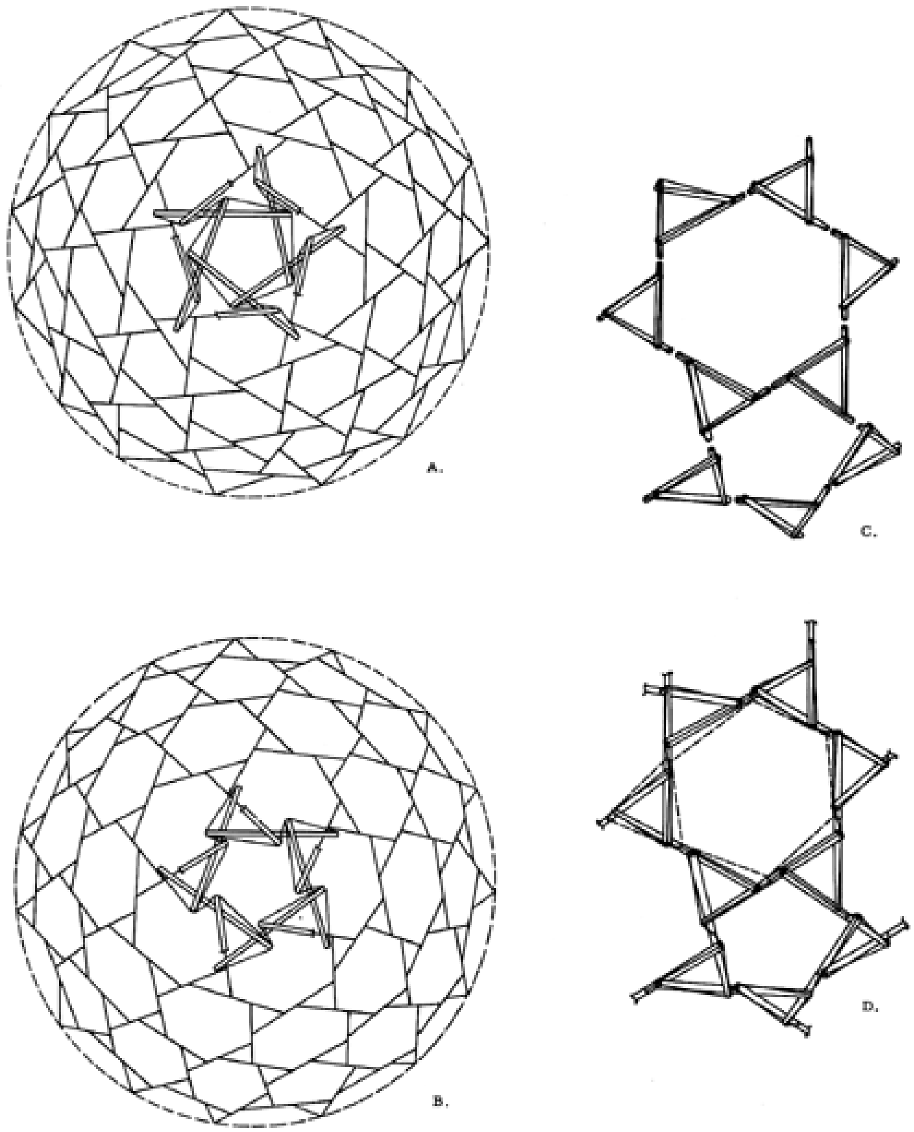


Fig. 717.01 Single and Double Bonding of Members in Tensegrity Spheres:

A. Negatively rotating triangles on a 270-strut tensegrity geodesic sphere with double-bonded triangles.
B. A 270-strut isotropic tensegrity geodesic sphere: single bonded turbo triangles forming a complex six-frequency triacontahedron tensegrity.
C. Complex of basic three-strut tensegrities, with axial alignment whose exterior terminals are to be joined in single bond as 90-strut tensegrity.
D. Complex of basic three-strut tensegrity units with exterior terminals now joined.

720.01 In basic tensegrity structures, the spheric-tension network system is completely continuous. The ends of each compression member connect only with the tension network at various points on the tensional catenaries nearest to the respective ends of the system's omni-islanded compression vector struts. The tension members running between the ends of the struts may be double or single. Double tension members best distribute the loads and most economically and nonredundantly accommodate the omnidistributive stress flows of the system. The catenaries always yield in obtuse or acute "V" shapes at their points of contact with the *strut* islands of compression.

720.02 Conventional building with continuous compression and discontinuous tension is accustomed to fastening compression members to their buildings in shear, that is, in predictably, calculatable, "slide-by" pushing actions, where one force opposes another in parallel but opposite directions.

720.03 But in tensegrity structures, the tension members pull away from the compression strut ends, which the V-shape tension connections demonstrate. If two people take positions on opposite sides of a tensegrity sphere and pull on polarly opposite struts in opposite directions from one another, it will be seen that all around the sphere there is a uniform and symmetrical response to the opposite pulling (or pushing). Pulling on two opposite parts makes the whole sphere grow symmetrically in size, while pushing forces the whole sphere to shrink contractively and symmetrically. Cessation of either the pulling or the pushing causes the sphere to take its size halfway between the largest and smallest conditions, i.e., in its equilibrious size. This phenomenon is a typical four-dimensional behavior of synergetic intertransforming. It explains why it is that all local celestial systems of Universe, being cohered with one another tensionally, pull on one another to bring about an omniexpanding physical Universe.

720.10 **Micro-Macro Structural Model:** If you just tauten one point in a tensegrity system, all the other parts of it tighten evenly. If you twang any tension member anywhere in the structure, it will give the same resonant note as the others. If you tauten any one part, the tuning goes to a higher note everywhere in the structure. Until its tension is altered, each tensegrity structure, as with every chemical element, has its own unique frequency. In a two-sling tensegrity sphere, every part is nonredundant. If tension goes up and the frequency goes up, it goes up uniformly all over. As tensegrity systems are tautened, they approach but never attain rigidity, being nonredundant structures. Anything that we would call rigid, such as one of the atoms of a very high integrity pattern, is explained by this type of tensegrity patterning.

720.11 The kinetically interbalanced behaviors of tensegrity systems manifest discretely and elucidate the energy-interference-event patternings that integrate to form and cohere all atoms. The tensegrity system is always the equilibrious-balance phase, i.e., the omnipotential-energy phase visually articulate of the push-pull, in-out-and-around, pulsating and orbiting, precessionally shunted reangulations, synergetically integrated.

720.12 The circumferentially islanded tensegrity struts are energy vectors in action, and the tension lines are the energy tensors in action. Their omnisystem interpatterning shows how the circumferentially orbiting tensegrity struts' lead ends are pulled by the center of mass of the next adjacent inwardly positioned vector strut. The mass attraction pulls inwardly on the lead ends of the precessionally articulating, self-orbiting, great-circle chord vector struts, thus changing their circumferential direction. They are precessionally and successively deflected from one tangent course to the next, circumferentially inward and onward, tangent vector course. Thus each of the vectors is successively steered to encircle the same tensegrity system center. In this manner, a variety of energy-interference, kinetic-equilibrium patterns results in a variety of cosmically local, self-regenerative, micro-macro structural systems such as atoms or star systems.

721.00 **Stability Requires Six Struts**

721.01 Stability requires six struts, each of which is a combinedly push-pull structural member. It is a synergetic (Sec. 101) characteristic of minimum structural (Sec. 610) systems (Sec. 402) that the system is not stable until the introduction of the last structural component (Sec. 621.10) essential to completion of minimum omnisymmetric array.

721.02 Redundancy (Sec. 723) can be neither predicted nor predetermined by observation of either the integral constraints or external freedoms of energetic behaviors of single struts, or beams, or columns, or any one chain link of a series that is less than 12 in number, i.e., six positive vectors and six negative tensors. Of these 12, six are open- endedly uncoordinate, disintegrative forces that are always omni-cohered by six integrative forces in finitely closed coordination.

722.00 **Push-Pull Members**

722.01 Minimum structural-system stability requires six struts, each of which is a push-pull member. Push-pull structural members embody in one superficially solid system both the axial-linear tension and compression functions.

722.02 Tensegrity differentiates out these axial-linears into separately cofunctioning compression vectors and tensional tensors. As in many instances of synergetic behavior, these differentiations are sometimes subtle. For instance, there is a subtle difference between Eulerian topology, which is polyhedrally superficial, and synergetic topology, which is nuclear and identifies spheres with vertexes, solids with faces, and struts with edges. The subtlety lies in the topological differentiation of the relative abundance of these three fundamental aspects whereby people do not look at the four closest-packed spheres forming a tetrahedron in the same way that they look at a seemingly solid stone tetrahedron, and quite differently again from their observation of the six strut edges of a tetrahedron, particularly when they do not accredit Earth with providing three of the struts invisibly cohering the base ends of the camera tripod.

723.00 **Redundance**

723.01 There are metaphysical redundancies, repeating the same thing, saying it in a little different way each time.

723.02 There are physical redundancies when, for instance, we have a mast stepped in a hole in the ground and three tensional stays at 120 degrees. When a fourth tension member is led to an anchor at an equiradiused distance from the mast base and at one degree of circular arc away from one of the original three anchors, we then have two tension stays running side by side. When the two stays are thus approximately parallel, we find it is impossible to equalize the tensions exactly. One or the other will get the load, not both .

723.03 It is structural redundancy when a square knot is tied and an amateur says, "I'm going to make that stronger by tying more square knots on top of it." The secondary knots are completely ineffective because the first square knot will not yield. There is a tendency of the second square knot to "work open" and thus deteriorate the first knot. Structural redundancies tend to deteriorate the effectiveness of the primary members.

723.04 There are two classes of redundant acts:

1. conscious and knowledgeably competent, and
2. subconscious and ignorantly fearful cautionaries.

723.05 Building codes of cities, formulated by politicians fearful of the calumny of what may befall them if buildings fall down, ignorantly insist on doubling the thickness of walls. Building codes require a safety factor of usually five, or more, to one.

723.06 Aircraft designing employs a safety factor of two to one—or even no safety factor at all, while cautioning the pilot through instrumental indication of when he is approaching limit condition. The deliberately imposed safety factors of society's building conglomerates introduce redundancy breeding redundancy, wherein—as with nuclear fusion, chain-reacting—the additional weights to carry the additional weights multiply in such a manner as to increase the inefficiency imposed by the redundancy at an exponential rate implicit in Newton's mass-attraction gravitational law: every time we double the safety factor, we fourfold the inefficiency and eightfold the unnecessary weight.

724.00 **Three and Only Basic Structures**

724.01 The original six vector-edge members of the tensegrity tetrahedron may be transformed through the tensegrity-octahedron phase and finally into the tensegrity- icosahedron phase. The same six members transform their relation to each other through the full range of the three (only) fundamental structures of nature: the tetrahedron, the octahedron, and the icosahedron. (See Secs. 532.40, 610.20, 724, 1010.20, 1011.30 and 1031.13.)

724.02 The same six members transform from containing one volume to containing 18.51 volumes. These are the principles actively operative in atomic-nucleus behavior in visual intertransformations.

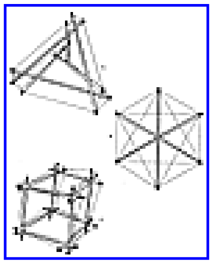


Fig. 724.10

724.10 **Tensegrity Octahedron:** The simplest form of tensegrity is the octahedron with three compression members crossing each other. The three compression struts do not touch each other as they pass at the center. They are held together only at their terminals by the comprehensive triangular tension net. The same three-islanded struts of the tensegrity octahedron may be mildly reorganized or asymmetrically transformed.

724.11 The struts may be the same length or of different lengths. Some tensional edges may be lengthened while other tensional edges of the surface triangles are shortened. The compression members still do not touch each other. One figure is a positive and the other a negative tensegrity octahedron. They can be joined together to make a new form: the tensegrity icosahedron.

724.20 **Tensegrity Icosahedron:** The six-islanded-strut icosahedron and its allspace-filling, closest-packing capability provide omni-equi-optimum economy tensegrity Universe structuring.

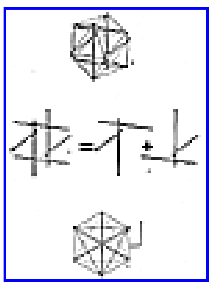


Fig. 724.30

724.30 **Six-Strut Tensegrities:** Two three-strut tensegrities may be joined together to make the tensegrity icosahedron. This form has six members in three parallel sets with their ends held together in tension. There are 12 terminals of the six struts (the two octahedra—each with three struts of six ends—combined). When you connect up these 12 terminals, you reveal the 12 vertexes of the icosahedron. There are 20 triangles of the icosahedron clearly described by the tension members connecting the 12 points in the most economical omnitriangular pattern.

724.31 In the tensegrity icosahedron, there are six tension members, which join parallel struts to each other. If these tension members are removed from the icosahedron, only eight triangles remain from the original 20. These eight triangles are the eight transforming triangles of the symmetrical contraction of the vector equilibrium "jitterbug." (See Sec. 460.) Consequently, this "incomplete" icosahedron demonstrates an expansion- contraction behavior similar to the "jitterbug," although pulsing symmetrically inward- outward within more restricted limits.

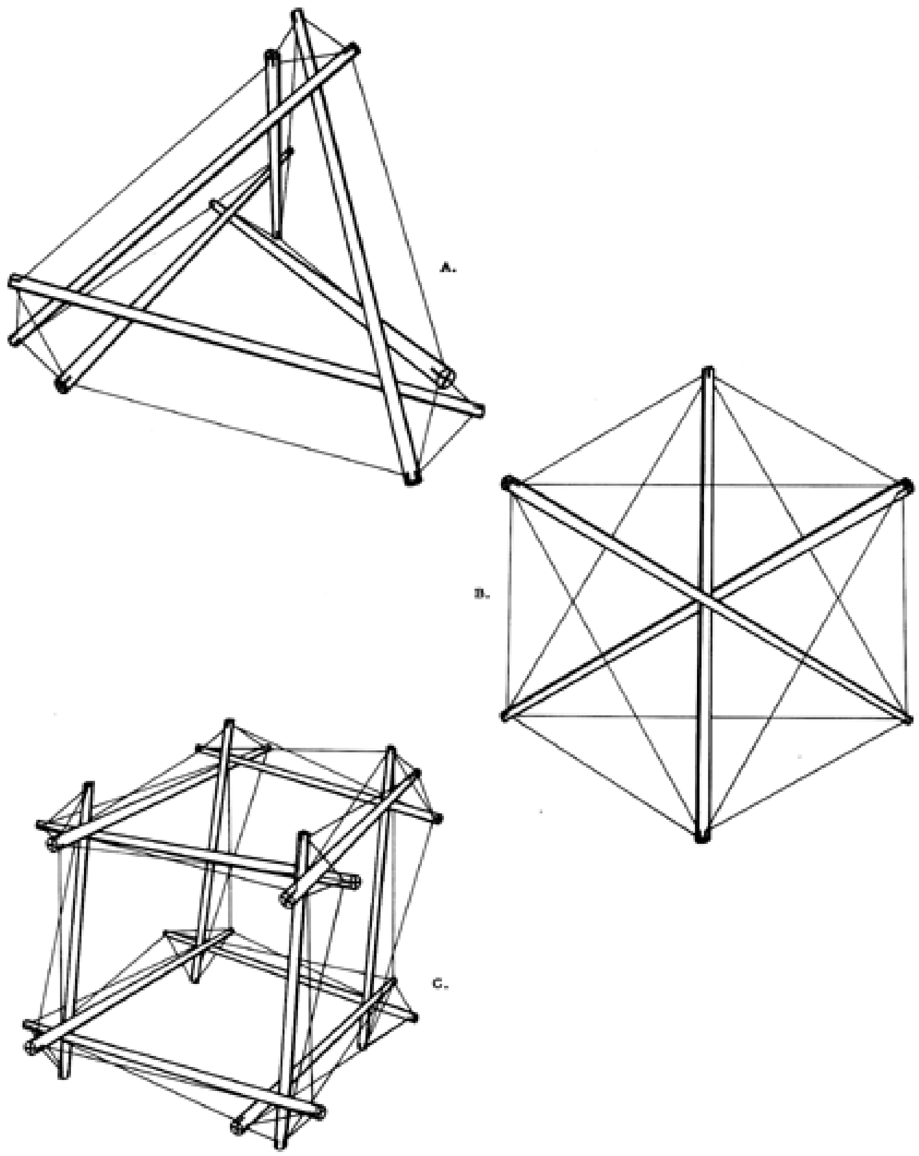


Fig. 724.10:

A. A six-strut tensegrity tetrahedron shows central-angle turbining.
B. The three-strut tensegrity octahedron. The three compression struts do not touch each other as they pass at the center of the octahedron. They are held together only at their terminals by the comprehensive, triangular tension net. It is the simplest form of tensegrity.
C. The 12-strut tensegrity cube, which is unstable.

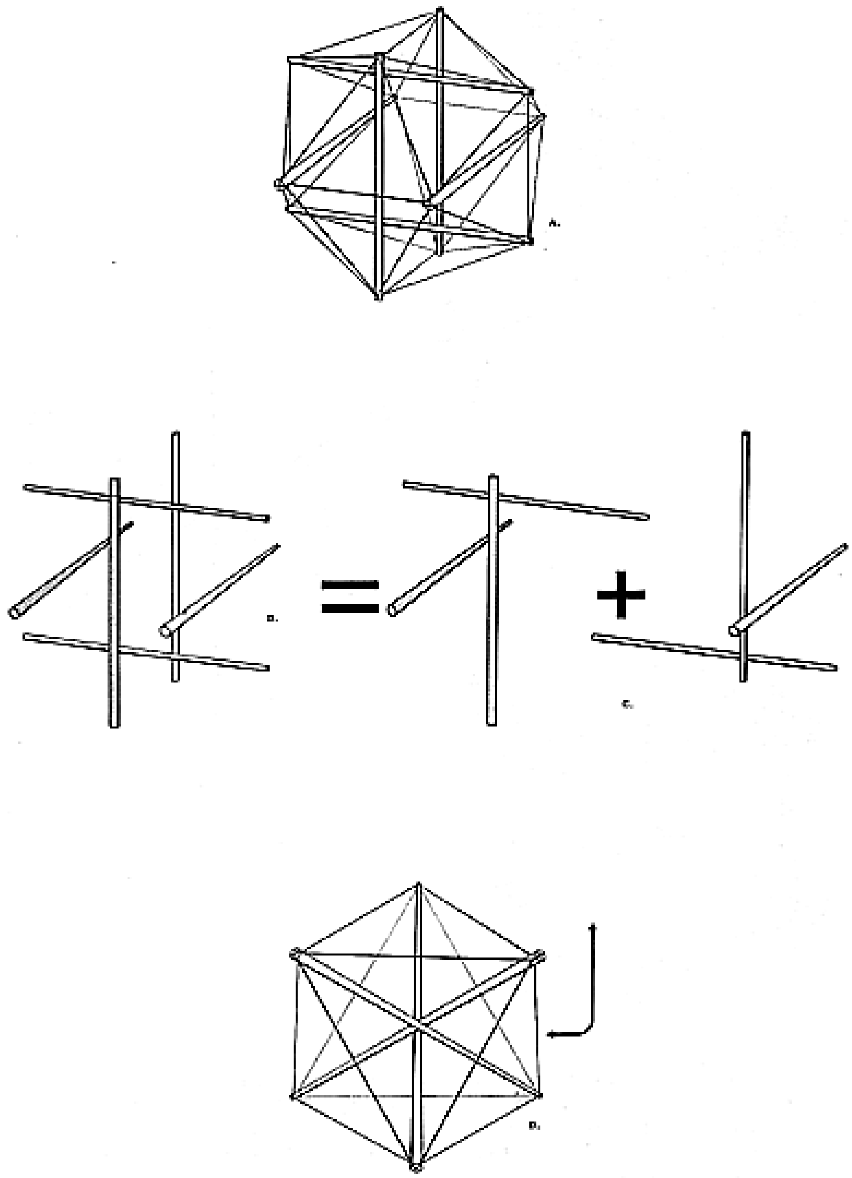


Fig. 724.30 Behavior of Tensegrity Icosahedron.

