A RECONSIDERATION OF THE PHOTOELECTRIC EFFECT AND ALPHA DECAY

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ABSTRACT

The photoelectric effect is considered as a resonant response of atomic electrons. The periodic nature of the electron is established by the work of Louis de Broglie unifying optical and dynamical path integrals. Finally, the atomic electron response to electromagnetic radiation is modeled using the solution of the damped oscillator. This concept is extended to nuclear phenomena by considering decay rates of alpha emitting nuclides. The implications for determinations of the age of the earth are then discussed.

INTRODUCTION

Resonance and the Photoelectric Effect

In his 1983 book, Physics of the Future, Thomas G. Barnes argues that a revised interpretation of the photoelectric effect is needed. The work of Herbert Ives is cited in describing the photoelectric effect as "due to an internal resonance in the atom, not in the incident light." It is this concept of resonance in the atom (or more properly at this point) the atomic electrons which this paper will initially address. The "photon" concept of light may then be reconsidered and the wave concept of light restored. Finally, a first conceptual attempt at extending this model to nuclear phenomena will be made. This will be done by considering alpha decay rates.

To study the atomic electron as a resonant system will require that the electron be considered as having wavelike properties. There are three reasons to do so.

- The Davisson-Germer experiment in which electrons were passed through crystals shows that electrons exhibit interference effects. This established that they possess wavelike properties.
- In Physics of the Future, Herbert Ives was quoted in his discussion of the photoelectric effect as saying "other attempts of explanation . . . have almost uniformly neglected or ignored the optical factors. These, instead of being secondary or negligible, really dominate." Wavelike properties in ejection of electrons are involved that resemble those of light.
- A unification of the optical and particle aspects of electron phenomena has already been done by Louis de Broglie.

PIONEERING

The Role of De Broglie's Wave Mechanics

Before considering the photoelectric effect as a resonant response by atomic electrons, a brief review of de Broglie's work is in order. To begin with, de Broglie wrote an expression for the momentum, J, of a particle in a potential A. (See Equation #1)

Equation #2 is the resulting Hamiltonian if the path integral for the particle motion is set up. That is, by the principle of Fermat, the derivative of the path integral (for the Lagrangian in generalized coordinates) is a minimum. The rewritten integral was then used to describe only the spatial coordinates, as noted in Equation #3.

Next, de Broglie considered the case in optical theory of a ray of light moving through a medium having a constant index of refraction. First, the phase of this wave is defined by Ø and the wave unit vector by n. The "principle of the shortest path" is then written in integral form as demonstrated in Equations #4 and #5.

The relationship between energy E and frequency of light, U, was postulated by Planck to be E = $h\nu$. de Broglie then postulated that Planck's principle was applicable to both cases just considered and allowed a relationship to be derived between them. Recall, at this point, that Planck's Principle was derived to solve the black-body radiation. It was derived under classical assumptions though its results went beyond them. de Broglie then considered the four-dimensional wave vector as previously referenced in Equations #4 and #5. Equation #6 gives the four-dimensional momentum of a particle.

The relativistic expression for momentum is easily recognized above. While Einstein receives the credit, the actual ground work was laid by Lorentz, again working under classical assumptions. de Broglie assumed relativistic invariance. Consider the case for i=4 for both cases and compare, substituting in W=$h\nu$(Planck's principle) and setting them equal:

$$P_{i=4} = \frac{h\nu}{c}$$

Expand this relationship to the complete vectors:

$$\vec{P} = \frac{M_o V_i}{\left(1-\frac{V^2}{C^2}\right)^{1/2}} = \frac{h\nu}{V}$$

upon simplification, this result is:

$$P = \frac{h}{\lambda}$$

This is the famous de Broglie equation. Having derived this relationship, the stage is set to consider the electron as a resonant system and how this may give rise to the photoelectric effect. For resonance to occur in a mechanical system (whether that of a mass on a spring or the nucleus) energy must be added to the system as some characteristic frequency which could, presumably, be the frequency of the electromagnetic radiation.

Next, de Broglie considered the electron as having periodic properties as part of its nature, not unlike a "clock" as it were. The electron, by virtue of its wavelike properties, could be represented by being associated with a stationary wave. This wave may be represented in the form:

$$e^{i\nu_o t_o}$$

where ν_o is the internal frequency of the electron, V is the electron "velocity", t_o is time and C is the speed of light. The "clock associated with the electron has a phase Ø. This phase may be calculated using the following two relations:

$$M_o C^2 = h\nu_o$$

where h is Planck's constant and m is mass. In addition, the following expression holds:

$$Vv = C^2$$

where V is the velocity of the phase wave of the electron and v is the velocity of the electron on its path. The quantity Ø is important in that energy must be supplied by electromagnetic radiation in phase with this internal wave for the photoelectric effect to occur. Equation #7 gives de Broglie's expression for Ø.

