ABSTRACT:

Niels Bohr's atom model of 1913 was abandoned by science over eighty years ago yet it is still introduced in all science classrooms and it remains famous the world over as the cartoon-symbol meaning "atom". In the dramatic causal/acausal debates of the 1920s, the Copenhagen people who argued to disallow any further "reality" atom models were declared the victors. Among the ideas left behind in the rush to get rid of physical models entirely was Louis de Broglie's adaptation of Bohr's model in which he replaced orbiting electrons with matter-waves. De Broglie's atom is remembered in classrooms but is given short shrift on the way to introducing wave mechanics that Erwin Schrödinger developed in 1926 after learning of de Broglie's matter wave theory. As an artist whose work and interest concerns fundamental structure, I became fascinated as far back as 1960, in developing a more complete picture of an atom for those still willing to speculate about a reality model, the kind physics gave up on so very long ago. This is what my paper is about: a qualitative reinterpretation of de Broglie's model of the hydrogen atom.

AN ARTIST'S MODEST PROPOSAL A VISUAL MODEL OF THE ATOM HOMAGE TO PRINCE LOUIS DE BROGLIE

"Systems scientific come and go. Each method of limited understanding is at length exhausted. In its prime each system is a triumphant success; in its decay it is an obstructive nuisance."

Alfred North Whitehead "All physical theories, their mathematical expression apart, ought to lend themselves to so simple a description that even a child could understand them."

Albert Einstein

"The dilemma posed to all scientific explanation is this: magic or geometry?"

Fig. 1 "Easy Landing", one my sculptures; sited at Baltimore's Inner Harbor.

Scientists who have grown up with quantum physics have been taught that all atomic problems were solved many years ago with wave mechanics and quantum mechanics. Though this may be so from the view of a physicist the one important question that has never been answered concerns the workings of the atom's electrons: How do they move or René Thom



Kenneth Snelson, Easy Landing 1977; 30' x 85' x 65', Baltimore, MD

circulate about the nucleus? How do these submicroscopic electrical particles give rise to the atom's architecture? Because it is impossible to see an atom up close and watch its electrons in action, such questions can be answered only by speculative reasoning, by creating a reality model the kind that the great majority of scientists have shunned for the past eighty years.

Fig. 1

The debates that took place in the 1920s, especially during the fifth and sixth Solvay Conferences of 1927 and 1930, settled the question of "real" atom models versus

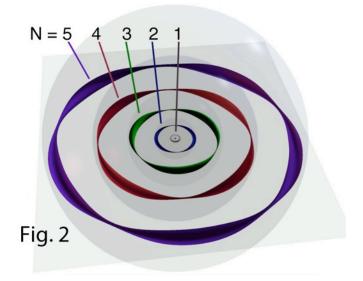
abstract non-visual mathematics in favor of Niels Bohr and his Copenhagen world view. There were to be no further atom models that purport to describe events that cannot be tested by experiment; visual models that could be in violation of Heisenberg's uncertainty principle. From that time on students gifted with visual sensibilities and imagination have been warned to avoid quantum physics.

Among the list of great men in that remarkable 1920s quantum-theory drama the physicist who has especially interested me is Prince Louis de Broglie who played a curious on-the-fence role during the causal/acausal worldview debate. His story is unusual: Louis de Broglie, was a young French physics student in Paris, when he published his doctoral dissertation in 1924 *Recherches sur la théorie des quanta* in which he proposed that just as Einstein had shown light to have a dual nature -- acting both as light-waves and particle-photons -- matter should also have a dual character. De Broglie hypothesized that the electron can act as a wave as well as a particle.

(Figure 2) As an example he used Bohr's hydrogen atom's electron. De Broglie calculated that his matter-waves fit perfectly in velocity and wavelength around Bohr's hydrogen atom model's quantized concentric orbits. In the first shell closest to the nucleus a single wave could fit in like a snake grabbing its tail. In shell two, two waves fit in; three waves in shell three, etc.

