ATONIC MECHANICS PART ONE – PARTICLES AS PARTICLES

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Abstract

We show an alternative interpretation of the Davisson-Germer experiments. Roger Penrose, in his 2004 book, **The Road to Reality * A Complete Guide to the Laws of the Universe**, presents these eighty year-old experiments as the quintessential demonstration of the so-called wave nature of particles. Bragg derived the law, $n\lambda = 2d \sin \theta$, for waves. We derive that law for particles. This law was used in the Davisson-Germer 1927 experiment. The phenomena involved in their experiments are, according to our models, those of virtual particles and plasma oscillations. We make measurable predictions for the first three spectral orders of their 1928 experiment. We suggest that Occam's razor would cull away the particle-wave idea of de Broglie. The implications of our interpretation may be significant.

We are not unmindful of the apparent great success of quantum mechanics and its derivative theories, *QED*, . . . , the *Standard Model of Particle Physics* in which some theoretical predictions agree with experiment to better than one part in 10^{11}. Nevertheless we are concerned with the intuitive, physical, and logical basis of quantum mechanics. We wonder whether the successful mathematical aspects of quantum mechanics may have led to very subtle and possibly incorrect implications about the physics. We also believe that there may be a simple way to join mechanics of the small with Einstein's General Relativity, while consistent with Bell's Theorem. We seek answers with simple, yet physical and empirically-base-predictive physics. We start with a plausible model of the Davisson-Germer experiments. More than seventy years later, these experiments are still regarded by some[1] as the "gold standard" experiments for the validation of de Broglie's matter-wave hypothesis, the basis of the Schrödinger equation.

The specific question dealt with here is: *Do the Davisson-Germer (D-G) experiments show that electrons behave uniquely according to de Broglie's matter-wave hypothesis, or can their experiments more reasonably be modeled as showing that colliding electrons generate virtual electron–plasma oscillation phenomena within the Ni crystal?* We proffer an answer to this question later. Many of the events in the1927 D-G experiment[2] are non-specular, resulting from random electron scatterings. We find a "*Braggs Law*" for particles. As Davisson and Germer *in effect* assumed Bragg's Law for waves in the 1927 paper, we will take this demonstration of a "particle Braggs Law" as showing consistency between our model and the specular phenomena of their 1927 paper. The D-G 1928 experiment[3] dealt with the spectra obtained by changing the energy of the incident electrons while keeping the angle fixed. We found that we were able to make predictions of the intensities in their unmeasured lowest spectral orders. We assert that the test for our model would be the accuracy of our intensity predictions for the first three spectral orders reduced by work function considerations.

Newton's mechanics and quantum harmonic oscillator notions from Planck's blackbody radiation theory are sufficient to show that the Davison-Germer experiments can be explained on a conventional particle basis with virtual electrons and plasma oscillations in the Ni crystal. (We feel free to use Planck's ideas because they were created well before both de Broglie's ideas and quantum mechanics as we know it.) The first consideration of this model is that of the impulse of the electron collisions on the nickel crystal. In this model, the collision effects of an electron moves as a virtual electron within the crystal, down to a place where it is reflected as a virtual electron and back towards the surface. In the passage of the virtual electron through a nickel atom region, it produces harmonic plasma oscillations. These oscillations then give back energy in the form of a virtual electron which travels to the next nickel atom region. This process can be repeated many times. In the D-G experiments, measurements are made of electrons that are reflected back and leave the surface.

In the Appendix, we considered a linear array of stationary identical perfectly elastic bowling-type balls in which we injected an identical ball with a velocity ***v*** into the left end of array along the line of their centers. After a brief interval, the rightmost ball emerges from the array with velocity ***v*** and the original ball is stationary at the left end. The interior balls were always apparently stationary. Nevertheless, it would be correct to think of the velocity being passed from ball-to-ball, although only the end balls exhibit apparent motion. In other words, it is as if a ball is injected into the array of identical balls and it passes through the still array as a <u>virtual ball</u> and comes out the other end. The energy and momentum of the virtual ball are passed through the array in the form of compressions and expansions. These compressions and expansions are disturbances and restorations of electric charges away from and back to their space charge neutral positions. The changes in the electrical charge distribution are fundamentally governed by *Exclusion* Principle. Even the motions of massive bowling balls demonstrate the principles discovered in the mechanics of the small.

