

Wave Mechanics without Waves: A New Classical Model for Nuclear Reactions

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Abstract

A comparison is made between the conventional way nuclear reactions were considered to take place circa 1960, and how they might take place using a new Classical electromagnetic model of the nucleus proposed by Charles Lucas. The old analysis used an analytic model of a compound nucleus and the linear Schrödinger wave equation to predict reaction cross sections by treating the wave solutions as quantum mechanical probabilities. Actual experimental data had to be inserted into the equation to get the response for each case.

The new model considers the perturbed nucleus in terms of mechanical vibrations that lead to unstable states that foster decay to restore stability. The form of the resulting balance equation is similar to the Schrödinger wave equation, so the mechanical model has the potential to produce similar results without using waves.

1. Introduction to the Conventional Model

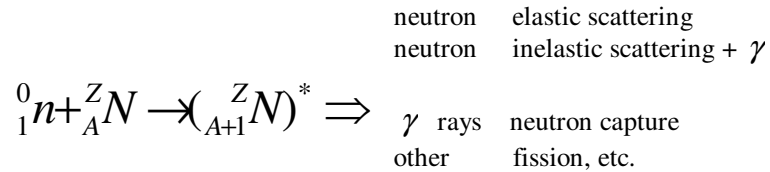
Nuclear reactions of particles striking nuclei have been considered historically in two steps: formation of a compound nucleus; and breakup of the compound nucleus into one of a number of outcomes, as discussed by Rydin [1]. A large amount of experimental data is available about decay products, energy level schemes, cross sections, and nuclear systematic behavior as discussed by Evans [2].

1.1 Summary of the Conventional Model

The entire quantum mechanical model is based on assigning wave properties to a particle, and then using experimental data about a specific nucleus to determine what happens in a specific case. Elementary non-relativistic quantum wave mechanics has been used to explain the process in a statistical way by calculating various outcomes in terms of wave transmission probabilities from the inside to the outside of the nucleus. In this sense, the whole process is a fit to data, without really knowing what is going on inside the nucleus, knowing why the nucleus has the properties it has, or knowing why the reaction proceeds the way it does. On the other hand, the method does produce usable results, like the Breit-Wigner single-level resonance formula, that can be used in other computations such as Doppler broadening of resonances.

1.2 Compound Nucleus Formation

For the interaction of a neutron with a target nucleus, we consider that the majority of events occur through the intermediary of formation of a compound nucleus that is in an excited state as a result of the addition of the binding energy of the extra neutron. This compound nucleus then decays by one of a number of processes as shown symbolically below:



Specifically, in order to examine the processes involved, we consider the energy level structure of the nucleus formed by the coalition of the neutron and the target nucleus. The kinetic energy of the neutron is transformed into internal energy of the compound nucleus and added to the neutron binding energy above the ground state to equal the total excitation energy in the Center of Mass (CM). The level schemes of the target and compound nuclei are shown in Figure 1, where several things can happen to the excited compound nucleus:

1. A capture gamma ray (or cascade) can be emitted dropping the excitation level of the nucleus. If enough energy is lost to go below the virtual levels to the bound states, the neutron is captured and the ground state is reached by gamma emission.
2. A neutron is re-emitted, with the same total kinetic energy shared between the particles, leaving the target nucleus in the ground state. A *transfer* of energy from one particle to the other usually takes place. This process is called n,n elastic scattering.
3. The neutron can be re-emitted with somewhat less than the total kinetic energy shared between the particles, leaving the target nucleus in an excited state that decays by gamma emission. This is called n,n' inelastic scattering. The scattered neutron appears at energy $E'_c = E_c - E_i$, where E_i corresponds to the *i*th bound level of the target nucleus.

