

## Schrodinger's Wave Model of the Atom – A Physical Interpretation.

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It has often been argued that one of the most problematic aspects of Quantum Mechanics has been the inability to describe its tenets in a realistic way – realism and physicality have been replaced by statistical and mathematical representations which divorce the initiate from rational understanding. One could argue that the theory of wave-particle duality of Quantum Mechanics is one of the most problematic in this regard, as conceptually it leads to paradoxes and contradictions if one attempts to understand it at face value. One is left instead with hand-waving and comforting words suggesting that the incomprehensibility of it all is perfectly normal – the “6 impossible things before breakfast.”

However, this is not necessarily how it was originally intended. In Schrodinger's Wave Mechanics that led to the most accurate description of the atom to date, his intention was to portray the atom with “Anschaulichkeit” (picturability)<sup>1</sup>. We will argue herein that the wave-particle dualism that emerged from the Copenhagen interpretation of Quantum Mechanics was an incongruous revision of Schrodinger's original “realism”. For this reason we would like to revisit Schrodinger's spherical wave model and explain it in a picturable way, while also addressing some of the issues brought forward by his detractors.

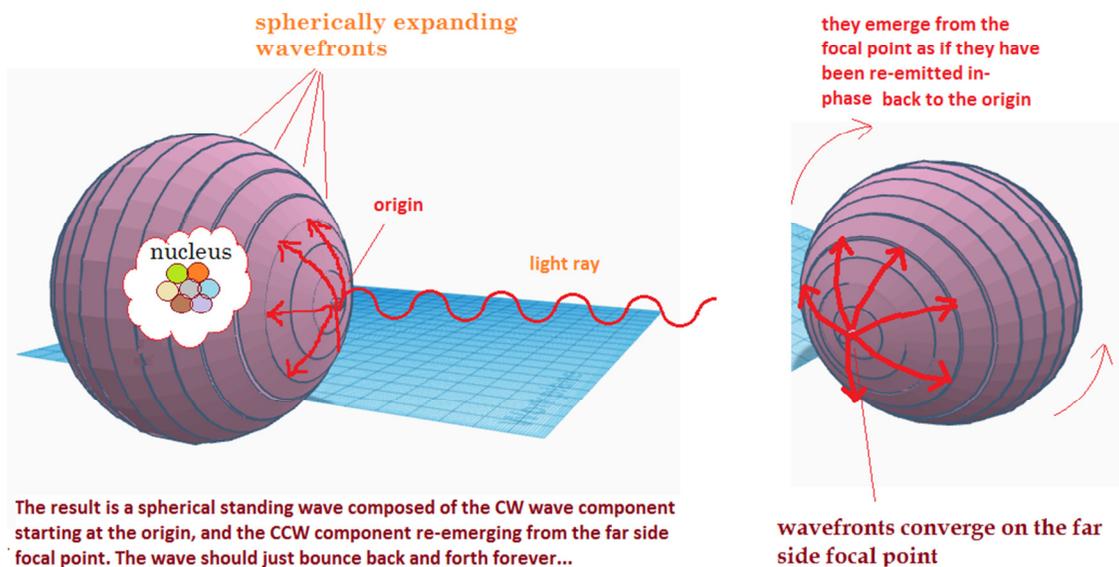
In 1925-1926 Schrodinger, inspired by the work of Louis de Broglie, sought to find a way to describe the electron orbitals using a new model he referred to as Wave Mechanics<sup>2</sup>. In de Broglie's theory the electron waves were considered to follow the orbit of the electron around the nucleus and an integral number of wavelengths would need to fit the circumference of each orbit. Schrodinger attempted instead to imagine electromagnetic (EM) waves circulating around the nucleus spherically, a process which is hard to imagine using ray optics, but is possible using wave-fronts. Schrodinger elucidated this physical model in his Nobel Prize lecture in 1933 entitled “The fundamental idea of wave mechanics.”<sup>3</sup> The lecture is remarkable in that although he won the prize for a quantum mechanical description of the atom, the lecture is almost entirely about optics!

The fundamental idea that led Schrodinger to his discovery can be described best in a quote from his lecture below:

“Instead of the electrons we introduce hypothetical waves, whose wavelengths are left entirely open, because we know nothing about them yet. This leaves a letter, say a, indicating a still unknown figure, in our calculation. We are, however, used to this in such calculations and it does not prevent us from calculating that the nucleus of the atom must produce a kind of diffraction phenomenon in these waves, similarly as a minute dust particle does in light waves. Analogously, it follows that there is a close relationship between the extent of the area of interference with which the nucleus surrounds itself and the wavelength, and that the two are of the same order of magnitude. What this is, we have had to leave open; but the most important step now follows: ***we identify the area of interference, the diffraction halo, with the atom; we assert that the atom in reality is merely the diffraction phenomenon of an electron wave captured as it were by the nucleus of the atom.*** It is no longer a matter of chance that the size of the atom and the wavelength are of the same order of magnitude: it is a matter of course.”<sup>3</sup> p. 314

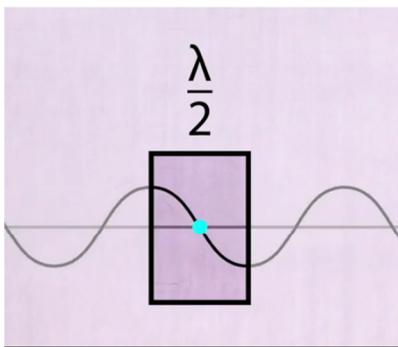
So in Schrodinger’s conception the electron is quite literally the EM wave diffraction halo surrounding the nucleus. We will try to picture what this would look like with some diagrams below. In this image an EM wave approaches a