724.32 If two opposite and parallel struts are pushed or pulled upon, all six members will move inwardly or outwardly, causing the icosahedron to contract or expand in a symmetrical fashion. When this structure is fully expanded, it is the regular icosahedron; in its contracted state, it becomes an icosahedron bounded by eight equilateral triangles and 12 isosceles triangles (when the missing six tension members are replaced). All 12 vertexes may recede from the common center in perfect symmetry of expansion or, if concentrated load is applied from without, the whole system contracts symmetrically, i.e., all the vertexes move toward their common center at the same rate.

724.33 This is not the behavior we are used to in any structures of our previous experiences. These compression members do not behave like conventional engineering beams. Ordinary beams deflect locally or, if fastened terminally in tension to their building, tend to contract the building in axial asymmetry. The tensegrity "beam" does not act independently but acts only in concert with "the whole building," which contracts only symmetrically when the beam is loaded.

724.34 The tensegrity system is synergetic—a behavior of the whole unpredicted by the behavior of the parts. Old stone-age columns and lintels are energetic and only interact locally with whole buildings. The whole tensegrity-icosahedron system, when loaded oppositely at two diametric points, contracts symmetrically, and because it contracts symmetrically, its parts get symmetrically closer to one another; therefore, gravity increases as of the second power, and the whole system gets uniformly stronger. This is the way atoms behave.

Next Section: 725.00

725.00 **Transformation of Tensegrity Structures**

725.01 Six-strut tensegrity tetrahedra can be transformed in a plurality of ways by changing the distribution and relative lengths of its tension members to the six-strut icosahedron.

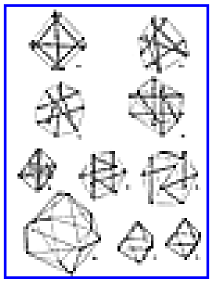


Fig. 725.02

725.02 A theoretical three-way coordinate expansion can be envisioned, with three parallel pairs of constant-length struts, in which a stretching of tension members is permitted as the struts move outwardly from a common center. Starting with a six-strut octahedron, the structure expands outwardly, going through the icosahedron phase to the vector-equilibrium phase.

725.03 When the structure expands beyond the vector equilibrium, the six struts become the edges of the figure; they consequently lose their structural function (assuming that the original distribution of tension and compression members remains unchanged). As the tension members become substantially longer than the struts, the struts tend to approach relative zero, and the overall shape of the structure approaches a super octahedron.

726.00 **Six-Pentagonal Tensegrity Sphere**

726.01 **The Symmetrical, Six-Great-Circle-Planed, Pentagonally Equatored Tensegrity Sphere:** A basic tensegrity sphere can be constituted of six equatorial-plane pentagons, each of which consists of five independent and nonintertouching compression struts, totaling 30 separate nonintertouching compression struts in all. This six-pentagon- equatored tensegrity sphere interacts in a self-balanced system, resulting in six polar axes that are each perpendicular to one of its six equatorial pentagonal planes. Twelve lesser- circle-planed polar pentagons are found to be arrayed perpendicular to the six polar axes and parallel to the equatorial pentagon planes. It also results in 20 triangular interweavings, which structuring stabilizes the system.

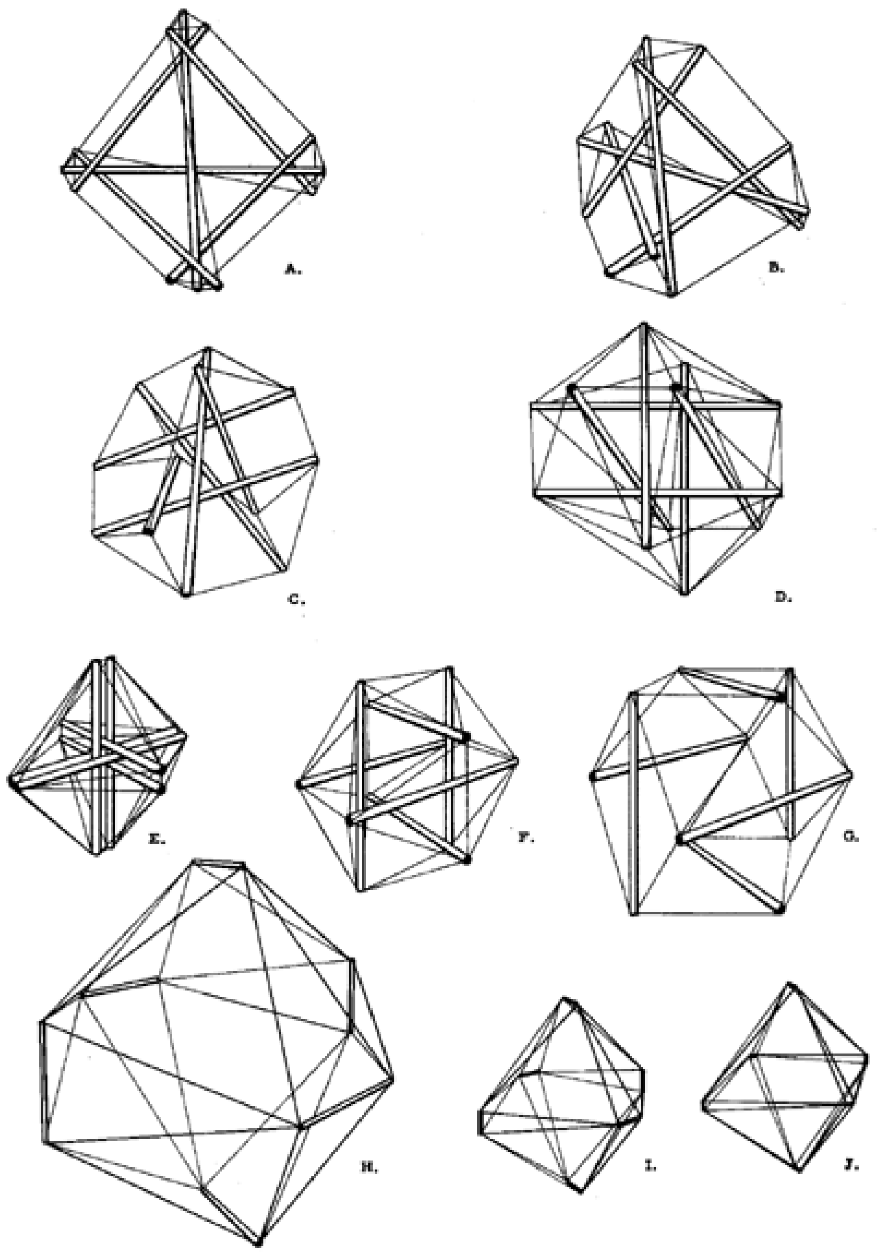


Fig. 725.02 Transformation of Six-Strut Tensegrity Structures: A six-strut tensegrity tetrahedron (A) can be transformed by changing the distribution and relative lengths of its tension members (B, C) to the six- strut icosahedron (D). A theoretical three-way coordinate expansion can be envisioned with three parallel pairs of constant-length struts in which a stretching of tension members is permitted as the struts move outwardly from a common center. Starting with a six-strut octahedron (E), the structure expands outwardly going through the icosahedron phase (F) to the vector-equilibrium phase (G). When the structure expands beyond the vector equilibrium, the six struts become the edges of figure H. They consequently lose their structural function (assuming the original distribution of tension and compression members remains unchanged). As the tension members become substantially longer than the struts, the struts tend to approach relative zero and the overall shape of the structure approaches a super octahedron (I, J).

726.02 Instead of having cables connecting the ends of the struts to the ends of the next adjacent struts in the six-axes-of-symmetry tensegrity structure, 60 short cables may be led from the ends of each prestressed strut either to the midpoint of the next adjacent strut or to the midpoint of tension lines running from one end to the other of each compression strut. Each of the two ends of the 30 spherical-chord compression struts emerges as an energy action? out over the center of action-and-reaction-effort vectors of the next adjacent strut, at which midpoint the impinging strut's effort is angularly precessed to its adjacent struts. Thus each strut precessionally transfers its effort and relayed interloadings to the next two adjacent struts. This produces a dynamically regenerative, self-interweaving basketry in which each compression strut is precessed symmetrically outwardly from the others while simultaneously precessing inwardly the force efforts of all the tensional network.

726.03 In this pattern of six separate, five-strut-membered pentagons, the six pentagonal, unsubstanced, but imaginable planes cut across each other equiangularly at the spheric center. In such a structure, we witness the cosmic principles that make possible the recurrence of locally regenerative structural patterns. We are witnessing here the principles cohering and regenerating the atoms. The struts are simple, dynamic, energy- event vectors that derive their regenerative energies from an eternally symmetrical interplay of inbound-outbound forces of systems that interfere with one another to maintain critical fall-in, shunt-out proximities to one another.

730.00 **Stabilization of Tension in Tensegrity Columns**

730.10 **Symmetric Juxtaposition of Tetrahedra**

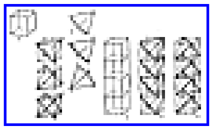


Fig. 730.11

730.11 All polyhedra may be subdivided into component tetrahedra. Every tetrahedron has four vertexes, and every cube has eight vertexes. Every cube contains two tetrahedra (ABCD and WXYZ). Each of its faces has two diagonals, the positive set and the negative set. These may be called the symmetrically juxtaposed positive and negative tetrahedra, whose centers of volume are congruent with one another as well as congruent with the center of volume of the cube. It is possible to stack cubes into two columns. One column can demonstrate the set of positive tetrahedra, and the other column can demonstrate the set of negative tetrahedra.

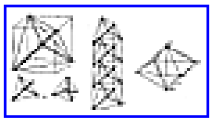


Fig. 730.12

730.12 In every tetrahedron, there are four radials from the center of volume to the four vertexes. These radials provide a model for the behavior of compression members in a column of tensegrity-stacked cubes. Vertical tension stays connect the ends of the tetrahedral compression members, and they also connect the successive centers of volume of the stacked spheres—the centers of volume being also the junction of the tetrahedral radials. As the two centers of volume are pulled toward one another by the vertical tension stays, the universally jointed radials are thrust outwardly but are finitely restrained by the sliding closure XYZW interlinking the tetrahedral integrities of the successive cubes.

730.13 This system is inherently nonredundant, as are all discontinuous-compression, continuous-tension tensegrity structures. The approximately horizontal slings cannot come any closer to one another, and the approximately vertical stays cannot get any farther from one another; thus they comprise a discrete-pattern, interstabilizing relationship, which is the essential characteristic of a structure.

740.00 **Tensegrity Masts: Miniaturization**

740.10 **Positive and Negative**

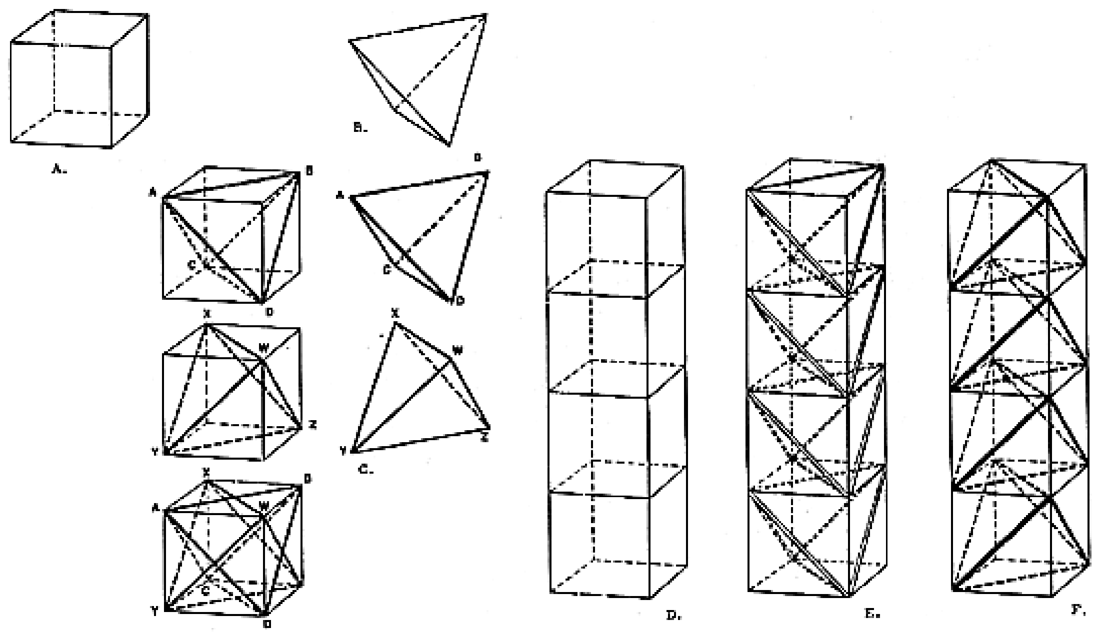


Fig. 730.11 Functions of Positive and Negative Tetrahedra in Tensegrity Stacked Cubes: Every cube has six faces (A). Every tetrahedron has six edges (B). Every cube has eight corners and every tetrahedron has four corners. Every cube contains two tetrahedra (ABCD and WXYZ) because each of its six faces has two diagonals, the positive and negative set. These may be called the symmetrically juxtaposed positive and negative tetrahedra whose centers of gravity are congruent with one another as well as congruent with the center of gravity of the cube (C). It is possible to stack cubes (D) into two columns. One column contains the positive tetrahedra (E) and the other contains the negative tetrahedra (F).

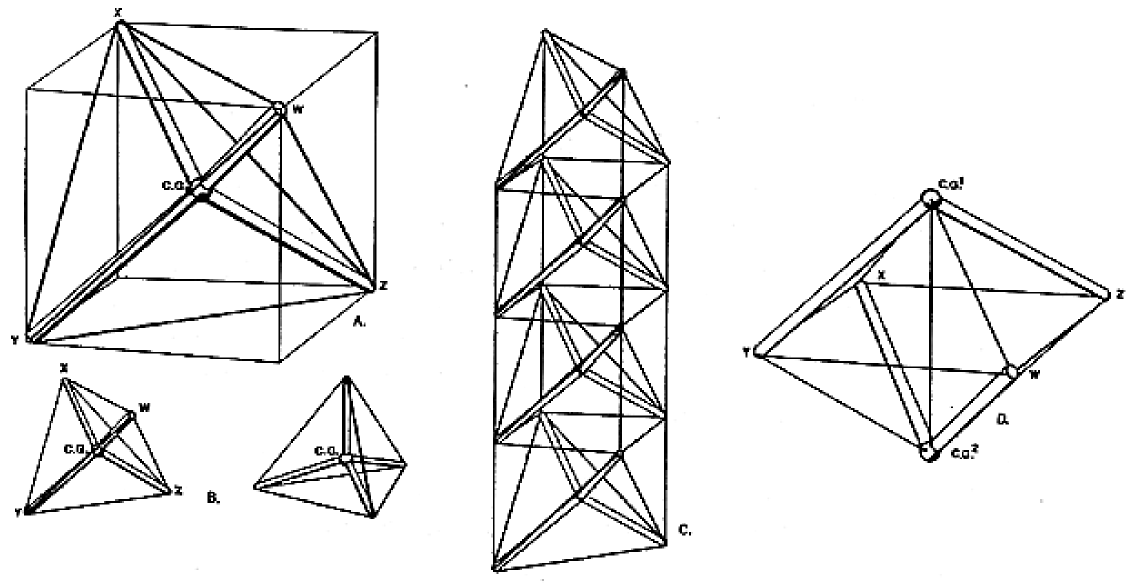


Fig. 730.12 Stabilization of Tension in Tensegrity Column: We put a steel sphere at the center of gravity of a cube which is also the center of gravity of tetrahedron and then run steel tubes from the center of gravity to four corners, W,X,Y, and Z, of negative tetrahedron (A). Every tetrahedron's center of gravity has four radials from the center of gravity to the four vertexes of the tetrahedron (B). In the juncture between the two tetrahedra (D), ball joints at the center of gravity are pulled toward one another by a vertical tension stay, thus thrusting universally jointed legs outwardly, and their outward thrust is stably restrained by finite sling closure WXYZ. This system is nonredundant: a basic discontinuous-compression continuous-tension or "tensegrity" structure. It is possible to have a stack (column) of center-of-gravity radial tube tetrahedra struts (C) with horizontal (approximate) tension slings and vertical tension guys and diagonal tension edges of the four superimposed tetrahedra, which, because of the (approximate) horizontal slings, cannot come any closer to one another, and, because of their vertical guys, cannot get any further away from one another, and therefore compose a stable relationship: a structure.

740.11 Stacked columns of "solidly," i.e., compressionally continuous and only compressionally combined, cubes demonstrate the simultaneous employment of both positive and negative tensegrities. Because both the positive and the negative tensegrity mast are independently self-supporting, either one provides the same overall capability. It is a kind of capability heretofore associated only with "solid" compressional struts, masts, beams, and levers—that is, either the positive- or the negative-tensegrity "beam-boom- mast" longitudinal structural integrity has the same capability independently as the two of them have together. When the two are combined, either the positive- or the negative- tensegrity set, whichever is a fraction stronger than the other, it is found experimentally, must be doing all the strut work at any one time. The unemployed set is entirely superfluous, ergo redundant. All "solid" structuring is redundant.