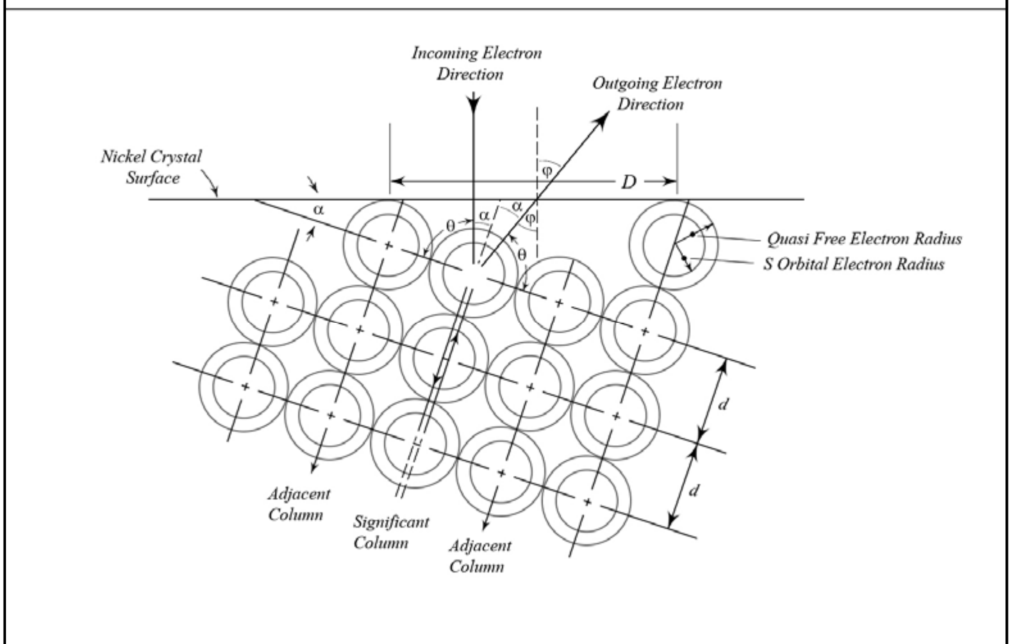

Figure 1

Figure 1 The electron incidence is normal to the crystal surface, but is at an angle θ with respect to the reflecting. The reflecting surface is at an angle α with respect to the crystal surface.

Consider a crystal array of nickel atoms and an impinging electron as in the Davisson-Germer experiment depicted in Figure 1. We schematically show the incoming electron direction, the path of the virtual electron moving into and out of the nickel crystal, and the outgoing electron direction. (The figure will be described more as the model is discussed subsequently.) We will use a similar logic to that described in the previous paragraph and in the Appendix, which consider both motion and internal phenomena.

Although this analysis deal with the D-G experiment, we posit that any crystal-based experiment that purports to verify the de Broglie wavelength could be explained by a mechanism similar to the virtual particle-plasma oscillation mechanism described herein. This may seem more physically sound (in the Occam razor sense) than ascribing wavelike properties to the electron itself if we were unaware of Bohr's and Born's ideas of *complementarity* and *probability densities*. Interference of matter waves at very low temperature (a small fraction of a degree above absolute zero) in Bose-Einstein condensates, like super conducting Cooper pairs, may be explicable as pairs of Fermions behaving like Bosons in composite objects. Such matter waves were not the subject of de Broglie's postulate.

Newtonian Component

Crystal nickel is formed in a cubic close-packed structure with a lattice constant of 352.4 pm. The radius of the *s orbital* of atomic nickel is 127.6 pm. Although the binding energies of the least two bound electrons (of the twenty-eight electrons) in atomic nickel are 66.2 eV and 68 eV, we have assumed that they are *quasi free* in crystal nickel, that is, they are only slightly bound to their ion cores. We assume that the volume occupied by the *quasi free* electrons of crystal nickel is that of a sphere with diameter the same as the lattice spacing. This is diagramed in Figure 1 where the reflecting planes are at an angle α with respect to the crystal surface. (A very clear explanation of the standard interpretation of the Davisson-Germer experiment is given in a book by French and Taylor.[4] Our Figure 1 was inspired by their Figure 2-7.)

