An Artist's Atom

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ABSTRACT

The author discusses his ongoing artwork visualized with the help of a graphics computer. Because quantum physics is mathematical and non-pictorial, most people find it difficult to understand how the atom's electron structure works. The artist's purpose is to develop an architecture for the atom, a model appealing to the visual mind. Through his artwork he attempts to aid in the visualization of the building block of matter, the atom.

The diversity of art in galleries and museums in the last decade suggests there are as many directions in art as there are facets of civilization. Much mainstream art remains close to literature, politics, philosophy, poetry, technology or theater.

My artistic interest has been based in the countless ways nature provides for organizing physical forces to form structures. My sculptures (Fig. 1) have been linked variously to constructivism, engineering, mathematics or science. The fact that I was schooled in art makes me feel most comfortable with the constructivists because, at root, we share a common interest: that of putting together separate parts to create a new whole.

For a long time I have been attracted to the mystery of the primal natural structure of the atom, an interest that inspired me to produce an open-ended artwork, Portrait of an Atom expressed in pictures, sculptures and writing. (I used a Silicon Graphics computer with Wavefront software to produce the images shown here.)

As a sculptor, I have longed for a life-sized replica of an atom, perhaps with robotic controls, in order to watch it perform its virtuoso assortment of tricks and tasks: transmitting light and catching it again, expanding and contracting, linking up with its sisters, brothers and cousins to form huge chains of geometrical precision, demolishing itself only to self-reconstruct, flashing its host of electrons about its nucleus and forming the frictionless perpetual motion machine that a real atom is.

Within the mechanism of those magical spheres of electrons, I perceive the supreme mystery and poetry of nature, a wondrous work whose details are still an unsolved riddle.

My art work on the atom grew out of the same kind of disappointment many inquisitive people experience when confronted with science's mathematical, non-pictorial atom, which invariably leaves the visual, non-algebraic mind feeling deprived of real understanding. I believe the reason that visualizations are limited goes back to the 1920s and 1930s and to those men who laid the rules for what was admissible and what was not in the "new quantum theory" after Werner Heisenberg discovered his uncertainty principle. The tone of the time comes through in a quote from the great physicist Max Born, Nobel prize winner for his interpretation of quantum wave mechanics:

Not every question about atoms can be answered, but only those questions which are compatible with Heisenberg's principle of uncertainty. What lies within the limits is knowable What lies beyond, the dry tracts of metaphysics, we willingly leave to speculative philosophy [11.

To me, this says that artists are granted title to the plot of ground where atom models grow. Perhaps artists are indeed the last of the metaphysicians and speculative philosophers.

In constructing my invented atom, I have freely rummaged through science's closets to locate models of the past, taking a good feature from this one and adding it to parts of another. The work of Niels Bohr [2], Louis de Broglie [3], G.N. Lewis [4], Irving Langmuir [5] and Alfred Parsons [6], as well as Erwin Schroedinger's statistical description [7], are part of my picture. Most of the work of these scientists comes from a time when models purporting to show how

electrons move around the nucleus were still legitimate. All of these models are interesting, and each poses reasonable questions. My aim as an artist is an attempt in this direction to design an atomic building block that a thoughtful creator might have planned while endowing basic matter the same reasoned beauty as the rest of the universe. Being not quite God, I have not created a model that explains everything, but my model does pose interesting questions. Since space here is limited for discussing its many features, I hope and trust that each computer-generated picture and caption will be worth a thousand words.