The electron as a spherical wave diffracting around a nucleus: Fig. 1



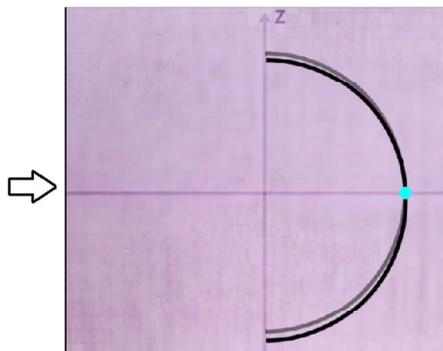
nucleus, and following Huygens principle, forms an expanding wave-front beginning at the origin which curves around the spherical path of the diffraction

halo. On the opposite side of the halo, it converges again to a point, where the wave-fronts pass through each other and begin to travel back again along the same spherical trajectory in reverse. The result is a spherical standing wave that oscillates indefinitely. This conception solves at least a first point regarding how an electromagnetic wave could form a continuous spherical shell. The process constraining the EM wave-fronts to follow the curved path might seem implausible when considered in terms of geometric optics, but Schrodinger felt that this form of optical science might not be the best to describe diffraction around microscopic objects where the wavelength was on the order of the dimensions of the object. Schrodinger saw that there was a close analogy between Hamilton's principle and Fermat's optical principle, and that the former could be used to express the proposed undulatory phenomenon in a manner better than via geometric optics alone. Consider an undulatory vibration on a string as shown below in figure 2A.<sup>4</sup> This will serve as our analogy of Schrodinger's model of the electron EM wave. The portion of the string highlighted in the box is  $\frac{1}{2}$  wavelength, which has one node at the zero crossing (blue), and two open ends at positive and negative. If this vibrating string is bent into a semicircle, it will then appear as in fig 2b, oscillating up and down with respect to the node. If this semicircle is then rotated around to form a sphere, then we have our spherical oscillator with the upper and lower portions of the sphere oscillating between positive and negative about the azimuthal nodal line at the equator of the sphere.



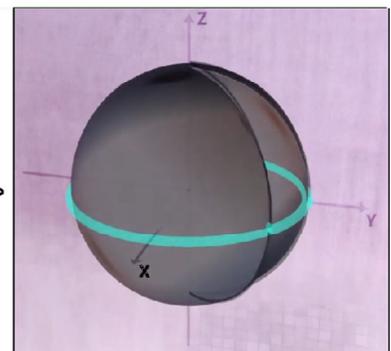
Consider a sinusoidal vibration with a node (zero) in blue and two open ends,  $\frac{1}{2}$  a wavelength long

Fig. 2A



the vibration is bent to form a semicircle, such that the wave now oscillates on the the surface of the hemisphere.

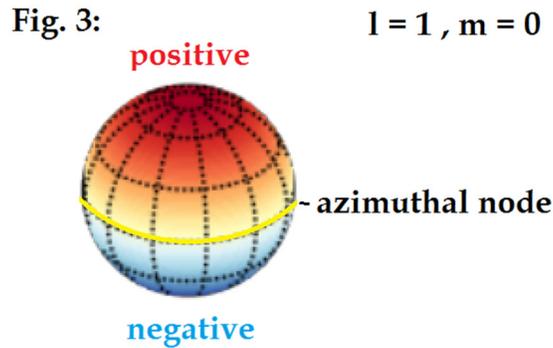
Fig. 2B



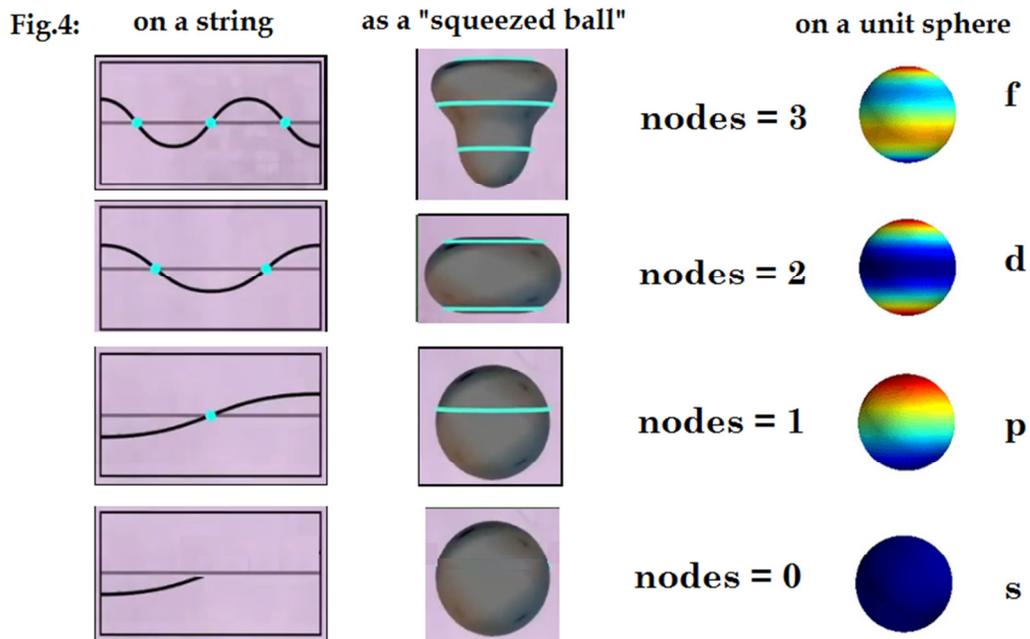
This semicircle is then rotated to form a sphere. The wave now oscillates on the surface of the sphere, with the blue node forming a line around the azimuth.

Fig. 3C

As the distance around the circumference from pole to pole is  $\frac{1}{2}$  wavelength, then the shell would form a standing wave with at a snapshot in time the positive part of the waveform is at one pole and the negative part at the other, as shown below mapped on a unit sphere:

