

The Three-body Model of Atomic Radiation⁽¹⁾

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Abstract

Einstein derived his coefficients of induced and spontaneous emission by assuming that electromagnetic radiation is directional, having the form of “needle radiation.” That idea is extended here and shown to suggest that stimulated emission should be described as a three-body problem: nucleus, electron, and photon. The photon is conceived of as having a central core with localized momentum surrounded laterally by a continuous sinusoidal field; stimulated emission is due to the coupling of its field with the bound electrons of nearby molecules. Coupling is directly proportional to the density of oscillators so that starlight is predicted to have a different microscopic structure than artificial light. Noncommutation does not occur in the three-body model of emission because the conservation of momentum fixes the order of observables. This allows the mathematical formalism of quantum mechanics to be assigned a more precise physical interpretation. Evidence for the three-body model is described at the macroscopic level by using high-speed photographs of spark discharges. It is hypothesized that all forces — gravitational, electroweak, and nuclear — have independent structure and are thus in agreement with the three-body model.

Key words: Einstein, Heisenberg, field theory, stimulated emission, needle radiation, wave-function, conservation laws, quantum mechanics, commutation relations, test charge

1. INTRODUCTION

1.1 The Quantum-Mechanical Concept of Field

A fundamental difference exists in the way electromagnetic fields are conceived of in the classical and quantum theories. Classical fields are described by using test charges of vanishing intensity, whereas in quantum theory, due to the uncertainty principle, detectors of infinitesimal influence do not exist. This distinction is particularly significant in nonrelativistic quantum mechanics, where fields are described classically by means of Fourier series while quantization is imposed only on the field energy. Quantization is thereby understood to be a localization of energy even though the fields extend to infinity and are therefore diffuse. Fictitious harmonic oscillators are used to reconcile the spatial continuity of radiation fields with the discrete energy states of an atom. As a result, the physical relationship between atomic energy states and the continuous fields they are coupled with is not well understood.

1.2 Historical Perspectives

To better understand the concept of field in quan-

tum mechanics it will be helpful to look at its origins. Quantum mechanics did not develop in direct progression from a single inspiration or insight. Instead, a series of seemingly disconnected contributions, theoretical and experimental, arrived in timely fashion so that from inception to completion a mere 10 years elapsed. The collective effort that produced quantum mechanics would not have proceeded so smoothly or so rapidly, however, were it not for the timely and highly incisive influence of Albert Einstein. This is because both wave and matrix mechanics have their origin in concepts that he introduced.

It is especially true of wave mechanics since de Broglie formulated the founding principles by extending concepts from the 1905 papers on special relativity and the photoelectric effect to material particles. Einstein also provided the stimulus that led to completion of these ideas in a series of papers on the quantum theory of gases by showing that the same statistics Bose had applied to light quanta could also be used to describe emission from a monatomic ideal gas.⁽²⁾ This led directly to the further development of wave mechanics by Schrödinger and the introduction

of the wave-function. He openly acknowledged his indebtedness to Einstein in a letter, “By the way, the whole thing would not have started at present or at any other time (I mean as far as I am concerned) had not your second paper on the degenerate gas directed my attention to the importance of de Broglie’s ideas.”⁽³⁾ His papers also stimulated Dirac to write the first paper on quantum electrodynamics introducing the concept of second quantization.⁽⁴⁾

Einstein contributed to Heisenberg’s matrix formulation of quantum mechanics as well with his paper on the induced and spontaneous emission of electromagnetic radiation.⁽⁵⁾ This marks the beginning of quantum mechanics, since all subsequent research on the absorption, emission, and dispersion of radiation is based upon it.⁽⁶⁾ Nevertheless, the paper did not appeal to Heisenberg when it first appeared.⁽⁷⁾ He only made use of its results in his paper on quantum mechanics after he had incorporated the idea that the atom consists of a twofold, infinite, denumerable array of virtual oscillators. Because of this and the fact that there are extensive differences in the mathematical formalism of these theories, Einstein’s influence is not generally appreciated.

1.3 Einstein’s Emission Theory

Because absorption processes cannot be directly analyzed, the only means we have for understanding atomic processes in order to formulate a theory of emission is to analyze the radiation that an atom or molecule emits. Due to the continuity of radiation fields, radiating bodies may be conceived of as emitting spherical waves with no net momentum transfer. On the other hand, Einstein derived his coefficients of emission and absorption under the assumption that electromagnetic radiation consists of localized quanta of energy $h\nu$ and momentum E/c , such that “outgoing radiation in the form of spherical waves does not exist.”⁽⁸⁾ Clearly there are fundamental differences in the physical assumptions and theoretical development of these two models. The Einstein emission theory treats electromagnetic radiation as a distribution of localized energy quanta with directed momentum in the form of “needle rays,” whereas the Heisenberg theory is based on a continuous wave interpretation.