The velocity of the particle in its orbit can be different than that of the phase wave. If the particle wave itself moves at a velocity, V, the phase of this wave (after using the classical Lorentz relations) is given in Equation #8.

The two phases are, in fact, equal. This provides the basis for viewing the electron as a resonant system. When this condition was applied to the orbit of electrons an important result emerges. Consider that an electron starts from a point, 0, at velocity, v, and describes a Bohr orbit. The wave associated with the electron begins to move simultaneously with velocity, $V = v/c^2$. Let us say that the wave overtakes the particle at a point, 0', at some time τ. The wave will have traveled the distance from 0 to 0' and an entire orbit in time $(\tau + T)$ where T is the classical period of the electron. At the instant this overtaking occurs, the following relationship described in Equation #9 holds. Requiring that the phases be the same gives the condition:

$$2\pi\nu_1\tau = 2n\pi$$

where n is the number of Bohr orbits. This was the Bohr condition that allowed the prediction of the hydrogen spectra.

The Electron's Resonance with Varying Fields

Having established that the electron can profitably be viewed as a resonant system, let us consider the electron in its orbit. As it moves around the nucleus, let it have a characteristic frequency in the orbit of w. Upon bombardment by electromagnetic energy of some energy w', some photoelectrons may be given off. To consider this as a resonance condition, let us use the classical expression for a damped oscillator. For a steady state solution, the result is exemplified in Equation #10.

If the force is applied as maximized because $w=w_0$, the amplitude will also achieve a maximum.

In the photoelectric effect, an electromagnetic wave with frequency w' bombards an atom. The maximum energy, E, for electrons given off is given by:

$$E_{max} = (h\nu - w)$$

where h is Planck's constant divided by 2π and W is the work function or binding energy of the lattice. If the E is used as the forcing function, the result is Equation #12.

Thus, the quantity $h\nu$ becomes a unit of resonant response of the electron itself, rather than a discrete unit of electromagnetic radiation that leads to ejection from the atom. This view may help resolve some difficulties with the current view of the electron as a basically inert charged point. This can explain why some electron orbitals seem to preferentially emit photoelectrons. This would be expected when the "clock" frequency of the electron must match that of the incident wave. Although, this phenomena does present difficulties for the strictest point charge view of the electron.

Extension of the Oscillator Concept to Nuclei

It is to be hoped that this treatment could be extended to the nucleus. Many phenomena already are partially viewed in this light, such as nuclear magnetic resonance and photofission. The still unexplained production of muons produced by 1 TeV electromagnetic radiation from high-energy galactic sources may also have a resonance explanation. In short, this concept offers fruitful possibilities for a model of nuclear and atomic phenomena with real explanatory power.

Any attempt to formulate a model of nuclear phenomena using this concept will require the insights provided by quantum mechanics. As the derivation by de Broglie illustrates, the predictions of quantum mechanics are based on fundamental physical principles and logical deductions. This is not to say that many of the current philosophical conclusions supposedly drawn from quantum mechanics are either logical or correct.

In attempting to apply the concept of a damped oscillator to nuclear phenomena, alpha decay will be the starting point. Since the early research by Rutherford, Soddy and others, alpha emitting nuclides have been of great interest to nuclear scientists.

The significance of alpha decay for this discussion is that the radioactive elements used to calculate long ages for the earth tend to be alpha emitters such as uranium, thorium, etc. The purpose of this paper is not an in depth critique of current age estimates. On the other hand, a new model of nuclear phenomena will be shown to be consistent with varying alpha decay rates. This would allow for a younger age of the earth when present data is re-examined.

Experimental History of Alpha Decay Studies Using Haloes

Another property of alpha particles is that they tend to produce visible tracks in certain solids. This is due to their massive nature and charged state which induces a large amount of ionization. In fact, many commercial companies use these tracks formed by alphas tracking through plastic to detect radon.

