New hypothesis shows geometry of atomic nucleus

Part 2 of an interview with Dr. Robert Moon, a pioneer in American nuclear and fusion energy development, on his recent discoveries.

In Part 1 of this interview, nuclear physicist Robert Moon discussed some of the formative experiences in his life which led to his becoming a scientist. Dr. Moon was one of the pioneers in the development of nuclear energy. Before World War II, he developed the most advanced cyclotron then known, and plans to build a synchrotron, which were prevented from being realized, by the outbreak of war. After the war he became intensely interested in research in neurophysiology, and was involved in the development of the CAT scan. He is a professor emeritus at the University of Chicago, and the editor-in-chief of the International Journal of Fusion Energy. *Dr. Moon was interviewed by Carol White.*

White: Before going into your most recent discoveries, would you please mention some of the work which you took part in during the war, for example the Manhattan Project.

Moon: During the 1930s we discovered that the cyclotron was a very good source of neutrons. We worked with deuterons, which are "heavy" isotopes of hydrogen. Their nucleus contains one proton and one neutron (the neutron is really a proton with an electron condensed on it) as opposed to ordin proton).

We found that by accelerating deuterons in the cyclotron, the charged part of the nucleus, the proton, would be left behind when the accelerated deuteron beam passed through a material target. Thus only neutrons emerge from the material target.

White: So you were able to turn the cyclotron which you had built at the university to good use, for the Manhattan Project?

Moon: Yes, indeed! We were able to utilize cyclotron-generated neutron beams to carry out many of the researches that were essential for the success of the World War II Manhattan Project. For example, with the cyclotron-generated neutron beam, we were able to explore the properties of graphite, in particular how neutrons interacted with the carbon nuclei in graphite. This was most crucial for the development and realization of the first nuclear pile—the first nuclear fission reactor.

White: The first nuclear reactor in the world was the one you built at Chicago, wasn't it?

Moon: It was. In order to get a chain-reaction going, we had to be able to slow down the neutron flux sufficiently to allow fission to take place; but on the other hand, we could not let the process get out of control, or we would have had a major accident. So we were very concerned with questions of nuclear safety even then.

One of the things we worked on with the cyclotron, was the development of a graphite moderator which would slow up the neutrons. At the time of the Manhattan Project, this was one of the three ways of doing this available to usy, "light" hydro

We rejected the alternative of using beryllium, although this is a beautiful metal. We had the abstract possibility of using beryllium as a moderator, but unfortunately, at that time we knew nothing about its metallurgy. No one had produced the metal yet, and we didn't have enough of it for a reactor.

There was the possibility of using heavy water. This was the route which the Germans took in their attempt to build an atomic bomb. Heavy water is water in which the ordinary light hydrogen in the H_2O is replaced with deuterons—heavy hydrogen. We had some, but not enough for a nuclear pile.

The third, graphite, was the one we chose. One reason was its availability to us. Chicago was then a great steel-producing center. This is no longer the case. They have shut down the Southworks and other major steel-making facilities. In any case, at the time, they were producing large blocks of graphite, about four feet long and four inches square, for use in steel-making. These blocks had rounded corners.

We tested this graphite and we used the cyclotron to do it. We would place a pile of these graphite blocks in front of the neutron beam emerging from the cyclotron target and see how long a neutron would last—bounce around within the graphite pile. That is, we would measure the lifetime of the neutron within the graphite pile.

This led—to our very great surprise—to the finding that the graphite blocks taken from the center of a production batch contained very pure carbon—graphite with very few impurities. This is quite important, since it is impurities which generally absorb neutrons, and we wanted to slow them up but we did not want them to be absorbed. When the graphite was produced, carbon would be pressed into blocks and a large electrical current would be passed through a pile of these blocks.

In this way graphite would be formed. But also the impurities in the carbon would diffuse out from the center of the pile, leaving very pure graphite blocks in the center—very close to pure carbon. And it was these pure carbon graphite blocks that we used as the neutron moderator in our first fission pile.