740.12 If the alternate capabilities of the positive and negative sets are approximately equal, they tend to exchange alternately the loading task and thus generate an oscillating interaction of positive vs. negative load transferral. The energies of their respective structural integrities tend to self-interdeterioration of their combined, alternating, strut-functioning longevity of structural capability. The phenomenon eventually approaches crystallization. All the redundant structures inherently accelerate their own destruction in relation to the potential longevity of their nonredundant tensegrity counterparts.

740.20 **Miniaturization**

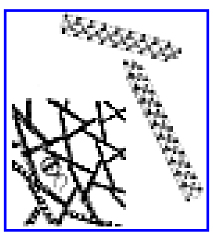


Fig. 740.21

740.21 It is obvious that each of the seemingly "solid" compression struts in tensegrity island complexes could be replaced by miniature tensegrity masts. There is nothing to keep us from doing this but technological techniques for operating at microlevels. It is simply that each of the struts gets smaller: as we look at each strut in the tensegrity mast, we see that we could make another much smaller miniature tensegrity mast to replace it. Every time we can see a separate strut and can devise means for making a tensegrity strut of that overall size, we can substitute it for the previously "solid" strut. By such a process of progressive substitutions in diminishing order of sizes, leading eventually via sub-sub-sub-miniaturizing tensegrities to discovery of the last remaining stage of the seemingly "solid" struts, we find that there is a minimum "solid-state" strut's column diameter, which corresponds exactly with two diameters of the atoms of which it is constructed. And this is perfectly compatible, because discontinuity characterizes the structuring of the atoms. The atom is a tensegrity, and there are no "solids" left in the entire structural system. We thus discover that tensegrity structuring and its omnirationally constituted regularities are cosmically a priori,

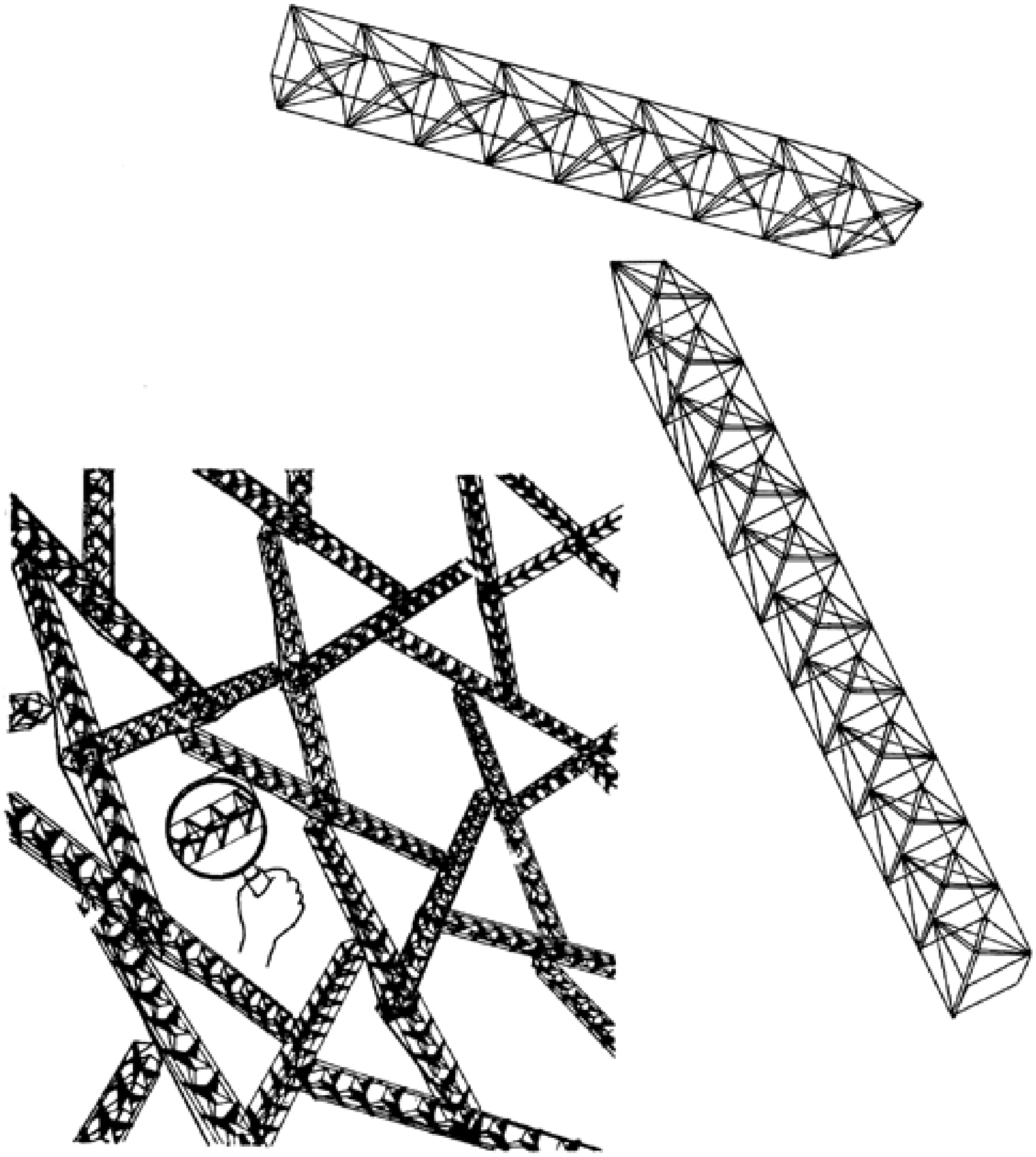


Fig. 740.21 Tensegrity Masts as Struts: Miniaturization Approaches Atomic Structure: The tensegrity masts can be substituted for the individual (so-called solid) struts in the tensegrity spheres. In each one of the separate tensegrity masts, acting as struts, in the tensegrity spheres it can be seen that there are little (so-called) solid struts. A miniature tensegrity mast may be substituted for each of those solid struts. The subminiature tensegrity mast within the tensegrity struts of the tensegrity struts of the tensegrity sphere and a subsubminiature tensegrity mast may be substituted for each of those solid struts, and so on to subsubsubminiature tensegrities until we finally get down to the size of the atom and this becomes completely compatible with the atom for the atom is tensegrity and there are no "solids" left in the entire structural system. There are no solids in structures, ergo no solids in Universe. There is nothing incompatible with what we may see as solid at the visual level and what we are finding out to be the structural relationships in nuclear physics.

disclosing that Universe is not redundant. It is only humanity's being born ignorant that has delayed all of humanity's escape from the self-annihilating effect of the omniredundance now characterizing most of humanity's activities.

740.30 **No Solids in Structures**

740.31 There are no solids in structures. Ergo, there are no solids in Universe. There is nothing incompatible with what we may see as "structure" at the superficial level and what we are finding out to be the structural relationships in nuclear physics. It is just that we did not have the information when yesterday we built so solidly. This eliminates any further requirement of the now utterly obsolete conception of "solid" anything as intervening in the man-tuned sensorial ranges between the macro- and micro-world of ultra- and infrasensorial integrity. We have tensegrity constellations of stars and tensegrity constellations of atoms, and they are just Milky Way-like star patterns of relative spaces and critical proximities.

750.00 **Unlimited Frequency of Geodesic Tensegrities**

750.10 **Progressive Subdividing**

750.11 The progressive subdivision of a given metal fiber into a plurality of fibers provides tensile capabilities of the smaller fibers at increased magnitudes up to hundreds and thousandsfold that of the originally considered unit section. This is because of the increased surface-to-mass ratios and because all tensile capability of structure is inherently invested in the external beginnings of structural systems, which are polyhedra, with the strength enclosing the microcosm that the structural system inwardly isolates.

750.12 Geodesic tensegrity spheres are capable of mathematical treatment in such a manner as to multiply the frequency of triangular modular subdivision in an orderly second-power progression. As relative polyhedral size is diminished, the surface decreases at a velocity of the second power of the linear-dimension shrinkage, while the system volume decreases at a velocity of the third power. Weight-per-surface area relates directly to the surface-to-volume rate of linear-size decrease or increase.

750.20 **Unlimited Subdivisibility of Tensional Components**

750.21 The higher the frequency, the greater the proportion of the structure that is invested in tensional components. Tensional components are unlimited in length in proportion to their cross-section diameter-to-length ratios. As we increase the frequency, each tension member is parted into a plurality of fibers, each of whose strength is multiplied many times per unit of weight and section. If we increase the frequency many times, the relative overall weight of structures rapidly diminishes, as ratioed to any linear increase in overall dimension of structure.

750.22 The only limit to frequency increase is the logistic practicality of more functions to be serviced, but the bigger the structure, the easier the local treatability of high-frequency components.

750.23 In contrast to all previous structural experience, the law of diminishing returns is operative in the direction of decreasing size of geodesic tensegrity structures, and increasing return is realized in the direction of their increasing dimensions.

Next Section: 751.00

751.00 **Pneumatic Model**

751.01 If the frequency is high enough, the size of the interstices of the tensegrity net may become so relatively small as to arrest the passage of any phenomena larger than the holes. If the frequency is high enough, neither water nor air molecules can pass through. The geodesic tensegrity may be designed to keep out the weather complex while admitting radar's microwaves and light from the Sun.

751.02 If we raise the structural-system frequency sufficiently, we will decrease the residual compression islands to the microcosmic magnitude of atoms, which only serves to disclose that the atoms and their nuclei are themselves geodesic tensegrity structures, ergo, compatible with this ultimate frequency limit—a fact that is now, in the 1960s and `70s, swiftly looming into the nuclear physicist's ken.

751.03 We now comprehend that geodesic tensegrity structuring provides the first true and visualizable model of pneumatic structures in which the relative thickness of the enclosing films, in proportion to diameter, rapidly decreases with the increasing size of the balloons or spheric networks.

751.04 In the case of geodesic tensegrity structures, no overcrowding of interior gas molecules, imprisoned within a submolecular mesh net, is necessary to thrust the net's structure outward from its spherical geometric center, because the compressional struts, locally islanded, as outward-thrusting struts at both their ends, push the spherical net outwardly at every vertexial advantage of network convergence. Geodesic tensegrities are the "hollowed-out" balloons discarding their redundantly "solid" air core.

751.05 The geodesic tensegrity is a hollowed-out balloon in which those specific molecules of gas that happen to be impinging from within against the skin at any one moment (thus pushing it outwardly) are replaced by the islanded geodesic struts, and all other redundant molecules are discarded. It is possible to sew pockets on the inside surface of a balloon skin corresponding in pattern to the islanded tensegrity geodesic strut- end positions and to insert into those pockets stiff battens that cause the otherwise limp balloon bag to take spherical shape, as it would if filled with a pressured-in gas.

751.06 Local stiffeners of skin suitable to preferred activities, at any structural focus, can be had by increasing the inward-outward angular strut depths and the local- surface-frequency patternings-thus thickening the truss depth without weight penalties. Here we have nature's own trick of local stiffening as accomplished by the higher- frequency, closest-packing pattern of isotropically moduled local cartilages, and even higher-frequency local bone structuring, as ratioed to the frequency of tissue cells of animal flesh.

751.07 If we employ hydraulic pressure within the local islands of compression for dimensional stability, and if we employ gas molecules between the liquid molecules for local shock-load compressibility (ergo, flexibility), we will find that our geodesic tensegrity structures will in every way have taken advantage of the same structural- strategy principles employed by nature in all her sizes of biological formulations.

751.08 Geodesic tensegrities are true pneumatic structures in purest design frequency principle. They obviate the randomness and redundance characterizing the work of designers dealing only with pneumatics who happen to be successful in blowing air into a bladder while being utterly dependent upon the subvisible behaviors of chemical phenomena. Geodesic tensegrity engineering enables discrete separation of all the structural events into two diametrically opposed magnitude classes: all the outward-bound phenomena which are too large to pass through all the interstices of all the inward-bound events in the too-small class. This is the same kind of redundancy that occurs in reinforced concrete which, if drilled out wherever redundant components exist, would disclose an orderly four-prime-magnitude complex octahedron-tetrahedron truss network, disencumbered of more than 50 percent of its weight.

751.09 Tensegrity geodesic spheroids have none of the portal pressure-lock problems of "solid-oozing" pneumatic balloons. The pressure is discretely localized and locked in place by the tension net, and therefore it cannot escape.

751.10 Tensegrity geodesic spheroids may have several frequencies simultaneously—a low-frequency major web and a high-frequency minor local web. If they are of sufficiently high frequency of secondary or minor webbing to exclude atmospheric molecules, they may be partially vacuumized; that is, they may be made air- floatable.

760.00 Balloons

761.00 **Net**

761.01 People think spontaneously of a balloon as a continuous skin or solidly impervious unitary and spherically enclosed membrane holding the gas. They say that because the gas cannot get out and because it is under pressure, the pressure makes the balloon spheroidal. This means that the gas is pushing the skin outwardly in all directions. People think of a solid mass of air jammed into a pneumatic bag. But if we look at this skin with a microscope, we find that it is not a continuous film at all; it is full of holes. It is made up of molecules that are fairly remote from one another. It is in reality a great energy aggregate of Milky Way-like atomic constellations cohering only gravitationally to act as the invisible, tensional integrities of the fibers with which the webbing of the pneumatic balloon's net is woven.

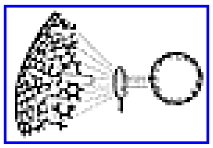


Fig. 761.02

761.02 In a gas balloon, we do not have a continuous membrane of film. There is no such thing as a continuous "solid" skin or a "solid" or a "continuous" anything in Universe. What we do have is a network pattern, a network of energy actions interspersed with vast spaces or lack of energy events. The mass-interattracted atomic components not only are not touching each other, but they are as remote from one another as are Sun and its planets in the relative terms of respective diameters of each of the phenomena involved.

761.03 The spaces between the energy-action-net components are smaller, however, than are the internally captivated and mutually interrepelled gas molecules; wherefore the gas molecules, which are complex low-frequency energy events, interfere with the higher- frequency, omnienclosing net-webbing energy events. The pattern is similar to that of fish crowded in a spherical net and therefore running tangentially outward into the net in approximately all directions. Fish caught in nets produce an enclosure-frustrated, would- be escape pattern. In the tensegrities, you have gravity or electromagnetism producing the ultimate tension forces, but you don't have any strings or ultimately smallest solid threads. The more we think about it and the more we experiment, the less reliable becomes our concept "solid." The balloon is indeed not only full of holes, but it is in fact utterly discontinuous. It is a net and not a bag. In fact, it is a spherical galaxy of critically neighboring energy events.

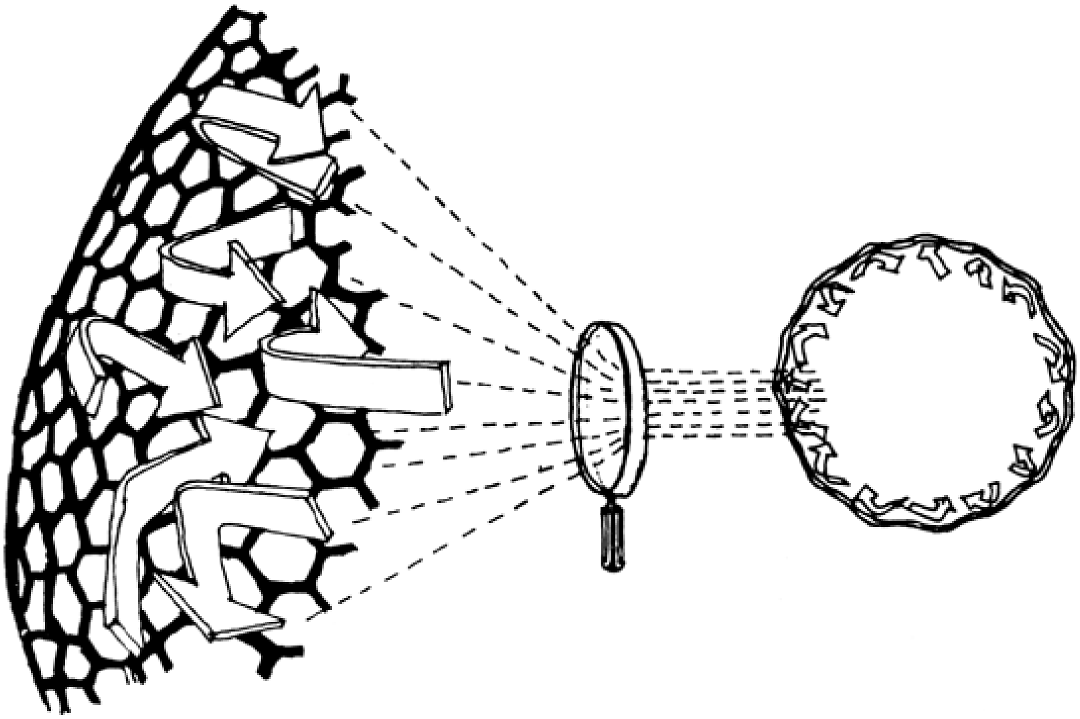


Fig. 761.02 Function of a Balloon as a Porous Network.

761.04 The balloon is a net in which the holes are so small that the molecules are larger than the holes and therefore cannot get out. The molecules are gas, but they have a minimum dimension, and they cannot get out of the holes. The next thing that we discover is the pressure of the gases explained by their kinetics. That is, the molecules are in motion; they are not rigid. There is nothing static at all pushing against the net. They are hitting it like projectiles. All of the molecules of gas are trying to get out of the system: this is what gives it the high pressure. The middle of the chord of an arc is always nearer to the center of the sphere than the ends of the chord. Chord ends are always pushing the net outwardly from the system's spherical center. The molecules are stretching the net outwardly until the skin acts to resist the outward motion and relaxes inwardly. The skin is finite and closes back upon itself in apparently all circumferential directions. The net represents a tensional force with the arrows bound inwardly, balancing all the molecules, hitting them, caroming around, with every molecular action having its chordal reaction. But the molecules do not huddle together at the center and then simultaneously explode outward to hit the balloon skin in one omnidirectionally outbound wave. Not only are there critical proximities that show up physically, but there are critical proximities tensionally and critical proximities compressionally—that is, there are repellings.

761.05 What makes the net take the shape that it does is simply the molecules that happen to hit it. The molecules that are not hitting it have nothing to do with its shape. There is potential that other molecules might hit the network, but that is not what we are talking about. The shape it has is by virtue of the ones that happen to hit it.

761.06 When we crowd the gassy molecules into a container, they manifest action, reaction, and resultant. When one molecule goes out to hit the net, it is also pushing another molecule inwardly or in some other direction. We discover mathematically that it would be impossible to get all of them to go to an absolute common center because that would require a lot more pressure. It would have to be a smaller space so the patterns are not all from the center outwardly against the bag. Each one of the patterns is ricocheting around the bag; some are hitting the net and some are only interfering with and precessing each other and changing angles without hitting the net.