Two years later, 1926, Erwin Schrödinger adapted de Broglie's matter-wave idea to create the Schrödinger wave equation which soon became one of the principle tools of quantum physics. In 1927 the Davisson Germer experiment proved that there are indeed electron matterwaves, that de Broglie waves are a fact of nature.

When Louis de Broglie submitted his dissertation he believed his matterwaves described reality, the actual condition of the electron in the atom. Because his wave idea was



subsumed and transformed from real waves into non-visual mathematics de Broglie decided during the 1927 Solvay Conference to join with the Copenhagen group and to concede that matter-waves were only fictional abstractions. Prince Louis de Broglie was awarded a Nobel prize in 1929 for his discovery of matter-waves.

Twenty-five years later a mature de Broglie looked back and reversed his belief once more, deciding he had been right in the first place, that his original "real" matter-waves could be developed (somehow) into a physical model. Though it never happened in his lifetime, he continued to believe in the possibility of a de Broglie-wave *real* model until the day he died in 1987 at the age of 95.

Today, after these many years, a search on the web will show that in classroom lectures, more often than not, professors recite the story of Bohr's hydrogen model then introduce de Broglie's matter-wave theory, moving on immediately to Schrödinger's wave equation without ever mentioning that de Broglie first demonstrated his theory in his 1924 paper by applying it to a matter-wave model of the hydrogen atom.

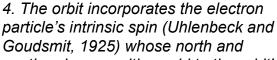
So begins my fantasy, a structural model-builder's interpretation of the Bohr-de Broglie atom model with its matter-waves vibrating in quantized circles surrounding the atom's nucleus. Perhaps I can resurrect and build upon Louis de Broglie's vision. As an artist, not a scientist, the language I use and the way I present my imagined atomic structure is surely out of key with the language expected of scientists. I hope that with the help of illustrations I can convey my mind's vision of the quantum atom. Despite the broadly accepted and celebrated Copenhagen Interpretation of quantum physics I am still convinced, as I have been since I first began imagining my *artist's atom* fifty years ago, that the atom is an elegant submicroscopic machine with its own quantum rules, not a puzzle so unworldly and so far from logical understanding that its workings will remain forever beyond human comprehension.

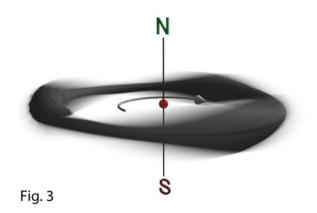
The quantum physicists' debate in the 1920s boiled down to the question of electron orbits versus no electron orbits. My atom model retains de Broglie's circular standing waves; call them orbits. I believe it is fair to describe de Broglie's matter-wave electron with its pilot wave continuity as an object in itself; an object comprising the following list of properties, Figure 3:

 As with Bohr's quantized electron, a de Broglie orbital wave remains at an energy shell and can move from one shell to another only by absorbing or transmitting light-energy.
The electron's negative electric electric energy.

charge is smeared over the orbital circle's circumference. 3. The de Broglie orbit has both orbital

magnetism and top-like angular momentum.





south poles can either add to the orbit's magnetism or, by inverting, subtract from it. 5. De Broglie matter-waves are matter-like. As with macro pieces of matter, de Broglie waves occupy exclusive space. Orbits cannot be in the same space at the same time. Figure 4: The diagram represents the electron's wavelength and its related velocity. The matter-wave stretches and shrinks, always in quantized steps. When the electron's speed increases its de Broglie wavelength shrinks by a quantized unit and vice versa; much like striking different notes on a piano, not like a glissando on a slide-trombone.