We built the first nuclear pile out on the squash court. They had to stop playing squash so we could build a reactor. It was a cubical design. But actually, since it was supported from the outside, the pile of graphite blocks which supported the uranium lattice, looked something like a football. I guess this was very apropos, since the squash court was part of the football field.

The graphite was supported all the way round. If OSHA had been around I don't think we could have gotten the thing made, because we had to cut off these round corners on the graphite blocks. We did it by using an end-mill on the graphite, so we all came out pretty black. I am sure that if they knew what we were doing, they would have shut us down, that is, if OSHA had existed at that time.

But, anyway, the pile was built and first ran on Dec. 1, 1942. It may seem that I am getting too much into the history, but I just wanted to give you a taste of how exciting it was.

White: Not at all. Tell me, what was your reaction, in 1939, when you first learned that Lise Meitner and Otto Hahn had demonstrated the existence of nuclear fission?
Moon: We were very shocked. Remember, Hitler was in power in Germany then, and we all knew that war might break out at any moment. A colleague, Aristide von Grosse, went over to Germany to confirm the reports we were hearing. He talked to the German physicists, Otto Hahn and Leo Strassman, and von Grosse brought the message that it was true, back to the physical chemistry department where I was then doing all of my work, all of my nuclear work.

We had several meetings in which we tried to decide what to do. We recognized the military potential of this even then. We checked out some of the things and found that it was really so, that nuclear fission was really taking place when neutrons bombarded uranium.

White: Were you worried?
Moon: Absolutely. The physicists had all decided never to tell anybody about it, but of course it wasn't really possible to keep such a major discovery a secret. We were given $2 billion to do the Manhattan Project. We recognized the necessity of proceeding with the Project, because we learned that the work was ongoing in Germany.

I do want to emphasize that, on the whole, not only were we concerned about the implications of developing such a destructive weapon, but we always talked about the spiritual and the moral implications of nuclear power. We questioned whether the world was ready for nuclear energy. It produced more energy, about 5 million times more energy per gram of fuel than that produced by combustion. What would this mean to industry, how would it change our way of life? That was always a question. We talked about that all throughout the project.

White: What was it like to be working on the Manhattan Project?
Moon: The most important thing was the way in which we were able to share ideas. That's important in the whole development of anything, the sharing of ideas with one another. We met and freely discussed our thoughts three times a week, despite attempts by the Army representative, General Groves, to impose security guidelines upon us, which would have compartmentalized our activities. Everyone participated in these discussions, regardless of sex, race, religion, or anything.

That was very good. It created an atmosphere in which everyone's creativity was increased, and some of our best ideas came from some of the youngest members of the group.

White: What other lessons can be learned from the way that the Manhattan Project was organized?
Moon: Another thing was that this was a genuine crash program. Work was done in parallel rather than sequentially. We started building in Oak Ridge, Tennessee, and in Los Alamos, New Mexico, and in Hanford, Washington, all at the same time, all together. Each site concentrated upon a different aspect of the problem. We didn't worry about cost accounting, and making sure that no mistakes were made on the way. We didn't put them in series: "If that happens, and that, and it works, then we will do this or do that," but we

did it all together. And it worked very well.

I will say that when we first got the Hanford reactor going and then shut it down, we couldn't get it to start up again. That turned out to be caused by an isotope with a very high capture cross-section for neutrons. This isotope had a half-life of about three days. So the reactor stayed shut down for three days and then it started right up. So we learned a lot of things that we didn't know about in nature.

White: Can we jump to more recent times? Please tell us your thinking about the structure of the nucleus.
Moon: Let me review the von Klitzing quantum Hall resistance experiments, first.

We published several articles on Klaus von Klitzing's work in *Fusion* and the *International Journal of Fusion Energy*. He is a German who looked at the conductivity of very thin pieces of semiconductor. A couple of electrodes are placed on it. The electrodes are designed to keep a constant current running through the thin semiconductor strip. A uniform magnetic field is applied perpendicular to the thin strip, cutting across the flow of the electron current in the semiconductor strip. This applied magnetic field, thus, bends the conduction electrons in the semiconductor so that they move toward the side. If the field is of sufficient strength, the electrons become trapped into circular orbits.