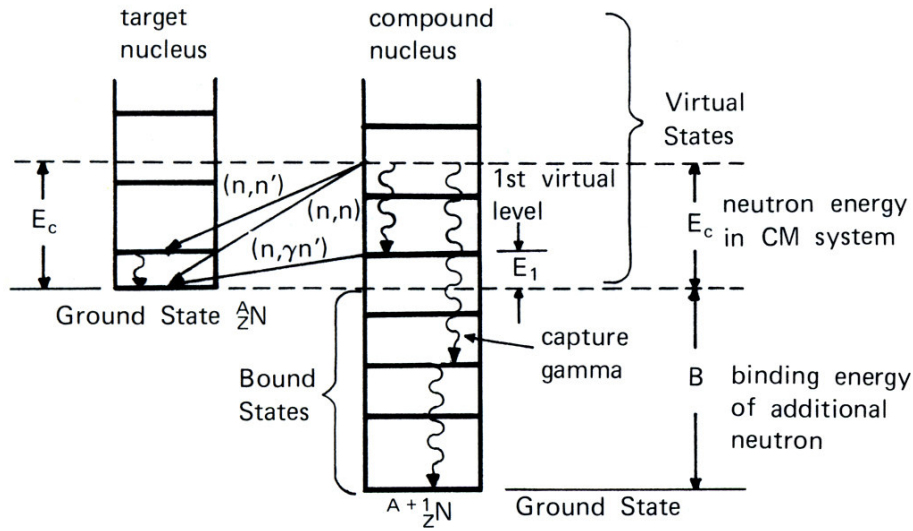


Figure 1. Energy Level Diagram for Compound Nucleus Formation

1.3 Interaction Mechanism

The reaction process is thought of as an interaction of an incident neutron wave with a square nuclear potential well. If the incident particle is charged, then a Coulomb potential barrier is constructed above the potential well, and the particle has to either have enough energy to pass over the barrier, or it has to tunnel through the barrier, as discussed by Evans [2]. This barrier penetration is almost magical, because the particle suddenly “appears” on the other side of the barrier without being changed in any way.

Because of the relative sizes of the nucleus and the incident uncharged neutron, the chance of having a hard collision is small. The interaction is explained by invoking the de Broglie relationship that ascribes wave properties to a particle, thus invoking wave-particle duality. The de Broglie equation is $\lambda = h / p$, where λ is the wavelength of a particle of mass m whose momentum is p , and h is Planck's constant. The particle is replaced by a wave train of poorly defined side-wise extent, which interacts with the nucleus. This artifice is needed because the particles obviously do collide with one another even at significant separation distances to the side. The actual collision is a two-body problem, but transformation to the CM system converts the collision to an equivalent one-body problem, that of a neutron colliding with the potential field of a nucleus and, if scattered, then receding with its original velocity. To complete the wave description we need Schrödinger's postulation that the frequency of the wave is related to its total energy. This takes the form $\nu = W / h$, where W is the total energy of the system. When the system is conservative, W is equal to the sum of the incident kinetic energy T and the potential energy U , i.e., $W = T + U$.

Analogous to light waves, the wave velocity is given by the product of the wavelength and the frequency of the wave, or

$$\omega = \lambda v = \frac{W}{\sqrt{2m(W-U)}} \quad (\text{cm/s}) . \quad (1)$$

Note that this velocity is not equal to the velocity of the particle. We can think of the collision as being made up of an incident particle wave traveling toward the nucleus and a reflected wave traveling away, both with velocity ω . But the energy in the wave moves with the speed of the beat frequency between these waves, which is called the group velocity; this is equal to the particle velocity, so that the wave and particle representations are consistent.

1.4 Wave Equation

The example discussed below is for the simple case of neutron reactions with zero angular momentum. The simplest equation that can be used to describe a traveling wave is the wave equation

$$\nabla^2 \Psi = \frac{1}{\omega^2} \frac{\partial^2 \Psi}{\partial t^2} . \quad (2)$$

This is called the non-relativistic Schrödinger equation, where $\Psi(\mathbf{r},t)$ is the wave function. We will solve this equation for a relatively simple physical model, and then interpret the wave functions that result in terms of reaction cross sections. If we assume a separable solution and furthermore assume that the time-dependent part is periodic, then we can substitute back into the Schrödinger wave equation to obtain what is known as the Schrödinger amplitude equation:

$$\nabla^2 \psi(r) + \frac{8\pi^2 m(W-U)}{h^2} \psi(r) = 0 . \quad (3)$$

This is a second-order linear homogeneous differential equation which must be satisfied over all space. It is a problem that admits solutions which are functions of the coefficient

$$k^2 = \frac{8\pi^2 m(W-U)}{h^2} , \quad (4)$$

where k is known as the wave number. The solutions that one obtains are, in fact, standing waves.