PORTRAIT OF AN ATOM

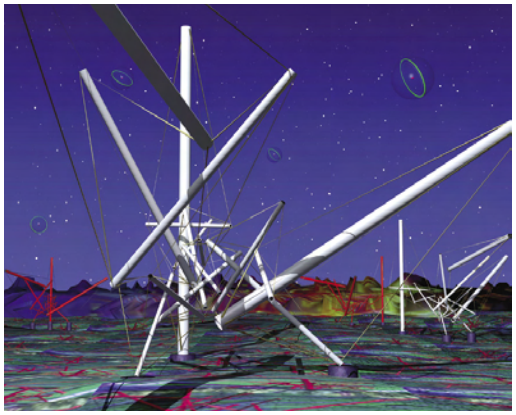

Fig. 1 *Forest Devils' MoonNight* 1989

Forest Devils *Forest Devils'Moon Night* (1989) (Fig. 1) [8] is a computer generated image with four views of my sculpture Forest Devil. The actual full-sized sculpture is made of metal tubes in compression and wire rope in tension. In this picture, through the sorcery of a 3D computer, I have placed the sculpture in an other worldly environment. The sculpture Forest Devil is an example of a complex order of push and pull forces, all resolved in a closed system. My interest in structure led me to want a better understanding of the atom, another kind of closed system of forces.

The Niels Bohr-Louis de Broglie hydrogen atom (Fig. 2) is flat-not spatial at all-but elegant, nonetheless. Described as a wave of matter, the electron in its orbit travels on specific racetracks around

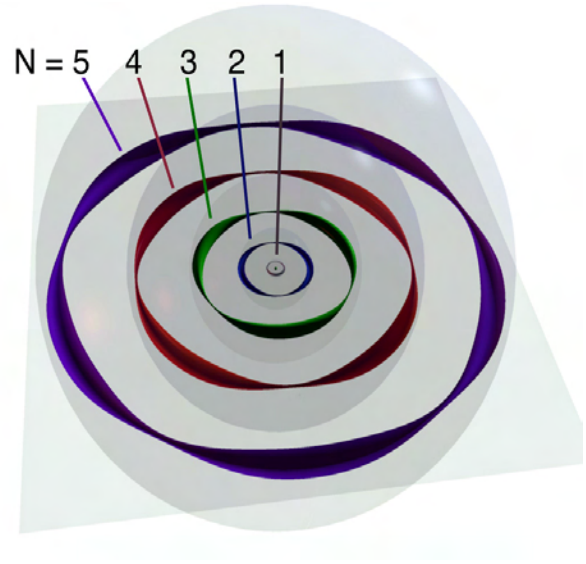

Fig. 2 The Bohr-de Broglie Hydrogen Atom Model

the nucleus. It jumps from one orbit to the next only by receiving or transmitting energy (light). just as Bohr's earlier model required the electron to perform electrical work when moving from shell to shell, so does de Broglie's. To maintain the proper wavelength at each shell, the electron flies at a unique velocity and altitude above the nucleus. In the first shell, where it travels fastest, its matter-wave is the shortest of any in the atom; there it can fit in one vibration, a single wave, like a snake grabbing its tail. In the second shell it accommodates two waves, in the third shell, three, and so on.

Markers on Bohr-dc Brogue Atom

The embellished Bohr-de Broglie picture shown in Fig. 3 is intended to illustrate a remarkable quantum feature inherent in even the simple, one-electron hydrogen atom. The little square hurdles strung around the matter-wave racetracks are simply markers similar to centimeter marks on a ruler. The distance between adjacent markers is the same as one circular trip around the ground state orbit, the electron's lowest rung on the energy ladder. I wish to show that, as the electron ascends or descends from one Bohr-de Broglie shell to the next, its matter-

wave increases or decreases at each change of shell by just this unit of measure. At shell two, each of the two waves in the picture is twice as long as the first shell's wave. At the fifth shell, where the orbit contains five whole waves, each of them is five times longer than the first shell wave. This makes the entire orbit 25 times as long as in the first shell.

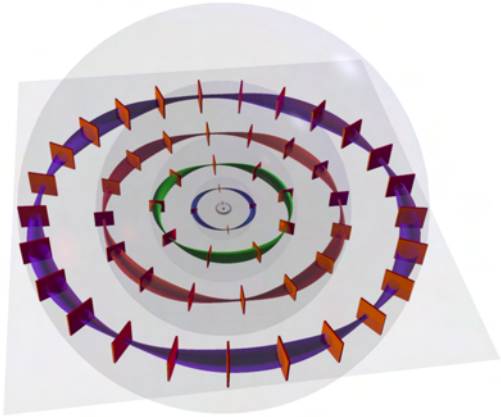

Fig. 3 Markers on Bohr-de Broglie Atom

The important point is that every shell in the atom requires the electron to have a specially assigned wavelength-a sort of bank-machine card that lets the electron into that shell. It is forever on automatic pilot, locking in at an exact altitude above the nucleus and keying its velocity and wavelength to suit that unique energy sphere.