This alteration of the paths of the conduction electrons produces what appears to be a charge potential across the strip and perpendicular to the original current flow.

White: This produces a resistance?
Moon: That's right. If you measure this new potential as you increase the magnetic field, you find that the horizontal charge potential will rise until a plateau is reached. You can continue to increase the magnetic field without anything happening, within certain boundaries, but then once the magnetic field is increased beyond a certain value, the potential will begin to rise again until another plateau is reached, where, within certain boundaries, the potential again does not increase with an increasing magnetic field.

White: What exactly are you measuring?
Moon: The Hall resistance measures the voltage across the current flow, horizontal to the direction of the original current, divided by the original current. That is the Hall resistance. It was this particular experiment which provided the immediate spark leading to the development of my model.

Of course all of this was done, by von Klitzing, at liquid hydrogen temperatures to keep it cool and prevent the vibration of particles in the semiconductor lattice, a silicon semiconductor. The current was kept constant by the electrodes embedded in it.

White: So what you had was essentially like a two-dimensional fluid.
Moon: Yes, and under these special conditions, as the current is plotted as a function of the magnetic field, we find that plateaus emerge. There are five distinct plateaus. At the highest field strength the resistance turns out to be 25,812.815 Ohms. As we reduce the field, we find the next plateau at 12,906 Ohms, and so on until after the fifth, the plateaus become less distinct.

The theory is that the strong magnetic field forces the electrons of a two-dimensional electron gas into closed paths. Just as in the atomic nucleus, only a definite number of rotational states is possible, and only a definite number of electrons can belong to the same state. This rotational state is called the Landau level.

So what we have here is a slowly increasing magnetic induction, and resistance increases until plateau values are found. At these values, there is no further drop in voltage over a certain band of increased magnetic induction. Some electrons now appear to travel through the semiconductor as if it were a superconductor.

The question which I asked myself was, why at higher field strengths did no more plateaus appear? Why did no higher plateau appear, for example at 51,625 Ohms? At the lower end it was clear what the boundary was—at the point at which six pairs of electrons were orbiting together, the electrons would be close-packed, but the magnetic field was too weak to create such a geometry. However, I asked myself what the limit was at the upper end.

White: Is this what led you to your model of the structure of the atomic nucleus?
Moon: That's right. I started out by considering that the orbital structure of the electrons would have to account for the occurrence of the plateaus which Klitzing found, and I realized that the electrons had to be spinning together in pairs as well as orbiting. That was the significance of the upper boundary occurring at the value of 25,000-plus Ohms.

I first concluded that this happens because the electron has a spin. It spins around its axis, and when it spins about its axis, a current is produced by the spin, and a little magnet is produced by the spinning charges.

According to Ohm's law, the current is equal to the field divided by the resistance, so that the resistance is equal to the field divided by the current. Klitzing found that the resistance in the last plateau was 25,812 Ohms. I wanted to find out why this was the last distinct plateau.

First of all I realized that the electrons seem to like each other very well. They travel in pairs, so that one will spin in one direction and the other in the opposite direction. They seem to like to go around in pairs, especially in solid-state materials such as semiconductors. The spins will be in opposite directions, so that the north pole of one will match up with the south pole of the other.

White: Isn't this like the formation of Cooper pairs in a superconductor?
Moon: Precisely. When the Landau number is 1, we have

two spinning electrons oriented north to south pole, which also orbit each other. The resistance is reduced and the Landau number increases at the next plateau, so that two spinning pairs of electrons orbit each other, and so on until we reach the fifth plateau. I began to wonder what was really being measured here. The answer turns out to be very exciting.

Well, as long as we are limited to a two-dimensional space, then we see that by the time we get six pairs orbiting, we will have close packing. We see a geometry emerging, a structure of the electron flow in the semiconductor.

Now, the Hall resistance is determined by Planck's constant divided by the ratio of the charge squared. But we also find this term in the fine structure constant. Here, however, the Hall resistance must be multiplied by the term $\mu_0 \times c$ [$c =$ the velocity of light]; in other words we must take the ratio of the Hall resistance to the impedance of free space. We can look at this as a ratio of two different kinds of resistance, that within a medium to that within free space itself.