Given the fundamental differences in their physical assumptions, it is not surprising that Einstein had a deep-rooted, long-lasting dissatisfaction with the final form that quantum mechanics took. Einstein described radiation processes by using a model that treats energy and momentum equivalently:⁽⁹⁾

Almost all theories of thermal radiation are

based on the study of the interaction between radiation and molecules. But in general one restricts oneself to a discussion of the energy exchange, without taking the momentum exchange into account. One feels easily justified in this, because the smallness of the impulses transmitted by the radiation field implies that these can almost always be neglected in practice, when compared with other effects causing the motion. For a theoretical discussion, however, such small effects should be considered on a completely equal footing with the more conspicuous effects of a radiative energy transfer, since energy and momentum are linked in the closest possible way.

Heisenberg rejected these ideas because he believed that the continuity of radiation should be included in a description of the emission and absorption of radiation. When he formulated his theory of matrix mechanics by using Fourier series, the differences in the theories were made irreconcilable. This is because a Fourier series is unable to describe the discontinuous aspects of radiation.

2. STIMULATED EMISSION

2.1 Theory

In nonrelativistic quantum mechanics momentum is derived by means of a quantum-mechanical reformulation of the classical Fourier series representing position coordinates. Thus the momentum of the electron radiating between energy states m and n of a hydrogen atom is expressed by the commutation relation as follows:

$$\sum_k (p_{nk} q_{km} - q_{nk} p_{km}) = \begin{cases} ih & \text{for } n = m, \\ 0 & \text{for } n \neq m. \end{cases} \quad (1)$$

The momentum p and position q are not numbers, but rather arrays of quantities, or matrices. Each component of the matrix is a Fourier series associated with any two of an infinite number of orbits. Thus the complete matrix has an infinite number of components and corresponds in its entirety to one of the dynamic variables of Newtonian theory. Because the orbits may extend to infinity both in space and in time, exchanges of momentum are delocalized.

If Einstein is correct, however, then a theoretical model of radiating atoms is required that includes both the continuous and discontinuous aspects of radiation. The continuity of radiation fields must be combined with the discrete nature of the emission and absorption processes such that momentum is local in

its action rather than diffuse. In this way a theory of atomic radiation is sought that places momentum exchange on an equal footing with energy exchange.

2.2 Wave-packets

At the time there was no direct evidence of discontinuity in the emission process and thus no overriding need to account for needle radiation. However, 25 years later, experimental techniques improved and this changed. Studies of nuclear magnetic resonance showed that radiating “molecules are interacting with a common radiation field and hence cannot be treated as independent.”⁽¹⁰⁾ The common radiation field causes a correlation of excited states so that the spontaneous emission of photons leads to an angular and spatial correlation of succeeding photons that is twice the incoherent rate, and it is manifested as coherent radiation. The coherence observed in nuclear emission anticipated the existence of a similar effect in much lower energy optical phenomena. This was soon confirmed experimentally through the observation of intensity fluctuations in partially coherent light.⁽¹¹⁾ Photodetectors detect these fluctuations as groups of discontinuous events that are referred to as photon “bunches.” Despite the experimentally observed discontinuities in radiation fields and the use of photons to describe emission processes, no changes have been made to the quantum-theoretical description of sources. Momentum continues to be constructed from fields as a delocalized parameter. It is an unsatisfactory state of the theory that emission is described as a highly delocalized process even though experiment has shown that it exhibits many discrete characteristics.

A comparison of nuclear and optical emission indicates that photon correlations have many of the same characteristics as wave-packets. If it is assumed that emission occurs in the same way for both nuclear and atomic systems, then the discontinuities that radiation fields exhibit may be explained in terms of field by the cooperative emission of photons from correlated states. The way this occurs together with a detailed model of the photon is described elsewhere (cf. Ref. 1). Thus the photon would have the same general characteristics as charged particles: an impenetrable core surrounded laterally by a sinusoidal electromagnetic field whose amplitude diminishes radially. The emission of radiation from a hydrogen atom is conceived of as a process involving three particles: proton, electron, and photon. The photon is introduced in atomic emission for the same reason the neutrino was introduced in beta emission, to account for missing momentum.