One-Wave Orbit

Appropriating Louis de Broglie's matterwave orbit, I portray the electron as a circular wave (Fig. 4). Inside each donut orbit the particle electron is a blur, its negative electrical force diffused equally over the entire circular cloud. It shifts from one shell to another only when obeying an energy transaction-taking in or transmitting light.

Shell Two's Two Styles of Orbit

By way of endowing the Bohr-de Broglie atom with three-dimensionality, I offer the electron at shell two, where two whole waves are expected, a one-wave, auxiliary state (Fig. 5). In this optional role the electron trims down its torus circumference by half. Keeping

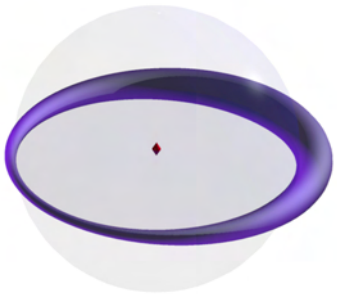

Fig. 4 One-Wave Orbit

its wavelength and velocity the same, the two-wave state is folded into a one-wave halo orbit. In the picture, the transparent cone reveals that the halo orbit, since it is not centered on the equator, projects itself in a specific direction out from the nucleus.

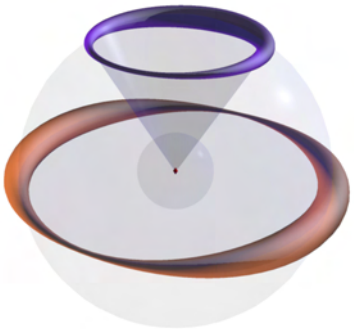

Fig. 5 Shell Two's Two Styles of Orbit

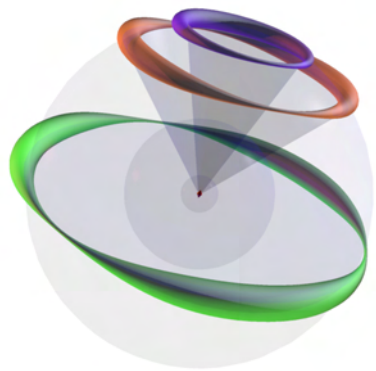

Fig. 6 Shell Three's Three Modes

Shell Three's Three Modes

At the third shell, where a three-wave orbit is expected, the electron gains yet another auxiliary form (Fig. 6). It has the following choices available for its geometrical uses and energy needs: (1) It can select its normal three-wave state at the equator, (2) it can choose an abbreviated, two-wave, displaced orbit or (3) by a final folding, it can achieve a one-wave, halo orbit. Again, the cone from the nucleus reveals how the onewave orbit comes to resemble an index finger pointing out from the nucleus. By this means, in my model, atoms achieve bonding contact with their neighbors.

Auxiliary Orbits

In Fig. 7 the hydrogen electron's entire assortment of orbital options for shells one through five is shown superimposed. The electron can be at only one of these energy levels at a time. Except for the ground level, which is its home base, each energy state is a metastable, momentary storage position for incoming and outgoing light. Those orbits lying on the equator are de Broglie's original paths. With these choices the atom has endless three-dimensional flexibility.