Let us return to the energy diagram of the compound nucleus. Denote the kinetic energy of the incident neutron by the CM energy E_c and denote the potential energy of the field that it enters by the letter U . We can identify these quantities on the diagram for formation of the compound nucleus. Outside the nuclear radius R , the potential energy U is zero, so that the total energy W is just equal to the kinetic energy, or $W = T = E_c$. Inside the nuclear radius, we have a potential well created by short-range attractive nuclear forces. The potential energy of attraction in this region is equal to the binding energy of the incident neutron, so that $U = -B$.

Specifically, for the square-well problem where the properties are region-wise uniform, we seek a separate wave solution in each region. The solutions must match at the interface of the two regions, both in magnitude and in slope. At the centerline of the nucleus we must have symmetry, and at infinity the amplitude must remain finite. Hence, we have the necessary boundary conditions for a solution. The solution outside of the nucleus consists of a linear combination of the incident wave and the reflected wave, which for the $\ell = 0$ angular momentum case (s-wave) can both be considered to be spherically symmetric wavelets about the center of mass. The solution inside the nucleus consists only of an outgoing wave of shorter wavelength than that existing outside the nucleus.

1.4 Cross Sections

In wave mechanics, the wave functions are physically interpreted in the following fashion. The square of the absolute value of the wave function, $|\psi|^2 d\mathbf{r}$ is the probability of finding a particle in the volume element $d\mathbf{r}$. If we normalize the volume integral over all space to unity, which states that the particle must be somewhere in space, then the corresponding integral over any sub-region, such as the entire nuclear volume, is the probability that the particle will occupy that space. But the probability of occupancy of the nuclear volume is qualitatively proportional to the cross section. The actual relationships are quite complicated, but we can see that the cross section will be large when ψ is large inside the nucleus, and small when ψ is small. Furthermore, the cross section will vary in magnitude much more rapidly than ψ because of the ψ^2 dependence.

The form of solution is a j_0 spherical Bessel function. The wave inside the nucleus starts from a symmetry point in all cases, so that the external wave, whose amplitude is essentially determined only by E_c , appears to shift in phase as E_c varies. When E_c is at a value that admits an integral number of internal waves in the distance R , the wave functions join with an essentially zero derivative and hence have maximum amplitude: this value of kinetic energy corresponds to a virtual level of the compound nucleus and a maximum resonance cross section. Note that this condition depends not only upon the nuclear radius R , which varies from nucleus to nucleus, but also on the binding energy B which likewise varies. The levels are not evenly spaced because of the square-root dependence of the wave number on the quantity $E_c + B$. Furthermore, these are just the $\ell = 0$ levels. Corresponding levels for $\ell \neq 0$ may be interspersed with attendant cross-section values. The higher Legendre angular moments must be included to treat these cases (called p-wave, d-wave, etc.).

The foregoing results can be directly related to the cross-section curve as a function of energy. The curve exhibits resonances which correspond directly to the virtual energy levels in the compound nucleus. For a single isolated resonance at energy E_c , the wave-mechanical solution can be put into a form called the Breit-Wigner single level formula. This is the cross section for formation of the compound nucleus. The probability of obtaining any given mode of de-excitation is proportional to the ratio of the partial level width for a specific outcome to the total level width at half-maximum, Γ . The level width Γ can be obtained from measured resonance cross sections.