In the early twentieth century, John Joly of the University of Dublin discovered that alpha emitting nuclides such as uranium can leave visible tracks in rocks. These take the form of tracks called **"pleochroic haloes."** Actually, as alphas leave bits of uranium and bombard the surrounding rock, a spherical pattern of defects is created. When the rock is cut in half, this track may be studied using a microscope. The size of these haloes can be used to determine the energy of the emitted alphas if their range in the substance is known. John Joly made extensive study of these plechroic haloes in rocks such as mica and biotite. As a result of his studies, he became convinced that the rate of radioactive decay for the alpha emitting nuclides had changed in time. Later, Professor G. H. Henderson at Dalhausie University continued these studies. The conventional scientific view became the rates of decay do not change over time but are constant. Any recognition of a change in decay rates would raise some fundamental questions about using radioactivity in dating the earth.

Questions about Varying Alpha Decay

In March 1972, however, Richard Spector re-examined the work of Joly and Henderson. Their data had previously been used to argue for an invariant alpha decay rate. Spector noted that both Henderson and Joly attempted to compare present day alpha ranges with the ranges in Precambrian rocks. These rocks were considered to be the oldest ones according to evolutionary time scales.

The fundamental issue raised in Spector's paper is as follows. Far from being evidence for invariance of decay rates, Henderson's work especially may indicate that alpha decay rates have changed. Henderson and Joly both compared the ranges of the alpha particles in rocks to those in air. The agreement they found was to within 3 percent. Today, however, with improved technology with which to examine the specimens, comparisons between ranges among rock samples is now possible, and to a much higher precision. The range, R, of an alpha particle with mass m in a material of atomic number Z, and ionization energy, I, is given in Equation #13 with the function of f given in Equation #14.

The whole assumption underlying Henderson's work was that the ratio of ranges for two energies would be the same in mica as in air. Mathematically, if we calculate an expression for ranges in air and mica for energies E_1 and E_2, then set them equal (as Henderson believed) the result will be Equation #15.

In Spector's paper, a comparison is made using E_1 = 4.5 MeV and E_2 = 7.5 MeV. The ratio on the left is found to be 0.442. The one on the right is found to be 0.474, an increase of more than 7 percent. From this, Spector has argued for a re-evaluation of plechroic haloes. The most notable recent attempt was by Robert Gentry during his stay at the Oak Ridge National Laboratory. Mr. Gentry concluded from his study of these haloes found in the basement granites that no uranium was initially present. Therefore, he believed the short lived polonium was primordial. For the haloes to provide a record of this polonium, the rock must have crystallized quickly. Though the plechroic halo research by Gentry is better known, there have also been important contributions made to age of the earth questions by his research on zircons. Zircons are crystals often found in granitic rocks having the chemical formula $ZrSiO_4$. As early as 1952, Vinogradov and his co-workers used isotopic dating to determine the ages of materials associated with well known rock types. The advantages to using zircons for dating is that common, non-radiogenic lead does not greatly effect the result. Equation #16 is the basic equation used to date zircons given in Lead Isotopes by B. R. Doe.

Zircons and Age Determinations

The paper by Gentry, et. al. on zircons entitled "Differential Lead Retention in Zircons: Implications for Nuclear Waste Containment" (Science, Vol 216, pp 296-298, 16 April 1982) provides important information regarding age of the earth questions. This paper presents data which calls into question some accepted views of earth history. Zircons pose a problem for evolutionary geology because they often give young ages for the geological formations where they occur. In a survey of the relevant work done in zircons, B. R. Doe notes that zircons are suspected of having low lead retention. This is believed to have caused the low age determinations associated with zircons. In fact, geologists were even willing to allow the possibility of leaching by water action to explain the low lead content. In his paper, Gentry analyzed zircons from a site in New Mexico being considered for a high level radioacitve waste depository. The resulting analysis showed the Pb-206/Pb-207 ratio was the same even at greater and greater depths. This deposit did not seem to have the lead loss noted in other zircons.

With the evidence of lead retention in the zircons presented by Gentry, the argument used by evolutionists against a younger earth is made open to question. In the book, Lead Isotopes by B. R. Doe, several anomalous ages calculated from zircons are given. For example, zircons from the La Sal Mountains of Utah were reported by Stern et. al., in 1965 to have an age of 494 million years. Also a Pb-determination of the age of zircons in the Leadville district of Colorado was made by Pearson et. al. in 1962. All of these results are significantly less than the billions of years assigned to many formations by the evolutionary times scale.