This led me to look for a three-space geometry analogous to that which I had found in the two-dimensional space in which the Hall effect takes place. I began to wonder how many electron pairs could be put together in three-space, and I saw that one might go up to 68 pairs plus a single electron, in order to produce 137, which is the inverse of the fine structure constant.

Well, that's the way ideas begin to grow. Then it becomes very exciting. And then you begin to wonder, why these pairs, and why does this happen?

It is common today to write formulae neglecting the units of measurement and values, such as magnetic permeability and the dielectric constant. The question of the standard of measurement is obscured, and even more important, the question of the structure of space is ignored. This takes the student away from the reality of an experiment, where the permeability of free space, or of a particular medium is crucial—for example, in the simple case of a condenser.

White: Am I correct that you were seeking a structure of space which would correspond to the way in which a semiconductor structured electron flow?

Moon: That's right. The velocity of light times the permeability of free space is what we call the impedance of free space. There is something very interesting about the impedance of free space. According to accepted theory, free space is a vacuum. If this is so, how can it exhibit impedance? But it does. The answer, of course, is that there is no such thing as a vacuum, and what we call free space has a structure.

The impedance of free space is called reactive impedance, since we can store energy in it without the energy dissipating. Similarly, radiation will travel through a vacuum without losing energy. Since there is no matter in free space, there is nothing there to dissipate the energy. There is nothing for the radiation to collide with, so to speak, or be absorbed by, so the energy just keeps there. This is what we call the reactive component.

It is "reactive," because it does not dissipate the energy, but is passive. And this equals 376+ Ohms. This reactive impedance is one of the important components of the equation of the fine structure constant.

The equations for the fine structure constant will always involve the ratio, 1:137, and actually this ratio as Bohr looked at it, was the ratio of the velocity of the electron in the first Bohr orbit to the velocity of light. That is, if you multiply the velocity of the electron in the first Bohr orbit of the hydrogen atom by 137, you get the velocity of light.

White: So then the electron orbiting the hydrogen is held in place by something like the Hall resistance?

Moon: In the sense that the orbiting electron is bound to the hydrogen atom, around which it is orbiting. This stuck in my mind for several years. Immediately you begin looking at this ratio, you see that this is identical with the impedance in a material medium like the semiconductor, which von Klitzing experimented with compared to the permeability of space.

Since the Hall resistance is dissipative, then we have here a ratio between two different kinds of resistance, a resistance within a material medium and a resistance of "space." That being the case, we are entitled to seek a geometry of space—or in other words, we are no longer able to talk about "empty space." From looking at von Klitzing's experiment, I was led to these new conclusions.

This is the equation for α, the fine structure constant:

$$\frac{1}{\alpha} = \frac{2h}{e^2 \mu_0 c}$$

Another conclusion which I was able to draw, was why the number "2" appears in the fine structure constant. Well, it turns out that the *2* indicates the pairing of the electrons.

And when you get this ratio, this turns out to be 1:137. So you have the ratio of the impedance of free space, which is non-dissipative, over the impedance in a material media, as measured by von Klitzing, which is dissipative, giving you approximately 1:137. We have seen major advances in semiconductors in recent decades which permit us to make very accurate measurements of the fine structure constant.

Today, we have even better methods based on superconductors. In a superconductor, the impedance will be very low, like that of free space. There is no place for the electron in the superconductor to lose energy.

As a result of this, I began to conclude that there must be structure in space, and that space must be quantized. Of course, I had been thinking about these ideas in a more general way, for a long time, but looking at von Klitzing's work in this way, allowed me to put them together in a new way, and make some new discoveries.

White: Weren't these ideas connected your original work in quantum theory?

Moon: Yes, I was led to reflect again on the ideas of de Broglie and Bohm on the quantum potential. To understand these, we must first take a look at some of the apparent paradoxes of quantum theory. A photon, or a particle, will behave differently if it travels through an obstacle in which either one or two slits are present. A single particle or a single photon can only go through one slit at a time, but it acts as if it knows that the other slit is there—it takes a different pathway depending upon whether one or two slits are present.