762.00 **Paired Swimmers**

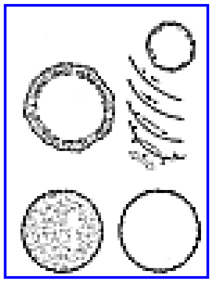


Fig. 762.01

762.01 The molecules near the surface of the net are coursing in chordally ricocheting great-circle patterns around the net's inner surface. Because every action has its reaction, it would be possible to pair all the molecules so that they would behave as, for instance, two swimmers who dive into a swimming tank from opposite ends, meet in the middle, and then, employing each other's inertia, shove off from each other's feet in opposite directions. We have an acceleration effectiveness equal to what they experience when shoving off from the tank's "solid" wall. When you are swimming, you dive from one end of the tank, which gives you a little acceleration into the water. When you get to the end of the tank, you can put up your feet, double up your body, and shove off from the wall again. Likewise, two swimmers can meet in the middle of the tank, double up their bodies, put the soles of their feet together, and thrust out in opposite directions. The phenomenon is similar to the discontinuous compression and continuous tension of geodesics. The molecules are in motion and have to have some kind of a reaction set; each molecule caroming around, great-circularly hitting glancing blows, then making a chord and then another glancing blow, has to have another molecule to shove off from. They are the ones that are accounting for all the work. Each one would have to be balanced as a balanced pair of forces. We discover that all we are accounting for can be paired. So there is a net of arrows outwardly in the middle of the chord pulling against the net of arrows pointing inwardly.

762.02 The pattern indicates that we could have each and all of the paired molecules bounce off their partners and dart away in opposite directions, with each finally hitting the balloon net and pushing it outwardly as they each angled in glancing blows in new directions, but always toward the net at another point where, in critical repelling proximities, they would all pair off nonsimultaneously but at high frequency of re- repellment shove-offs to ricochet off the net at such a high frequency of events as to keep the net stretched outwardly in all directions. This represents what the molecules of balloon confined gases are doing. With discontinuous compression and continuous tension, we can make geodesic structures function in the same way.

763.00 **Speed and Concentration of Airplanes**

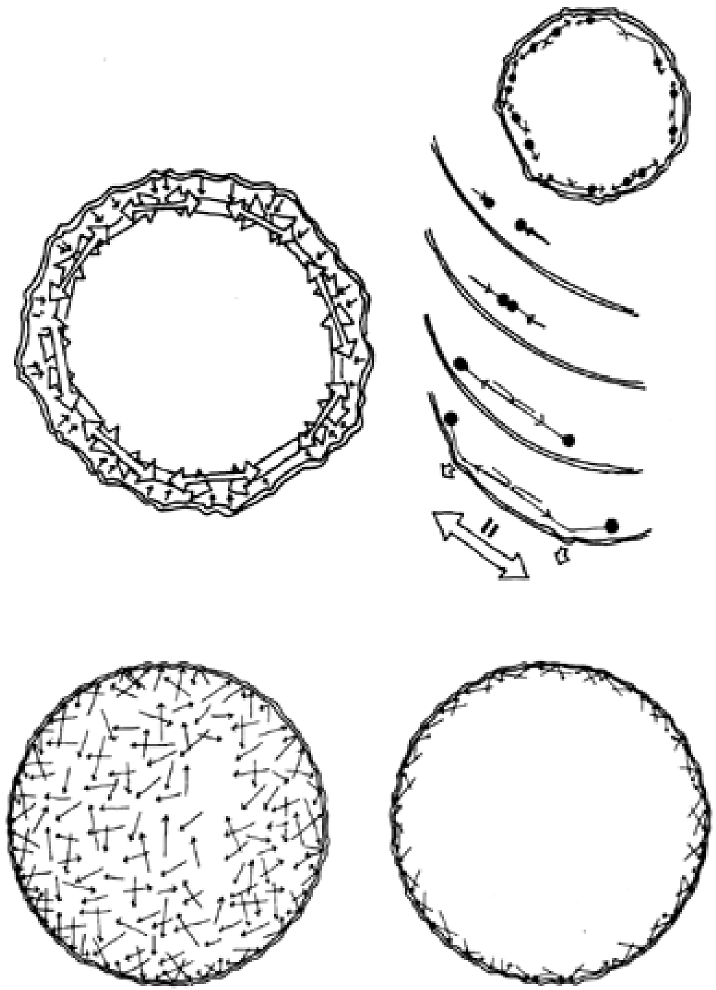


Fig. 762.01 Chordal Ricochet Pattern in Stretch Action of a Balloon Net: A gas balloon's exterior tension "net" has the shape that it has because some of the molecules are too large to escape and, crowed by the other molecules, are hitting the balloon. But the molecules do not huddle together at the center and then simultaneously explode outwardly to hit the balloon skin in one omnidirectionally outbound wave. The molecules near the surface are coursing in chordally ricocheting patterns all around the inner net's surface. I therefore saw that—because every action has its reaction—it would be possible to pair all the molecules so that they would behave as can two swimmers who dive into a swimming tank from opposite ends, meet in the middle and then, employing each other's inertia, shove off from each other's feet in opposite directions.

763.01 As we find out in electromagnetics where there are repellings and domains of actions, the kinetic actions of these gas molecules seem to require certain turning-radius magnitudes. When you pressure too many of these patterns into the same area, there is not enough room to avoid interferences, and they develop a very high speed. Increased speed decreases interference probability caused by increased crowding.

763.02 Airplanes in the sky seem to be great distances apart. But the minute they come in for a landing, they are slowed down and are very much closer to each other. If you have phenomena at very high speeds, their amount of time at any one point is a very short time: the amount of time there would be at a given point for something to hit it would be very much lessened by the speed. The higher the velocity, the lesser the possibility of interference at any one point. So we have the motion patterns of the molecules making themselves more comfortable inside the balloon by increasing their velocity, thereby reducing the interferences that are developing. The velocity then gives us what we call pressure or heat: it can be read either way. If you feel the pneumatic bag, you may find it getting hotter. You can feel an automobile tire getting hotter as it is pumped full.

Next Section: 764.00

764.00 **Escape from Compression Structuring**

764.01 Geodesics introduces tension as the integrity of structure. Geodesics is in fundamental contradistinction to the compressional arches where men made lesser rings of stone and bricks and so forth, like Santa Sophia, fitting them together beautifully and shaping them very mathematically to prevent their slipping or falling inwardly from one another to break the integrity of the compressional rings. In Santa Sophia, they put a chain around the bottom of the dome to take care of the outward thrust of the enormous weights of the aggregate trying to come apart. They could not build an exclusively compressionally composed dome that would not thrust outwardly at the base, so they put the chains around the bases to prevent their collapsing.

764.02 We have seen that in tensional structures there is no limit of length to cross section: you can make as big a pneumatic bag as you want. In the comprehensive, geodesically omnitriangulated, tensegrity structures, we are able to reach unlimited spans because our only limitation is tension, where there is no inherent limit to cross section due to length. We get to where there is no cross section visible at all, as in the pull between the Earth and the Moon. With such structural insights we can comprehend the structure of an apple in terms of noncompressible hydraulic compression and critical proximity cellular wall tensioning. Synergetics identifies tensegrity with high-tensile alloys, pneumatics, hydraulics, and load distribution.

765.00 **Snow Mound**

765.01 A child playing in sticky snow may make a big mound of snow and hollow it out with his hands or a shovel to make a cave. The snow is fascinating because you can push it together and it will take on shapes. It has coherence. Almost every child with mittens on has built himself a mound and then started chipping away to make a cave. Looking at the hollowed mound from the outside, he may discover that he has made a rough dome. He might then conclude that whatever makes the structure stand up has to do with the circumferential interactions of the snow crystals and their molecules and the latter's atoms. He finds that he can get in it and that the structural integrity has nothing to do with the snow that used to be at the middle. So we may develop a strong intuition about this when we are very young: that it is the circumferential set of molecules that are accounting for the structural integrity of the dome.

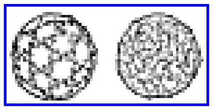


Fig. 765.02

765.02 The child may then find by experiment that he might hollow out the pneumatic network and put not only one hole, but many holes, in the snowdome shell, and it continues to stand up. It becomes apparent that it would be possible to take a pneumatic balloon, pair the molecules doing the work, and get rid of all the molecules at the center that were not hitting the balloon—for it is only the molecules that hit the balloon at high frequency of successive bounce-offs that give the balloon its shape.

766.00 **Tensegrity Geodesic Three-Way Grid**

766.01 What happens in the snow mound is also what happens in the three-way tensegrity geodesic spherical grid. In the balloon, we get paths of these positively and negatively paired kinetic molecules reacting from one another in a random set of directions. If they went into one path only, they would make a single circle, which would push the balloon outwardly only at its equator, making a disc and allowing the poles to collapse. If they made a two-way stack of parallel lesser circles as a cylinder, the cylinder would contract axially into a disc.

766.02 A gas-filled balloon is not stratified. If it were, it would collapse like a Japanese lantern.

766.03 A two-way grid would make only unstable squares and diamonds, which would elongate into a tubular snake.

766.04 Once we have three or more sets of angularly independent, great-circularly continued, push-pull paths, they must inherently triangulate by push-pull into stabilization of opposite angles. Triangulation means selfstabilizing; which creates omnidirectional symmetry; which makes an inherent three-way spherical symmetry grid; which is the geodesic structure.

770.00 **System Turbining in Tensegrity Structures**

770.10 **Comprehensive System Turbining**

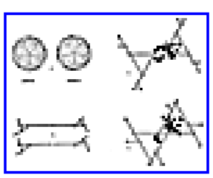


Fig. 770.11

770.11 The whole system turbines positively, or the whole system turbines negatively. There are no polar or opposite hemisphere differences of these systems. There are no "rights" or "lefts" in Universe.

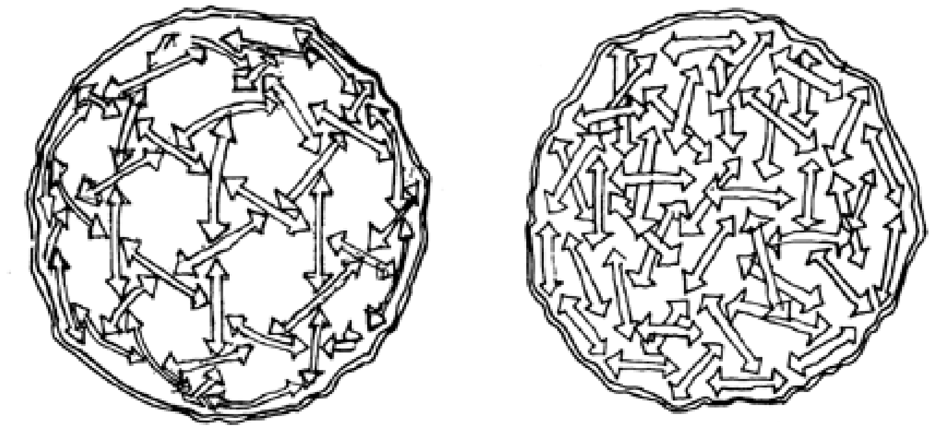


Fig. 765.02 Stabilization of Three-Way-Grid Tensegrity Sphere: What happens with the snow mound is also exactly what happens in a three-way-grid tensegrity-geodesic spherical grid. In the balloon we get paths of these positively and negatively paired, kinetic molecules reacting from one another in a random set of directions. If they went into one path only, they would make a single circle which would push the balloon outwardly only at its equator making a disc and allowing the poles to collapse. If they made a two-way stack of parallel lesser circles as a cylinder, the cylinder would contract axially into a disc. A two-way grid would make only unstable squares and diamonds, which would elongate into a tubular snake. But once we have three or more sets of angularly independent circularly continued push-pull paths, they must inherently triangulate by push-pull stabilization of opposite angles. Triangulation means self-stabilizing, which creates omnidirectional symmetry, which makes an inherent three-way spherical symmetry grid, which is the geodesic structure.

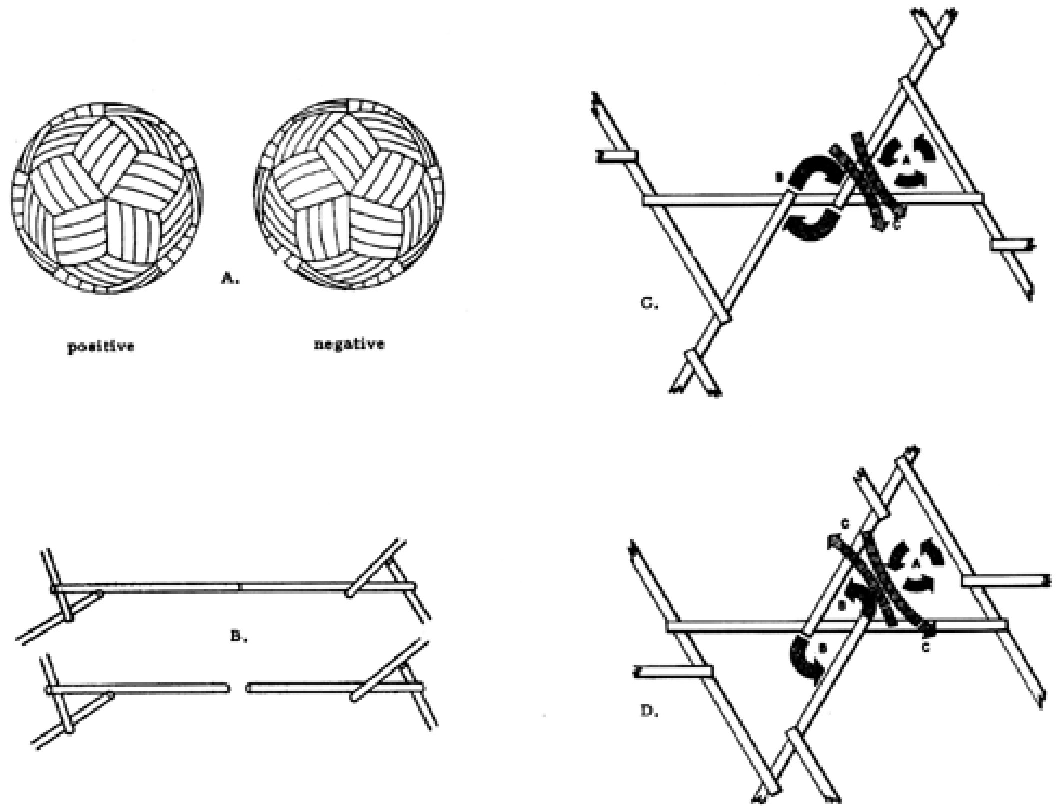


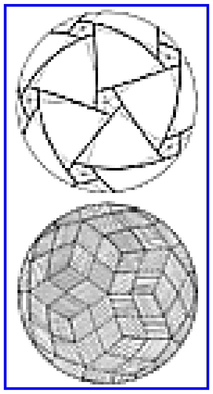
Fig. 770.11 System Turbining in Tensegrity Structures:

A. The two above both have six axes of symmetry. It is the patterning of the thirty diamond domains of the icosahedron's thirty edges, the rhombic triacontahedron.
B. The linear-congruence juncture of two positive or two negative turbining-surface three-strut tensegrity units.
C. Single-bonded tensegrity: turbining tendencies of thrusts of C about A and B are additive.
D. Double-bonded tensegrity: turbining tendencies of thrusts of C about A are opposed to those about B.

770.12 Three-strut tensegrity units exhibit either two positive or two negative turbining surfaces at their linear congruence junctures.

770.13 In single-bonded tensegrity structures, turbining tendencies are additive. In double-bonded tensegrity structures, turbining tendencies are opposed.

770.20 **Central-Angle and Surface-Angle Turbining**



770.21 Turbining in tensegrity systems may derive from either central angles or surface angles. There is inherent comprehensive positive or negative turbining of finite systems in both central and surface angles. Central-angle turbining effects surface-angle turbining.

Fig. 770.21

780.00 **Allspace Filling**

780.10 **Conceptual Definition of Allspace Filling:** The multiply furnished but thought-integrated complex called space by humans occurs only as a consequence of the imaginatively recallable consideration (see Sec. 509) of an insideness-and-outsideness- defining array of contiguously occurring and consciously experienced time-energy events.

780.11 Unitary conceptuality requires spontaneous aggregating of relevant magnitudes and frequencies of experience recalls.

780.12 Conceptualization is inherently local in time as are the separate frames of scenario Universe's conceptualities nonconceptually identical. Conceptuality is always momentary and local.

780.13 When we speak of allspace filling, we refer only to a conceptual set of in-time local relationships. This is what we mean by tunability.

780.14 The limits of an allspace-filling array are nondefinable. Nondefinable is not the same as infinite.

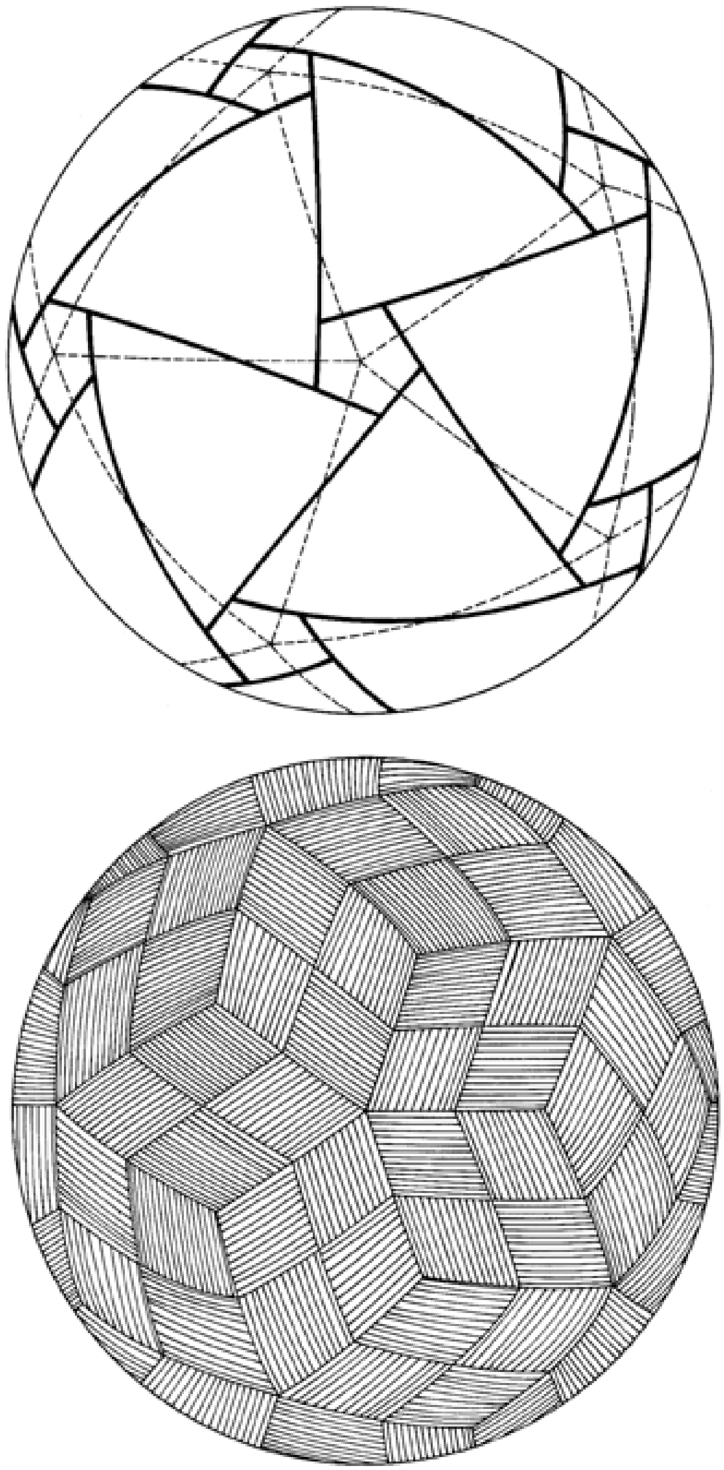


Fig. 770.21

780.20 **Galactic Orientation:** Apparently simultaneous static-system conceptualization is "relatively" misinterpretable as an environmentally experienceable condition of the individual which he reflexively identifies as "instantaneous"—a word as yet frequently used with omnipopularly misassumed fidelity to reality.