We give further physical considerations in our model by discussing one electron before we introduce mathematics. The electron is injected perpendicular to the surface. Although the crystal surface is at an angle α with respect to the reflecting surfaces, the initial velocity of the electron is at an angle θ with these reflecting surfaces, as shown in Figure 1. The electron travels as a virtual electron within the crystal, analogous to that of a virtual bowling ball discussed above and in the Appendix. The virtual electron is constrained to its initial column (called *significant column*) of crystal nickel atoms as it is attracted by its positive ion core and repelled by the outer electrons in *adjacent parallel columns* of the three-dimensional close-packed structure. The *significant velocity component* of the virtual electron is in the direction perpendicular to the reflecting surfaces. This velocity component partakes in the phenomena associated with the Davisson-Germer experiment. The *non-significant velocity component* of the virtual velocity is in the direction parallel to the reflecting surface. (We do not show the *non-significant velocity component* which is perpendicular to the *significant velocity component* as showing it may make the figure too busy.) This latter velocity component, always less than the former component, does not partakes in the phenomena associated with the Davisson-Germer experiment.

The impulse on a *quasi free* electron contained in a crystal nickel atom located near the surface produced by an incident electron is

$$\boldsymbol{F_n} \Delta t = m_e \boldsymbol{u_2} - m_e \boldsymbol{v}_2. \qquad (1)$$

$\boldsymbol{F_n}$ is the normal force exerted by the incoming electron, Δt is the collision time, $\boldsymbol{u_2}$ is the instantaneous velocity of the quasi free electron after collision, $\boldsymbol{v_2}$ is the velocity of this *quasi free* electron before collision, and m_e is the electron mass (see Figure 1). The velocity $\boldsymbol{u_2}$ corresponds to 25 V to 343 V electrons used in the Davisson Germer experiments. We have taken $\boldsymbol{v_2}$ as zero as we have assumed that these *quasi free* electrons in crystal nickel are only slightly bound to their ion cores. The velocity component of $\boldsymbol{u_2}$ that allows propagation of the significant impulse of the virtual electron is $u_2 \sin \theta$. Similarly, the significant force, F, is normal to the reflecting planes (not to the crystal surface as was $\boldsymbol{F_n}$). With the understanding that the physics in the subsequent discussion is perpendicular to the reflecting planes, we have usually dropped vector notation. So the equation becomes

$$F\Delta t = m_e\, u_2 \sin \theta. \qquad (2)$$

If the extent of the collision impulse effect in the crystal is Δx, then Eq. (2) becomes

$$F\left(\frac{\Delta t}{\Delta x}\right)(\Delta x) = m_e\, u_2 \sin \theta. \qquad (3)$$

The velocity of a virtual electron, u_v, in the region of significance in the D-G experiment is the impulse extent divided by the time duration of the impulse. Equation (3) becomes

$$\frac{F}{u_v}(\Delta x) = m_e\, \boldsymbol{u_2} \sin \theta \qquad (4)$$

The motion of this virtual electron is between the first of the reflecting planes and the last significant one μ lattice spacing away. Among the mechanism that can cause reflection are impurity atoms, structural defects, the end of the crystalline region, and lattice vibrations under suitable conditions. It is reasonable (and it is the assumption here) that the energy of the virtual electron is sufficient to cause motion of the electrons in each crystal nickel region but insufficient to move the massive nucleus; thus the oscillations are harmonic plasma oscillations**.** The impulse effect, Δx, extends over μ lattice plane of spacing, d. We assume that d is the diameter occupied by the *quasi free* electrons for the cubic close-packed nickel lattice. We can now write

$$\mu d = \frac{u_v}{F}\, m_e\, \boldsymbol{u_2} \sin \theta. \qquad (5)$$

This then is the mechanistic model of a virtual electron which moves from one crystal atom generating within it plasma oscillation before moving to the next crystal atom as a virtual electron, repeating the process for μ crystal atoms where it is reflected back to the surface.

Planck Component

We assert that the harmonic plasma oscillations produced within the nickel crystal are subject to Planck Black Body radiation theory. We will later give a relevant Feynman quote aligned with this assertion. If the incoming particle has the minimum energy required to produce plasma oscillations, then Planck's model necessitates the maximum wavelength, λ, that is, the oscillations are over the entire atomic region spacing, *d*. Equation (5) becomes,

$$\mu\lambda = \frac{u_v}{F} m_e\, u_{\mathbf{2}} \sin\theta. \qquad (6)$$

The kinetic energy given to a *quasi free* electron that is struck by a virtual electron is

$$\Delta T = T(u_2) - T(v_2) \;=\; T(u_v) = \frac{1}{2} m_e \boldsymbol{u_v} \cdot \boldsymbol{u_v} = \int_1^2 F\, dx \cong F\, \Delta x. \qquad (7)$$