Stimulated emission is conceived of then as occur-

ring when a spontaneously emitted photon of a single wave cycle induces cooperative emission in neighboring molecules by means of its field. This causes photon cascades to be generated that possess the characteristics of wave-packets/photon bunches. The phase of the spontaneously emitted photon is random, while that of the induced radiation is correlated. The coherent pulses are of small cross-sectional area and extremely high intensity within a partially coherent beam whose time-averaged intensity, due to field cancellation between pulses, is much lower. The light emitted by a thermal source would therefore have a highly complex microscopic structure rather than a continuous, uniformly expanding wavefront. Clearly, the density of atomic oscillators determines the photon density of the wave-packet. As a result, starlight and artificial light will have distinct microscopic structures even though their observable properties, such as intensity and frequency, may appear to be the same.

2.3 Noncommutation

A measurement consists of a transfer of momentum and energy to or from a recording instrument. Quantum observables, which are expressed by Hermitian matrices, differ from classical observables because they do not commute, so the order in which they appear in an expression is important. They also differ because classical momentum is localized in space and time, while in quantum mechanics momentum is an operator that is constructed from fields that may be expressed in continuous form by

$$i\hbar \frac{\partial}{\partial x}.$$

Now consider how momentum is transferred during the emission of a photon. The photon carries away a momentum E/c while the atom or molecule recoils in the opposite direction, thereby conserving momentum. However, if the order of the observables is reversed so that a photon is emitted first and the electron is stimulated afterward, momentum is *not conserved*. Thus noncommutation cannot occur when momentum is conserved because the order of observables is fixed. Noncommutation is due to the use of reversible field equations to describe an irreversible phenomenon, the emission process. We can define field equations that are consistent with the conservation of momentum by using them to describe a photon’s external field (cf. Ref. 1). The fields will then be directed in time, yet the time reversibility of the equations is maintained. In other words, reversing

a photon's direction must not alter the nature of the field equations. It remains to be determined why this leads to an asymmetry equal to \hbar .

It has long been known that the commutation relations refer to quantities at different points in space at the same instant in time.⁽¹²⁾ However, cause and effect are sequentially ordered in time so they cannot be represented by distinct quantities at a single instant. Thus it is not possible *from first principles* to make a statement about causality, the future behavior of a particle, or the emission process that is based upon the commutation relations because all three depend upon the flow of time. We conclude that Heisenberg's microscope experiment is fundamentally flawed because it does not include time as an observable.⁽¹³⁾

Position measurements executed at two different points in space at a single instant in time define a length determination performed relativistically. Therefore we may use the position measurements q_{km} and q_{nk} in (1) to specify a single observable, the photon's wavelength. The absorption process for energy states m and n , $m < n$, is now given by

$$p_{mn}\lambda_{mn} = \hbar, \quad (2)$$

where observables refer to the field excitation process and the equal sign refers to a change from linear to angular momentum. Subsequently, for emission we have a return to linear momentum:

$$\hbar = p_{nm}\lambda_{nm}. \quad (3)$$

A physical interpretation of (1) may now be obtained by subtracting (3) from (2), where the conservation of momentum dictates that the flow of time is from left to right:

$$p_{mn}\lambda_{mn} - p_{nm}\lambda_{nm} = \begin{cases} i\hbar & \text{for } m = n, \\ 0 & \text{for } m \neq n. \end{cases} \quad (4)$$

For $m \neq n$ we have zero, indicating that the absorption and emission processes are symmetrical. The nonzero result $i\hbar$ that occurs for $m = n$ may be explained if the diagonal components represent both absorption and emission and a return to the ground state. An asymmetry is created because emissions are observable, whereas *absorptions are not*. In other words, the momentum associated with field excitation, which introduces an angular momentum \hbar to the atom, has been excluded from the commutation relation (1).

Therefore noncommutation may be said to result from the insistence in quantum mechanics that only observables be included in a theory of nature.⁽¹⁴⁾

3. ENERGY CONSERVATION

3.1 The Electron Oscillator

The linear harmonic oscillator is only able to reproduce continuous oscillatory motion. Energy conservation is then satisfied in a roundabout fashion by means of the anharmonic oscillator.⁽¹⁵⁾ A more direct physical connection between the emission process and oscillators may be established by introducing the concept of an "electron oscillator," one cycle of which is defined to be an electron's displacement into a different energy state and its subsequent return to the original state. The off-diagonal components of the energy matrix, $i \neq j$, represent one half cycle of the electron oscillator and one complete cycle of an electromagnetic wave, or one photon. The diagonal components of the array, $i = j$, represent one complete cycle of the electron and include both absorption and emission. Each nonzero component of the matrix would describe an electron-photon pair. In other words, the matrix is a composite of all electron transition possibilities and photon characteristics. Because energy is conserved for each component, it is automatically satisfied for the entire matrix.