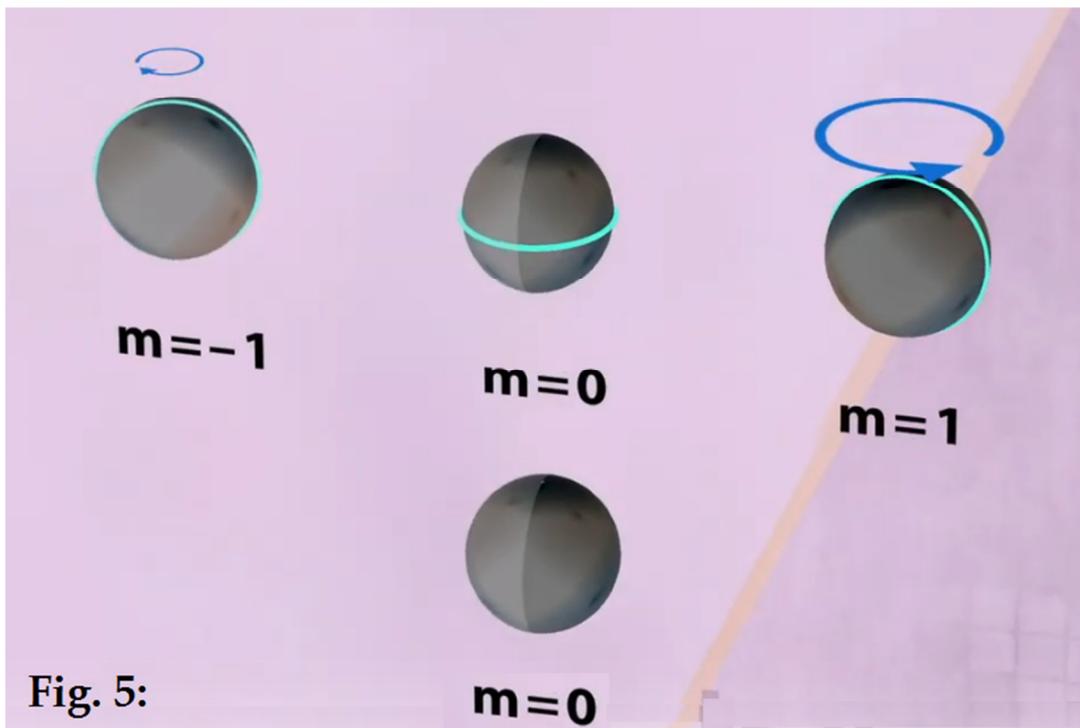


The spherical harmonics as described by Schrodinger follow a series where the letter  $l$  designates the number of nodes on the sphere. The first level,  $l=0$ , corresponds to the  $s$  orbital and has zero nodes, so the oscillation comprises a  $\frac{1}{4}$  wave from pole to pole. The second level  $l=1$  corresponds to the  $p$  orbital with 1 node, so  $\frac{1}{2}$  wavelength from pole to pole. The  $l=2$  ( $d$  orbital, 2 nodes) is 1 wavelength from pole to pole, and finally the  $l=3$  ( $f$  orbital, 3 nodes) is 1.5 wavelengths from pole to pole. This is shown diagrammatically below in Fig 4 starting with the wave vibration shown on a linear string with its nodes in blue.

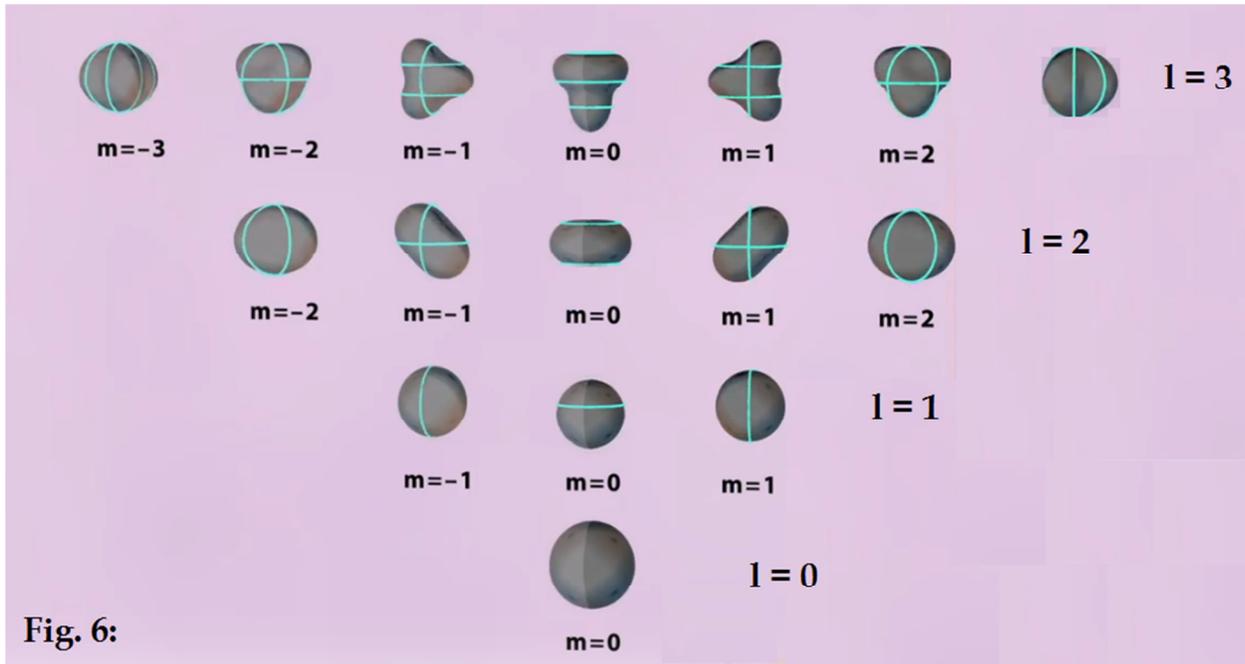


Then in the middle, the corresponding spherical wave is shown as a ball squeezed by the wave. On the right, the wave polarization is shown mapped onto the unit sphere, where the red contours show where the positive charge is, the blue the negative the intensity of the colour reflecting the intensity of the charge. The advantage of the unit sphere projection is that it shows the “path” of the waves as following the surface of the sphere.