Our assumption is that the quasi free electron have zero velocity, i.e., $v_2 = 0$. The component of force normal to the colliding surface, *F*, equals the kinetic energy of the incoming electron divided by the range of the collision effect, Δx. In our model, we take the velocity squared part of the kinetic energy as a scalar product. It is the projection of $\boldsymbol{u_2}$ in the direction normal to the colliding surface, u_v, times u_2, the magnitude of $\boldsymbol{u_2}$. Equation (2) then becomes

$$\frac{1}{2}\, m_e u_v u_2 = F\, \Delta x. \qquad (8)$$

But the collision effect extent is μd, and we obtain

$$\frac{1}{2}\, m_e u_v u_2 = F\, \mu d. \qquad (9)$$

Accordingly, the previous expression for $\mu\lambda$, Equation (6), becomes

$$\mu\lambda = \frac{u_v \mu d}{\frac{1}{2} m_e u_v u_2} m_e u_{\mathbf{2}}\; sin\theta \qquad (10)$$

After cancellations, we can write

$$\lambda = 2\, d \sin\theta. \qquad (11)$$

Electron Flux and Ni Crystal Reaction

Since we have asserted that Planck's black-body radiation model is appropriate here, harmonic plasma oscillation energies are quantized in the Planck sense. Therefore, the next incident electron energy that could result in specular reflection would correspond to a frequency of twice that of the first oscillation. This would render a wavelength of one-half that of the first wavelength. The n^{th} incident particle energy that would cause plasma oscillations has a wavelength *1/n* that of the first. Specular particle reflection occurs when the <u>number of waves</u> generated in the collision-induced plasma-oscillations is an integer, *n*, times that corresponding to the minimum energy case. Thus, a Bragg law for particles

$$n\lambda = 2\, d \sin\theta \qquad (12)$$

is the response of the nickel crystal to electron collisions for specular events in the 1927 Davisson-Germer experiment. Bragg's law, derived for waves, was implicit in their "conformation" of de Brogilie's hypothesis for the so-called wave nature of particles. In their 1927 paper, Davisson and Germer used the following equation

$$\lambda = D \sin\varphi, \qquad (13)$$

where *D* is the separation of atomic planes at the surface, and φ is the exit angle (again see Fig. 1). This is equivalent to the Bragg Law at the surface when *n* equals one. The model presented herein involves a volume response to depth μ lattice spacings, not a surface response. We conclude that our model of the D-G experiment is consistent, in principle, with their 1927 results. We now turn to a quantitative and predictive aspect of our model by considering the 1928 D-G experiment.

Davisson and Germer give a graph of spectral intensity as a function of spectral order (1/λ) in their 1928 paper (see Figure 2). We model this phenomenon. We again mention that a virtual electron enters into a nickel atom region causes harmonic plasma oscillations there and leaves as a virtual electron. The virtual electron-plasma oscillation "dance" goes to a depth of μd where it is reflected back to the surface region. As our assertion is that these oscillations are harmonic, they are then separated by the energy difference, $\hbar\omega_p$, where $\hbar$ is Planck's constant divided by 2π and ω_p is the plasma oscillation frequency. In order to excite higher order plasma oscillations, the electron's energy (the accelerating potential) had to be increased. Our model of the D-G spectral intensities was inspired by Feynman's discussion of Black-Body radiation. In the section