780.21 This instantaneously infinite static Universe misconception is vastly fortified as the living observers go outside the house on a clear, "still" night and stand fixedly *under* the stars, gazing fixedly at the fixed stars, and, as we say poetically, "turn this instant into eternity," within which cosmically arrested moment, subconsciously stimulated by the latest newspaper item regarding a way-up-there quasar or other astro discovery, we say in spontaneously expressed curiosity: "I wonder what's outside the outside of all these omnidirectionally positioned stars?"

780.22 This brain-fixing fixity's conceptual interpretation of experience is permitted only by the infinitesimally short life span of humans in the thus-far-discovered historical magnitudes of universal history's events. As we stand "fixedly" in "space" at the terrestrial latitude most occupied by Earthian humans, we are revolving around the-Earth's axis at 600 m.p.h. Together with our Moon, we orbit around Sun at 60,000 m.p.h. (which orbital speed is three times as fast as the Earth-Moon-ferrying, Apollo-rocketed space vehicle), and all the while our solar system, situated about three-quarters of the way outward from the center of our celestial galaxy—together with all that inwardly active galaxy's billions of stars—are cosmically merry-go-rounding at approximately a million miles per hour, and all the while we participate in all these motions, our Milky Way merry-go-round galaxy itself may be, and is scientifically thought to be, involved in comprehensive motion at an even higher velocity. Due to the omnieverywhere-expanding Universe (interpretation of observed data), our galaxy and all the other of the billions of galaxies of Universe are alike in traveling outwardly from one another isotropically at additional millions of miles per hour.

780.23 This expanding-Universe concept is easy to phrase in words as reported, but lucid comprehension of its import involves experientially "impossible," three-dimensional, space-motion conceptionalizing, for in order to travel away cosmically from each of all the spherically surrounding galaxies of our Milky Way, any one of the billions of galaxies seemingly would have to go outwardly in all directions in order to go away from each of them simultaneously. Obviously, however, this could not be accomplished by any one of them moving in only one direction—which is humanity's way of thinking of motion-unless there were a center of galaxy of Universe outwardly from which all others move *exactly* and only radially, *or* unless all of Universe and all of the galaxies and each and all phenomena within them, including the smallest nuclear particle, are either *expanding* systematically and simultaneously or are *shrinking* systematically and simultaneously, all changing in size at a rate that is just a bit faster than the speed of light, with either the universal contraction or universal expansion of all points in Universe producing the same effect of uniform withdrawal from one another.

780.24 This may be the universal effect of the *speed* of gravity, whose force (possibly in order to eternally cohere Universe) is, as is often found experimentally, always just a fraction greater than the cosmic speed of inherently disintegrative radiation. (See Sec. 231.) This conceptioning becomes lucid if one is familiar with the vector equilibria and their identity with isotropism, which spontaneously accommodates coexpansion or contraction independent of any Universe center, every nuclear point within the system being a Universe center, with all its 12 most immediate neighbors always being equidistant and bearing at the same total of central-angle magnitudes from one another,[1] with the circumferentially closed, embracing vector forces always more effective than their equal and opposite radial vectors' noncooperative, open-ended, disintegrative forces.

(Footnote 1: I.e., 60 degress. The nucleus of a square would have a completely different distance to its corners than the corners would have to each other.)

780.25 Humans standing on Earth gazing outwardly from Earth at the stars cannot see the stars in the celestial sphere in the direction of their feet. Earth is in the way. Earth is so much in the way that humans at sea on a calm, clear night can see only about half the celestial sphere at any one time. An astronaut out "space-walking" can see approximately all of the stars of the celestial array omnisurrounding him at vast varieties of distances from him, though they all seem to be superficially on the same concave surface of the same black sphere at whose center the astro-observer seems to be. Remembering the difference between the Earth-standing observer's totality of sky and the astronaut's also optically illusioned but far more comprehensively stimulated conjuring of the concept "totality," we can understand why the Earth-standing observer on a completely overcast day cannot see the cloud cover as a dimensionally definable phenomenon, whereas the astronaut seeing the Earth at a distance wrapped in its cloud cover can see Earth and its biosphere as a dimensionally defined entity.

780.26 When we speak of the cosmic limits of seemingly allspace filling, we refer to the totally surrounding, indefinable, extensive allspace-filling effect of fog upon an observer in that dense fog. It seemingly has no shape. Nor has that fog a "shape" even when it lifts into the sky above the observer and fills the whole overhead spherical domain. Observed from outer space at the same moment, however, mantling Earth may seem to have momentarily stable descriptability akin to that of a frozen icefield. Then the same fog or cloud blanket may be viewed at the same time by a third human from a mountaintop just protruding through the cloud. The third observer sees that the clouds are intertransforming in complex, high-speed turbulence, vanishing here in rain and being newly formed elsewhere by Sun-drawn evaporation. Every atom involved in Earth's ocean-atmosphere-intertransforming H_2O cloud-cover phenomena, visible or invisible, has its integrity, and the allspace-filling events become other than visible transformation events, yet may indeed be kept account of by you and me and Universe, with its mathematical integrities of complexedly interaccommodative principles of intertransformative events always occurring interconsiderately.

780.27 Seen from Moon, the total local dimensional involvement of such Earthian atmospheric-oceanic intertransforming events is well within the field of a telephoto-lensed, video-recording camera as well as of a battery of frequency sensors ``seeing" the humanly invisible events transpire. The intertransformings are finitely packagable and analyzable in conformity to allspace-filling laws. That these same events seem boundless to the Earthian observer uninformed by the celestial-scanning instruments need not obscure our realization that what we mean by allspace-filling regularities are omni-intertransformable—ergo, are scenarios of an aggregate of nonsimultaneously overlapping, energy-transforming events in which one or a few isolated frames of special-case considerations fail to disclose the meaning accruing only to large-continuity consideration of the whole story.

780.28 As a cosmic, generalized, intertransformability system *field*, our allspace-filling synergetics matrix accommodates and equates these behaviors. Allspace filling is a scenario: the eternally self-regenerative scenario of cosmic integrity.

780.30 **Eternality:** "Eternal" identifies only the metaphysical, weightless, abstract principles, which, to hold true in all special-case experiences, are inherently eternal.

780.31 Angles are eternally transcendental to time-size limits. The angle is a subdivision of one cycle quite independent of the length size (time) of the angle-defining radii edges of the angle. One-sixth of unity: the circle is one-sixth independent of time and size.

780.32 Regularity is eternal. But the regularities are eternally omni-interaccommodative, permitting approximately limitless freedoms of selectable alternative developments involving a vast plurality of time-dimensioned frequency involvements.

780.40 **Unitary Conceptuality of Allspace Filling:** Allspace filling means all unitarily conceptual space filling, because Universe, though finite, is an aggregate of nonsimultaneous and only partially overlapping event transformations which, being nonsimultaneous and differentially rate-frequenced, are never momentarily subject to total unitarily synchronized—ergo, simultaneous, apparently static system—conceptualization.

Next Section: 781.00

781.00 **Accommodation of Aberration**

781.01 We can take hold of any two parts of a tensegrity sphere and treat it as an omnidirectional, expansion-contraction accordion. In the same way, we can take hold of any two parts of a rubber-vectored, isotropic-vector matrix and, so long as the contiguous faces of the octahedron-tetrahedron field remain congruent, the matrix can be distorted by angular variation, spin, orbit, inside-outing, expansion, knotting, or torque without losing any of all the fundamental regularities of the omniconsidered, allspace-filling set.

781.02 Activated by tension and compression, two remote-from-one-another external triangles of an elongated isotropic rubber-vectored matrix structural system may be congruently associated to close the system's "insideness" back upon itself to form a large, flexible structural-system ring with a circularly closed insideness, like a serpent biting off its own tail and swallowing the "open" end.

781.03 In order to be a system definitively ergo, topologically accommodated throughout all transformative transactions of dividing the insideness from the outsideness—and to be structural, the system-dividing medium must be omnitriangulated—ergo, having only triangular openings.

781.04 When the structural system's remote structural parts are joined back on themselves to continue the insideness-integrity's division from the outsideness, the only "holes" in the system (which may be coupled to join the insideness back on itself) are triangular wholes, with their respective three corners identifiable as A, B, C, and A', B', C', respectively. They could be nontwistingly joined A to A`, B to B`, C to C`, or by twisting the elongated rubber-vectored system's ends 120 degrees, they could be joined as A to B`, B to C`, C to A`, or twisted more to A to C`, B to A`, C to B'—or they could be twisted 360 degrees and fastened A to A', B to B', and C to C'—or several such always 120-degree-incremented twists and multiples thereof could occur.

782.00 **Distortion of Vector-Equilibrium Frame**

782.10 **Accommodation of Aberration: Corollary:** An allspace-filling isotropic complex consisting entirely of triple-bonded tetrahedra and octahedra can become nonisotropically distorted yet remain allspace filling, i.e., all six or several edges of the tetrahedron and the correspondingly bonded edges of the octahedra can become coordinatedly dissimilar and yet be allspace filling.

782.11 Throughout the distortions and aberrations of the octahedron-tetrahedron field, the ratio of the octahedral volume as fourfold the tetrahedral volume remains constant.

782.12 The whole synergetic hierarchy of rationally related A and B Quanta Modules and topological values remains constant.

782.20 **Regularities:** Such potential distortion of the vector-equilibrium frame of reference introduces an almost infinite variety of nuclear sphere's connect-and-disconnect conditions without in any way altering any of the other topological regularities discussed throughout synergetics.

782.21 Infinite variety of local, individual initiations and terminations within eternal cosmic integrity of total order is implicit.

782.22 Regularity is total.
Variability is local.

782.23 Finite—and the concept *finite's* only-speculatively-inferred impossible condition of conditionless "infinite"—identify only special-case physical experience, ergo, are experientially always finitely terminal. Frequency is of time and is finitely terminated.

782.30 **Variability of Spherical Magnitudes:** All or partial differentialing of the six always-congruent tetrahedron and octahedron edges of allspace filling also introduces variation in the size of the spheres that could surround any one vertex of the system. Whereas the original isotropic vector matrix, with all its vector "lines" the same, provided the set of vertexes that were the centers of unit-radius, omni-closest-packed spheres, we now witness experimentally with a stretchable, rubber-vectored, allspace-filling, originally unit-edged, triple-bonded complex of tetrahedra and octahedra, that the whole system may be stretched, torqued, and angularly wrench-distorted. Ergo, we witness the ways in which the vector equilibrium, or most inter-economical vectorial relationship of 12-around-one sphere centers in closest packing, may be omnidirectionally distorted to accommodate a plurality of spherical magnitudes in an as-yet closest possible interrelated neighborhood array of the respective centers of disparate-size spheres, with some spheres tangent to their neighbors and others disconnected.

782.40 **Isotropic Modular Grid:** In the same experimental model exploring manner, we discover that whereas locally verifiable parallel lines running off to the horizon appear to converge, it becomes a local observational experience reality that what is constructed as a many-miles-wide, -high, and -long isotropic vector matrix of 10-foot modules, with its vertexes occupied by omniuniform radius spheres of 10-foot diameters each, in omniclosest packing, may be photographed or drawn as seen in perspective from one locus outside the system. The sizes of the individual spheres and of the edge lengths and triangular "areas" are experientially witnessable as progressively diminishing in size as they extend, respectively, remote from the observer. The size variations may be measured accurately on a viewer's modular-gridded, hairwire-in-glass screen, mounted vertically, immediately in front of the viewer. It is also experientially observable and documentable that despite these observed progressively diminishing alterations of relative intersystem size, the topological-inventory characteristics of relative abundance of vertexes, faces, edges, A and B Modules, and the sum total of angles around the vertexes—all remain unaltered.

782.50 **Time as Relative Size Experience:** Local variability within total order synergetically explains and defines the experience ``time," which is relative size experience. The magnitude of the event characteristics is always accounted in respect to other time cycles of experiences. The cosmically permitted and experientially accommodated actuality of the individual's unique variety of sensorially differentiated local in time-space experiences also accommodates the experienceability in pure principle of individually unique physical life in concert with the only metaphysically operative, cosmically liaisoned, weightless, abstractly conceptual mind, by means of all of which physically and metaphysically coordinate experienceable principles it is experimentally discoverable how genetic programming accomplishes the ``instinctive" conditioning of subconscious, brain-monitored, relative pulsation aberration and transformation controls, which are all reliably referenced entirely subconsciously to the eternally undisturbed, cosmic-coordination regularities unbeknownst to the individual biological organism "experience."

783.00 **Moebius Strip and Klein Bottle**

783.01 Moebius's arbitrarily shadow-edged strip and Klein's rimless bottle are only self-deceptively conceivable as absolute solids or as absolute continuities with inherently absolute edges and lines. The Moebius strip does not have an edge: it is a tube. Lack of any experimental evidence of any such phenomena as absolute solids or absolute continuities with inherently absolute edges and lines induced physicists to abandon the concepts of solids and absolute continuities.

783.02 In their bottle and strip propositions, both Klein and Moebius employ the working assumption of absolute solids and surface continuums. The humanly experienceable surprise qualities of their findings are the same surprise experiences of audiences of expert magicians who seem to produce results by means other than those which they actually employ. The implied significance of the bottle and strip findings vanishes in the presence of the synergetic surprise of the topological constants of the vector equilibrium's hierarchical regularities independent of size, inside-outing, turbining, and so forth. Unlike Moebius's and Klein's experimentally undemonstrable constructed substances, the information input of synergetics and tensegrity are wedded experientially only with the full gamut of the thus far published experimental findings of astrophysics, chemistry, and microbiology.

784.00 **Allspace-Filling Tensegrity Arrays**

784.10 **Basic Allspace Fillers:** The tensegrity tetrahedron and the tensegrity octahedron are volumetrically complementary, and together they may fill allspace. The tensegrity icosahedron refuses to complement either itself or the tetrahedron or octahedron in filling allspace, but isolates itself in space, or goes on to make up triple- bondedly into larger octahedra, which may then complement tetrahedra to fill allspace.

784.11 Tensegrity icosahedra provide by far the most volume with the least structural effort of the three basic structural systems. The tetrahedron has the least volume with the most surface; the octahedron is in the middle; and the icosahedron gives the most with the least.

784.12 In the icosahedron, five quanta give twenty units of enclosed volume, which means four units of volume for each energy quantum invested in the enclosing structure. Whereas in the tetrahedron one quantum will enclose only one unit of volume. The octahedron gives two units of volume for each quantum. Therefore, the icosahedron gives the most for the least effort.

784.13 The three-islanded tensegrity octahedron, in its positive and negative phases, is fundamental to all tensegrity structures. (See illustration 724.10.)

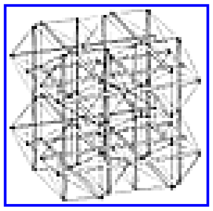


Fig. 784.20

784.20 **Eight-Icosahedra Tensegrity Array:** The three sets of parallel pairs of struts which form the tensegrity icosahedron may be considered as parallel to the three axes of the XYZ coordinate system. The same three sets of parallel pairs of the tensegrity icosahedron may be considered also as two omni-axial sets of tensegrity octahedra. This octahedron-icosahedron parallelism relationship explains why it is possible to collect tensegrity icosahedra in approximately unlimited periodic arrays. A set of eight icosahedra is shown in the illustration.

784.21 Note that the rows of parallel struts can be repeated to infinity and the length of each strut can be infinitely long. The tension net that forms the icosahedron edges stabilizes the array of struts.

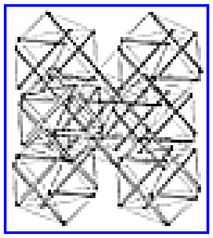


Fig. 784.30

784.30 **Tensegrity Icosahedra Surrounding a Nuclear Icosahedron:** Six icosahedra may be arrayed around a nuclear icosahedron in a true XYZ-coordinate model.

784.40 **Limitless Array of Tensegrity Icosahedra:** In addition to single-strut tensegrity icosahedral systems, it is possible to organize an only-time-limited, omnidirectionally extensible, uniformly periodic array of tensegrity icosahedra in which each compression member of finite length is common to only two icosahedra.

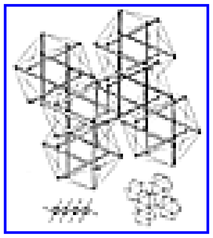


Fig. 784.41

784.41 This system consists of a series of omnidirectionally staggered layers of icosahedra. A spatial array of six icosahedra is shown both as a tensegrity system and as a collection of "transparent" icosahedra. The lower diagram indicates the method of staggering which results in each compression strut being shared by only two adjacent icosahedra.