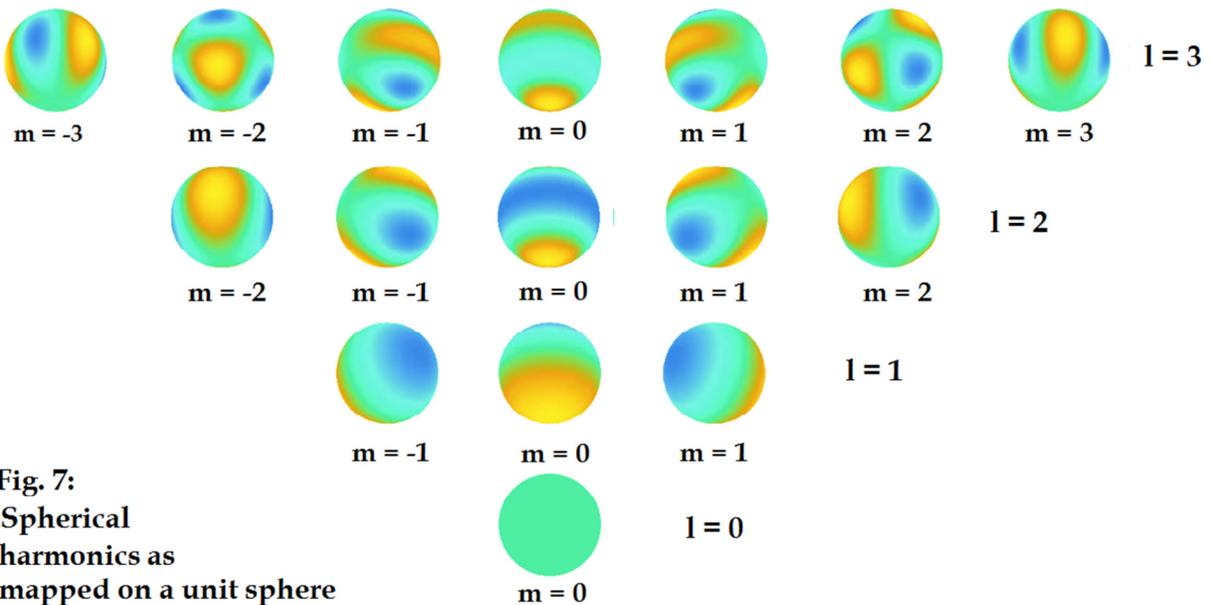
These harmonics can be expanded further if we consider that the azimuthal nodes can also rotate about the z axis. This is shown below. The  $l = 0, m = 0$  harmonic has



no node so it can't be rotated, but the  $l = 1$  can have its azimuthal nodal line rotated clockwise or counter-clockwise about the z-axis, leading to three possible modes  $m = -1, 0, 1$ . The same is true of the higher harmonics :  $l = 2$  having 2 nodal lines has three possible modes  $-2, -1, 0, 1, 2$  where 0, 1, or 2 of the nodal lines are rotated clockwise or CCW about the z axis. For  $l = 3$ , there are 7 possible modes. These are all shown diagrammatically below in Fig. 6. Again, in this representation, we are showing the spheres as “squeezed balls” with the azimuthal nodal lines of the waves shown in blue.



When Fig. 6 is represented as spherical waves with their polarization intensity projected on the unit sphere, similar to in Fig. 4, they appear as below (Fig. 7):

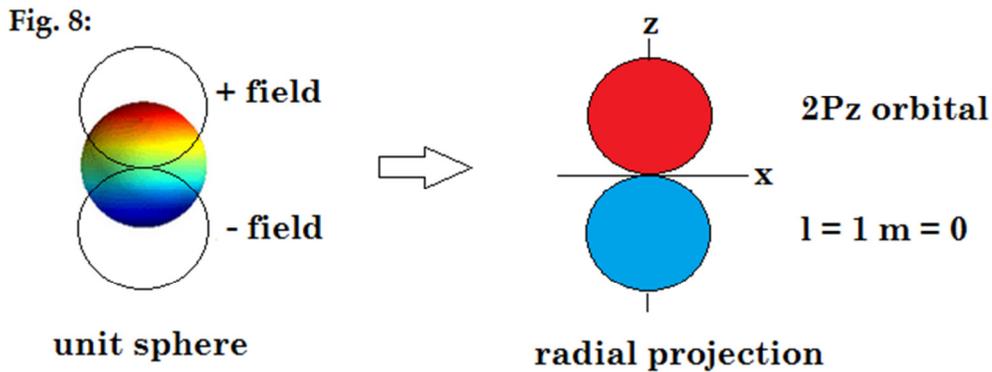


**Fig. 7:**  
Spherical harmonics as mapped on a unit sphere

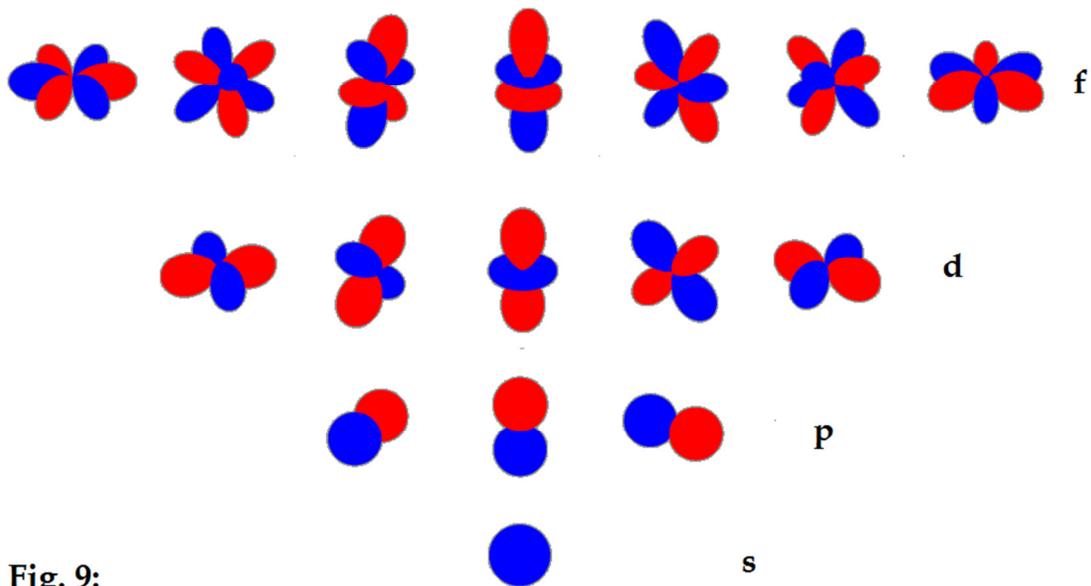
In this case yellow represents the most positive crest of the waves, blue the most negative crests, again, the colour intensity maps the charge intensity in a topological way.