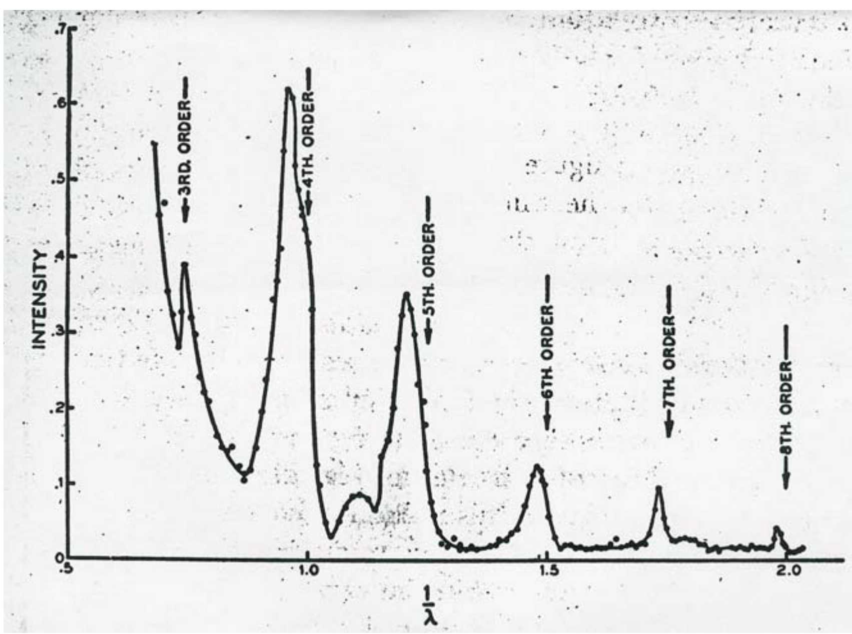

Figure 2 The Davisson-Germer spectra from their 1928 paper.

Equipartition and the quantum oscillator[5] he wrote, "According to the hypothesis (which we have not proved) that in quantum mechanics the law that replaced the probability that $e^{-\text{P.E.}/kT}$ or $e^{-\text{K.E.}/kT}$ in classical mechanics is that the probability goes down as $e^{-\Delta E/kT}$ where ΔE is the excess energy, we shall assume that the number N_1 that are in the first state will be the number N_0 that are in the ground state, times $e^{-\hbar\omega/kT}$." We note that Feynman was alluding to "quantum mechanics" pre de Broglie as he was deriving Planck's equation for the average energy. That is to say, the intensity of the n[th] order is that of the first order reduced by the factor

$$e^{\frac{-nh\omega_p}{kT}}. \qquad (14)$$

Feynman, discussing plasma oscillations in metals[6] wrote, "Now, according to quantum mechanics, a harmonic oscillator with a natural frequency ω_p has energy levels which are separated by the energy increments $\hbar\omega_p$." In that section, *Plasma Oscillations*, they (Leighton and Sands are co-authors, but Feynman gave almost all of the lectures) show that the square of the oscillation frequency, ω_p, is given by

$$\omega_p^2 = \frac{n_0 q_e^2}{\varepsilon_0 m_e} \qquad (15)$$

where n_0 is the density of electrons in the undisturbed, equilibrium state, and where the other quantities have their usual meanings. The density of nickel atoms, n_{Ni}, is about 2.29 x 10^{22} cm^{-3}. As we have assumed that only the two least bound electrons participate in this process, n_0 is about twice n_{Ni}. Our model shows that not all electrons participate in the plasma oscillations. If $f_{D\text{-}G}$ is the fraction of n_0 that participate in the oscillations then

$$\omega_{p,D-G}^2 = \frac{f_{D-G} n_0 q_e^2}{\varepsilon_0 m_e} \qquad (16)$$

If $f_{D\text{-}G}$ = 4.73 x 10^{-6}, and we fit our spectral intensity to n = 4, we obtain the results shown in Figure 3A and Figure 3B. We fitted to the value n = 4, rather than n = 3 since we believe that there is more error for intensity values of the lower spectral orders than there is for the higher orders. Davisson-Germer (see Figure 2) did not give intensity values for n = 1, and 2. Electron energies are smaller for the lower spectral orders. All emerging electrons must overcome the surface work function. The more energetic electrons of the higher spectral orders do so more easily. In the interpretation of this model, the electrons associated with spectral order three only marginally overcome surface influences. A <u>test of this model</u> would be finding whether or not the spectral predictions for n = 1, 2, and 3 in the 1928 D-G experiment agree with our predictions when made with state-of-the-art instrumentation having work function considerations. This model can also be tested using elements in crystalline form that have lower work functions. (Note: the respective work functions given in eV of Ni, K, Sm, and Ce are 5.15, 2.3, 2.7, and 2.9.)