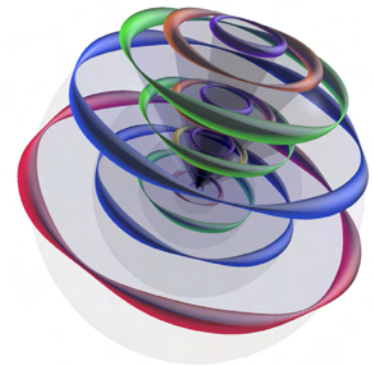

Fig. 7 Auxiliary Orbits

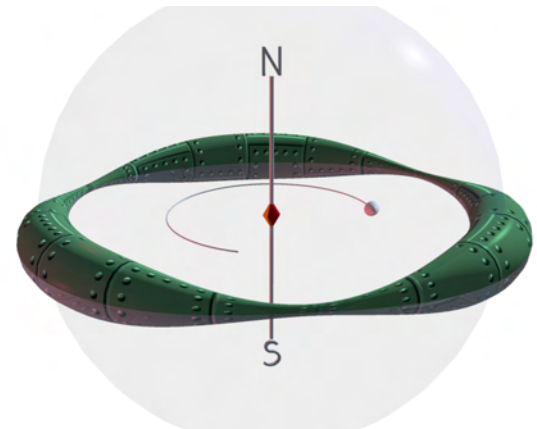

Fig. 8 Armored Orbit with Arrow Indicators

Armored Orbit with Arrow Indicators

Each matter-wave comes equipped with a set of forces that makes it seem like a small self-contained engine. In addition to its negative electricity, which binds the electron to the atom, the circulating charge generates its own orbital magnetic field. Figure 8 shows a primitive current-loop magnet with north on one face and south on the other, like heads and tails of a coin.

A third force also arises from the particle electron's circulating motion. The orbiting tiny mass of the particle generates an angular momentum that gives each orbit the stability of a guidance gyroscope.

What can possibly be the meaning of the steel cladding in this image? It is merely a graphic way of noting that matter-waves are different from light waves that pass through one another like ectoplasm. The riveted steel is a metaphor for the electron wave's powerful cushioning against encroachment by other electrons.

The matter-wave is its own shield, and its effectiveness depends not merely on electrical repulsion but on a space-filling phenomenon known in books as Pauli's exclusion principle. Pauli's numbers are a kind of inventory system used for labeling electrons in the atom. No two electrons are allowed to have the same set of identification labels any more that two theater-goers can have the same seat numbers. For my needs, I prefer to consider that Pauli's principle speaks of a physical phenomenon-an as yet unnamed force that amounts to the sum total of what we know as solid matter-and explains why we cannot walk through walls or pass our hands through tables. This elusive yet ever-present force finds its threshold at the individual electron's orbit and provides the atom with its "bones," the compressive strength that enables matter to behave as matter rather than light. Thus, the atomic electrons meet one another, not as tiny flying objects jostling about the atom, but as building blocks, each with its own set of useful forces.

A Sky Full of Atoms in Armor

Figure 9 depicts war games and jousting events with brigades of armored atoms. In this imaginary landscape, each atom's electronic clouds are clad in steel plating. All electrons act as barriers, preventing infringement of their space by other electrons in either the same atom or a neighboring atom.