Now in this way, it is acting like a wave rather than a particle. It chooses a pathway which would reflect the interference pattern of a wave which divided itself between the two slits. The same kind of behavior occurs when there is just one slit, but the electrons travel one behind the other in single file. The first electron acts so as to take into account the behavior of the succeeding electron, even though that electron may not travel through the slit for a whole hour after the release of the first.

The quantum potential says that if a photon is approaching a slit somewhere—or even if, instead of a photon, you have a particle—the quantum potential says that the photon or particle "knows" that the slit is there. This is what the second solution to the quantum equation shows. Now isn't that strange? It doesn't have eyes, but it sees. That was probably the reason why de Broglie's ideas were rejected in 1927 at the Solvay Congress.

As I told you before, de Broglie had brought up this second solution to the quantum equation at that 1927 Congress. Now, this quantum potential has reality, as Bohm has shown. David Bohm has recently been publishing quite a bit on it.

According to Bohm's explanation, which I believe is correct, the quantum potential can be understood simply if we accept that there are two kinds of time. The secret being that, just as space is quantized, so must time be quantized as well. In order to demystify the quantum potential, we must accept the quantization of time.

In the quantization of time you would have time move along in *chronos*, that's the time we know, the time you have when you turn on your radio station. That's man's time. Then there is the other time, *kairos*, and *kairos* is God's time.

Periodic table of the elements

1
H
1.0079

atomic number

atomic mass

PERIODS	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIIA	NOBLE GASES O
1	1 H 1.00797																	2 He 4.00260
2	3 Li 6.941	4 Be 9.01218											5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.99840	10 Ne 20.179
3	11 Na 22.98977	12 Mg 24.305											13 Al 26.98154	14 Si 28.086	15 P 30.97376	16 S 32.06	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.90	23 V 50.9414	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.70	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.22	41 Nb 92.9064	42 Mo 95.94	43 Tc 98	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.4	47 Ag 107.868	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9045	54 Xe 131.30
6	55 Cs 132.9054	56 Ba 137.34	57 *La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.9665	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.9804	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.0254	89 †Ac (227)	104 Ku	105 Ha	106												

*	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (147)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9304	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.97
†	90 Th 232.0381	91 Pa 231.0359	92 U 238.029	93 Np 237.0482	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (258)	102 No (255)	103 Lr (256)

These are Greek terms used by Plato. *Kairos* is God's time; *chronos* is man's time. When your alarm goes off in the morning, or you have to meet someone at such and such a time, that is *chronos*.

This is where *chronos* and *kairos* come in. *Chronos* goes along as a linear function, which is increasing with the lapse of time; but if there is a gap between each instance of time, because time is quantized, how would we know it? There could be gaps in time right now, and since we are going by *chronos* we wouldn't know it, would we?

I began to explore the concept that time, like space, is quantized, since *kairos* is coexistent with *chronos*. In God's time, events occur virtually instantaneously. This is completely different from time as we ordinarily experience it. Information is not transmitted sequentially, as if a person were giving orders to a subordinate, or one biological system giving information to another.

It is a question of the velocity of transmission of information. In *kairos* time, this is instantaneous. I can't say how long the transmission period lasts, perhaps it is a microsecond, maybe a femtosecond. Anyway instantaneous transmission doesn't require much time, does it?

This means that every particle instantaneously knows about every other particle in the universe, which is exactly de Broglie's idea, and David Bohm is who rediscovered it. They worked together on this general idea up until de Broglie died, this past year.

White: This seems to me to have some very curious implications.
Moon: It would mean that every one of us must, to some extent, be aware of everything else in the universe. Of course, though we may be aware of it, we may not comprehend it. That is another thing.

White: I find that hard to believe.
Moon: At any rate this is the situation, I think, in which we live. There is a knowledge of what is happening in the universe.

Even though it was 155,000 light-years away, we had this supernova. And to think that the light coming from it, the radiation coming from it would keep together for 155,000 light-years. That's quite a distance. Just think how difficult it is to keep together, if you are just walking with somebody, even walking a block. But, these waves are keeping together. And there even seem to be some neutrinos coming along. And the neutrino is a particle. It seems to get here. At least a few did. I think there were seven at last count.