Theory of Alpha Decay

If there is a real variation in alpha decay rates as suggested in Spector's paper, then both the deposits with old ages and young apparent ages can be accounted for. Higher decay rates would cause relatively recent deposits to appear old while some deposits could be expected to appear much younger. The much younger ages would be a result of a lower decay rate in recent geological history. Evolutionists have suggested time dependent diffusion as one mechanism to explain the anomalous zircon data. Gentry's evidence for high retention of lead in the zircons indicate that another mechanism should be considered. As Spector has noted there are experimental considerations that point toward variation in alpha decay rates. There are certain theoretical considerations that point in this direction as well. First, let us consider the background to our current theoretical understanding of alpha decay. This was brought about by the work of George Gamow along with R. W. Gurney and E. U. Condon working independently. The problem was to find a way to predict λ, the decay constant for an alpha to be emitted from a nucleus in a given state. This was done by considering the alpha as a charged particle bouncing back and forth between the walls of a potential well. This potential well was of course the attractive potential of the nucleus. The new understanding quantum mechanics brought to the problem was that it was possible for the alpha to escape the nucleus even though it might not possess the energy to go over the wall. The results of the Gamow-Gurney-Condon theory were calculated as follows. Let λ be the decay constant for alpha emission and may be calculated using:

$$\lambda = fp$$

where f is the frequency of the alpha particles motion inside the nucleus and p is the probability of an alpha particle with mass M escaping the nucleus. The probability p was calculated using Equation #17.

When the following expression for U(r) is used, the integral assumes a new form. The potential is:

$$U = \frac{Zze^2}{r}$$

where Z is the nuclear atomic number and z is 2. The final result for λ appears in Equation #18.

When this integral is evaluated analytically after certain substitutions, predictions for λ can be made. The calculated and actual values for λ are given in Appendix B for selected even A nuclides (taken from Friedlander & Kennedy).

There are some differences for these nuclei between the calculated and actual values but also some striking agreements. These agreements were mainly for nuclides with even atomic weights. For nuclides with even Z, or atomic number and odd A or atomic weight, the calculated values were very disparate. In Friedlander and Kennedy it is noted that λ for the transition from U-235 to the ground state of Th-231 is approximately 1000 times greater than the experimental value.

Since Th-231 has a half-life of approximately 25 hours, very little Th-231 should remain on earth. Well, Th-231 is found still, Friedlander and Kennedy resolve this problem by simply stating the fact of the "hindrance factor" or delay by a factor of 1000 for the decay rate. This could be explained as well by a varying alpha decay rate and a much younger earth. Next, let us consider how this might be done in the context of the current theory of alpha decay.

Possible Basis for Varying Decay Rates in Current Theory

In the paper "Alpha Decay", by H. J. Mang, the current state of alpha decay theory is explained. The decay constant λ is given by the following expression:

$$\lambda = \frac{1}{\hbar} \sum_{jl} P\gamma(\varepsilon)^2$$

Where P is the barrier penetration probability and γ (ε) which is determined by properties in the nucleus. The quantity γ (ε) is referred to as the "reduced width" and refers to the probability of alpha particle production. The indices e and j refer to angular momentum states of the daughter nucleus and the alpha particle. The quantity γ is further defined in Equation #19.

This time dependent probability will be considered in more detail here. The g is considered to be a function of space and time variable, and can be described by quantum mechanical wave functions. The most important expression for this probability in our case is given in Equation #20.

The indices j, l, and J have been previously defined, while Γ is defined by the expression:

$$\Gamma = \frac{\lambda \hbar}{4\pi}$$

for the system.

In his paper on alpha decay, Mang notes that the above expression applies only in a very limited space time region. This region's size is less than $R = vt$ where v is the alpha's velocity and t is the travel time since decay. There must be a region of space time for the nucleus where there is time dependent exponential decay of the alpha generation probability. This condition may well be the source of a variable rate of alpha decay. This is the importance of this condition for the study of decay rates. This condition also can be conceptually assigned the role of a damping mechanism to a resonant oscillator as discussed in earlier considerations of the photoelectric effect.

Indeed this time dependent exponential decay may not be the only damping system for this phenomena. Mang notes that the dispersion of a wave packet will produce a time dependence of the form $t^{-3/2}$. If the optical analogy holds for this system, as it does for the electron, this might also produce a damping effect.

In conclusion, there exists experimental evidence that has re-opened the question of variable decay rates for alpha emitters. Some of this evidence has come with increasing precision of instrumentation as noted by Spector. Also as has been noted by Gentry and others studying radionuclide retention in zircons, there are evidences for a much more restricted timescale for earth history. Previous mechanisms for lead diffusion from the zircons were invoked to account for the discrepancies with current age of the earth estimates. With Gentry's determination of low diffusion rates there anomalous values must be reconsidered. A variable alpha decay rate then becomes more plausible. Finally, alpha decay can provide another application for the damped resonant oscillator concept to atomic and nuclear systems. This is certainly worthy of further investigation.