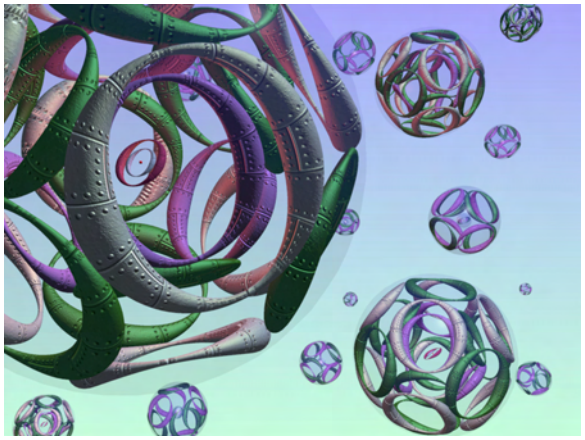

Fig. 9 A Sky Full of Atoms in Armor

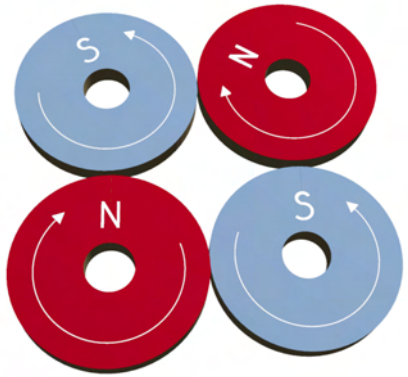

Fig. 10 Four Magnets, Antiparallel

Four Magnets, Antiparallel

An electron orbiting in a circle produces a ring-shaped magnetic field, as shown in Fig. 7. It is a planar magnet with poles arranged north to south on opposite faces. A pair of them will attract one another when edge to edge, north to south-an antiparallel association. They also attract face to face in parallel. By these magnetic means electrons can join together despite their electrical aversion to one another. The image

in Fig. 10 shows permanent magnets substituting for electron orbits. In north-south alternating arrangement, they cling together in a ring of four. As indicated by the arrows on the magnets, electrons would need to arrange their orbits with opposing clockwise and counterclockwise rotation in order to be antiparallel and attract magnetically.

Seven Spheres with Magnets of Alternating Polarity

The magnetic north-south relationships of Fig. 10 can be applied to spheres as well (Fig. 11). Spherical patterns can be formed with 2, 5, 8, 10, 14, 18 or 32 ringshaped magnets. These mosaic configurations

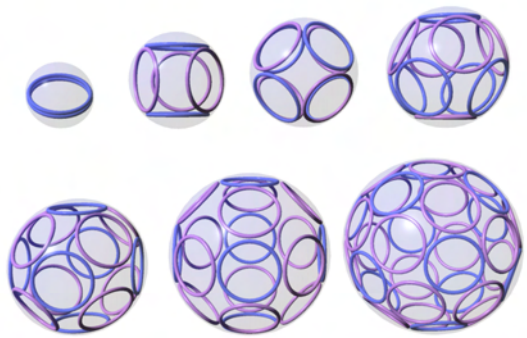

Fig. 11 Seven Spheres with Magnets of Alternating Polarity

in my atom model describe filled shells and subshells of electrons. Magnetism permits them to bond together despite their urge to fend one another off. Though the electrons' magnetic force is calculated to be far weaker than the electrical force, magnetism, in my model, becomes effective when acting within an atom that, overall, is a sphere of electrical neutrality.

Cubic Packing of Cells with Magnetic Continuity

Several of the spherical magnetic mosaics are capable of spatially repeating cell after cell with perfect magnetic continuity, each magnet touching its neighbors in an antiparallel edge-to-edge relationship. In Fig. 12, for example, the 14 magnet spheres alternate with the eight magnet spheres housed in between to form a body-centered cubic relationship. When such spatial arrays are constructed out of ring-shaped permanent magnets, if any one of the magnets is revolved by hand, all the magnets in the array will follow, rotating in a continuum similar to one big chain of gears.

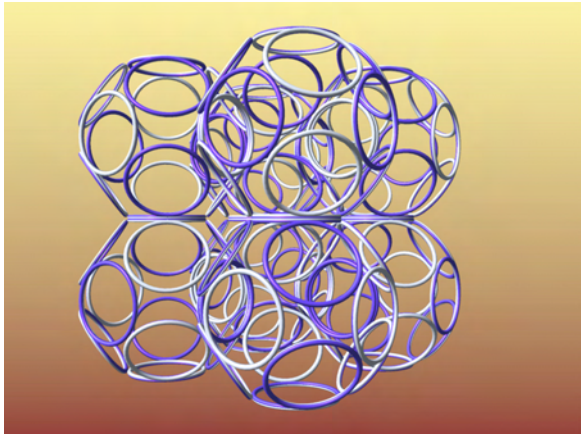

Fig. 12 Cubic Packing of Cells with Magnetic Continuity

Fig. 13 Chain Bridge Structure

Chain Bridge Structure

The spherical chain bridge shown in Fig. 13, reminiscent of a da Vinci war machine, is useful as an analogy for the atom, even though it tells only part of the story. The stones are like the electrons' orbits, which push at one another around their sphere at the same time as they are pulled toward the centerhere, by means of massive chains. These are analogous to the atom's electrical forces, which draw the electrons inwardly toward the positively charged nucleus. As sturdy solid matter, the stones press on one another with a force equivalent to the tension on the chains. In an oversimplified way, this image explains why atoms do not collapse. The structure also points out that while the atom is, all in all, a dynamic one, it ends up having static characteristics. Missing from this visual analog, though, is the electron's quantum condition, which enables even a single "stone" to avoid falling into the nucleus.