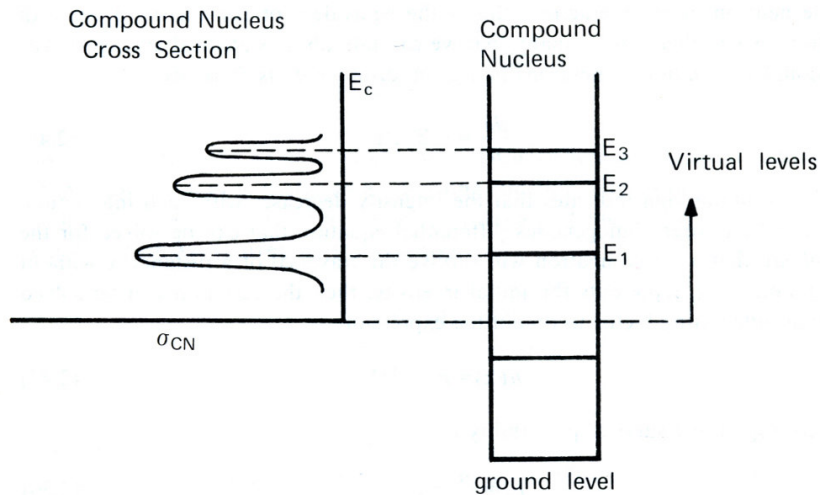


Figure 2. Relationship Between Cross Section Resonances and Virtual Levels

2. Electromagnetic Particle Models

Bergman has adapted a particle model originally proposed by Arthur H. Compton [3 - 5] (Compton Effect), which was later extended by one of Compton's last graduate students, Winston Bostick. Bostick worked on experimental plasma physics, and created something called a plasmoid, or a stable blob of charged particles. Based on Hofstadter's [6] experimental work on neutrons and protons, Bostick [7] proposed that an electron behaved as if it were composed of a charged fiber toroidal loop that had both electric and magnetic properties.

Bergman and Wesley [8] considered an electron to be a single spinning charged ring of charge $-e$, and adjusted its size to give it correct physical properties. Bergman [9] made a similar model of a proton as a single spinning charged ring of charge $+e$ with a different size. Bergman [10] finally made a model of a neutron as a coplanar proton ring inside an electron ring, with sizes adjusted to match experiment.

2.1 Crude Nuclear Model

Lucas [11] used Bergman's charged fiber models of neutrons and protons, and set about ordering them in space to make nuclei.

Using the notion that smaller shells may come apart and rearrange themselves into larger more stable shell configurations, Lucas predicted the entire pattern of the Magic Numbers of closed shells of neutrons and protons. One sees that the notion of shells rearranging into larger more stable shells due to the lack of an attractive nuclear center seems capable of explaining the magic number shell-like features of the nuclides.

Lucas then decided to model all 3000 nuclei in the Chart of the Nuclides, and fit his own Semi-Empirical Mass Formula to the binding energy per nucleon versus mass number, A .

His new fit predicts the entire structure of the data, including the peaks, with accuracy within the measurement errors of the isotope masses.

2.2 Detailed Nuclear Model with Decay

Boudreaux and Baxter [12] have adapted Bergman's model of a proton, and a neutron made up of an associated proton/electron, to make nuclear models based on detailed electromagnetic force balances between particles. The nucleons are allowed to separate and rotate to reach positions of minimum energy using a variational technique. When selected nuclei are approximately positioned according to Lucas' selection rules, the final positions converge quickly to the same pattern. By separately clustering particles, they tested several cases for decay, including Be-8, Na-24 and K-40, obtaining approximately correct decay energies.

2.3 Advanced Nuclear Model

Lucas has now extended the three-level charged fiber particle model to all of the elementary particles and their decay products treated by the Standard Model [13]. Neutrons and protons consist of parallel primary fibers made up of intertwined secondary and tertiary fibers. Depending on spatial orientation of the fibers, these models have the ability to match Hofstadter's [2] experimental data which showed that each nucleon has an internal charge distribution. The result may be a neutron that can polarize to produce an even more accurate nucleus model, as well as providing the needed neutrino and electron fibers for beta decay.