TECHNICAL SUMMARY

In this paper, the photoelectric effect is re-examined with the ejection of photoelectrons considered by viewing the electron as a resonant system. This view is derived from de Broglie's work to unify optical and dynamical formulations for light waves and particles, which resulted in the principle of phase harmony. This allows emission of photoelectrons to be viewed as the resonant response of a damped oscillator. The quantity "$h\nu$ " becomes a characteristic quantity of resonant response in the atomic electron rather than a discrete unit of electromagnetic energy. This concept of a damped resonant oscillator is then applied to the nuclei of alpha emitting elements in nature. This was done by examining possible variations in decay rates. Evidence of possible variations in even Z, odd A, nuclides will be considered along with implications for age of the earth determinations.

Thank you for your consideration. The opinions and conclusions expressed in this paper are those of the author alone. No other endorsements by any authors cited here are implied.

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COMPARISON OF DECAY CONSTANTS CALCULATED FROM (3-6) WITH EXPERIMENTAL DATA

Alpha Emitter	T (MeV)	R_1 X E+13 cm[a]	λ_{calc} (s^{-1})	λ_{exp}[b] (s^{-1})
Nd-144	1.9	7.950	2.7 X E-24	1.0 X E-23
Gd-148	3.27	8.014	2.6 X E-10	2.2 X E-10
Po-210	5.408	8.878	1.0 X E-6	5.80 X E-8
Po-214	7.835	8.927	4.9 X E+3	4.23 X E+3
Th-226	6.448	9.072	2.6 X E-4	2.95 X E-4
Th-228	5.521	9.095	8.0 X E-9	8.35 X E-9
Th-230	4.767	9.118	1.7 X E-13	2.09 X E-13
Th-232	4.080	9.142	7.8 X E-19	1.20 X E-18
Fm-254	7.310	9.390	1.3 X E-4	5.1 X E-5

<u>Nuclear and Radiochemistry</u>, 3rd Edition, Friedlander & Kennedy.

Zircon depth (m)	Filaments analyzed	Average zircons per filament	Total Pb counts	Counts of Pb-204	$\frac{\text{Pb-204}}{\text{total Pb}}$	Average Pb-206/ Pb-207	Range Pb-206/ Pb-208
960	4	~ 10	1.2 X E+6	235	2.0 X E-4	9.6 ± 0.3	6.5- 9.2
960	4	1	1.3 X E+5	35	2.7 X E-4	9.9 ± 0.4	5.8-14
2170	3	~ 5	8.9 X E+5	269	3.0 X E-4	10.0 ± 0.4	6.4-12.4
2900	3	~ 4	4.1 X E+5	114	2.8 X E-4	11.2 ± 0.3	0.4-11.4
3930	2	~ 10	6.5 X E+5	132	2.0 X E-4	11.0 ± 0.4	5.9- 8.7
3930	2	1	8.0 X E+4	46	5.8 X E-4	10.4 ± 0.1	3.1- 6.9
4310	7	~ 10	5.6 X E+6	1400	2.5 X E-4	9.7 ± 0.6	3.4- 9.8
4310	2	1	1.6 X E+5	100	6.0 X E-4	9.8 ± 0.4	4.5-10.7

Results of thermal ionization mass measurements for zircons with a Pb-205/Pb ratio of less than 2 X E-3. The background correction was taken from 208.5 mass position; it was applied to the raw data to obtain the isotopic abundances, which were used to compute the isotopic ratios. Standard deviations are listed with the Pb isotopic ratios.

From Gentry et. al., <u>Science</u>, Vol. 216, pp. 296-298.

a - radius values calculated using $R_1 = (1.30 \times A^{1/3} + 1.20) \times 10^{-13}$ cm

b - λ is the partial decay constant for ground state transitions

$$J_\alpha = M_o c U_\alpha + eA_\alpha \tag{1}$$

where: M_o = rest mass
C^o = speed of light
U = velocity as a relativistic function
α = three space variables and time

$$\delta\int_P^Q J_\alpha dx^\alpha = 0 \tag{2}$$

$$\delta\int_P^Q Jidx^i = 0 \tag{3}$$

where: P = path endpoint
Q = path endpoint

$$\delta\int_P^Q d\phi = \delta\int 2\pi 0_\alpha dx^\alpha \ (\alpha = \ 1,2,3,4) \tag{4}$$

where: 0 = a four dimensional wave vector given by:

$$\vec{0}_i = \frac{\nu}{V}\vec{n}_i \ (i = 1,2,3) \ \vec{0}_4 = \frac{\nu}{c} \tag{5}$$