One complete cycle of the electron oscillator is equal to two complete cycles of an electromagnetic wave (i.e., two photons) and results in a doubling of the frequency of oscillation. The same thing is observed to occur when the wave-function of a half odd integer spin particle is rotated through 4π radians.⁽¹⁶⁾ If we interpret the wave-function as a photon-particle pair, then a "rotation" of 2π radians corresponds to one cycle of an electromagnetic wave (one photon) and 4π radians equals two photons. One rotation of the wave-function correspond to absorption *or* emission, while two rotations correspond to absorption *and* emission, and a return to the ground state. This is in conformance with the formal requirements of quantum theory.

3.2 Photon Detection

It is well known that intense electric and magnetic fields will not deflect a photon from its path; nevertheless, field intensity is thought to be an indication of photon number. But if force cannot be transmitted to the photon via an external field, how is it possible for the reverse to occur? We conclude that neither particle deflections nor detection events can be caused by the field of a single photon.

An analysis of field laws shows that the sinusoidal

fields of single photons have a net field strength of zero. Because field detectors have spatially and temporally averaged inputs, the fields of a photon or single wave-train must cancel. This does not mean that a photon's field cannot transmit force, only that it cannot transmit a *net* force by means of its integrated field. We may conclude therefore that a photon's field only becomes observable as a result of superpositions of field that are asymmetric. Thus the smallest unit of electromagnetic radiation that can be detected by means of field is the wave-packet. Detection events that are referred to in the literature as "photons" must be attributed to field superpositions instead (cf. Ref. 1). They are discrete because changes in state are discrete. From these arguments we conclude that although energy is always conserved microscopically it need not be conserved macroscopically, as, for example, in interference fringes.

Experimental evidence from intensity interferometers confirms that thermal sources whose time-averaged emission is incoherent exhibit coherence properties at a deeper level. This would indicate that wave-packets are locally coherent, but their phase is shifted with respect to packets overlapping with them. When detected by time-averaging it leads to a net cancellation of field and reduction in observable field intensity such that the total potential energy of the photons in these beams will be greater than the observed field intensity. Because coherent light may be as much as 10 magnitudes more intense than incoherent light, vastly higher energy content may be present in incoherent light than what is actually observed.⁽¹⁷⁾

4. PHYSICAL INTERPRETATIONS

4.1 Field Geometry

In quantum theory the force that is transmitted by a field is believed to be a consequence of exchanges of momentum by energy quanta. Such a model of force is asymmetric since a distinction must be made between the source and the recipient of the quanta. Field models that use advanced and retarded potentials also distinguish between source and recipient. However, in the three-body model of atomic radiation force is represented by an independent entity, the photon. If force were conceived of in general as having independent geometry, then perfect symmetry would exist for all dynamic interactions. Rather than the electromagnetic field of one particle acting at the location of a second particle, force may be conceived of as acting on both particles/field sources simultaneously, thereby causing both to pivot about a common center. This would occur in a manner similar to the

way gravitational forces act by "curving space" rather than by directly altering particle motion through "action at a distance." Force would be described therefore in terms of the field geometry that exists between the field sources.

There is evidence from experiments with spark breakdowns that the electrostatic force has geometric symmetry of this type. If oppositely charged spheres are placed approximately 1 cm apart and illuminated with ultraviolet light to ensure an ample supply of photoelectrons, then initial breakdown occurs in the middle of the gap connecting first with the cathode and then with the anode.⁽¹⁸⁾ Because there is a uniform distribution of photoelectrons in the gap, we may conclude that the discharge initiates where field strength is greatest. These findings are also confirmed in photographs of spark discharges from both Tesla coils (alternating current) and van de Graaf generators (direct current), indicating that field intensity is greatest halfway between the electrodes (Fig. 1).

Due to the linearity of the electromagnetic field, these experiments represent a simple magnification to macroscopic proportions of field effects that occur during interactions with atomic oscillators. Therefore Coulomb's law is an approximation that only applies in cases of large field imbalance. When field sources are of imbalanced intensity, the test charge is a good approximation and fields behave classically, while field sources of balanced intensity cannot be approximated by test charges and may exhibit quantum-mechanical behavior.

4.2 Mathematical Formalism

The "disappearance of a photon" by absorption and its subsequent reappearance by emission are represented formally in quantum mechanics by the creation and annihilation operators. However, if "photon annihilation" is actually field superposition (cf. Ref. 1), then the use of operators may be interpreted as describing the transformation of unobserved fields into observable photon emission. Similarly, we interpret "second quantization" as the separation of the wave-function into its physical components, electron and photon. In other words, these are formal expressions that distinguish bound states described by energy from free states described by field.

