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EFFECT OF VACUUM ENERGY ON THE ATOMIC SPECTRA

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The effect of vacuum energy on the spectrum of atomic H is investigated using a Schrödinger equation and Higgs mechanism. It is shown that the effect of the latter is to decrease the energy level of the ground state of the H atom emitting energy in the process. This mechanism has been observed empirically in recently reported reproducible and repeatable experiments.

Key words: energy inherent in the vacuum; Higgs mechanism; atomic spectra.

1. INTRODUCTION

Recently, the energy inherent in the vacuum has been observed repeatedly and reproducibly in atomic H [1] as an emission caused by a lowering of the ground state of the atom. A mechanism for this phenomenon is suggested in this paper using a Higgs mechanism [2] in the Schrödinger equation, which is derived from the non-relativistic limit of the Einstein equation obtained as the classical limit of a Klein-Gordon equation with Higgs mechanism incorporated. The effect of the Higgs mechanism (spontaneous symmetry breaking of the vacuum) can be calculated straightforwardly, and provides a qualitative explanation of the empirically observed vacuum energy [1]. An explanation is given as to why the Higgs mechanism does not affect relativistic classical dynamics in terms of quantum tunneling. The method used is to start with a Lagrangian for the Higgs mechanism in matter fields, derive a Klein-Gordon equation, and from that, an Einstein equation, then to take the non-relativistic limit of the Einstein equation, and finally quantize that to give the Schrödinger equation. The Higgs minimum is at an energy $\frac{1}{2}m_0c^2$ below the symmetry unbroken vacuum. Some examples are given of the effect of this negative potential energy on analytical solutions of the Schrödinger equation.

2. LAGRANGIAN FOR THE HIGGS MECHANISM

The starting Lagrangian on the U(1) level for a free particle such as an electron is the standard Lagrangian for the Higgs mechanism:

$$\mathcal{L} = \partial_\mu \phi \partial^\mu \phi^* - m^2 \phi^* \phi - \lambda \left(\phi^* \phi\right)^2, \tag{1}$$

which gives the Klein-Gordon equations

$$\left(\Box + m^2\right) \phi^* = -2\lambda \left(\phi \phi^*\right) \phi^*, \tag{2}$$

$$\left(\Box + m^2\right) \phi = -2\lambda \left(\phi^* \phi\right) \phi \tag{3}$$

in which ϕ and ϕ^* are considered to be complex valued one-particle wave functions. The Higgs mechanism (spontaneous symmetry breaking of the vacuum) increases the mass term m^2 to $m^2 + 2\lambda\phi^*\phi$. The classical equivalent of these equations is the Einstein equation for one particle:

$$En^2 = p^2c^2 + m_0^2c^4 + 2\lambda\left(\phi\phi^*\right)c^4, \tag{4}$$

in which spontaneous symmetry breaking of the vacuum leads to an additional rest energy

$$En_0(\text{Higgs}) = 2\lambda\left(\phi\phi^*\right)c^4. \tag{5}$$

In this equation, En is the total energy and it can be written as:

$$\begin{aligned} p^2c^2 &= En^2 - En_0^2 \\ &= m_0^2c^4\left(1 - \tfrac{u^2}{c^2}\right)^{-1} - m_0^2c^4 - 2\lambda\langle\phi^2\rangle c^4 \end{aligned} \tag{6}$$

To derive the non-relativistic limit of this equation, the right hand side is expanded as Eq. (7) below. (If you apply the McLaurin series (Taylor with $a = 0$), there is no term for $(c - u)$ in the denominator of Eq. (7) requiring the approximation that the denominator approaches c for small u.)

$$p^2c^2 = m_0^2c^4\frac{u^2}{c^2} - 2\lambda\langle\phi^2\rangle c^4, \quad u \ll c, \tag{7}$$

which, for $u \ll c$, results in the non-relativistic equation

$$p^2c^2 = m_0^2c^4\frac{u^2}{c^2} - 2\lambda\langle\phi^2\rangle c^4 = En^2 - En_0^2. \tag{8}$$

The equation can be developed as

$$m^2u^2 = p^2 + 2\lambda\langle\phi^2\rangle c^2, \quad u \ll c, \tag{9}$$

that is,

$$\frac{1}{2}mu^2 = \frac{p^2}{2m} + \frac{\lambda}{m}\langle\phi^2\rangle c^2. \tag{10}$$