where: ν = wave frequency
V = phase velocity
P = spatial endpoint
Q = spatial endpoint

$$J_\alpha = M_o C U_i = \frac{M_o V_i}{(1-\frac{v^2}{c^2})^{1/2}} = P_i \ (i = 1,2,3) \ J_4 = \frac{W}{c} \tag{6}$$

where: V = velocity
P = momentum
W = energy
C = speed of light

$$\phi \text{ clock} = \nu_1 t = \frac{m_o c^2}{h} (1-\frac{v^2}{c^z})^{1/2} \frac{X}{V} \tag{7}$$

where: X = the location of the particle as viewed by an observer in a non-accelerating frame of reference
t = time

$$\phi = \nu(t-\frac{vx}{c^2}) = \frac{m_o c^2}{h} \frac{1}{(1-\frac{v^2}{c^2})^{1/2}} (\frac{x}{v} - \frac{vx}{c^2}) = \frac{m_o c^2}{h} (1-\frac{v^2}{c^z})^{1/2} \frac{x}{v} \tag{8}$$

$$2\pi\nu_1\tau = \frac{2\pi m_o c^2}{h} (1-\frac{v^2}{c^2})^{1/2} X \frac{v^2}{c^2-v^2} X T \tag{9}$$

$$u = \frac{F_o \cos(wt - \delta)}{(m^2(w_o^2 - w^2)^2 + c^2w^2)^{1/2}} \qquad (10)$$

where: u = the amplitude of the vibration
w_o = the characteristic angular frequency
c = a constant and can be calculated from Equation #11

$$\delta = \cos^{-1} \frac{m(w_o2 - w^2)}{(m^2(w_o2 - w^2)^2 + c^2w^2)^{1/2}} \qquad (11)$$

where: w = the angular frequency of application of the force F_o

$$E = \frac{(h\nu - W)|\cos wt|(wc)}{(m^2(w_o^2 - w^2) + c^2w^2)^{1/2}} \qquad (12)$$

$$R = \frac{1}{128\pi}\frac{m_\alpha}{m_e} I^2 \frac{1}{NZe^4} \left(\frac{4m_e}{m_\alpha} \cdot \frac{E}{I}\right) \qquad (13)$$

where: N = atomic density
E = alpha energy
m_α = alpha mass
m_e = electron mass
e = charge of the electron

$$F^{-1} = \left[\frac{EdE}{\left(\ln \frac{4m_e}{m_\alpha}\frac{E}{I}\right)}\right]_0^E \qquad (14)$$

where: F^{-1} = antiderivative of function between limits 0 and E

$$\frac{f\left(\frac{4m_e}{m_\alpha}\frac{E_1}{I_{air}}\right)}{f\left(\frac{4m_e}{m_\alpha}\frac{E_2}{I_{air}}\right)} = \frac{f\left(\frac{4m_e}{m_\alpha}\frac{E_1}{I_{mica}}\right)}{f\left(\frac{4m_e}{m_\alpha}\frac{E_2}{I_{mica}}\right)} \qquad (15)$$

$$\frac{\left(\frac{Pb_{207}^{obs} - Pb_{207}^{init}}{Pb_{204}^{obs} - Pb_{204}^{init}}\right)}{\left(\frac{Pb_{206}^{obs} - Pb_{206}^{init}}{Pb_{204}^{obs} - Pb_{204}^{init}}\right)} = \frac{\left(\frac{U_{235}}{U_{238}}\right)_{obs}(e^{\lambda_5 t} - 1)}{(e^{\lambda_8 T} - 1)} \qquad (16)$$

where: "obs" = superscript presently observed isotopic ratios for radiogenic lead
"init" = superscript for ratios at crystallization
λ_5 = decay constant for U-235 (equal to 9.71×10^{-10} yr^{-1})
λ_8 = decay constant for U-238 (equal to 1.54×10^{-10} yr^{-1})
T = elapsed time

$$P = \exp\left(\frac{-4\pi}{(\frac{h}{2\pi})} (2\mu)^{1/2} F^{-1}[(U(r)-T)dR]_{R_1}^{R_2}\right) \tag{17}$$

where: μ = the reduced mass of the nucleus
U(r) = the attractive potential as a function of nuclear radius r
T = the total kinetic energy of the alpha particle and recoil nucleus

$$\lambda = f \exp\left(\frac{-4\pi}{(\frac{h}{2\pi})} (2\mu)^{1/2} F^{-1}[(\frac{Zze^2-Tr}{r^{1/2}})^{1/2} dr]_{R_1}^{R_2}\right) \tag{18}$$