It is important to point out the meaning of electron “spin” in this model. The rotation of the azimuthal nodal line(s) around the z-axis corresponds to **extrinsic** spin. So for each azimuthal line that rotates, the spin increases by  $\frac{1}{2}$  or  $-\frac{1}{2}$  depending on the rotation direction. The base oscillation of the wave on the sphere corresponds to **intrinsic** spin. So an orbital with 2 rotating azimuthal lines would have a spin of either  $+1\frac{1}{2}$  or  $-1\frac{1}{2}$ .

There is another way of displaying spherical harmonics. They can be plotted as the magnitude of the function along each direction to define a radial distance, and then plot the function at that radial distance. If we were to regard the polarity of the waves on the sphere as a distribution of electric field, then the radial distance plot would show the field intensity in space around the sphere.



This radial projection is shown below for the orbitals from s through f.



**Fig. 9:**

These are then the familiar shapes of the electron orbitals expressed as solutions of Schrodinger's equation for the electron.

In Schrodinger's writings, he repeatedly emphasized that the wave-function  $\Psi$  was describing a physical electromagnetic wave, which is not what the current consensus view of what the orbitals are in quantum mechanics. For example, in Schrodinger's "collected Papers on Wave Mechanics", he stated:

"It is necessary to ascribe to  $\Psi$  a physical, namely an electromagnetic, meaning in order to make the fact that a small mechanical system can emit electromagnetic waves of a frequency equal to a term difference (difference of two proper values divided by  $h$ ) intelligible at all, and further, in order to obtain a theoretical statement for the intensity and polarization of these electromagnetic waves." Ref 3, Abstract, P. x

And also:

"A definite  $\Psi$  distribution in configuration space is interpreted as a continuous distribution of electricity (and of electric current density) in actual space. If from this distribution of electricity we calculate the component of the electric moment of the whole system in any direction in the usual way..." Ref 3, Abstract, P. x

It is important to note that Schrodinger rejected the notion of the electron as a "point charge." As shown above, his interpretation is that the electron was the spherical harmonic, i.e. the "diffraction halo" around the nucleus, not individual point charges located indeterminately in a statistical probability distribution around the nucleus. On this matter, he said:

"We shall be obliged to attempt to take over the idea of Uhlenbeck and Goudsmit into wave mechanics. I believe that the latter is a very fertile soil for this idea, since in it the electron is not considered as a point charge, but as continuously flowing through space, and so the unpleasing conception of a "rotating point-charge" is avoided." Ref. 3 P, 64.

And in his interpretation of the square of the wavefunction, he stated explicitly that this refers to the density of electricity:

"According to the hypothesis of wave mechanics, which up to now has always proved trustworthy, it is not the  $\Psi$ -function itself but the square of its absolute value that is given a physical meaning, namely, density of electricity." Ref. 3, P. 126

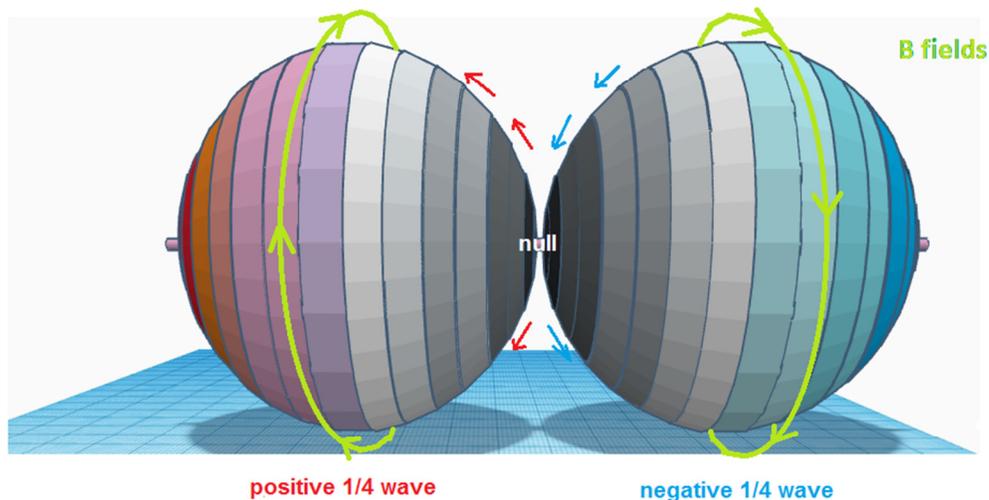
The primary criticism levelled against Schrodinger's physical model was that the spherical EM wave could not be sustained because EM waves tend to disperse with time. This was particularly true for Schrodinger's wave packet concept applied to his study of gases, where superimposing, quasi-continuous spectrum of frequencies in a wave packet would be expected to disperse rapidly.<sup>5</sup> Such arguments were also levelled at Schrodinger by Lorentz in his May 1926 letter.<sup>6</sup> The problem with these arguments is that it assumes that the EM wave properties do not change with frequency – there is some evidence that as EM waves approach very high frequencies, their dispersion becomes less and less. For example, RF radiation in the radio or microwave range will tend to radiate in all directions, but as the EM radiation approaches the X-ray range the EM propagation becomes more particle-like, travelling in straight lines and capable of colliding with targets and particles. This is precisely why the concept of the "photon" applies well to short wavelength emissions but not the long wavelength radio waves with wavelengths of many meters, where applying the photon concept seems completely inappropriate. If EM dispersion is frequency-dependent, one could conceive of a very high frequency threshold, above which EM dispersion is effectively zero. We must remember that the frequency of the gamma radiation required to generate an electron/positron pair is quite specifically  $511 \text{ KeV} \times 2$  or greater, this is not an arbitrary value, but rather corresponds to very specific and unique physical conditions by which the pair can be produced. We should not try to deny the obvious spherical wave structure of the electron orbital, its generation from EM radiation and its annihilation into EM radiation, and the fact that the "jumps" in position absorb and emit EM radiation. Rather, we should try to understand instead how EM radiation at these specific frequencies could behave in unexpected ways such that a dispersion free structure could be sustained. I believe the unwillingness of Schrodinger's colleagues to consider this line of reasoning has more to do with their inherent bias of preserving the corpuscular theory of the atom. An effective wave model of the atom and the disappearance of the material particle was an idea which was likely alien and repulsive to the academic leaders of the time.