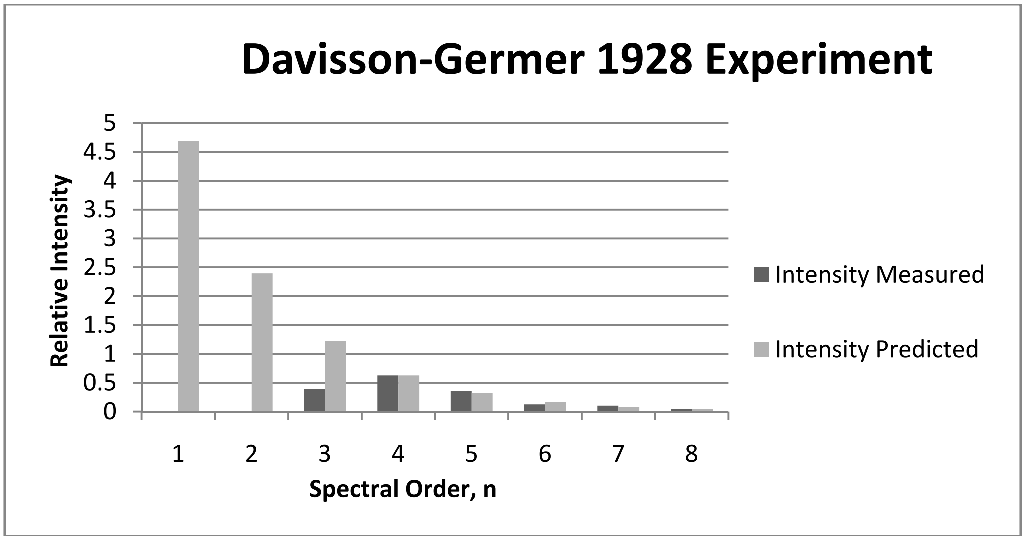

Figure 3A ***Relative Intensity*** **measured and predicted, fitted at n == 4. Davisson and Germer did not give intensity values for the first and second spectral orders. We question the accuracy of the third spectral order.**

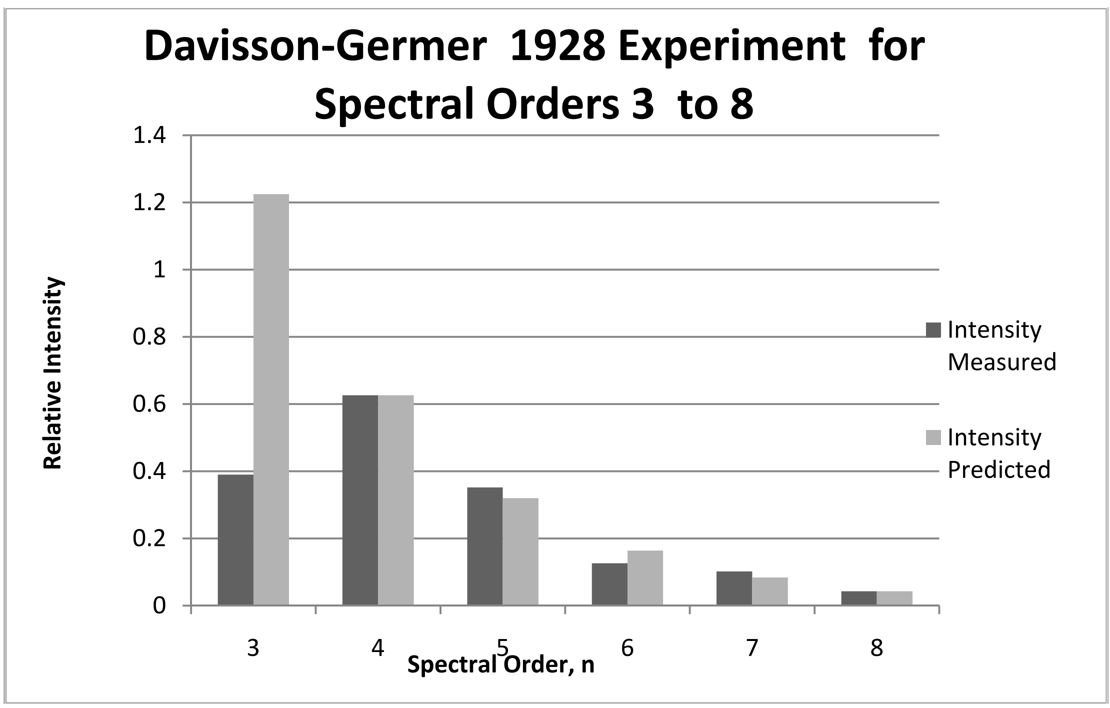

Figure 3B The measured and predicted ***Relative Intensity*** **histograms matched for n = 4 are plotted again to show the details of the reasonable match for spectral orders 5 through 8.**

Answer to the question "Do the Davisson-Germer (D-G) experiments show that electrons behave uniquely according to de Broglie's matter-wave hypothesis, or can they more reasonably be modeled as showing that colliding electrons generate virtual electron–plasma oscillation phenomena within the Ni crystal?"