The left-hand side is the non-relativistic kinetic energy of one particle, and it can be seen that spontaneous symmetry breaking changes the classical non-relativistic expression

$$En = \frac{1}{2}mu^2 = \frac{p^2}{2m} = T \tag{11}$$

in Eq. (10). The Schrödinger equation without the Higgs mechanism is obtained as usual by applying the quantum *ansatz*

$$En \rightarrow i\hbar\frac{\partial}{\partial t}, \quad \mathbf{p} \rightarrow -i\hbar\boldsymbol{\nabla} \tag{12}$$

in Eq. (10), giving

$$-i\hbar\frac{\partial\phi}{\partial t} = \frac{\hbar^2}{2m}\nabla^2\phi \tag{13}$$

The Schrödinger equation in the presence of the Higgs mechanism is therefore

$$-i\hbar\frac{\partial\phi}{\partial t} = \frac{\hbar^2}{2m}\nabla^2\phi + \frac{\lambda}{m}\langle\phi^2\rangle c^2, \tag{14}$$

where $\langle\phi^2\rangle$ is the expectation value of the wave function. At the Higgs minimum [3], this expectation value is

$$\langle\phi^2\rangle = -\frac{m^2}{2\lambda}, \tag{15}$$

and so the Schrödinger equation at the Higgs minimum becomes

$$-i\hbar\frac{\partial\phi}{\partial t} = \frac{\hbar^2}{2m}\phi - \frac{1}{2}mc^2\phi. \tag{16}$$

This result can be written in the familiar form

$$En\phi = H\phi = (T+V)\,\phi, \quad T := -\frac{\hbar}{2m}\nabla^2, \tag{17}$$

where

$$V = -\frac{1}{2}mc^2 = min\left(\frac{\lambda}{m}\langle\phi^2\rangle c^2\right) \tag{18}$$

is a negative potential energy produced by spontaneous symmetry breaking of the vacuum. The symmetry broken vacuum is at an energy

$$V(\text{Higgs}) = -\frac{1}{2}mc^2 \tag{19}$$

below the vacuum for the ordinary Schrödinger equation (17), whose vacuum expectation value is

$$\langle\phi^2\rangle = 0. \tag{20}$$

Therefore, a non-relativistic Schrödinger equation for a free particle has been devised with an additional potential energy term. In order to apply this method to the hydrogen atom, the Schrödinger equation becomes

$$\left(-\frac{\hbar^2}{2\mu}\nabla^2 - V_C + V\right)\phi = En\phi, \quad V_C := \frac{e^2}{4\pi\varepsilon_0}\frac{1}{r} \tag{21}$$

where V_C is the classical Coulomb interaction energy between one electron and one proton, and where μ is the reduced mass:

$$\mu := \frac{m_e m_p}{m_e + m_p}. \tag{22}$$

3. QUANTUM TUNNELING

The Higgs mechanism is th basis of electroweak theory and other elementary particle and gauge field theories, so that there is a firm foundation for the fact that the energy $\frac{1}{2}m_0c^2$ can be emitted from the vacuum where there is a shift between the Higgs minimum in the symmetry broken vacuum and the ground state H atom in the symmetry unbroken vacuum. Mills et al. [1] have recently patented a device for this energy emission based on the postulated collapse of the H atom below its ground state. The theory presented in Sec. 2 may be a qualitative explanation for the energy observed by Mills et al. [1], reproducibly and repeatedly. The Schrödinger equation in the symmetry broken vacuum shows that there is an extra potential energy term present whose effect on the electronic states of the H atom can be found by solving Eq. (17) analytically. The effect of V on simple analytical solutions of the Schrödinger equation can be illustrated as follows.

The wave function for Eq. (17) is well known to be of the form [4]

$$\phi = A'e^{i\kappa' Z} + B'e^{-i\kappa' Z}, \quad \kappa' := \left(\frac{2m\,(E-V)}{\hbar^2}\right)^{\frac{1}{2}}; \tag{23}$$

where the particle momentum is given by $\hbar\kappa'$. The diagram below explains the role of the two parts of the wave function:

$$\begin{aligned} \rightarrow p = \hbar\kappa', \qquad \psi = A'e^{i\kappa' Z}; \\ \leftarrow p = \hbar\kappa', \qquad \psi = B'e^{-i\kappa' Z}. \end{aligned} \tag{24}$$