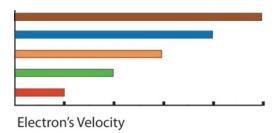
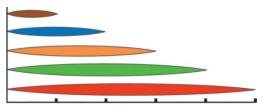
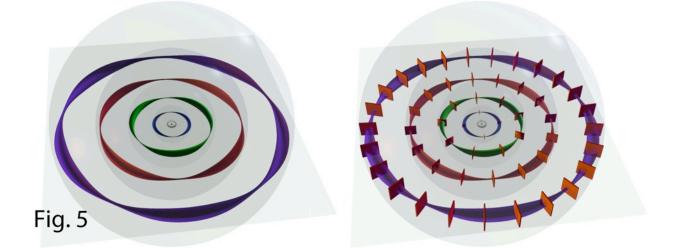


Fig. 4



Electron's de Broglie Wavelength

Figure 5: To the left is de Broglie's atom. To the right is the same image except that square hurdles are added marking how the electron's velocity-change effects the **length** of the waves from one energy level to the next. The ground shell's one-wave circle is the electron's "quantum yardstick", the unit the wavelength grows by at each larger orbit. Throughout the concentric shells, the distance between the red hurdles is the same length as the circumference of the ground state orbit. Yes, the second shell has two de Broglie waves but it is important to notice that each of its waves is twice the ground state wave's circumference. The third shell has three waves and each wave is three times the length of shell one's circumference, and so on from shell to shell.



At each higher shell or orbit the electron slows down and increases its de Broglie wavelength by one notch. This quantization was of course the main feature of Niels Bohr's 1913 atom model and its orbital jumps matching the energy changes indicated in the hydrogen's spectrograph.

In examining de Broglie's wave adjustment from shell to shell, I believe it deserves a closer look and a somewhat different interpretation. Instead of simply describing that "at each larger shell the matter-waves are longer", this remarkable quantum mechanism can be stated differently: *At each shell the electron acquires a unique wavelength and velocity, a special combination, a code number workable only at that particular energy level.* Or: *the electron requires a passkey at each energy level in order to enter the shell.*

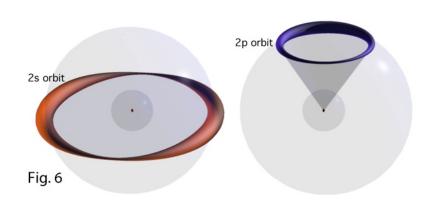
Considered this way the de Broglie matter-wave electron can be thought of in a way quite different from the left-over image of Bohr's planetary particle circling the nucleus.

My hypothesis is that the matter-wave electron's relationship to the shell's electrical field is based not on the rule of astronomy, a planet orbiting the Sun at its equator, but on the "passkey" principle: that the electron's velocity and wavelength determine which energy sphere the matter-wave is allowed to attach itself to and that it can attach itself to **any portion** of the quantized electrical sphere.

Of course this central principle in my atom model defies the world-wide, popular image, of tiny planet-electrons circling the nucleus, a picture that has been carved in stone in the public's mind for the past hundred years. Strange and even improbable as non-equatorial matter-wave orbits may seem at first, I hope to demonstrate that they are both attractive and highly useful.

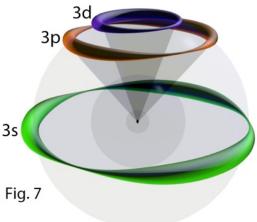
Figure 6 illustrates the freedom the electron gains with small- circle orbits. On the left, at the second shell, the electron keeps its *great circle* equatorial two-wave de Broglie orbit (the 2s state).

On the right in Fig. 6 is its new option: a single-wave orbit having the same



velocity/wavelength as the standard 2-wave orbit. Because it is only half the size, unable to surround the equator, the one-wave orbit takes up space on a small meridian of the sphere and becomes a 2p electron. Because it completes its circle in half the time of the 2s state and because, as its transparent cone shows, the orbit extends outwardly relative to the nucleus, intuition tells me that it will to give rise to a stronger orbital magnetism than the 2s state. Figure 7: At the third shell, de Broglie's original three-wave equatorial orbit is the 3s state. Reduced to a two-wave orbit, it becomes the 3p state. The final one-wave orbit is the 3d state. The velocity and wavelength the 3s, 3p and 3d are the same. The smaller the orbit on the shell, the farther it projects away from the nucleus.