### Addressing further shortcomings of the model:

Having come this far, we recognize there are some further issues that arise with taking Schrodinger's model literally. These are:

- 1) How do we account for unipolar charge when the waves are bipolar?
- 2) How do we obey Pauli's exclusion principle – 2 electrons per orbital?
- 3) How do we explain pair production/annihilation?
- 4) What about the magnetic fields?

Let's consider the spherical harmonic of figure 3. If it was genuinely an electromagnetic wave whose wave-front advances around the sphere to form a standing wave, then the object would be bipolar, not single-charged as expected for an electron or positron. Further, it would fill the entire orbital rather than leaving space for another electron – as we know from Pauli's exclusion principle, each orbital can hold up to two electrons. If each electron is a unit sphere, then this would require two unit spheres to overlap per orbital to properly fill the electron placements. In an attempt to find a model that fits, we will examine an example of two hypothetical  $\frac{1}{4}$  wavelength (pole to pole) spherical resonators as shown below, with the colours showing the charge and the green band showing the magnetic field direction. **Fig. 10:**

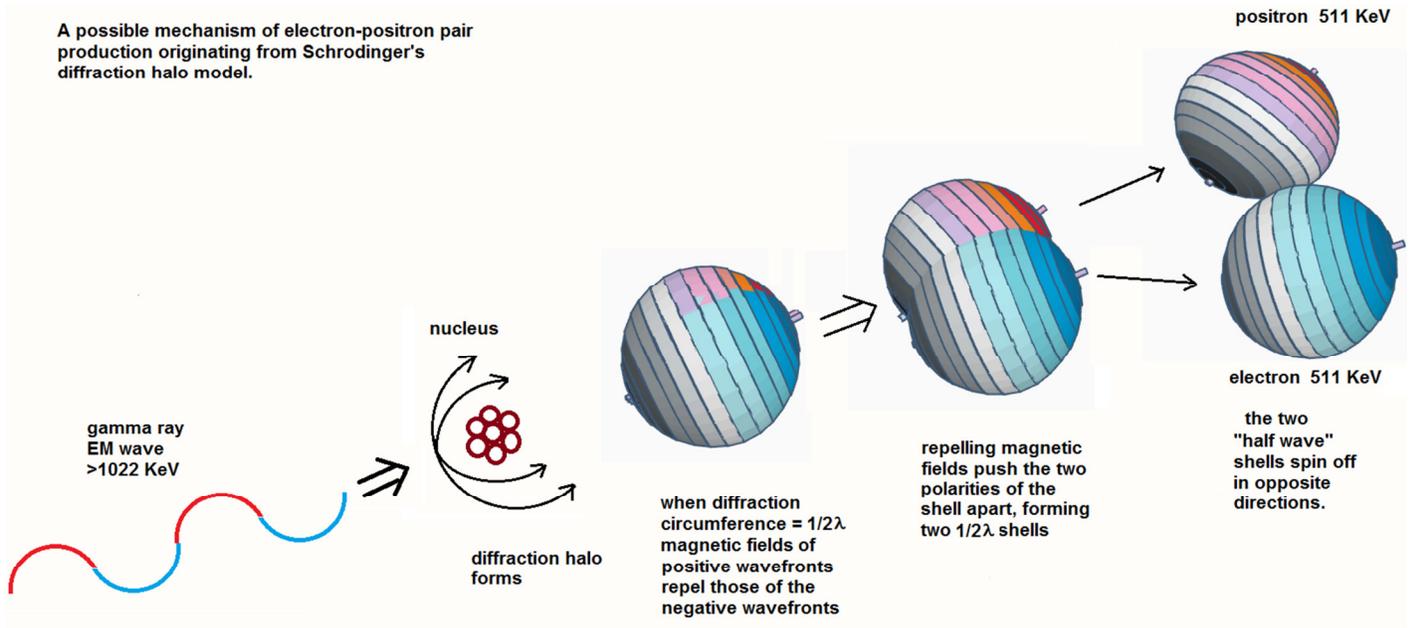


A  $\frac{1}{2}$  wave traverses the spheres with  $\frac{1}{4}$  wave across one sphere and then continues to the second  $\frac{1}{4}$  of the wave on the other. The wave starts at the right

origin at a negative peak, travels to the null point at the opposite pole, and then continues onto the left side resonator as the positive-going side of the wave, reaching a positive peak at the leftmost pole. The magnetic field for each sphere is shown – the magnetic fields counter-rotate with respect to each other obeying the right hand rule. Now imagine that this  $\frac{1}{2}$  wave traverses only the right side sphere as a forward/ reverse standing wave– it would go from the rightmost pole to the null at the center, then pass through the focal point and head back towards the right side pole, but this time as the positive going side of the wave. This would be equivalent to taking the left side sphere shown above, rotating it 180 degrees, and superimposing it on the right side sphere. The fields on the right side sphere would then comprise two  $\frac{1}{4}$  wave sections of the same wave that are opposite in polarity and overlapping, and their magnetic fields would now be co-rotating.