Next Section: 790.00

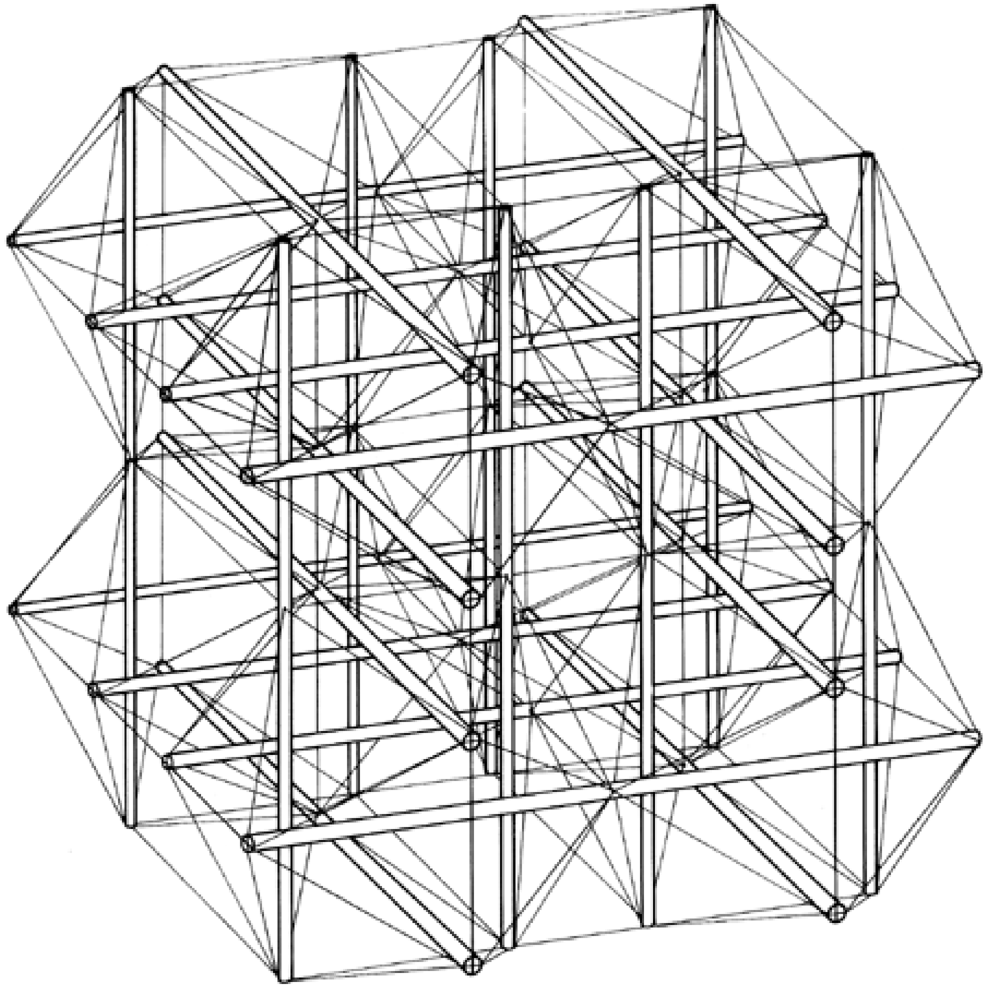


Fig. 784.20

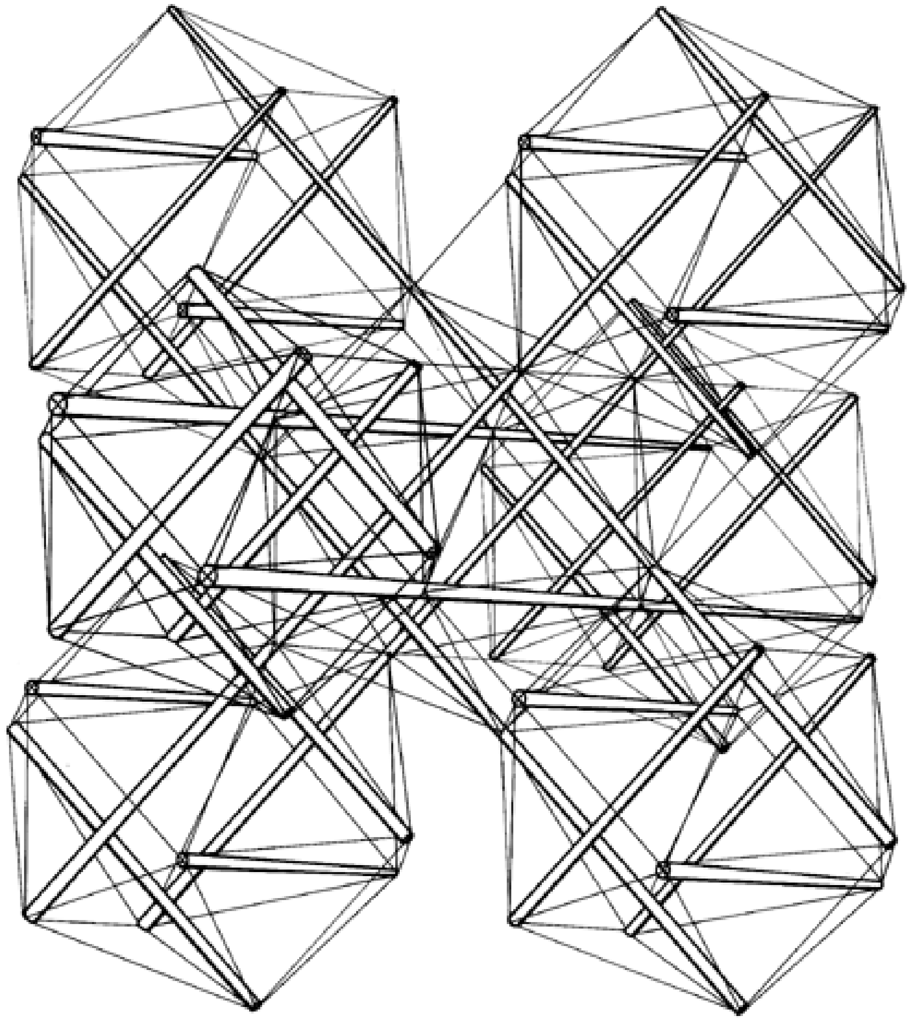


Fig. 784.30

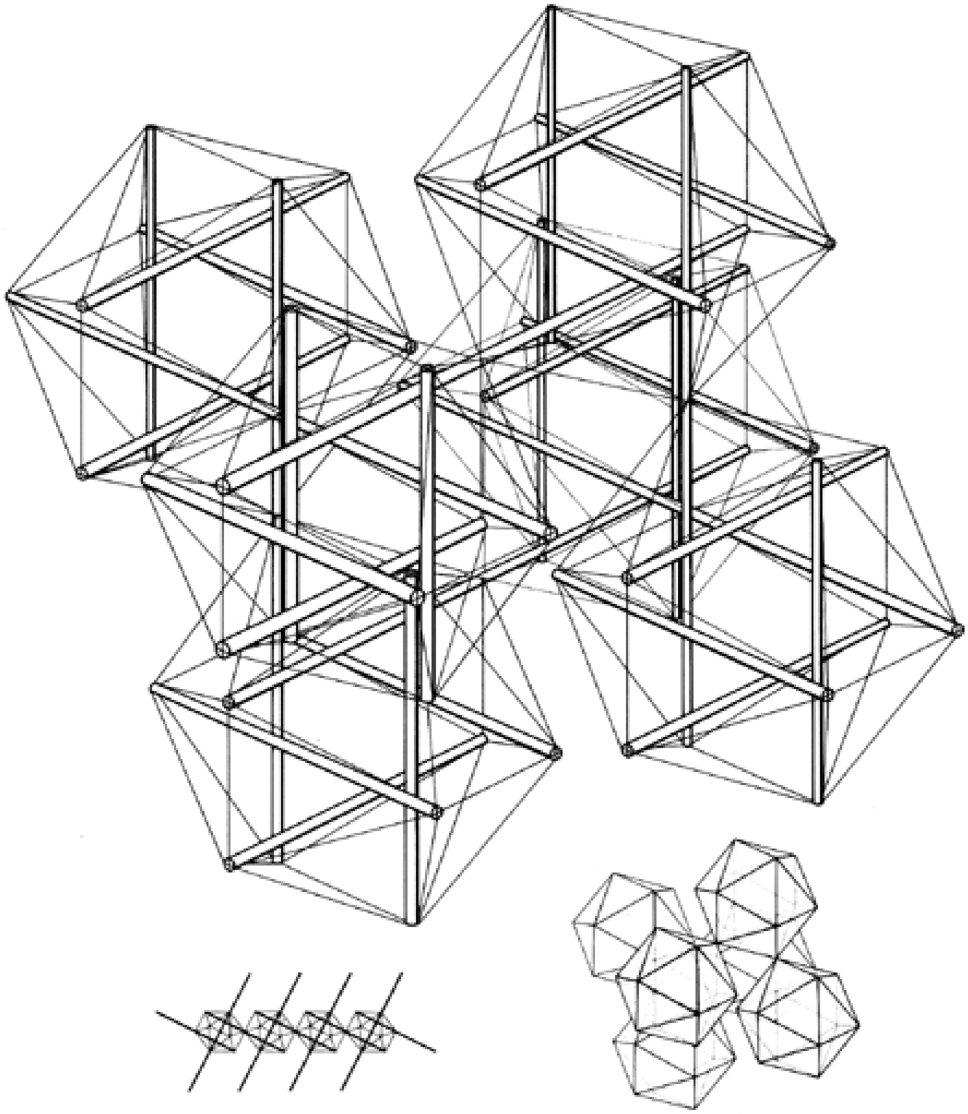


Fig. 784.41 Indefinitely Extensive Array of Tensegrity Icosahedra.

790.00 **Tensegrity Structures**

[790.10-795.11 Tensegrity Scenario]

790.10 **Definition**

790.11 Everyone thinks he knows the meaning of the word structure. We point to a stone wall or a bridge or a barn and say, "That's a structure." What is common to a steel bridge, a wooden barn, a jumbo jet, an iceberg, a starfish, a star, a fern, a diamond jewel, an elephant, a cloud, and a human baby? They are all structures. Some are more versatile than others; some last longer than others. Why? Why do the stone or wood or steel cohere at all? If we understood a little more about structure, it could lead to a better understanding of the political and economic dilemmas of our time. Political and economic systems are structures—often so ill-conceived as to require constant local patching and mending. Even structural engineering has as yet failed to comprehend adequately or to define and cope with structure.

790.12 We all have experiences of *pushing* and *pulling*, and we think of them as 180-degree experiences directly away from us or toward us. But (as we shall soon discover) pushing and pulling both produce 90-degree resultants, which we mistakenly call "side effects." Our side effects are nature's primary effects, and vice versa. Pushing is outwardly explosive from a center of effort: that is why a ping pong ball can ride on the parting outward and downward of the waters of an only-vertically-aimed fountain nozzle. Gravity and magnetism are embracingly contractive around—and radially inward toward—a center of gravity. With gases, *pull* is a partial vacuum whereas *push* is an explosion: attraction vs propulsion, tension vs compression.

790.13 Tension and compression always and only coexist and covary inversely. We experience tension and compression continuously as they interaccommodate the eternally intertransforming and eternally regenerative interplay of the gravitational and radiational forces of Universe.

790.14 The gravitational or omnidirectional tension totality in Universe is quantitatively equal to the totality of the radiational or explosive compression of Universe, but the sum total of tensional coherence is more effectively arranged than the sum total of explosively disintegrative forces. This is why Universe is finite. (See Sec. 231.)

790.15 **Barrel:** A barrel as the sum total of its staves and its encircling hoop bands illustrates the cosmic gravity-vs-radiation balance. (See Figs. 705.01-.02.) The staves are wedges—each stave is wedged between two other truncated-triangle wooden staves. When seen in cross-section, each stave is the outer-arc-chord-truncation segment of a long, thin, isosceles triangle whose inner, sharply pointed section-truncated and dispensed with—would have had its apex at the central axis of the barrel. Each stave's outer chord is always a little wider than its inner chord, wherefore the staves cannot fall inward of one another but could very readily move outwardly and apart, were it not for the tension bands that go completely around the barrel and close back on themselves as a finite integrated system.

790.16 The staves are separate, disassociative, inherently disintegrative, and self-differentiating, while the barrel's external ring-bands are self-integrating: though separate, the two groups of members are operating complementarily to produce union. It is the embracing tension that successfully maintains the integrity of the barrel despite the disintegrative tendencies of the individual staves. The push-pull components are more effective associatively than they are separately. The disintegrative explosive force is embracingly cohered by the gravitational. So it is with Universe.

790.17 Push and pull, disassociative and associative in omnidirectional balance, characterize the essence of structure.

790.18 **Column:** If you load the top center of a thin column, it tends to bend like a banana-its radius of curvature in the bending area gets smaller and smaller. (See Fig. 640.20.) A tensed line tends to get straighter and straighter, though never absolutely straight. Physics has not found any straight lines. Physics has found only waves—the superficially straighter waves being of ever higher frequency and ever shorter wavelength, and always locally and discontinuously particled.

790.19 Compression tends to break a slender one-wavelength column into two columns of two wavelengths, thus tending to focus the ever smaller radius between them into one point, which increases the leverage of either half to consummate the breakage. (See Fig. 640.20G.)

790.20 By contracting their girth, tensed lines of tension tend to pull their fibers together ever more tightly so that the atoms get nearer to one another—their mass interattractiveness increases as the second power of the decrease in the distance between the atoms. (See Fig. 641.01B.) Tensional strength increases initially, and therewith lies its capability to cope with loading; when the girth contraction rate is exceeded by the elongation of the tension member, the atoms recede from one another and coherence decreases rapidly.

790.21 Ropes can be pulled around corners. Neither stiff poles nor flexible ropes can be pushed around corners. Tension has a greater distance range of capability than has compression: witness the compression masts and the only-tensionally-suspended long center spans of the great suspension bridges. Tensional capabilities are always more versatile and energetically effective than are compressional capabilities. The variable live loads of suspension bridges are applied directly only to its cables, which distribute the loads evenly. In the same way the tensed tubes of automobile tires receive the shock loads locally and distribute them evenly.

790.22 The taller a column is in proportion to its mid-girth cross-section dimension, the less the load it will bear before it tends to buckle, which means to bend twistingly outward in one direction, and—if further loaded—ultimately to break into two columns. In principle, tension members of structures have no limit ratio of cross-section-to-length. With materials of higher and higher tensile strength it is possible to make longer and longer and thinner and thinner tension cables-approaching a condition of very great length and no cross-section at all. (See Figs. 641.01C-D.) With better and better alloys it is possible to make longer and longer, thinner and thinner, clear-span suspension bridges. People tend erroneously to think of those cables as "solid"—and of the steel as solid—but they are not solid: the atoms are not touching one another. The distances between the nuclei of the atoms and their orbiting electrons-as measured in diameters of their nuclei—are approximately the same proportionally as the distance between our star Sun and its planets. The individual atoms are in sufficiently critical proximity to be sustainingly attracted to one another as are the Earth and Moon, which obviously are not touching each other. In aeronautical terms they are all in dynamic "flying formation." As the Earth and the Moon co-orbit the Sun, and as the Sun and its planets together are in flight formation in our galactic system's merry-go-round, and as the billions of galaxies omnirecede from one another, they are all intersecured by comprehensive mass attraction. The mutual interpull force between Sun, Earth, and Moon is manifest rotationally around opposite sides of the Earth by the twice-a-day tides as quadrillions of tons of water are progressively pulled outward from Earth's surface jointly by the Moon and the Sun-and then are allowed to subside. In the Milky Way periphery of our galaxy the stars do not touch one another: they are in critical proximity. The Universe itself is held together by tension-invisible, substanceless tension that allows for local motions and transformations.

790.23 The same structural laws of Universe operate at both macro- and microlevels: they are the structural laws of our planet Earth.

790.24 Architecture on our planet Earth is the design process of building macrostructures out of microstructures, the building of visible structures out of invisible structures.

791.00 **Cosmic Structuring**

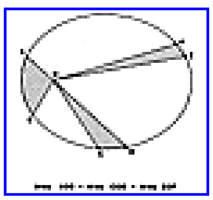


Fig. 791.01

791.01 With the advent of mathematical calculating capability into the public domain only 500 years ago, we had the beginnings of mathematically derived knowledge of cosmic structuring principles. To understand the significance of these principles we begin with Isaac Newton. Newton was inspired by the prior discoveries of Kepler, Galileo, and Copernicus, and he derived his laws of motion from consideration of their basic concepts, as follows:

1. Kepler discovered that all of the Sun's then known six planets orbit the Sun in elliptical paths.
2. The planets are of different sizes, each going around the Sun at different rates and at vastly different distances from the Sun.
3. In a given amount of time all of the planets "sweep out" equal areas. For instance, in a period of 21 days each planet describes a relatively short elliptical arc of travel around the Sun. If we connect the two ends of those arcs by the shortest radial lines to the Sun, and if we make proportionally accurate diagrams of each of the six pie-shaped pieces of sky enclosed by the respective arc-and-radii-bound areas, and if we use Kepler's carefully measured dimensions of those arcs and radii, we will find that the several triangular pieces of pie are very different in shape—ranging from very thin and long to very short and wide-but when calculated for area, they are all

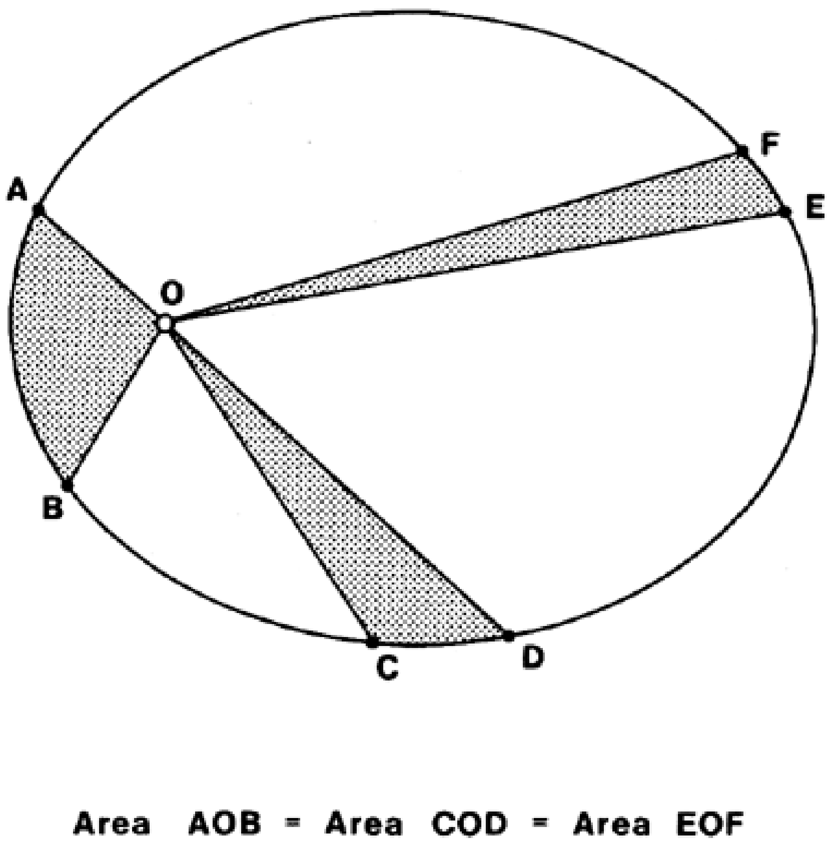


Fig. 791.01(3) Diagram of Equal Area Planetary Sweepouts: Each of the irregular pie-shaped pieces of sky enclose identical areas.

found to be of exactly identical areas. (Compare Sec. 646.11.)