3. New Vibratory Nuclear Model

In the Semi-Empirical Mass Formula, the mass predictions are obtained by fitting to known mass data. Granted, the number of fitting constants needed is small, but only approximate nucleon masses were used. Lucas neglected the compression of the fibers in bound structures (my conception of how the weak force acts), as well as neutron polarization, and hence missed getting the exact masses which are equal to the total E&M binding energy of the particles.

It is interesting to speculate what the equations would look like if each of the three forces were replaced by non-linear springs, and the entire balance was treated as a vibration problem. There is hope that such a model can be constructed. The weak force compression springs produce work done over a short compression distance, and can be modeled as a spring with a negative spring constant.

The strong force magnetic attraction may be a contact force, effectively pressing on the weak force compression spring in conjunction with the effects of Coulomb forces, but it can also be modeled as a spring with a positive spring constant. The inter-nucleon distance is about $x_0 = 3.0 \text{ E-13 cm}$.

The primary Coulomb compression springs act similarly, but only between protons located at different multiples of x_0 , at distances $x'_0 = n x_0$ from each other, and hence over several individual compressions with a negative spring constant.

However, a new complication arises if the neutron has an internal charge distribution, and polarizes and arranges itself such that the net torque from all the other neutrons and protons is zero. This results in a small net Coulomb effect from the nearest nucleons, which adds to the compression force. It also produces some work, which can be thought of as the spin pairing effect. In principle, each time a nucleon of either kind is added to the nucleus, the neutrons will turn their axes slightly to a zero torque position, in some cases adding and other cases subtracting from the binding energy. This effect is not readily included in a linear model.

3.1 Finding Approximate Spring Constants

If we assume that the work done is proportional to the mass lost in binding the nucleons together to form a nucleus, in principle we can write coupled equations and fit the spring constants for the first few nucleons using published mass differences. Deuterium is the simplest nucleus, where the nucleons are co-linear, and only the strong and weak forces are present. If the weak compression resistance were absent, the two nucleons would merge! This is an alternate explanation to a strong force that changes direction at short distances. The neutron polarizes and also produces a small net Coulomb attraction along the centerline between nucleons.

The next two nuclei are Tritium and Helium-3, which are both coplanar and form a triangular structure. The strong forces add in a vector sense, making the three magnetic attractions each 50% larger. In Tritium, both neutrons polarize relative to the proton, and with respect to each other, effectively cancelling the Coulomb force from the proton, but producing a small net attraction to each other which is not along the centerline between neutrons. Again, the weak compression resistance keeps them from merging!

For He-3, there is one repulsive Coulomb bond of known force between protons, effectively weakening one of the strong bonds. However, the neutron polarizes with its negative end towards the protons, giving a small net attraction towards each which is not along the centerlines between nucleons. The weak compressions respond to these forces, doing more relative work.

He-4 is very tightly bound. It forms a tetrahedron structure, with the four strong bonds now doubling the forces by vector addition. These forces are resisted by one full Coulomb bond plus the weak force compressions. Again, the two neutrons polarize with their positive ends far away from both protons and each other, producing a slight net attraction towards each proton. There is no stable He-5 isotope. He-6 is made stable by adding two paired neutrons to the tetrahedral structure. The position of these nucleons would again be far away from the protons, near the neutrons, and polarized such that there is a slight attractive Coulomb force between themselves and the two protons.

The main conclusion to be made is that sorting out all of these forces to derive spring constants from this data is not easy to do. The resulting expressions are non-linear, requiring a least squares fit.

4. Schrödinger-like Vibratory Nuclear Model

This linear model of a nucleus, using springs, may only be valid over a small range of particle movement. Nonetheless, it is worth seeing what the conceptual consequences of such a model may be. It is known that light nuclei have only a few excited levels, widely spaced in energy, while heavy nuclei have many excited levels, closely spaced in energy. It is tempting to think of these levels as vibration resonances, the number of which is equal to the number of degrees of vibrational freedom, which is proportional to the number of nucleons present. For vibration problems, there is a steady state where all of the forces balance, and then there are excited modes where the frequencies are proportional to the square roots of combinations of spring constants divided by masses. For complex eigenvalues, the oscillation growth rates may be proportional to decay constants.