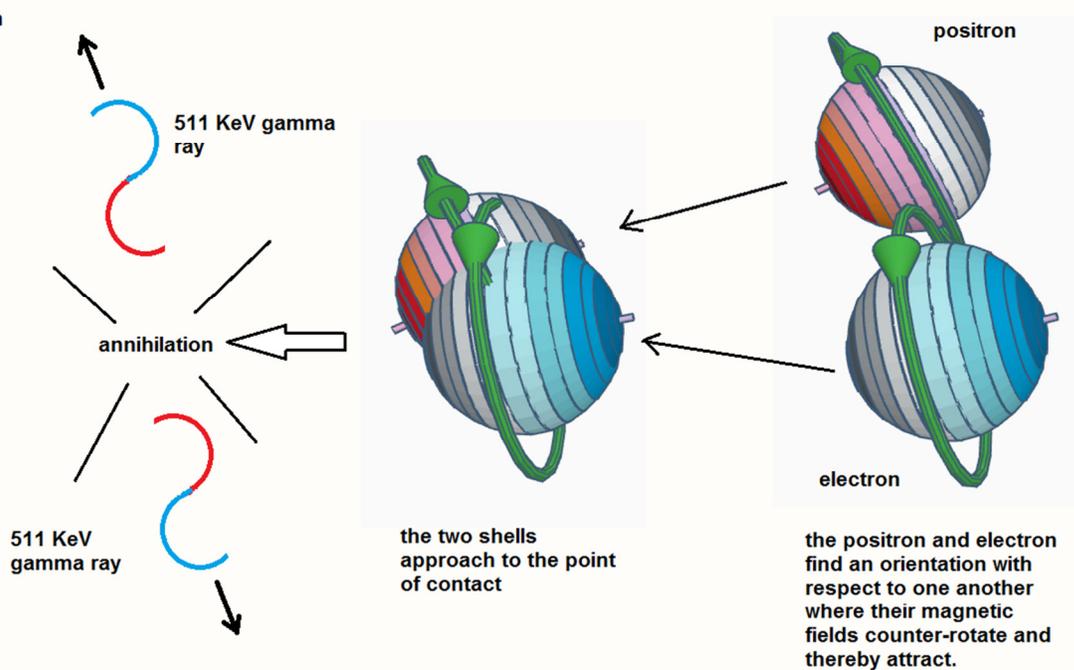
We could argue that this latter scenario would be forbidden, since in vortex theory co-rotating magnetic vortices repel, so the positive going  $\frac{1}{4}$  wavelength would be pushed away from the negative going  $\frac{1}{4}$  wavelength that it overlaps. I speculate that it is this kind of process that could potentially lead to electron-positron pair production if the correct conditions, currently not fully understood, could be met. The electromagnetic wave, on being constrained in a diffraction halo, and then forced to overlap on itself such that its magnetic fields are set up in a repulsive conformation, would literally break the EM wave into two “half-wave” components, one positive and one negative, almost like a form of electronic rectification. In this scenario, each shell oscillates between positive and null, or negative and null, but not positive and negative. This is not a process of reflection at the focal point of each sphere – rather, the wavefront passes through the focal point and continues in the opposite direction on the sphere unabated, but the wave only oscillates between negative and zero around the new electron sphere (or positive and null for the positron), so the new azimuthal node becomes the potential half way between these two. So the oscillation remains a sine wave on both spheres, but their reference to the original “zero” level is changed. Their forced separation into two entities is then conceived of as being something like that shown diagrammatically in the figure below.

A possible mechanism of electron-positron pair production originating from Schrodinger's diffraction halo model.



Conversely, if the two shells, positive and negative, then re-approach one another in the attractive orientation where the magnetic fields are counter-rotating (as shown in the next figure) they will be pulled together and will annihilate, recreating the original EM waves which will be emitted from the annihilation site.

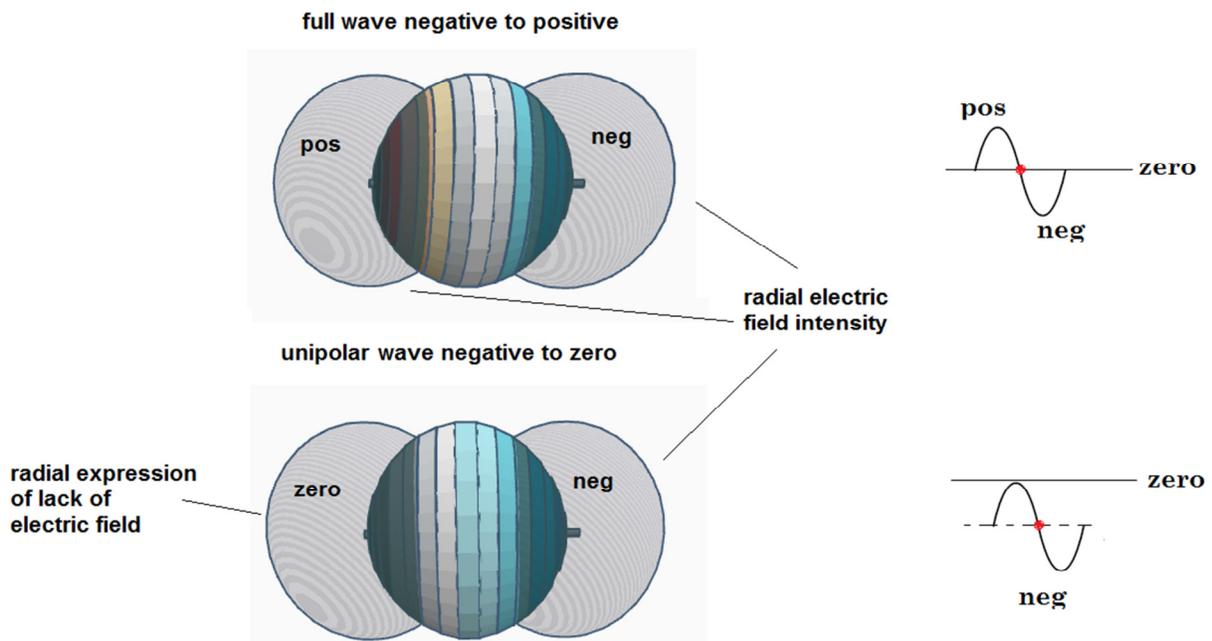
A possible mechanism of positron-electron annihilation using Schrodinger's diffraction halo model.



Again we can speculate on the process of annihilation, knowing that it would require that energy is conserved. The transformation from one state (the shells)

to the new state (the linear gamma rays) might best be explained using the Maxwell-Lorentz theory referred to by Schrodinger in his writings.<sup>2</sup> This theory would define the electric field as a strain in the medium between the magnetic fields<sup>7</sup>, and thus the environment becomes part of the annihilation sequence. The complete cancellation of the magnetic field loops would then lead to a release of the strain energy into the surrounding medium, where new oscillating magnetic fields would be reconstituted to allow the energy to propagate away as high frequency gamma rays.