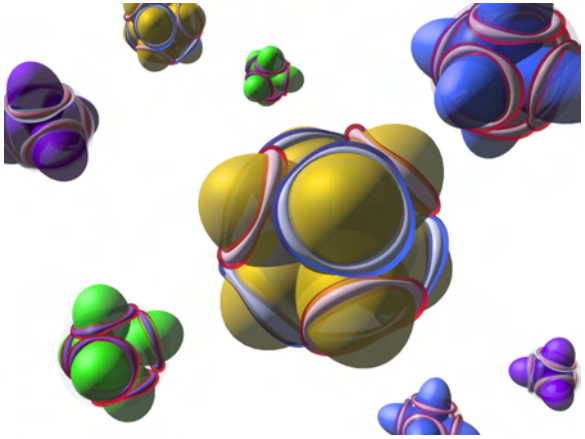

Fig. 14 Charge Clouds With Orbital Ring Collars

Charge Clouds with Orbital Ring Collars

Figure 14 shows the identity between the geometry of the orthodox balloon charge cloud atom and my orbital wave electrons. These are shown overlaid on the textbook bonding orbital balloons. In terms of probability, the electron in any one lobe spends most of its time in the fattest portion. These domains are where the electrons in my model spend all their time.

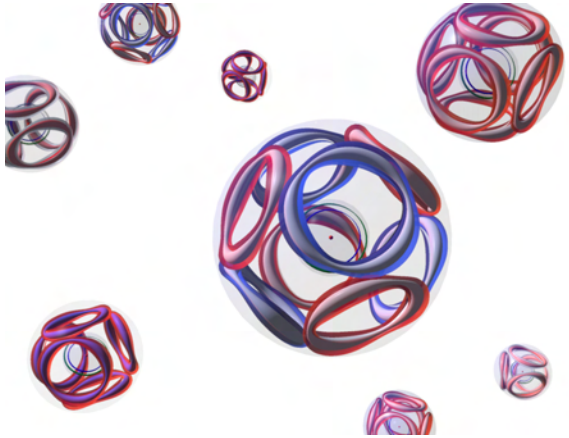

Fig. 15 Matter-Wave Configurations

Matter-Wave Configurations

The bulbous clouds of Fig. 14, which occupied most of the atom's space from the outer boundary to the nucleus, have been eliminated in Fig. 15. Remaining are the torus-like orbital waves, which all lie at a uniform distance from the nucleus. For the purposes of my model, these skeletal configurations replace the usual bonding orbital balloons of the charge cloud model.

Neon Atoms

Six wandering neon atoms plus an unidentified odd atom at the lower right are shown in Fig. 16. Each neon has 10 electrons. The two nearest the nucleus form a closed, first shell. Eight in the larger sphere form a closed, second shell. Each of these-the helium shell and the neon shell-are bound with magnetically paired sets of electrons.