$$\gamma^2_{Jjl} = \frac{h}{8\pi^2 m} R_o |g_{jlJ}(R_o)|^2 \tag{19}$$

where: γ^2_{Jjl} = the square of the reduced width of the system containing an alpha particle of angular momentum state l, and a daughter nucleus having an angular momentum state, j, with a total angular momentum J
R_o = the radius of the parent nucleus
g = time dependent probability amplitude for the generation of alpha decay

$$g_{jl}^J(R,t) = \exp\left(\frac{-2\pi i}{h}(E-i\Gamma)t\right) g_{jl}^J(R) \tag{20}$$

where: E = the α energy
i = the complex quantity
R = the relative distance between the α particle and the nucleus
t = time

DISCUSSION

This paper begins by referring to Barnes' book, *Physics of the Future*, in which it is argued that it is impossible for anything to exhibit both wave and particle properties. However, this paper presents some of the convincing evidence indicating the wave nature of electrons and other particles. Indeed, the alpha particle decay of nuclei seems to be predicted correctly through the theories of quantum mechanics and seems to be impossible to explain through any classical theory that denies that an alpha particle might exhibit any wave-like properties. However, it is not clear whether this paper rejects any or all of the particle-like aspects of electromagnetic radiation that have been used to explain the photoelectric effect. Specifically, the equation $E_{max}=(hn-W)$ is quoted and then modified. The derivation of this equation is usually based on the photon or particle-like behavior or electromagnetic radiation. The modification of this equation is given as equation (12) in this paper, but the notation is not clear. Care must be taken to distinguish between two experimental quantities: (1) E_{max}, which is the energy of the most energetic photoelectron, and (2) the number of photoelectrons emitted at some energy. The equation $E_{max}=(hn-W)$ makes no reference to the number of photoelectrons. Understanding the number of emitted photoelectrons may indeed require an analysis which involves resonance, as the author notes, "This can explain why some electron orbitals seem to preferentially emit photoelectrons." However, equation (12) must be clarified before its validity can be discussed. Specifically, a dimensional analysis indicates that the equation must be modified if E stands or energy. If E does not stand for energy, what does it stand for? If E does stand for energy, is it the energy E_{max} or is it the energy of some of the less energetic photoelectrons? Since cos(wt) can be both positive and negative, can E be both positive and negative? If the cos(wt) term is ignored, this equation predicts that E will decrease as w increases, as long as w is greater than w_0. While this decrease may be true for the number of photoelectrons observed at some energy, this is not true for the energy of the photoelectrons themselves. Thus, the author's analysis of the photoelectric effect may be correct, but clarification is needed.

Mr. Dusenbury then mentions some experimental evidence indicating that the present quantum mechanical treatment of alpha decay may be inadequate in explaining all the features of alpha decay, especially when examining haloes and/or zircons, and he suggests that a damped resonance effect may explain some of these discrepancies. The mathematical application of damped resonance to alpha decay does not seem to be presented, and the present reader does not see how the concept of damped resonance can be applied to alpha decay for two reasons:

1. As the author mentions, "For resonance to occur in a mechanical system (whether that of a mass on a spring or the nucleus) energy must be added to the system at some characteristic frequency . . . ." However, in alpha decay, there is no source of energy that is adding energy. There is no outside frequency at which energy is being added and which can establish resonance with the internal system of the nucleus.
2. The author indicates that a damped resonance would predict a changing decay rate for the alpha decay of a given isotope. Thus, the decay rate should be different if the time at which the decay is measured is greater. However, what is the starting point for this time that is greater or less when the decay rates are being compared? Perhaps the author was referring to the elapsed time since the isotope had been formed. If so, this would seem to predict that a quantity of a radioisotope that was newly formed would have a different decay rate from the same quantity of that same isotope, if all the latter isotopes had existed for some time. While it is difficult to check the accuracy of this experimental prediction with isotopes whose half-lives are millions of years, this prediction can be checked with great accuracy with short-lived alpha emitters, such as Rn-222, Rn-218, Po-210, Rn-220, Po-216, etc. I know of no evidence of changing decay rates even for nuclei whose ages are hundreds of half-lives. Thus, it seems that the author would have to refine his theory if he is predicting that the decay rate will change in several half-lives for long-lived radioisotopes but will not change in hundreds of half-lives for short-lived radioisotopes.