In the Schrödinger equation (17), the maximum value of the vacuum potential energy is the symmetry unbroken Newton vacuum:

$$V = 0 \tag{25}$$

and its minimum is the symmetry broken vacuum:

$$V = -\frac{1}{2}mc^2. \tag{26}$$

In Newtonian mechanics, the particle cannot be found below V = 0, and so Newtonian mechanics always corresponds to $V = 0$, Eq. (25) and the Newtonian concept effectively presents an insurmountable barrier to a classical particle such as the classical electron attempting to enter the symmetry broken vacuum below $V = 0$. In quantum mechanics, however, an electron may enter the symmetry broken vacuum by quantum tunneling, which occurs when $E < V = 0$. The wave function for this process is well known to be [4]

$$\phi = Ae^{-\kappa Z} \tag{27}$$

and has a non-zero amplitude. An electron of energy 1.6×10^{-19} J incident on a barrier of height 3.2×10^{-19} J has a wave function which decays with distance as $e^{-5.12(Z/nm)}$, and decays to $1/e$ of its initial value after 0.2 nm, about the diameter of an atom [4]. Therefore, quantum tunneling is important on atomic scales, and, in quantum mechanics, an electron can enter the symmetry broken vacuum and emit energy by gaining negative energy. The maximum amount of energy that can be radiated is determined by the minimum value in the Higgs mechanism. This minimum value defines the ground state, which is the symmetry broken vacuum state. These considerations have been made on the basis of Eq. (17) for the free electron.

The states of the hydrogen atom must be found from Eq. (21). When $V = 0$, the ground state of the H atom is well known [4] to be determined by the expectation value

$$En = -\frac{\mu e^4}{32\pi^2\varepsilon_0^2\hbar^2}\frac{1}{n}, \quad n = 1, \tag{28}$$

from the Schrödinger equation

$$-\frac{\hbar^2}{2\mu}\nabla^2\phi - \frac{e^2}{4\pi\varepsilon_0 r}\phi = En\phi. \tag{29}$$

When V is not zero, Eq. (29) reads

$$-\frac{\hbar^2}{2\mu}\nabla^2\phi - \frac{e^2}{4\pi\varepsilon_0 r}\phi = (En - V)\,\phi \tag{30}$$

and the electronic orbital energy becomes

$$En = -\frac{\mu e^4}{32\pi^2\varepsilon_0^2\hbar^2}\frac{1}{n} + V \tag{31}$$

where n is the principal quantum number. So for $V = 0$, the electronic orbital energy in the H atom becomes less negative as n increases. However, if we add $V < 0$ from the symmetry broken vacuum to the ground state of H determined by $n = 1$, the electronic orbital energy falls below its ground state, emitting energy [5] in the same way as an electron falling from a higher to lower electronic orbital state emits energy.

4. DISCUSSION

The Klein-Gordon equation is the equation obtained from the classical Einstein equation of relativistic classical dynamics using the quantum *ansatz* (12). The interpretation given to the wave function in the Klein-Gordon equation is therefore that of a single particle wave function. The Dirac equation, which is the accepted relativistic quantum equation for the electron, must reduce to four Klein-Gordon equations [2,6] because of the fact that the latter reduces to the Einstein equation. Therefore, in this paper, we have proceeded on the valid basis of introducing a Higgs mechanism into a Klein-Gordon equation and working backwards to the Einstein equation, hose non-relativistic limit has been found in the symmetry broken vacuum. It has been argued that the latter presents an insurmountable barrier in classical relativistic mechanics and its Newtonian limit, so the well known equations of classical dynamics remain intact. In quantum mechanics, a mechanism of quantum tunneling has been suggested to show how a quantized electron may enter the spontaneously broken vacuum and emit energy as observed empirically [1]. Finally, it has been shown that the ground electronic state of the H atom can be decreased in energy by spontaneous symmetry breaking of the vacuum in non-relativistic quantum mechanics.

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REFERENCES

1. R. L. Mills, W. R. Good, J. Phillips, and A. I. Popov, *Lower Energy Hydrogen Methods and Structures,* U.S. Patent No. 6024935 (2000), with 499 claims.
2. L. H. Ryder, *Quantum Field Theory,* 2nd edn. (Cambridge, University Press, 1987).
3. M. W. Evans, ed., *Contemporary Optics and Electrodynamics,*

a special topical issue in three parts of I. Prigogine and S. A. Rice, series eds., *Advances in Chemical Physics* (Wiley, New York, 2001), Vol. **114** (3), of M.W. Evans and S. Kielich, eds., *Modern Nonlinear Optics*, 2nd edn., a special topical issue in three parts of I. Prigogine and S. A. Rice, series eds., *Advances in Chemical Physics* (Wiley, New York, 1992, 1993, 1997), Vol. **85**.
4. P. W. Atkins, *Molecular Quantum Mechanics*, 2nd edn. (Oxford, University Press, 1989).
5. M. W. Evans et al., AIAS Group papers, "Higher symmetry electrodynamics," (*Special Issue 2000 J. New Energy*, **4** (3), Winter 1999) (Trenergy, Salt Lake City, UT, 2000).
6. M. W. Evans, J. P. Vigier, S. Roy, and S. Jeffers, *The Enigmatic Photon*, Vols. 1–5 (Kluwer Academic, Dordrecht, 1994 to 1999).