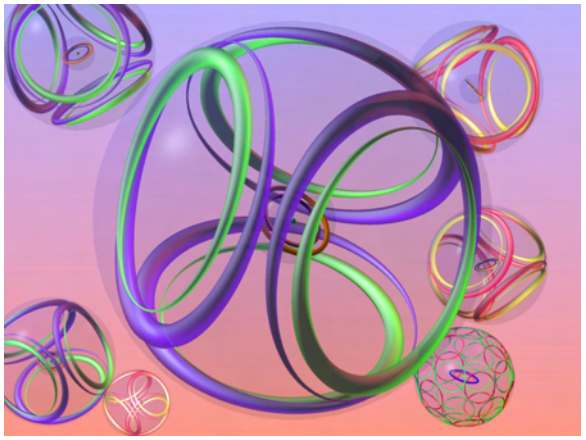

Fig. 16 Neon Atoms

C60 Soccer Ball Molecule

A picture of the C fullerene, or soccer ball molecule, composed of 60 carbon atoms linked together in a ball, is shown in Fig. 17. This elegant, icosohedrally formed molecule has attracted great scientific interest. One theory has it that, in stellar space, the soccer

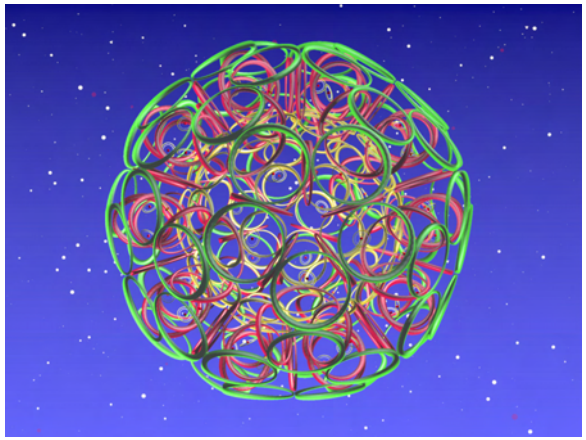

Fig. 17 C60 Soccer Ball Molecule

ball molecule's bulk may provide the holding platform necessary for simpler molecules to sustain bonding collisions with one another and give rise to organic molecules that evolve into elemental life. On Earth, various fullerenes occur in carbon soot or lamp black.

Eighty-Two Electron Atom

Shown in Fig. 18 is an example how my atom model can represent even the heaviest of atoms with all electrons stored neatly in their proper shells and subshells. This one contains 82 matterwave orbits, which, by atomic number, identifies it as an atom of lead. With the alchemy of a computer, discarding three electrons, it can readily be transmuted into gold.

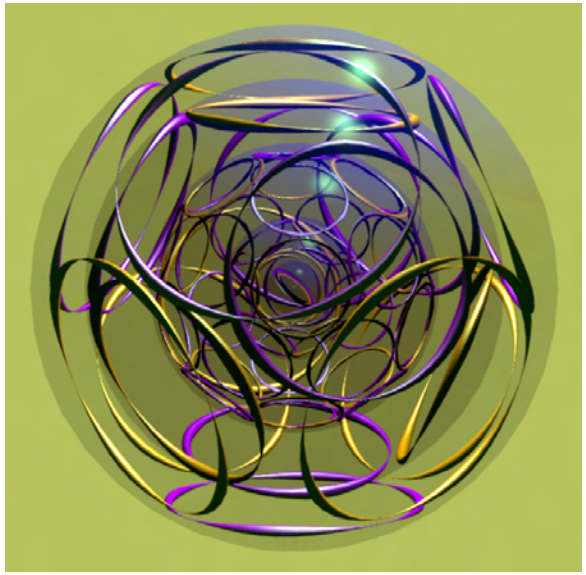

Fig. 18 Eighty-Two Electron Atom

CONCLUSION

My atom project began in 1960. Because of my interest in atomism, I have tried in many ways and through many different media -- sculptures, drawings, writing and computer pictures -- to transform the atom's form into an art form (Color Plate A No. 2). It took more than 5,000 years for the artists of China to develop a great art based on the form of a dragon, surely as elusive a creature as the atom. Sinuous, writhing and frightening, the dragon lent itself to wonderfully inventive

and appealing images. Perhaps the invisible atom, because of its closed symmetry, is a tougher challenge for making art. On the other hand, my solitary project has consumed a mere 34 years. In another 30 years, if I still feel humbled by the bronzes and jades of the Shang and Zhou artists, I vow to abandon picturing the atom and take up the dragon.