White: The neutrino's a curious litttle beast, isn't it?
Moon: It is a curious particle to say the least. It travels at the velocity of light. It is a particle without mass, and it never seems to collide with any other matter.

In any event, I was struck by the implications of the quantization of time as well as space. Perhaps this is a bit far afield, for this discussion. The thing that seems absolutely clear to me, is that if space is going to be quantized, it should be quantized with the highest degree of symmetry. This leads immediately to the Platonic solids, since these are the only regular solids which we can build in three-space, the only solid figures, with the exception of the circle itself, which have perfect symmetry. It seems very obvious how these solids should fit. You start out with the tetrahedron. And the tetrahedron fits into the cube. Two tetrahedrons fit into a cube.

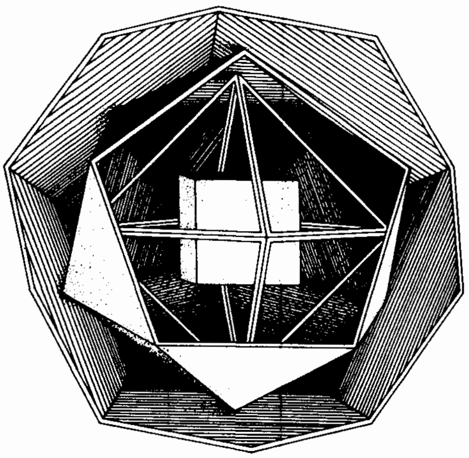
The tetrahedron has this kind of symmetry, doesn't it? The four corners of one tetrahedron would take up four of the eight corners of the cube, if we allow the two tetrahedrons to intersect. So that one crosses the other and the cube is made up of two tetrahedrons.

The first tetrahedron has just one proton on it. That's hydrogen. Sometimes it gets another neutron. That's deuterium. With two neutrons added to the proton you have tritium. But these neutrons don't have to be on a vertex. The neutron has no electrical charge and therefore they can be scattered about. When you have two protons and two neutrons on the tetrahedron you have helium.

I want to say, with helium, that with this structure, we have known for a long time that among all the elements there is a periodicity of four, in terms of atomic weight—two protons, two neutrons.

The way the model which I have developed works for the nucleus, is that there is a series of nested Platonic solids, one inside the other (**Figure 1.**) Each succeeding inscribing solid is placed such that the vertices of the inscribed solid fall on the face centers of the outer solid [except for the icosahedron-octahedron, discussed below]. This acts as an exclusion principle. There is only one proton per face center. One and only

FIGURE 1
Nested sequence of four Platonic solids



one. This is an exclusion principle. The protons are on the vertices of a solid which is inscribed so that it touches the face.

We need not worry about the neutrons, because they have no force acting upon them really, other than the gravitational force. Therefore, their position on the structure is not constrained.

Just imagine a cube with four protons on its upper edge and four below. When all of the vertices of the cube are filled we have eight protons, which gives us oxygen.

Now we fit an octahedron around the cube, and each one of its faces will touch the face of an icosahedron that circumscribes the octahedron. Of course, since there are six vertices of the octahedron, it will not be centered within the icosahedron, but will tilt (**Figure 2a.**) When the vertices of the octahedron are filled we come to silicon, which is the most abundant element on Earth, in the form of sand—silicon dioxide. The icosahedron is directly related to the Golden Mean, because its structure is composed of pentagons. It is therefore intriguing to find that, when we fill the first vertex of the icosahedron, we have phosphorus, which is a major source of energy for nerves and muscles within the body.

We fill up the 12 vertices of the icosahedron, thus getting iron, and then, the 20 vertices of the dodecahedron give us the 46 element, palladium (**Figure 2b.**) Some astronomers believe it to be the building block of the universe.