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Herbert Ives argued that the optical data is compatible with an atomic model with finite size electrons in some sort of resonant states and not with quantum mechanics of point-like electrons and quanta. De Broglie continued this idea when he equated Einstein's mass $m_o c^2$ with Planck's energy hv_o, i.e. $m_o c^2 = hv_o$. This identified the frequency v_o of the resonant state with the particle and not the wave or quantum. Dr. Thomas Barnes has given qualitative arguments indicating that such a model is feasible. However, Dr. Barnes left the development of explicit models to future scientists. Such models will need to predict the energy levels of the known atoms, at least as well as the Dirac equation, including such effects as spin-orbit coupling and the Lamb shift. No such models yet exist.

It may be somewhat presumptuous at this point in the development of theory to assume that the processes going on in the interior of the nucleus are the same as those involving the atomic electrons. However, those scientists willing to work on these problems leading to truth should be commended.

In this paper the use of quantum mechanics to derive a formula for alpha decay to test the idea of the nucleon being a finite size particle in a resonant state is inconsistent. Quantum mechanics is based on Hamiltonian mechanics for point-like particles only!. A finite size nucleon or electron in a resonant state is incompatible with point-like particles. One needs to use a classical type derivation for alpha decay if one wants to be consistent.

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CLOSURE

The discussion by Dr. Junkin indicates several areas that may need clarification in my paper. I will do this on the conceptual level primarily. The wave characteristics of subatomic particles are experimentally well established. The point of the paper was to seek an understanding of these properties using an oscillator model. Two separate phenomena were considered, namely the photoelectric effect and alpha decay. There were two different approaches put forth as models, but both utilized the concept of a damped oscillator. In the case of the photoelectric effect, the electromagnetic radiation falling on the metal acts like a forcing function on the electron, while the binding energy of the metal acts like a damping force. It's as if a weight were attached to the end of a spring. If the top of the spring was moved up and down the weight would be set in motion. Under the proper conditions, the weight could even break the spring, and fly off into space. This breaking of the spring is similar to the ejection of an electron in the oscillator model of the photoelectric effect. The energy of the ejected electron depends on the frequency of the impinging light being in phase with an internal frequency of the electron. This internal frequency was first discussed by Louis de Broglie, and I believe it has been demonstrated by Hans Dehmelt. The mathematical expression of this concept is found in equation 12. The reviewer is correct to note that this is only an expression for the maximum energy of the ejected electron. Ejected electrons of lesser energy would result when the light frequency does not approximate the internal electron frequency.

In regard to alpha decay, when a damped oscillator model is used, there is an important difference. There is no forcing function for one thing. The damping force would possibly cause a reduction of the rate of decay in time. This case is similar to a spring with one end hooked to a beam and a weight on the other. If the weight is pulled down and released, the weight will move up and down. The damping force of friction will bring it to a stop however. No attempt was made to quantify this in the paper, but merely to suggest it as one approach for understanding experimental results that may indicate changing decay rates. To detect changes in decay rates for short lived nuclides may be possible using the tracks produced in solids by the decay of the nuclides. For example, the decay of radon-222 produces tracks in solids such as glass or plastics. This process is described in *Nuclear Tracks in Solids* by Fleischer, et al. If objects with such tracks are available they might be used to check known to make such a determination, however. The decay rate for different periods of historical time might be compared between objects of different ages.

The comments by Dr. Lucas raised an important point. It is true that the Schrodinger formulation of quantum mechanics was only for point particles. The experiments carried out by Hans Dehmelt indicating that the electron has real structure creates real problems for the point particle approach. However, this does not indicate to me that there is no role for other tools that quantum mechanics might possibly provide. There are several possible options that may be pursued in the study of the electron as a resonant system.

First, a classical solution may be possible if the electron is considered to be made up of constituent particles. The stability of the particle orbits in the electron must be demonstrated in such a treatment.

The next possible option does involve using the tools of quantum mechanics by constructing wave functions to model an electron of finite radius. This approach has been used to generate nuclear wave functions and may be useable in this case. The wave functions would of course have to meet certain mathematical conditions such as orthogonality and being single valued. There is a greater ease of physical understanding using a classical methodology that this approach might lack, however.

Finally, a nonlinear approach might be used. Optical phenomena can sometimes be understood using such an approach. In the case of the electron, it may be that scattering, and resonance conditions could be predicted using a non-linear Schrodinger equation. The principle of superposition is not always obeyed under such a treatment. For this reason, the greater depth of physical understanding may result from the semi-classical approach. Until this is demonstrated there is still a use for quantum mechanical tools as they can be brought to bear on the problem.

Bernard, D. Dusenbury, B.S.