Let the nucleon position distribution vector, $\mathbf{P}(\mathbf{r},t)$, show where in the 3D space of a nucleus a given nucleon is located as a function of time. This vector conveniently orders the Z protons and the N neutrons, equals A nucleons, in their preferred nucleon shell positions for any given nucleus. Hence, it requires as input the positions established by Lucas' shell model for the nucleus under study. It gives sufficient information to evaluate the change in separation distances between each nucleon such that the time-dependent forces may be computed along any line between nucleons. If the forms of the force fields are known, the spring constants can be adjusted iteratively during the calculation. This position vector is defined as,

$$\mathbf{P}(\mathbf{r},t) = \begin{bmatrix} P_{p1} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ P_{pZ} \\ P_{n1} \\ \cdot \\ \cdot \\ \cdot \\ P_{nN} \end{bmatrix} . \quad (5)$$

The spring constant matrix, \mathbf{F} , which represents where the energy (or mass equivalent) is stored, is defined as the sum of the Coulomb, strong and weak force equivalents.

$$\mathbf{F} = -\mathbf{C} + \mathbf{M} - \mathbf{W} . \quad (6)$$

Each of the three components in \mathbf{F} is approximated as a linear spring stretched between some of the other nucleons. This leads to linear equations. For convenience, the weak force springs at the interfaces between nucleons are replaced with weaker equivalent springs between nucleon centers. A more accurate treatment would be nonlinear. The component matrices are defined below, using the above proton/neutron order.

For the Coulomb term, each proton repels each other proton, but there is no self-repulsion, and no repulsion of neutrons. Hence, the diagonal is zero, the proton sub-matrix is full, and the neutron sub-matrix is empty. To preserve the linear approximation, the Coulomb spring constants have to be adjusted for the nominal distance between protons, to make them weaker with separation.

The strong force action works only between nearest neighbors, so the magnetic attraction matrix, \mathbf{M} , has a zero diagonal and non-zero terms where the nucleons are adjacent to one another. The weak force compression matrix, \mathbf{W} , has a similar form. The terms in the matrices whose values are zero are determined from the shell assignments for a particular nucleus. These matrices are,

$$\mathbf{C} = \begin{bmatrix} 0 & C_{p12} & \cdot & \cdot & \cdot & \cdot & C_{p1Z} & 0 & \cdot & \cdot & \cdot & 0 \\ C_{p21} & 0 & C_{p23} & \cdot & \cdot & \cdot & C_{p2Z} & 0 & \cdot & \cdot & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot \\ C_{pZ1} & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & 0 & \cdot & \cdot & \cdot & 0 \\ 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 \end{bmatrix}. \quad (7)$$

$$\mathbf{M} = \begin{bmatrix}
0 & M_{p12} & \cdot & \cdot & \cdot & \cdot & M_{p1Z} & M_{n11} & \cdot & \cdot & \cdot & M_{n1N} \\
M_{p21} & 0 & M_{p23} & \cdot & \cdot & \cdot & M_{p2Z} & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
M_{pZ1} & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot \\
M_{n11} & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
M_{nN} & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0
\end{bmatrix} \quad (8)$$

and

$$\mathbf{W} = \begin{bmatrix}
0 & W_{p12} & \cdot & \cdot & \cdot & \cdot & W_{p1Z} & W_{n11} & \cdot & \cdot & \cdot & W_{n1N} \\
W_{p21} & 0 & W_{p23} & \cdot & \cdot & \cdot & W_{p2Z} & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
W_{pZ1} & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot & \cdot & \cdot \\
W_{n11} & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0 & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
W_{nN} & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 0
\end{bmatrix} \quad (9)$$