Now we wish to add a second set of nested solids to the first. We place a second dodecahedron on the first, and find that we can fill up an additional 10 positions on the new dodecahedron, and one more to begin to close the face. This gives us minimal stability; however, we don't wish to close up the second dodecahedron until we have placed an icosahedron, octahedron, and cube within it. Therefore, we fill up 11 positions on the second dodecahedron, leaving an additional four to be closed up at the end.

These 11 positions bring us to lanthium, and following this we begin building up the inside of the second dodecahedron first with a cube and then an octahedron around it as before. These 14 additional positions give us the 14 rare earths. When we finish filling up the second series of nested Platonic solids we reach element 86—the last of the noble gases.

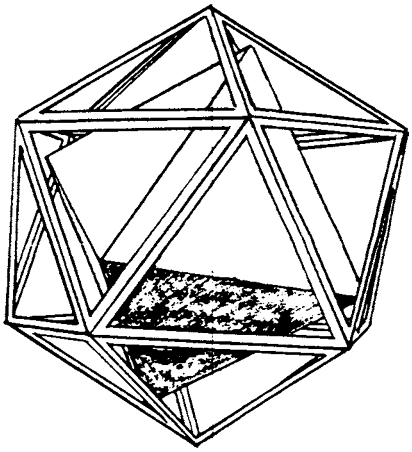
In this nucleus, the two sets of nested solids share a dodecahedron face (**Figure 3a**)—that is five vertices of one face are shared by each of the nested sets—and one vertex of the two icosahedrons (the ones located on that face) is also shared by a proton. This configuration generates 86 available places for protons.

White: You've used up your two dodecahedrons, but there are still more elements left. What happens now?

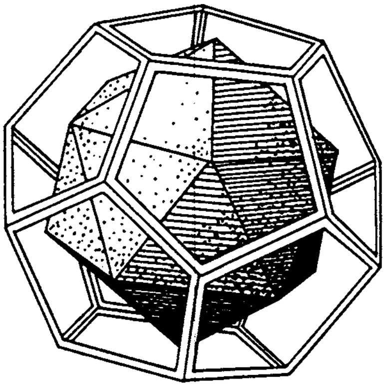
Moon: Now the fun begins. How do we place the next six protons? We must open up the shared face. Perhaps it opens like a door on a hinge. This would free four vertices and take us up to element 90, thorium, since three of the vertices of the shared dodecahedron face and one of the shared icosahedron face would have become available. In order to get element 91, protactinium, the hinge is broken and the two sets of solids only share one vertex (**Figure 3b.**)

FIGURE 3

a) Nesting of octahedron in icosahedron



b) Nesting of icosahedron and dodecahedron



This brings us to element 92, uranium. In this case all of the vertices of the two series of nested Platonic solids must have occupied vertices. This means that none of the vertices can share a proton. Therefore, if our rule about only one proton to a vertex is to hold, uranium must represent a situation in which the two dodecahedrons inter-penetrate each other. This inter-penetration of the two dodecahedron vertices provides the linkage between the two complete sets of the four nested Platonic solids.

This configuration leads quite naturally to the possibility of fission. The configuration is not very stable. Simply adding a low-energy neutron to uranium-235 produces nuclear fission. When the two dodecahedrons break apart—when nuclear fission occurs—it is very unlikely that both of the outer dodecahedrons will survive intact; and that is what we find in the spectrum of fission products. Very few of these products are, or are near, palladium. That means that a large part of one of the outer dodecahdrons shatters during nuclear fission, which is what you would expect from the model of two inter-penetrating vertices.

There is another extremely interesting feature of this model. Back in the early 1930s, an effort was made to describe a kind of periodic table for the nucleus. Certain key values either of neutrons or protons give particularly stable configurations. These are known as magic numbers. The nuclear magic numbers are 2, 8, 20, 28, 50, 82, and 126. Two and eight are obvious, giving helium and oxygen. Twenty, in my model, falls in the sixth position of the icosahedron, filling up a pentagon (if we consider the edges of the icosahedron). The element calcium falls here, one of the most crucial for the health of bones and tissue. Zinc, number 50, is positioned on the second dodecahedron, as we complete the first five positions of the new dodecahedron, circling it once. Tin, number 82, occurs as the point at which we have encircled the second pentagon of the icosahedron which is placed inside the dodecahedron, right before we move to close the dodecahedron, and move to close the last vertex of the octahedron, which will rest on the upper face of the dodecahedron.