We answer the question posed at the outset in the following manner: the Davisson-Germer experiments can be interpreted as showing that the electrons incident on the nickel crystal pass through the crystal as virtual electrons, produce plasma oscillations in the process, are reflected back to the surface, and some have sufficient energy to leave the nickel. Other experiments, done after the invention of quantum mechanics, such as that of G. P. Thomson's electron beam in polycrystalline foil or Esterman's He atom scattering from LiF crystal, would also have similar projectile-crystal-interaction explanations. (See reference 4 for a discussion of these experiment and the citations.) Although this analysis dealt with the D-G experiment, we posit that any crystal-based experiment that purports to verify the de Broglie wave nature of particles could be interpreted by a mechanism like that of the virtual-particle, plasma-oscillation mechanism described in this model. To a fresh mind, this mechanism may seem more physically sound (in the Occam razor sense) than ascribing wavelike properties to the electron itself. Interference of matter waves at very low temperature (a small fraction of a degree above absolute zero) in Bose-Einstein condensates, and super conducting Cooper pairs, may be explicable as pairs of Fermions behaving like Bosons in composite particles. Such matter waves are not the subject of de Broglie's postulate

Inferences of this work

If new measurements of the D-G experiment correspond to the predictions given in this paper for the lowest three spectral values, the implications may be profound. First, the crystal has wavelike manifestations manner, not the electrons. Second, electrons having non-relativistic energies can be modeled entirely as particles. Third, interference is not in the nature of the particles (electrons) themselves, but it is in the interaction of particles (electrons) under some conditions with other matter. Fourth, the Schrödinger equation may be the fortuitous, as its derivation was based upon the de Broglie postulates. The prevailing interpretation of the wave function is that it is probabilistic. Although Schrödinger envisioned ψ as a charge density, Born's probabilistic interpretation of ψ may make the most sense for the meaning of his theory and other similar theories. Probabilities, however, would not be in the nature of particles themselves. In some experiments, we can effectively model the constituents as one particle (e.g., electron) problems. One is the hydrogen atom; others are NIST He I, and II. These atoms are modeled in *Atonic Mechanics, Part Two.* The prime implication of this work is that there may be another way to do atomic mechanics. Our candidate is *Atonic Mechanics*.

References

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Personal Note

We are mindful of the adage, "*If it ain't broke, don't fix it."* Many physicists may say that quantum mechanics is not broke. They may say, "Look, some of our predictions agree with measurements to one part in 10^{11}." What Atonic Mechanics may be able to do is to take the *mysticism* out of quantum mechanics that even Schrödinger's cat was mindful of. Yes, there must be some predictions in *Atonic Mechanics* too. Hey, go re-do the Davisson Germer experiment as a start!

This paper is not written in the standard form of scientific papers. I, for example, use the pronoun "we" rather than "I." I did not attempt to publish this work in established journals principally because I wanted it to have maximum impact in creating scientists and engineers in the *Hip-Hop* generation

If what I have done make sense, then I have simply re-arranged the thoughts of many others and on rare occasions I have entered a new thought or novel arrangement of the ideas of others in my models. If one stands on the shoulders of giants, then one should mention this human ladder in one's writings. Some of the people who are significant to me as a physicist are above all my parents, my children, some ladies, J. Donald Roll, Thurman Spriggs, Francis Board, Herman Branson, Herbert Kyle, Maharishi M. Yogi, a few IBMers, the NSBP, the African American engineering students at Cornell University during 1991-1992, the legacy of "Black" students at Cornell, the Teaching Company, and the ensemble of writers whose work is on the web. I learned a lot about physics, insofar as I know it, from Feynman's books and recently audio versions thereof, as well as other books by Eisberg, Freier, Landau & Lifshitz, Eddington, Hartle, and Penrose. Unfortunately, I could have greatly benefitted from more discussion of physics with my peers, but my personality, and my culture, to a certain extent, did not make this easy or often available. I, nevertheless, have been guided by Newton's reflection that he gave his work "patient attention." I have also tried to incorporate within my consciousness Einstein realization, "I have always thought of myself as myself at my best.