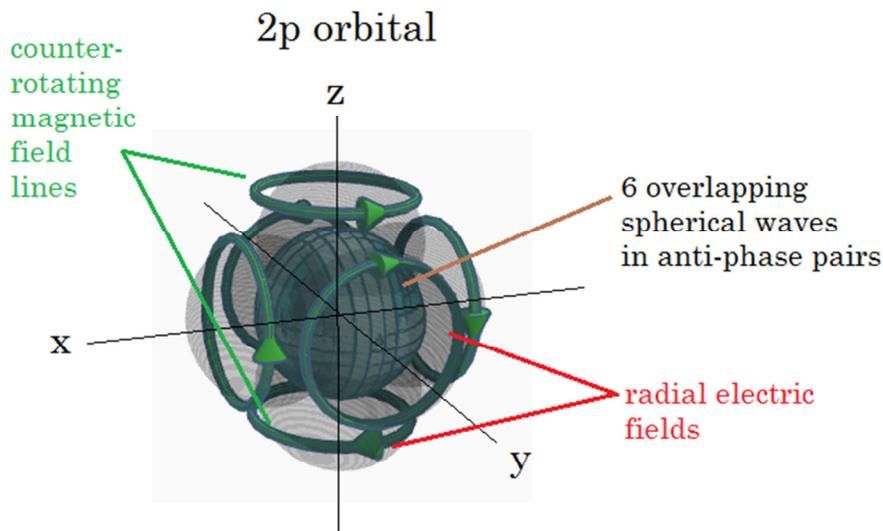
With this speculative model of the **unipolar** wave spherical shell resonator, we note a few things. With the shells shown in Fig 11 and 12, when the origin is a peak, then the opposite pole is a null. This  $\frac{1}{2}$  wave circumference shell might best match the 2p orbital. We first contrast this with a shell where the circumference is equal to one full **bipolar** EM wavelength, so the left pole is positive and the right pole is negative, as was originally pictured by Schrodinger in for example fig. 3. When expressed this way, the radial electric field intensity from each positive and negative segment of the shell adds up to form in radial projection two lobes, one positive and one negative, similar to the shape of one segment of the 2p orbital, as shown below.



However, if the same exercise is performed on the unipolar wave shell, the same kind of lobes can be used to express the charge, where the negative lobe expresses the electric field as “furthest from zero negative” and the zero lobe expresses “closest to zero in the positive direction”. The spherical shell in this unipolar form can then at least meet the necessary condition that the charge is always positive or always negative, but never both.

The advantage of this latter shell is that the zero lobe is essentially empty, so it can be filled by another electron standing wave in the opposite orientation, matching the quantum criteria that two electrons can be in the same  $2p_x$ ,  $2p_y$ , or  $2p_z$  orbital but not in the same position. This would effectively be two **unipolar** wave vibrations in anti-phase on the same unit sphere. The magnetic fields of the two vibrations would always be counter-rotating, thus attractive and cancelling, whereas the charges would be repulsive, forming a balance of forces.

When all 6 are added in the x,y, and z orientations, the electric field density would look somewhat like below, corresponding to the  $2p_x$ ,  $2p_y$  and  $2p_z$  orbitals, as shown distributed on the spherical harmonic unit sphere. Each pair of electron standing waves would be 180 degrees out of phase on the unit sphere, forming 6 magnetic fields which counter-rotate for each pair and thus cancel out. The resulting electric charge distribution is then cloudlike and symmetrically distributed about the sphere.



Similar rules apply to the other orbitals as are summarized below:

s =  $\frac{1}{4}$  lambda from pole to pole unipolar wave on the unit sphere

d =  $\frac{1}{2}$  lambda from pole to pole unipolar wave on the unit sphere

d = 1 lambda from pole to pole unipolar wave on the unit sphere

f = 1.5 lambda from pole to pole unipolar wave on the unit sphere

The model solves some issues in an obvious way – electrons do not travel in orbits, but instead EM waves simply pass over each other on spherical shells. This eliminates the issue of collision since the EM waves can pass through each other without resistance. Pauli's exclusion principle is met since electron shells overlap in a manner such that counter-rotating magnetic fields cancel, thus balancing charge with magnetic attraction. The electrons don't radiate energy in part since they don't move in a conventional sense. However the wavelengths do not appear to define a standard physical size of the orbitals – the s or p orbital radius differs from atom to atom, and is also much larger in dimensions than the wavelength of the 511 KeV gamma ray that created it. So in order to take the model literally, we must imagine that each orbital would have to follow the rules of pole to pole wavelength as set above, but the value of this wavelength is a variable that depends on the specific conditions of the nucleus the electron shell surrounds.

We have herein attempted to visualize a possible model of the Schrodinger electron orbitals that is true to Schrodinger's original vision, at least for the figures 1-9. In our "Addressing further shortcomings of the model" we have speculated on some possible revisions that could potentially make the model compatible with Pauli's exclusion principle, pair production /annihilation, and proper charge expression. As a final point, we would also like to note that Schrodinger's spherical wave hypothesis can also be applied to the nucleus. This is because the nucleus has been discovered to have a shell structure similar to that of the electrons, with the protons and neutrons existing in s, p, d, f, g orbitals as was first proposed by Maria Goeppert Mayer, who received the Nobel prize in Physics for this work in 1963 along with Hans Jensen. This then allows for all of

the stable atomic particles to potentially be composed of spherical standing wave shells, and, to follow that to its logical conclusion, probably all stable particles with mass. Schrodinger's model opens the door to the notion that the "particle" doesn't exist at all in the conventional sense, that the underlying substratum of the universe is the medium in which these waves move, rather than the universe being entirely particulate. This discussion can by no means answer all of the questions and issues that arise from his model, but that hasn't been our purpose, rather I have attempted here to put Schrodinger's model into a rough form that can be comprehended visually, to be true to his notion of " Anschaulichkeit. "

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- 8) Maria Goeppert Mayer Biographical, [nobelprize.org](#)