4. The coordination of these planetary motions was found to be exquisitely accurate but hidden invisibly in disparate observational data. Considered separately, each planet had unique behavioral characteristics that could not be explained by any mechanics of physical contact such as that of a train of teeth- meshed gears. The planets and the Sun are vast distances apart. Kepler must have noted that a weight on the end of a string hand-swung by a human around the head will—when released into orbit—travel tangentially and horizontally away from the human, while being progressively diverted toward Earth by the gravitational pull. Thus Kepler concluded that invisible tensile forces were intercohering the orbiting planets with the Sun and, to a lesser extent, with each other.
5. Galileo's measurement of the accelerating acceleration in the rate of bodies falling freely toward Earth indicated that each time the distance between the falling body and the Earth was halved, the speed of falling increased fourfold.
6. Newton was also impressed by the enormous magnitude of the tidal pulling of the Earth's waters by the Moon and the Sun.
7. The astronomers and navigators had established information governing the seemingly "fixed" interpositions of certain celestial star patterns at any given moment of the year as viewed from any given position on Earth. Of course, much of the celestial sphere patterning is obscured from any human observer on Earth's surface by the vast bulk of our planet. But Newton knew from personal experience that the position (as calculated by spherical geometry) of any one of the viewable stars as measured in angular height above the observer's horizon in any given compass direction at any chronometer- recorded moment of time on any given annual calendar day will permit the observer to make accurate calculation of his position on Earth.

791.02 In consideration of all the foregoing seven concepts—and much other information—Isaac Newton concluded that the relative magnitude of interpull forces of planetary coordination was proportional to the masses of the bodies involved. He concluded that the interpull between two apples would be so insignificant in proportion to the pull of massive Earth upon both apples that the two apples near one another on the table would be so powerfully pulled against the table as to manifest no measurable pull toward each other. Apparently the extraordinary interpulling of Universe could only be manifested in free space; thus it had never been noticed by humans in their preoccupation with Earthian affairs.

791.03 Newton reasoned from Kepler's work that if he swung a weight around his head and then let go of it, it would start off in a horizontal line but become overpowered by gravity and swiftly veer away 90 degrees vertically toward Earth. Thus Newton formulated his first law of motion, that all bodies will persist in a state of rest or in a line of motion *except* as affected by other bodies.

791.04 Newton reasoned that if Earth were to be annihilated, it would relinquish its pull on the Moon, and then the Moon would be free to fly off tangentially on an approximately linear course. He chose a night of full Moon at a given moment of clock time to observe the Moon—well above the horizon—predictably positioned against the celestial pattern of the "fixed" stars. He then calculated the line of tangential direction along which a released Moon would travel as traced against the sky pattern. Newton then observed and calculated the rate at which the Moon would travel away from the theoretical trajectory of release and "fall" toward the Earth as they both orbited the Sun at 60,000 miles per hour.

791.05 As a result of this observation and calculation Newton found that the path of the Moon's "fall" agreed exactly with the falling body data of (Galileo. Wherefore Newton concluded it was celestially manifest that

1. relative to all known bodies, the magnitude of mutual interattraction between any two bodies is proportional to the product of their paired and intermultiplied masses; and
2. whenever the distance between two bodies is halved, the force of their interattraction increases fourfold, which is to say that the interattraction varies exponentially at a second-power rate as the distance between the considered bodies varies at only an arithmetical rate.

791.06 For millennia humans had endeavored to explain the apparently random independence, the seemingly uncoordinated individual motions, of the five planetary bodies visible from Earth, orderly interpositioned against the background of the vast myriads of "fixed" stars of the celestial sphere. What Newton had discovered is relevant to our comprehension of the universal nature of structures. He had discovered a pair of integral characteristics of two bodies, with one interrelationship varying at an exponential rate and the other interrelationship covarying arithmetically. Kepler and Newton had found synergetic behaviors of whole systems that were unpredicted by the behaviors or the integral characteristics of any parts of the system considered separately. Kepler and Newton had found synergy.

791.07 If you were a contemporary of Kepler or Newton and were to have asked them what the mass interattraction called "gravity" *is*, they would have told you that they had no way of knowing. And there is as yet no way to explain the interrelationship behaviors found experimentally to exist "between" and not "of " any two objects in Universe. The relationships they discovered are elegantly reliable, but they are also an absolute a priori mystery.

791.08 Humanity has inherited an inventory of generalized laws of Universe from the Copernicus-Kepler-Galileo-Newton discoveries, which they in turn inherited from their Greek, Mesopotamian, Egyptian, Indian, and Chinese predecessors. There is no information to suggest that the inventory has been completed. All of the generalized laws can be expressed in mathematical terms. They are all eternally operative and interaccommodative. Together, the thus-far-discovered generalized laws guarantee the integrity of nonsimultaneous, only partially overlapping, Scenario Universe.

792.00 **Design**

792.01 The word *design* is used in contradistinction to random happenstance. Design is intellectually deliberate. Design means that all the components of the composition are interconsiderately arranged. In a design the component behaviors, proclivities, and mathematical behaviors are interaccommodative. The family of generalized principles constitutes an eternal cosmic design whose interrelationships are expressible only in abstract mathematical terms.

792.02 Speaking in terms of generalized law, *structure* is always and only the consequence of a complex of six energy events—three dominantly tensive and three dominantly compressive—with each set interacting in complement to produce a self- regeneratively stabilized pattern.

792.03 Contrary to common opinion (even that of engineers), structures are always dynamic and never static. All structural realizations are special case. Structural realizations have specific longevities; they are entropic; they give off energy. The energies are often syntropically replaceable in the consequence of structural transformations.

792.04 Any and all of what humans identify as substances are structural systems. Any and all structure consists entirely of atoms. Atoms are not things: they are energy events occurring in pure principle. Each and every experimentally evidenced atom is a complex of unique structural-system interrelationships—both internal and external—that manifest generalized pattern integrities in special case scenario continuities.

792.10 **Universe:** Universe is synergetic. Universe is synergetically consequent to all the generalized principles, known or unknown. Universe is not a structure. Universe embraces all structures and more. While a plurality of generalizations governs all structures, *realized* structuring is always special case. Structures are synergetic consequences of the intimate interaction of a complex of special case factors. Superficially, the overall limits of the manifold omniintertransformability of structures are unitarily conceptual.

792.20 *Scenario Universe:* Scenario Universe embraces all the nonsimultaneous, only-local-in-time-and-place structurings, destructurings, unstructurings, and restructurings. All the somethingnesses are structures. All the nothingness is unstructure. All the somethingnesses are special case. All the nothingness is generalized.

792.30 **Tension and Compression:** Everything we call structure is synergetic and exists only as a consequence of interactions between divergent compressional forces and convergent tension forces.

792.31 I take a piece of rope and tense it. As I purposely tense it, I inadvertently make it more taut. But I was not tensing the rope for the purpose of making it taut; my brain was only trying to elongate the rope. As I do so, however, the girth is inadvertently contracting and the rope is inadvertently getting harder. In getting harder the cross-section of the rope is contracting radially in a plane at 90 degrees to the axis of my purposeful tensing, thus inadvertently producing the always and only coexisting action-reaction-and- resultant complementations of myopic preoccupation.

792.32 Next I purposely produce compression. I take tempered steel rods, each three feet long and one-eighth of an inch in diameter. The rods bend flexively. We find that two rods cannot get closer to one another than in parallel tangency of their circular cross- sections. A third rod cannot get closer to the other two than by nestling in the parallel valley between them. With each of the three rods in parallel tangency, the centers of their three circular cross-sections form an equilateral triangle.

792.33 Hexagons consist of six equiangular triangles. Hexagons have six circumferential points and a center point—seven in all—all equidistant from their neighbors. Six rods now huddle in closest-packed tangency around the original rod. (See Fig. 412.01.) And 12 more rods may be huddled around the first seven to complete an additional hexagonal perimeter. Successive perimeters aggregate, each time with six more rods than those of the previous ring. The outermost rods will be tangentially closest packed in triangular stabilization with their neighbors; the rod at the center is at the symmetrical nucleus of the aggregate. We note in nature that the rodlike Earthward trajectories of closely falling, inter-mass-attracted raindrops passing through freezing temperatures nucleate in hexagonal snowflake arrays under just such hexagonal close- packing laws.

792.34 The Greek architects found experientially that when the height of a stone column exceeded its girth by 18 diameters, it tended to fail by buckling out of the central stone cylinder section. The length-to-diameter ratio of a compressional column is called its *slenderness ratio.* Continuous steel columns are more stable than stone columns and may be used structurally with slenderness ratios as high as 30 to 1—these are long columns. Short columns-with a slenderness ratio of 12 to 1—tend to fail by crushing rather than by buckling.

792.35 For our further experiment in *purposeful compression* we assemble a column 36 inches high with a minimum girth diameter of three inches. It requires 547 of our 36- inch-long, one-eighth-inch-diameter rods to produce this 12-to-1 short column. Each individual rod is slender and highly buckleable, but bound circumferentially together for its full length by tightly wound steel wire. The rods will close-pack symmetrically in a hexagonal set of 13 concentric rings around a nuclear rod: the maximum diameter will be three and three-eighths inches. We can then add forged steel caps over the hexagonal ends of this integrated short column.

792.36 We may next insert the column perpendicularly between the upper and lower jaws of a hydraulic press and load the composite column in vertical compression. We know from our earlier trial that each rod taken by itself can bend when end-loaded. Being close-packed together, they cannot bend further inwardly toward the center rod: they can only bend outwardly, straining the binding wire wrapped around the rods and causing them ultimately to yield to the severe outward force at the column's mid-girth. The bunched ends are held together by the hexagonal steel caps as the force of the hydraulic press increases. This results in the whole column twisting mildly and bulging out to become cigar-shaped as seen in vertical profile. If loaded sufficiently, the bundle approaches sphericity.

792.37 This experiment indicates that our purposeful loading of the column in compression inadvertently results in its girth increasing in diameter, which brings about *tension* in the horizontally bound wires. An inadvertent tension occurs in a plane at 90 degrees to the axis of compression.

792.40 **Tidal Complementarities:** By two visibly different experiments—one with rope and the other with steel rods—we have demonstrated experimentally that tension and compression always and only coexist. One can be at *high tide* of visibility and the other coincidentally at *low tide,* or vice versa. These tidal covariables are typical complementarities: they are not mirror images of one another, but must always balance one another complexedly in physical equations. Both demonstrate 90-degree inadvertent resultants. In engineering this behavior is known as the *Poisson effect,* and in physics it is known as *precession.*

792.50 **Spherical Islands:** Short columns loaded on their neutral axes tend to bulge toward sphericity of conformation. In the spherical form-and only in the spherical-we find that the system has no unique axis. Any diametric loading in the sphere is in effect a neutral axis. In coping with compressive loads, spheres act most effectively regardless of which is the loaded axis. Since spheres have the greatest volume with the least surface, loads are evenly distributed radially from the center to all of the enclosing mass. Thus ball bearings constitute the most effective of universal load-bearing designs for compressional functioning.

792.51 We find nature preferentially investing her compressionally assigned energy tasks in sphericals—whether stars, planets, asteroids, oranges, or atoms. Universe isolates all her major compression functions in spherical islands that are vastly remote from one another and that are intercohered only by Kepler's and Newton's invisible tension: gravity. The star Sun gravitationally precesses its compressionally islanded planets to orbit around it; the atomic nucleus gravitationally precesses its islanded electrons to orbit around it. Nature's cosmic structuring strategy employs only discontinuous islanded compression and only omni-everywhere continuous tension, *gravity*. Paradoxically, Earthian engineers as yet design their structures only as compressional continuities, sometimes tied together by tension rods and reinforcements. Humans still use a primarily direct-compressional Stone Age logic, using tension only as a secondary reinforcement. Nature—both macrocosmically and microcosmically—uses a primary tensional logic, with compression as a secondary islanded back-up.

792.52 The Stone Age logic said that the wider and heavier the walls, the more happily secure would be the inhabitants. The advent of metal alloys in the 20th century has brought an abrupt change from the advantage of structural ponderousness to the advantage of structural lightness. This is at the heart of all ephemeralization: that is the dymaxion principle of doing ever more with ever less weight, time, and ergs per each given level of functional performance. With an average recycling rate for all metals of 22 years, and with comparable design improvements in performance per pound, ephemeralization means that ever more people are being served at ever higher standards with the same old materials.

Next Section: 793.00

793.00 **Tree Structures**

793.01 Among nature's most efficient—and therefore most beautiful—designs are the structuring of the great trees. To examine the structural effectiveness of trees we can make an experiment. Take two suitcases, each weighing 50 pounds, one in each hand. Try to hold them out horizontally at arm's length. It is easy for our arms to hang them vertically from our shoulders, but the more horizontally they are held, the more difficult. It is almost impossible to hold out 50 pounds horizontally. Yet look at a tree's shoulders where the branches are attached. Look at the branch of a tree with the same girth as that of your shoulder when your arm is extended and flexed. Such a tree branch may weigh 500 pounds—ten times what you can hold out horizontally. Many larger-shouldered tree branches weighing five tons and more are held out horizontally. "Wing root" is an aeronautical engineering term for shoulder—that is, where the plane's airframe fuselage joins the jet-pod-carrying aluminum wing. These air transport wing roots accomplish great load-bearing tasks with very low weight ratios. The way trees hold out five-ton branches while yielding in streamline and flexing gracefully without breaking in great winds is a design accomplishment unparalleled in aeronautical engineering—even in the wing roots of jumbo jets and supersonic fighters. How can a tree do that? Biological structures cope hydraulically with all compressional loadings.

793.02 The paramount function of trees is to expose as much leafage as possible under varying wind conditions in order to impound Sun radiation. By a complex of relationships with other biologicals, this impoundment supports life on our planet, since few mammals can directly convert Sun energy into life support. Since the function of trees requires maximum leafage exposure, their progeny will prosper best when planted outside the shadow of the parent. Each tree seed is a beautiful flying machine designed to ride the wind until reaching propitious soil. Because few seeds will find propitious sites in this random distribution, the tree launches many thousands of seeds. The seeds contain the geometric design instructions for associating the locally available resources of air and water and the atomic chemistries of the locally available soil and rock in the environs of seed-landing.

793.03 Seeds contain coded programs for associating local atoms in triple-bonded crystal structures. Triple-bonded structures have high tensile capabilities, and when further interbonded they produce long, overlapping, fibrous sacs to be filled with local water and air derivatives. These closepacked, liquid-filled fibrous sacs compound first to produce the "wood" of the tree's roots and trunk. What nature ships in the seeds are the DNA-RNA coded instructions on how to utilize the resources of the locally occurring water, gases, and chemical elements at the planting site. The high-tensile fiber sacs are filled with liquid sap developed from water brought in from the roots by osmosis. By one-way capillary valving the hydrogen and oxygen of the water combine with the carbon- and oxygen-laden gases of the atmosphere to produce the hydrocarbon crystal cells of the tree while at the same time giving off to the atmosphere oxygen atoms with which the growth of mammals will be respiratorially sustained.

793.04 Enormous amounts of water are continuously being elevated through the one-way, antigravity valving system. The tree feeds the rain-forming atmosphere by leaking atomized water out through its leaves while at the same time sucking in fresh water through its roots. The tree's high-tensile fiber cell sacs are everywhere full of liquid. Liquids are noncompressible; they distribute their local stress loadings evenly in all directions to all the fiber cell sacs. The hydraulic compression function firmly fills out the predesigned overall high-tensile fiber shaping of the tree. In between the liquid molecules nature inserts tiny gaseous molecules that are highly compressible and absorb the tree's high-shock loadings, such as from the gusts of hurricanes. The branches can wave wildly, but they rarely break off unless they are dehydratively dying—which means they are losing the integrity of their hydraulic, noncompressible load-distribution system. Sometimes in an ice storm the tree freezes so that the liquids cannot distribute their loads; then the branches break off and fall to the ground.

793.05 In trees the liquids distribute the loads and the gases absorb the shocks in an overall high-tension crystalline fiber network predesigned by the DNA-RNA programming. The system transmits its hydraulic load-distribution impulses through each liquid-filled cell's contacts with adjacent liquid-loaded sacs. Starting with one tetrahedral bud "shoot," the tree grows as a series of concentric tetrahedral cones. Revolved tetrahedra generate cones. The constant reorienting of the direction from which the Sun radiation is coming, the frequent shift in the wind direction, and the consequent drag forces on the tetra-tree produce a conic revolution effect on the tree growth. Each year a new cambium layer cone grows over the entire outside of the previous year's tetra-cone. Each branch of the tree also starts as a tetrahedral shoulder cone sprouting out of the main tree cone.

793.06 This high-tension sac's web design with its hydraulic compression coping and pneumatic shock absorbing is much the same structural system nature employs in the design of human beings. To be sure, with humans the liquid does not freeze under normal environmental conditions; nature creates a good-health temperature control of 98.6 degrees F. for all its humans. Instead of the larger tetra cone form, over which the tree builds from the roots outward into its successive live layers, nature introduced in the mobile mammals the skeleton around which all their hydraulically actuated muscles and cushioning cells are grown in crystalline patterns as scheduled by the DNA-RNA program and as thereafter automated by genetic coding.

793.07 When humans tried to make solid crystalline machinery and ship it from here to there over the ground, the objects could move only very slowly without being shattered. So pneumatic tires were put on the wheels so as to distribute the working loads throughout all the freely moving compressional molecules, which in turn distribute the workload energies over the whole uniformly tensioned surface of the high-tensile tire casing. The aeronautical engineers finally adopted nature's biological structuring strategies to cope with 150 tons of fully loaded jumbo jets coming out of the sky to land at 150 miles per hour—with the music going and the people putting on their coats, paying no attention to the extraordinary engineering accomplishment. The plane's tires are pneumatic. Rubber makes the first contact. Pneumatics take the shock load. Next the hydraulic struts distribute the shock loading evenly through metered orifices, and all the shock load energy is thereafter distributed as heat through the high conductivity aluminum walls of the hydraulic system. The heat is completely dispersed by the metal surfaces. Only in the landing gear of great airplanes have humans employed nature's really beautiful structuring of crystalline tension in complement with hydraulic compression and pneumatic elasticity for shock absorption.

794.00 **Geodesic Domes**

794.01 The great structural systems of Universe are accomplished by islanded compression and omnicontinuous tension. *Tensegrity* is a contraction of *tensional integrity* structuring. All geodesic domes are tensegrity structures, whether the tension- islanded compression differentiations are visible to the observer or not. Tensegrity geodesic spheres do what they do because they have the properties of hydraulically or pneumatically inflated structures.