The Schrödinger wave equation for a radiating atom describes the flow of probability for finding the electron. Because electrons are most likely to be found where field intensity is greatest, we may give an equivalent interpretation of the Schrödinger equation as describing field intensity. In the case of an excited atomic state this consists of the superposition of periodic and constant fields due to their

respective sources, photon and electron. An electron diffraction experiment may be interpreted therefore in terms of a periodically varying field that exists within atoms interacting with the field of incident electrons to cause deflections corresponding to the combined field of both particles.

Quantum mechanics is an attempt to obtain the equations of motion of three independent field sources in an isolated system. Ordinary mathematical methods cannot be used to solve the problem of a simultaneous superposition of three field sources, all of them continuous. The best possible solution is obtained by performing two successive mathematical operations. First, a composite of any two vector fields is obtained (the state vector), giving an infinite number of possibilities (the probability amplitudes). The influence of the third vector field (the operator) is then applied, giving an infinite number of possible values for the physical variable (the eigenvalues). Combining the vector fields in a different order gives distinct, but mathematically equivalent, solutions. In this manner quantum mechanics may be expressed in two mathematically equivalent ways, either by matrix mechanics or by wave mechanics.

5. CONCLUSION

Both the Hamiltonian and Lagrangian formulations of quantum mechanics use a field potential to describe excited atomic states. The introduction of a continuous field into the interior of the atom cannot be justified, however. This is because classical fields depend upon the idea of a test charge and with it the assumption of an infinitesimal influence, or force, upon charged particles. The use of a test charge is valid for describing fields in free space, where the classical limit can be taken and the relative field intensity of a charged particle made vanishingly small. However, the overwhelming success of the

shell model of the atom tells us that the force binding an electron to the nucleus is not continuous. In other words, the use of a potential to describe discrete energy states is inaccurate because the test charge is based upon the concept of continuous field. The force within an atom must be conceived of as arising due to a quantized field, a field that is temporally discrete so that it is repeating, yet whose spatial influence extends to all points of the atom. Otherwise, the idea of an independent existence for atoms has no meaning.

Quantum theory describes force asymmetrically by means of the exchange of quanta. Previous arguments have shown that a symmetrical description of force is only possible by means of a field theory. A field theory is also preferred because force is transmitted locally without action at a distance. An electromagnetic force is characterized by a low density of field lines with a relatively large radius of curvature, while strong, or nuclear, force is characterized by a high density and a very small radius of curvature. Thus force is conceived of as having structure that is independent of material particles, the field sources. In fact, independent structure is evident in all of the known forces: gravitational, electroweak, and strong. At one end of the spectrum, in general relativity theory, we see that gravitational force has a well-defined structure, and although it derives its existence from the mass points it is independent of their internal structure. At the other end, in quantum electrodynamics, asymptotic freedom requires that strong forces possess independent structure in the form of a vector boson, or "gluon." Thus a more accurate description of force may be achieved by taking into account the geometry of independent fields.

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Résumé

Einstein a calculé ses coefficients pour les émissions induites et spontanées en émettant l'hypothèse que le rayonnement électromagnétique est directionnel (c'est-à-dire orienté). Cette idée, reprise et développée dans le présent document, permet de considérer les émissions induites comme un problème à trois corps comprenant un noyau atomique, un électron et un photon. En supposant que le photon est doté d'un noyau central dont la quantité de mouvement localisée est latéralement entourée par un champ sinusoïdal continu, l'émission induite résulte de l'appariement de ce champ avec les électrons liés des molécules avoisinantes. Cet appariement étant directement proportionnel à la densité des oscillateurs, la structure microscopique de la lumière des étoiles devrait logiquement être différente de celle de la lumière artificielle. Aucun phénomène de non commutation ne se produit avec un modèle d'émission à trois corps, la conservation de la quantité

de mouvement définissant l'ordre des éléments observables. Ceci permet d'attribuer au formalisme mathématique une interprétation physique plus précise. La théorie du modèle à trois corps est confortée au niveau macroscopique lorsque des photographies à haute fréquence des décharges par étincelles sont utilisées. On part de l'hypothèse que toutes les forces, gravitationnelles, électrofaibles et atomiques disposent d'une structure indépendante, et ne remettent donc pas en question la thèse du modèle à trois corps.

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Figure Captions

Figure 1. Spark discharge taken from a video clip showing a greater intensity in the middle of the gap. Courtesy of Charles Hobson.