White: What other significance do you see in your model, besides the question of the symmetry of the five regular, Platonic solids?

Moon: I was quite delighted to note that the ratio of the edge of the dodecahedron is in the Divine Ratio to the edge of the inscribed cube. This is the best ratio you get after you have completed the model, so that the solids fit together. You get the Divine Ratio, that is, $(1 + \sqrt{5}) \div 2$

Here are the measurements which I used in building the model.

Edge length in millimeters: cube—100; octahedron—117.106; icosahedron—131; dodecahedron—61.8033

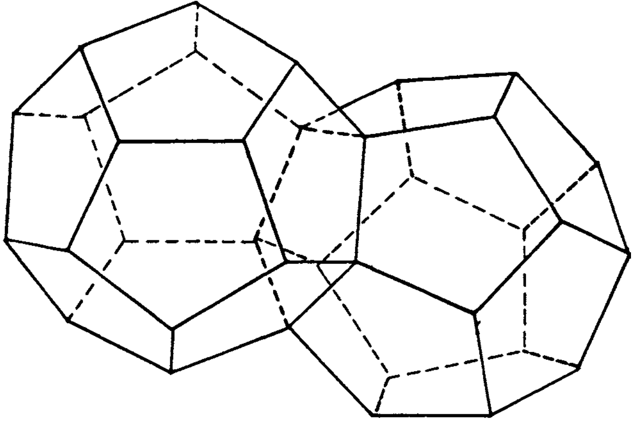
Now notice that, as you proceed inward from the dodecahedron, the edge length at first increases. Now the idea is that they all fit together well with one vertex in each face. We really begin to have fun when we have to chose the best symmetry for fitting the octahedron inside the icosahedron. We can have quite a bit of wobble, when we place the octahedron inside the icosahedron. But we are dealing with a very peculiar type of element here in this transition.

White: In a sense, you have a break, something like a register shift in music or a phase-shift like the asteroid belt in the solar system.

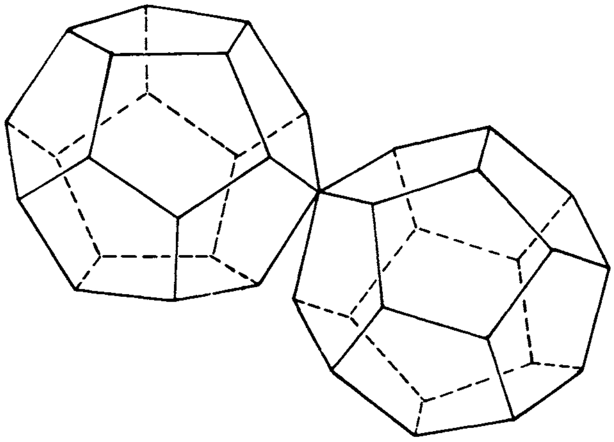
Moon: Yes. If you look at the properties you find that they vary, very, very rapidly with this element. We have 8 with the cube and 6 with the octahedron, to get 14 altogether before proceeding to the 15th element, the first with part of the icosahedron. What is element 15? Phosphorus. Phosphorus, which is so important in living things.

FIGURE 4

a) Twin dodecahedra joined at one face



b)Twin dodecahedra with "hinge" broken



White: We have been talking about particles which fill up points in space. How does this accord with de Broglie's insight? From each other?

Moon: The particles are really singularities in space. They are not really particles, it is only more convenient to refer to them in that way. These singularities are where these particles can go. When you go beyond the icosahedron, you have the dodecahedron. The icosahedron will fit exactly into the dodecahedron because there is an exact fit between the vertices and faces.

We can now see the problem more clearly. There is a proton flux in the universe, cosmic rays in outer space. It is from this that the elements are created. It is as if they have to find a "parking place." The protons find their parking place at what corresponds to the vertices of these nested Platonic solids. And the neutrons, which are also out there, we simply fit in, because they have no charge and they can go almost anyplace.