794.02 Pneumatic structures—such as footballs—provide a firm shape when inflated because the kinetically accelerated atmospheric molecules are trying to escape and are impinging outwardly against the skin, stretching outwardly into whatever accommodating roundness has been designed into the omniembracing tension system. (Compare Sec. 760.) When more molecules are introduced into the enclosure by an air pump, their overcrowding increases the pressure. A fleet of ships maneuvering under power needs more sea room than does another fleet of ships moored side by side. The higher the speed of the individual ship, the greater the minimum turning radius and the more sea room required. This means that the enclosed and pressurized molecules in pneumatic structural systems are accelerated in outward-bound paths by the addition of more molecules by the pump; without additional room each must move faster to get out of the way of the others.

794.03 Pressurized liquid or gaseous molecules try to escape from their confining enclosure. When a football is kicked on one outside spot the outward-bound molecules impact evenly on the entire inside surface of the football's flexible skin. The many outward-bound impactings force the skin outwardly and firmly in all directions; the faster the molecules move, the more powerful their impact, and the harder and more resilient the football. The effect is dynamic; there is no firm or static condition. The outward forces are met by the compressive embracement of the tensile envelope enclosure.

794.04 Geodesic domes are designed as enclosing tensile structures to meet discretely—ergo, nonredundantly—the patterns of outwardly impinging forces. A fishing net's mesh need be no finer than that through which the smallest fish worth catching cannot pass. If we know exactly the size of the fish we wish to catch, and how many of them are going to hit the net, exactly where, at what force, at what angle, and when, we then have a model for the realistic engineering analysis of geodesic domes.

794.05 The conventional engineering profession has been analyzing geodesics strictly in terms of compression, on a crystalline, non-load-distributing, "post and lintel" basis. For this reason the big geodesic domes erected so far have been many times overbuilt, way beyond the appropriate safety factor of 2 :1 as adopted by aeronautical science. The building business uses safety factors of 5 or 6:1. The greater the ignorance of the art, the greater the safety factor demanded by probability mathematics. The greater the safety factor, the greater the redundance and the less the freedom of load distribution.

794.06 We have a mathematical phenomenon known as a geodesic. A geodesic is the most economical relationship between any two events. A special case geodesic finds that a seemingly straight line is the shortest distance between two points in a plane. Geodesic lines are the shortest surface distances between two points on the outside of a sphere. Spherical great circles are geodesics.

794.07 A great circle is a line formed on the surface of a sphere by a plane passing through the sphere's center. The Earth's equator is a great-circle geodesic; so too are the Earth's meridians of longitude. Any two great circles of the same system must cross each other twice in a symmetrical manner, with their crossings always 180 degrees apart.

794.08 Each of any three great circles of a sphere not having common polar crossings must cross each of the others twice. This makes for a total of four crossings for each of the three great circles and a total of six crossings for the whole set of three great circles; the whole set of three great circles entirely divides the entire sphere into four hemispherically opposed pairs of similar spherical triangles, and—in one special case—into the eight similar spherical triangles of the regular spherical octahedron. All cases are thus omnitriangular spherical octahedra, regular or irregular.

794.09 Because both ends of spherical chords always impinge on their sphere at identical angles, molecules of gas reactively accelerate chordally away from one another in a spherical enclosure, trying to proceed in straight-line trajectories. The molecules must follow the *shortest-distance,* geodesic great-circle law, and the angular reflectance law; they will carom around the inside of the sphere or football or balloon only in circular paths describing the greatest diameter possible, therefore always in the planes of great circles except as deflected by other forces.

794.10 When two force vectors operating in great-circle paths inside a sphere impinge on each other at any happenstance angle, that angle has no amplitude stability. But when a third force vector operating in a third greatcircle path crosses the other two spherical great circles, eight great-circle-edged triangles are formed with their four sets of two inherent, opposite-hemisphered, mirror-image triangles.

794.11 With successive inside-surface caromings and angular intervector impingements, the dynamic symmetry imposed by a sphere tends averagingly to equalize the angular interrelationships of all the millions of triangle-forming sets of those three great circles. The intershunting triangulation in greatcircle paths automatically tends averagingly to produce a spherically closed system of omnisimilar triangles. This means that if there were only three great circles, they would tend swiftly to interstabilize comprehensively as the spherical octahedron, all of whose surface angles and arcs average as 90 degrees.

794.12 If we successively shoot at the same high velocity three steel ball bearings of the same size and weight into a smoothly walled, spherical steel container, and if we do that shooting through a carefully timed pop-open-and-pop-closed hole, and if we aim the ball bearing gun as far away from the sphere center as the pop-open hole permitted, each of the three balls would start describing a great-circle path of bouncings off the sphere. Each would have to cross the other four times and would carom off each other as well, swiftly to work toward the spherical octahedron.

794.13 Because each of the three gas molecules must have its reactor molecule, we will always have six initial great circles operative in the pressurized pneumatic containers; all the additional molecules will be six-teamed, and each team of six will increase the system frequency by one, and all the teams will averagingly parallel one another.

794.14 The great-circle chords of all polyhedra are always found to be systematically developed out of sets of exactly six great-circle chords—never more or less. These six vectors are the six vectors of the energy quantum. The 12 vector-edged chords of the octahedron equal the two sets of six chord vectors: two quanta. The 30 vector- edged chords of the icosahedron equal the five sets of six chord vectors: five quanta. In the tetrahedron one quantum of structurally invested energy encloses one unit of volume. In the octahedron one quantum of structurally invested energy encloses two units of volume. In the icosahedron one quantum of energy invested in structure encloses almost four units of volume. Of the three prime structural systems of Universe, the tetrahedron is the strongest per unit of volume enclosed; the octahedron is "middling"; and the icosahedron is least strong, but encloses the greatest volume per unit of invested energy. Whenever nature uses the icosahedron, the maximum volume enclosure per units of invested energy is the principal function served. For this reason all pneumatic and hydraulic structuring of nature employs icosahedral spherical geometry. When maximum structural strength per unit of invested energy is the principal function served, nature uses the tetrahedron. When the principal function to be served is a balance of strength and volume, nature uses the octahedron as her preferred structural system.

794.15 A vast number of molecules of gas interacting in great circles inside of a sphere will produce a number of great-circle triangles. The triangles, being dynamically resilient, mutually intertransform one another to evolve an "averaging" of the random- force vectors, resulting in angular self-interstabilizing as a pattern of omnispherical symmetry. The aggregate of all the inter-great-circlings resolves typically into a regular pattern of 12 pentagons and 20 triangles, or sometimes more complexly into 12 pentagons, 30 hexagons, and 80 triangles described by 240 great-circle chords.

794.16 This is the pattern of the geodesic tensegrity sphere. The numbers of hexagons and triangles and chords may be multiplied in regular arithmetical or geometrical series, but the 12—and only 12—pentagons will persist as constants, as will the number of triangles occur in multiples of 20, and the number of edges in multiples of 6.

794.17 In the geodesic tensegrity sphere each of the entirely independent, compressional-chord struts represents two oppositely directioned and force paired molecules. The paired-outward caroming of the two chord ends produces a single radially outward force of each chord strut. The tensegrity compressional chords do not touch one another: they operate independently, each trying to escape outwardly from the sphere, but they are restrained by the spherical tensional integrity's closed-network system of great- circle connectors, which alone can complete the great-circle paths between the ends of the entirely separate, non-directly-interconnecting, compressional chords. Were the chordal struts to be pushing circumferentially from the sphere, their ends would touch one another or slide by one another, but the tension lines show clearly that the struts each pull away from their nearest neighbor and strain to escape radially outward of the system.

794.18 Central angles of great circles are defined by two radii, the outer ends of which are connected by both an arc and a chord—which arc and chord are directly proportional to each unique such central angle. The chord and two radii form an isosceles triangle. The distance between the mid-arc and the mid-chord is called the *arc altitude*. Every point on a great-circle arc is at full-radius distance from the sphere's center. In developing the triangular subgridding of the icosahedral geodesic prime structural system, the greatcircle arc edges of the icosahedron (each of which has a central angle of 63 degrees, 26 minutes, and several seconds) are equally subdivided into two, three, or four equal-arc increments—or as many more equal-arc increments as the engineering calculation finds desirable in consideration of all the optional variables, such as the diameter of the structure, the structural properties of the materials with which it is to be produced, and the logistics of delivery, installation, and assembly.

794.19 **Frequency:** Whatever the number of the equal subdivisions of the icosa arc—whose subdivision points are to be interconnected with a threeway omnitriangulated grid of great-circle arcs—that icosa arc edge subdivision number is spoken of as the *frequency*, of the system. The higher the frequency of the system, the lesser in dimension will each of the arc, chord, and arc-altitude increments become. All these dimensions covary at identical rates and are therefore uniformly proportional for any given frequency. Uniform dimensions, chord factors, and ratios may be listed for any size dome; the only numerical variable in geodesic spheroidal structures is that of the system's radius.

794.20 Because each islanded compression strut in a tensegrity sphere addresses its adjacent (but untouched) struts at an angle of approximately 60 degrees, that strut is aimed at but does not reach the midpoints of the adjacent struts. Each of the struts is a chord of the sphere, with its ends at greater distance from the center of the sphere than the radial distance of the midpoint of the chordal strut-that difference in distance being exactly that of the arc altitude. The arc altitude decreases as the system frequency is increased, which occurs logically as the system radius increases.

794.21 The mid-girth of each chordal compression strut is proportional to its length and is always substantial. The strut is most efficient when cigar-shaped and pin-ended. As the frequency increases and the arc altitude decreases, there develops a special size geodesic sphere, wherein—employing the most economical material for the struts—the mid-girth of the chordal strut is exactly the same as the arc altitude, at which point the pin- ends of the struts approaching at 60 degrees may exactly touch the mid-girths of the impinged-upon struts. But this kind of touching does not mean pushing against, because the struts (as their tension slings show) are trying to escape radially outward from the dome center. What this touching does is to dampen the vibratory resonance of the tensegrity sphere.

794.22 One of the impressive behavioral characteristics of tensegrity spheres, witnessed at low frequencies, is that when any two islanded struts 180 degrees apart around the sphere are pulled outwardly from one another, the whole sphere expands symmetrically. When the same two 180-degrees-apart struts are pushed toward one another, the whole sphere contracts symmetrically. When the polar pulling apart or pushing together ceases, the tensegrity sphere assumes a radius halfway between the radii of the most pullingly expandable and pushingly contractable conditions; that is, it will rest in dynamic equilibrium.

794.23 When the tension-member lengths between the islanded struts are everywhere the same, the twanging of any of them sounds the same vibration note as any and all the others. Tightening any one tension member or increasing the length of any one strut tightens the whole system uniformly, as is tunably demonstrable. The equilibrium state, which tensegrity spheres spontaneously assume, is the state wherein all the parts are most comfortable but are always subject to spherical oscillatability. Thus the coming into contact of the pin-end cigar struts with the neighboring struts' mid-girth points provides a condition at which—if the pin-point is locked to the mid-strut—it will be prevented from leaving its most energetically efficient state of repose, and the locking together will prevent either the expansion or contraction of the sphere and will mute its resonance and deaden its springiness.

794.24 At the low-frequency, push-pull, contraction-expansion susceptible state, tensegrity spheres act like basketballs. Bouncing them against the floor makes them contract locally, after which they spring back powerfully to their original shape, which impels them back against gravity. Geodesic spheres are in strict physical fact true pneumatic structures with a discrete number of oppositely paired molecules—and their respective atomic colonies—all averagingly aggregated together in the form of the islanded struts instead of being in their invisible gaseous state.

795.00 **Reduction to Practice**

795.01 We can take advantage of the fact that lumber cut at the "two-by-four" size represents the lumber industry's most frequently used and lowest-cost structural lumber. The average length of the two-by-fours is 12 feet. We can take the approximately two- inch dimension as the mid-girth size of a strut, and we can use an average of 10-foot lengths of the tensilely strongest two-by-four wood worked by the trade (and pay the premium to have it selected and free of knotholes). We can then calculate what size of the spherical dome—and what frequency—will produce the condition of "just-kissing" contact of the two-by-four ends of the islanded two-by-four chordal struts with the mid-girth contact points of one another. This calculates out to a 12-frequency, 72-foot-diameter sphere that, if truncated as a three-quarter sphere, has 20 hexagonal openings around its base, each high enough and wide enough to allow the passage of a closed body truck.

795.02 We calculated and produced such a 72-foot, three-quarter-sphere geodesic dome at the Edwardsville campus of Southern Illinois University in 1962. The static load testing of all the parts as well as the final assembly found it performing exactly as described in the above paragraphs. The static load testing demonstrated performance on the basis of the load-distributing capabilities of pneumatics and hydraulics and exceeded those that would have been predicted solely on the basis of continuous compression.

795.03 As the world's high-performance metallic technologies are freed from concentration on armaments, their structural and mechanical and chemical performances (together with the electrodynamic remote control of systems in general) will permit dimensional exquisiteness of mass-production-forming tolerances to be reduced to an accuracy of one-hundredth-thousandths of an inch. This fine tolerance will permit the use of hydraulically pressure-filled glands of high-tensile metallic tubing using liquids that are nonfreezable at space-program temperature ranges, to act when pressurized as the discontinuously isolated compressional struts of large geodesic tensegrity spheres. Since the fitting tolerances will be less than the size of the liquid molecules, there will be no leakage. This will obviate the collapsibility of the air-lock-and-pressure-maintained pneumatic domes that require continuous pump-pressurizing to avoid being drag-rotated to flatten like a candle flame in a hurricane. Hydro-compressed tensegrities are less vulnerable as liquids are noncompressible.

795.04 Geodesic tensegrity spheres may be produced at enormous *city-enclosing* diameters. They may be assembled by helicopters with great economy. This will reduce the investment of metals in large tensegrity structures to a small fraction of the metals invested in geodesic structures of the past. It will be possible to produce geodesic domes of enormous diameters to cover whole communities with a relatively minor investment of structural materials. With the combined capabilities of mass production and aerospace technology it becomes feasible to turn out whole rolls of noncorrosive, flexible-cable networks with high-tensile, interswaged fittings to be manufactured in one gossamer piece, like a great fishing net whose whole unitary tension system can be air-delivered anywhere to be compression-strutted by swift local insertions of remote-controlled, expandable hydro-struts, which, as the spheric structure takes shape, may be hydro-pumped to firm completion by radio control.

795.05 In the advanced-space-structures research program it has been discovered that—in the absence of unidirectional gravity and atmosphere—it is highly feasible to centrifugally spin-open spherical or cylindrical structures in such a manner that if one-half of the spherical net is prepacked by folding below the equator and being tucked back into the other and outer half to form a dome within a dome when spun open, it is possible to produce domes that are miles in diameter. When such structures consist at the outset of only gossamer, high-tensile, low-weight, spider-web-diameter filaments, and when the spheres spun open can hold their shape unchallenged by gravity, then all the filaments' local molecules could be chemically activated to produce local monomer tubes interconnecting the network joints, which could be hydraulically expanded to form an omniintertrussed double dome. Such a dome could then be retrorocketed to subside deceleratingly into the Earth's atmosphere, within which it will lower only slowly, due to its extremely low comprehensive specific gravity and its vast webbing surface, permitting it to be aimingly-landed slowly, very much like an air-floatable dandelion seed ball: the multi-mile-diametered tensegrity dome would seem to be a giant cousin. Such a space- spun, Earth-landed structure could then be further fortified locally by the insertion of larger hydro-struttings from helicopters or rigid lighter-than-air-ships—or even by remote- control electroplating, employing the atmosphere as an electrolyte. It would also be feasible to expand large dome networks progressively from the assembly of smaller pneumatic and surface-skinning components.

795.06 The fact that the dome volume increases exponentially at a third-power rate, while the structural component lengths increase at only a fraction more than an arithmetical rate, means that their air volume is so great in comparison to the enclosing skin that its inside atmosphere temperature would remain approximately tropically constant independent of outside weather variations. A dome in this vast scale would also be structurally fail-safe in that the amount of air inside would take months to be evacuated should any air vehicle smash through its upper structure or break any of its trussing.

795.07 In air-floatable dome systems metals will be used exclusively in tension, and all compression will be furnished by the tensionally contained, antifreeze-treated liquids. Metals with tensile strengths of a million p.s.i. will be balance-opposed structurally by liquids that will remain noncompressible even at a million p.s.i. Complete shock-load absorption will be provided by the highly compressible gas molecules—interpermeating the hydraulic molecules—to provide symmetrical distribution of all forces. The hydraulic compressive forces will be evenly distributed outwardly to the tension skins of the individual struts and thence even further to the comprehensive metal- or glass-skinned hydro-glands of the spheroidally enclosed, concentrically-trussed-together, dome-within- dome foldback, omnitriangulated, nonredundant, tensegrity network structural system.

795.08 Design Strategies: All the calculations required for the design of geodesic domes may be derived from the three basic triangles of the three basic structural systems:
-the 120 right spherical triangles of the icosahedron,
-the 48 right spherical triangles of the octahedron, and
-the 24 right spherical triangles of the tetrahedron.
All the great-circle behaviors occurring around the whole sphere take place within just one of those three basic right triangles and repeat themselves in all others.

795.09 The data mathematically developed within the three basic triangles become constants for spheres of any size. What we need to know structurally is the length of the chordal lines between any two adjacent points in the three-way great-circle grid and the angles at which they intersect. The spherical surface angles of the sphere and the central angles may all be expressed in the same decimal fractions, which remain constant for any size sphere since they are fractions of a unit finite whole system. We assign the name *chord factors* to all the constant lengths of a sphere's connecting lines, whether between any two spherical surface points or between two concentric spheres that are intertriangularly trussed. We assign the word *frequency* to the number of uniform-edge subdivisions of the spherical arc edges of the basic spherical triangles.

795.10 There is a set of unique chord factors for each frequency. There are six alternate ways of organizing the triangular subgridding, some of which permit planar base cutoffs of the sphere at other than its equator. Various fractions of the sphere are permitted, as some produce more overall structural economy for differing applications than others. The most economical total lengths for a given frequency are also the most equilibriously comfortable—that is, where it requires the least energy to maintain its integrity under any and all environmental conditions.

795.11 Competent designing of geodesic tensegrity domes also requires monitoring the evolving increases in performance of the various chemical materials and metal alloys available. The full design science responsibility includes developing, prototyping, testing, production, engineering, tooling, manufacturing, transporting from factory to use point, assembly, and removing and recycling of the materials: only from consideration of each such successive cycle can we learn how to do it again more efficiently and satisfactorily to society. I.e., 60 degrees. The nucleus of a square would have a completely different distance to its corners than the corners would have to each other.

Next Chapter: 800.00