What causes electrons to form orbits with fewer whole waves? Matter-wave orbits in my model F cannot occupy the same space at the same time. As with passengers in a packed subway car, electron orbits packed on shell crowd one another, pushing all occupants into one-wave states.



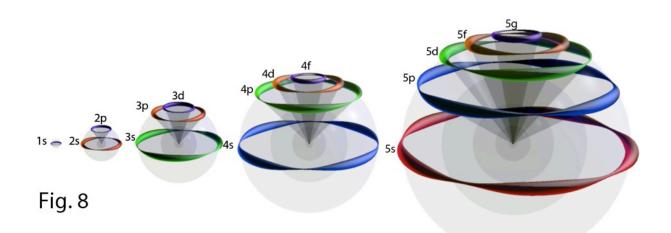
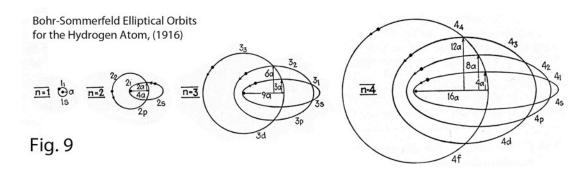


Figure 8 Represents the full range of orbits available to hydrogen atom's electron, from the first shell through the fifth. The s,p,d,f... labels are derived from of the *old quantum theory* and Arnold Sommerfeld's elliptical orbits of 1916 which were intended to satisfy the azimuthal quantum number symbolized by *l* (lower-case L). The *l* quantum number describes the electron's angular momentum for orbits at each shell. Sommerfeld's "ellipses" varied from true circles, to ovals, to straight lines.

Figure 9. Sommerfeld's orbits shown here for shells one through four are from Harvey Elliot White's 1934 *Introduction to Atomic Spectra*. The straight-line orbits, have zero angular momentum, the electron's trajectory is a pulsation in and out from the nucleus like a sewing machine needle. The rounder the orbit's oval the greater its angular momentum.



Though de Broglie's matter-waves represented a markedly different conception from Bohr's orbiting electron, and despite Sommerfeld's ellipses reaching out from the nucleus, both physicists' atoms were flat as a pancake.

It was largely for this reason that chemists in the 1920s took no interest in Bohr's quantized hydrogen atom model. Chemistry required three-dimensional atoms in order to build molecules. As early as 1902, the American chemist Gilbert Newton Lewis made sketches of an "octet atom", simply a cube with an electron at each corner. Irving Langmuir, a chemist and physicist, extended Lewis' atom by adding shells surrounding the nucleus with pockets to hold additional of electrons. By 1916 most chemists would have been familiar with the Lewis-Langmuir model. Physicists ignored it completely since it failed to explain how the electrons could stay fixed in space around the nucleus. Irving Langmuir wrote a list of eleven postulates describing the Lewis-Langmuir atom model. Postulates 2 and 3 read:

2. The electrons in any given atom are distributed through a series of concentric (nearly) spherical shells, all of equal thickness. Thus the mean radii of the shells form an arithmetic series 1, 2, 3, 4, and the effective areas are in the ratios $1 : 2^2 : 3^2 : 4^2$.

3. Each shell is divided into cellular spaces or cells occupying equal areas in their respective shells and distributed over the surface of the shells according to the symmetry Postulate 1. The first shell thus contains 2 cells, the second 8, and third 18, and the fourth 32.

I believe that if de Broglie's matter-waves had been understood to be real "matter" not merely vaporous clouds infiltrating one another's space, they could have helped Langmuir explain how his atom's electrons were able maintain their positions in shells surrounding the nucleus.

By what structural rationale do the electrons in my model remain stable in these confined halo states?