The intrinsic mass matrix, \mathbf{I} , is diagonal, since it represents the intrinsic or inertial energy content of the fibers that make up each nucleon, i.e., their intrinsic particle masses,

$$\mathbf{I} = \begin{bmatrix} I_{p1} & 0 & \cdot & \cdot & \cdot & \cdot & 0 & 0 & \cdot & \cdot & \cdot & 0 \\ 0 & I_{p2} & 0 & \cdot & \cdot & \cdot & 0 & 0 & & & & 0 \\ \cdot & & \cdot & & & & \cdot & \cdot & & & & \cdot \\ \cdot & & & \cdot & & & \cdot & \cdot & & & & \cdot \\ \cdot & & & & \cdot & & \cdot & \cdot & & & & \cdot \\ \cdot & & & & & \cdot & \cdot & \cdot & & & & \cdot \\ 0 & \cdot & \cdot & \cdot & \cdot & \cdot & I_{pz} & 0 & \cdot & \cdot & \cdot & 0 \\ 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & I_{n1} & \cdot & \cdot & \cdot & 0 \\ \cdot & & & & & & & & \cdot & & & \cdot \\ \cdot & & & & & & & & & \cdot & & \cdot \\ \cdot & & & & & & & & & & \cdot & \cdot \\ 0 & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & I_{nN} \end{bmatrix} . \quad (10)$$

When the nucleus is perturbed by an impinging gamma ray or other particle which turns it into a compound nucleus, the entire structure starts to vibrate. These vibrations follow Newton's law, $F = ma$, where \mathbf{I} represents the masses, or in this case,

$$\mathbf{F}\mathbf{P} = \mathbf{I} \frac{\partial^2 \mathbf{P}}{\partial t^2} . \quad (11)$$

As in the case of the Schrödinger equation, assume a separable damped periodic solution of the form,

$$\mathbf{P}(\mathbf{r}, t) = \mathbf{P}(\mathbf{r})e^{\alpha t} . \quad (12)$$

This gives the eigenvalue problem,

$$[\mathbf{F} - \alpha^2 \mathbf{I}]\mathbf{P} = 0 . \quad (13)$$

Formally, this equation can be rewritten by pre-multiplying both sides by \mathbf{I}^{-1} , and its eigenvalues can then be found by writing the corresponding characteristic equation. An eigenvalue of zero corresponds to the ground state, and the others will be proportional to the square roots of combinations of spring constants divided by masses. The other eigenstates correspond to the bound and unbound virtual energy levels in the nucleus. Hence, this mechanical model of a nucleus conceptually predicts the energy level structure of the nucleus in terms of the stable or semi-stable positions of its nucleons. The levels formally correspond to mechanical resonances.

Because of the use of linear approximations to forces that vary with distance in a quadratic sense, the model, even when adjusted, will be valid only for small perturbations about the ground state. Hence, the values of the elements in the above matrices should be chosen to get the best approximation to the actual ground state. The computational

method developed by Baxter [12] essentially finds one mode at a time from an initial configuration. Unfortunately the code does not contain either fiber compression or polarization at this time.

A neutron can impinge on the nucleus in one of many spatial orientations, each of which can produce a slightly different response because of an oriented momentum transfer. Since experiments show the overall effect of thousands of individual reactions, perhaps a portion of the measured level widths shown in the resonance curves (Figure 2) are the result of these orientations, and are not due to statistics or experimental resolution: i.e., the level widths may have a theoretical basis.

Equation 11 is a mechanical wave equation, structurally similar to Schrödinger's equation (Equation 2), but it does not produce spatial waves. However, the behavior of an excited nucleus in the new model is similar to that predicted by Wave Mechanics! The perturbation can be inserted into the initial conditions by specifying an initial harmonic state or an approximation to it. The nucleons will oscillate about their present equilibrium positions until they reach an amplitude position where another mode is more stable. At this point, the positions will change to the new configuration state and the excess energy will be emitted as a gamma ray or possibly another particle. The time it takes to make the transition once vibration begins depends on the rate of increase of the position distortion to the tipping point, so the decay constants are built into the model. All that is needed is a complex exponential time solution which represents a damped or growing oscillation.