References and Notes

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2. See Niels Bohr, Collected Works, Vols. 2, 3 and 6,J. Rud Nielsen, ed. (Amsterdam: North Holland; New York: Elsevier, 1972-1977); see also Niels Bohr, "On the Constitution of Atoms and Molecules" (1913), reprinted in On the Constitution of Atoms and Molecules: Papers for the Philosophical Magazine with an Introduction by L. Rosenfield (Copenhagen: Munksgaard Ltd.; New York: W.A. Benjamin, 1963).

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6. See AL. Parsons, "A Magneton Theory of the Structure of the Atom," Smithsonian Miscellaneous Collections 65, No. 11 (1915).

7. Erwin Schroedinger, "Quantization as a Problem of Proper Values (Part III)," Annalen dec Physik 80, No. 4 (1926).

8. For a color version of this artwork, see Digital Image-Digital Cinema, SIGGGRAPH '90 Art Show Catalog, supplemental issue of Leonardo (1990) p. 84.

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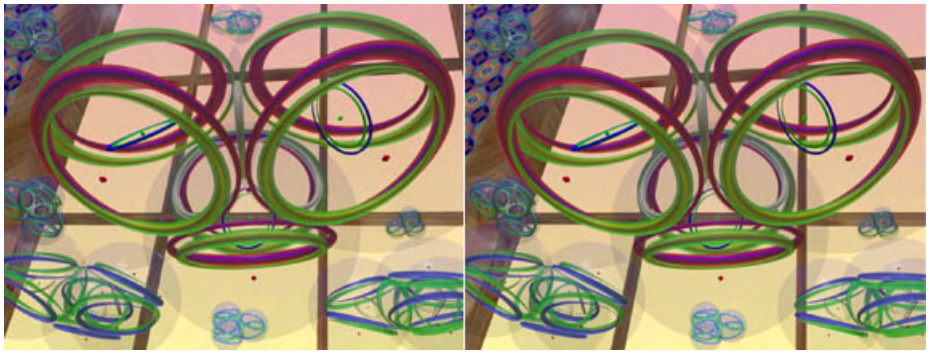
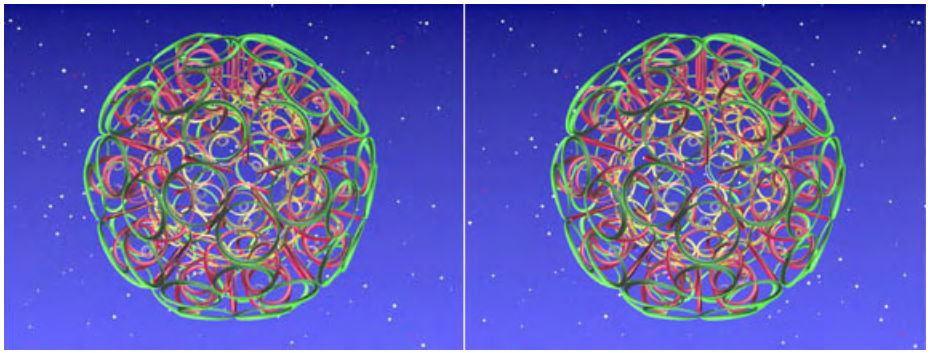


(a) *Invasion of Cyclopropane*



(b) *C60 Soccer Ball Molecule*

No. 2. Kenneth Snelson, computer-generated stereo slide pairs, 1989. (a) Invasion of Cyclopropane. (b) C60 Soccer Ball Molecule. The double images of each of these stereo slide pairs can be seen as apparently three dimensional through “free fusion.” To achieve stereopsis, the viewer holds the paired images about 16 inches from the eyes and gazes at the image without actually focusing on it, almost as if viewing a distant planet. This should reveal not two but three frames, the center one being a combined overlay fusion of the two real pictures. The next step may not be so easy at first, but it can be learned with practice: without permitting the central image to evaporate, one lets the eyes slowly focus on the central frame that combines both pictures. When successfully done, the reward will be rather magical -- a vision of the scene in stereo without a stereo viewing device.