1. An electron can sustain its matter-wave orbit only at its unique energy shell, the energy level that suits its passkey velocity and wavelength.

2. Since it can remain only at its prescribed shell, the electron wave can neither fall into the nucleus nor find a place in a fully occupied lower shell because, as in musical chairs, each electron needs its own place to sit, its own set of four quantum numbers.

- 3. A matter-wave orbit is like solid matter, a barricade to other matter-waves. In my model the individual electron's matter-wave "solidity" barrier is the physical expression of Pauli's exclusion principle.
- 4. Magnetism, both orbital and spin, assist matter-waves in linking together, to overcome their mutual electrical repulsion.

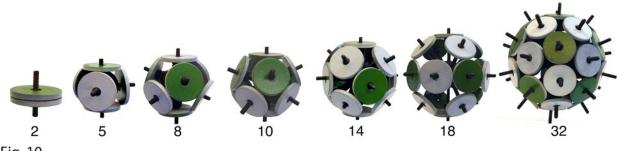


Fig. 10

Figure 10 is a photograph of small geometric figures composed of equal diameter ceramic magnets. These seven magnet-mosaics contain 2, 5, 8, 10, 14, 18 or 32 identical magnets. Mounted on armatures the magnets cling together edge-to-edge in magnetic antiparallel, with north poles touching only south poles, etc., like magnetic, spherical, checkerboards. If one of the magnets is made to rotate by hand the others follow as a gear train. If the magnets were current loops instead of permanent magnets each loop's current would flow in the reverse direction from its neighbors'.

These magnet spheres are useful for visualizing and for counting electrons in accord with the aufbau principle of building shells and subshells in the periodic table of elements. Their geometry corresponds to Lewis' and Langmuir's electron shells.

THE FUNCTION OF THE ATOMIC ELECTRONS' MAGNETIC FORCE

In textbook comparisons the strength of spin plus orbital magnetism combined is calculated to be but a hundredth that of the electrostatic repelling force of free-electrons. In my model's architecture this overwhelming hundred-to-one comparison applies only to electrons outside the atom, not to atomic electrons. Once on the inside, the particle electron's electrical force is depleted the moment it enters the atom, drawn in with the purpose of equalling the nuclear protons' positive field, which makes the atom electrically neutral. The result is that, with all electrical forces nulled, it is the orbits' combined spin and orbital magnetism and their companion gyroscopic angular momentum that remain in full-strength. The electron-to-electron *long-distance* electrical repulsion is readily superseded by the de Broglie matter-waves' (Pauli) repulsion, an incontact force. It is these long-undervalued forces that are free to interact orbit-to-orbit, to conduct energy transactions, to link with other atoms, to form molecules and crystals, to arrange north/south magnet alignments and to instantaneously rearrange their geometry to maintain the tiny atom-machine's most efficient energy-efficient

configuration.

An analogy, substituting gravity for electricity: a beached great Blue Whale weighs as much as two-hundred tons, yet, in its ocean world, buoyed by the water it displaces, the giant whale is effectively weightless. The whale's apparent weight loss does not reduce its enormous mass which is still two-hundred tons. By analogy, though the electrons' Coulomb forces are nulled, their several remaining forces stay the same, preserved in full-strength.



Fig. 11 is a computer rendering of an imagined many-electron atom.

More information about my atom model and other works can be found at <u>www.kennethsnelson.net</u>

Also, in these U.S. Patents:

Snelson, K 1965, *Continuous Tension, Discontinuous Compression Structures,* U.S. Patent 3169611 Snelson, K 1966, *Model For Atomic Forms*, US Patent 3276148 Snelson, K 1978, *Model For Atomic Forms*, US Patent 4099339 Snelson, K 1997, *Magnetic Geometric Building System*, US Patent 6017220 Snelson, K 2004 *Space Frame Structure Made By 3-D Weaving of Rod Members*, U.S. Patent 6739937

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