These equations do not contain enough detail to decide how the transition takes place or what new state will be chosen. That subject would require additional work, or built in rules of transition.

5. Conclusions

The primary conclusion is that the wrapped charged fiber model of a nucleus has the potential to predict the masses of the nuclei from first principles as being equal to the total E&M energy content of all of its fiber components arranged in space and pressing against one another. The nucleon compression term represents a part of the mass loss that takes place when particles combine to form a nucleus whose mass is then less than the sum of its parts. Most of this mass loss is tied up in the spatial positioning, but the compression part makes up an important component. It also implies that the gravitational effect of this mass is transmitted electromagnetically.

In principle, compression-initiated vibration of a single nucleon is the process whereby beta decay or positron decay occurs through this weak force equivalent. For a two body model of a proton next to an electron, the oscillation frequency would depend only on the electron mass and the weak force spring constant, and thus be rather high with the electron moving relative to a stationary proton. The Standard Model cannot predict any masses, and relies on exchange particles of high equivalent mass to mediate these low energy decays. This new beta decay process would be analogous to the liquid drop model of neutron fission.

The internal energy structure of the excited levels of the nucleus shown in Figure 1 is inherent in the multiple semi-stable positions the nucleons can take with respect to their neighbors. The linear equation that governs the vibration of an excited nucleus is similar to Schrödinger's wave equation. The s-wave, p-wave and d-wave collisions occur due to the effect of the E&M fields interacting over a distance. In this sense, we do not need wave-particle duality, because the entire collision is Classical. But since the nuclear spins in Lucas' model can only change by half-integer multiples, the interactions also appear to be quantized. Finally, the decay of an excited nucleus to the ground state by gamma emission depends on the rate at which the vibration approaches the next stable configuration, which is part of the time-dependent oscillatory solution.

References

- 1) R. A. Rydin, **Nuclear Reactor Theory and Design**, Chapter 2, University Publications, Blacksburg, VA, 1977.
- 2) R. D. Evans, **The Atomic Nucleus**, Chapter 2, McGraw Hill, 1955.
- 3) A. H. Compton, American Physical Society address December 1917, **Physical Review Series II**, p. 330 (1918).
- 4) A. H. Compton, **Physical Review Series II, Vol. XIV, No. 1**, pp. 20-43 (1919).
- 5) A. H. Compton, **Physical Review Series II, Vol. XIV, No. 3**, pp. 247-259 (1919).
- 6) R. Hofstadter, **Reviews of Modern Physics, Vol. 28**, p. 213 (1956).
- 7) W. H. Bostick, **Physics of Fluids, Vol. 9**, p. 2079 (1966).
- 8) D. L. Bergman and J. P. Wesley, "Spinning Charged Ring Model of Electron Yielding Anomalous Magnetic Moment," **Galilean Electrodynamics, Vol 1, No 5**, pp 63-67, 1990.
- 9) D. L. Bergman, "Spinning Charged Ring Model of Elementary Particles," **Galilean Electrodynamics, Vol 2, No 2**, pp 30-32, 1991.
- 10) D. L. Bergman, "Notions of a Neutron", **Foundations of Science**, Vol. 4, No. 2, pp.1 – 8, May 2001.
- 11) C. W. Lucas, Jr., "A Classical Electrodynamics Theory of the Nucleus", **Galilean Electrodynamics, Vol. 7, No. 1**, Jan/Feb 1996.
- 12) E. A. Boudreaux, and E. C. Baxter, "Testing Classical Interactions between Finite Particles as a Model of Nuclear Structure", unpublished, 2008.
- 13) C. W. Lucas, Jr., "A Classical Electromagnetic Theory of Elementary Particles – Part 2, Intertwining Charge Fibers", **Foundations of Science**, Vol. 8, No. 2, pp. 1 – 16, May 2005.