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Around the notion of state and the Superposition Principle

En torno a la noción de estado y Principio de Superposición

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ABSTRACT

This article presents a reflection on the concepts of state and principle superposition within classical and quantum context. Are highlighted the strategies that serve as the basis for the explanation of phenomena at the atomic level, explanation than requires a formalization and an image as a support for their elaboration. In addition, the processes of formalization are characterized by the construction of relations than gives account of the phenomenon. In this sense, are given examples than allow conceptualize the notion of state and the superposition principle within the two contexts which play a key role in the formalism of every physical theory. This analysis allows us to contribute elements for the teaching the quantum mechanics giving the possibility of develop a different pedagogical and didactic practice than the usual.

RESUMEN

En el presente artículo se presenta una reflexión en torno a los conceptos de estado y principio de superposición desde el contexto clásico y cuántico. Se resaltan las estrategias y nociones que utilizan los pensadores para la explicación de los fenómenos a nivel atómico; explicación que esta soportada por una formalización que el sujeto hace y por una imagen como soporte de su elaboración. Además, el proceso de formalización se caracteriza por la construcción de relaciones que dan cuenta del sistema. En este sentido, se dan ejemplos que permiten conceptualizar la noción de estado y el principio de superposición dentro de los dos contextos ya que estos juegan un papel fundamental en el formalismo de toda teoría física. El abordar este análisis permite aportar elementos para la enseñanza de la mecánica cuántica en ingeniería dando la posibilidad de desarrollar una práctica pedagógica y didáctica diferente a la usual.

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1. Introduction

Traditionally cut Newtonian mechanics is considered the gateway to physics and his teaching which is based on the relationship that exists between her and disciplinary fields such as thermodynamics, electromagnetism, etc. [1], [2]. This relationship is that these disciplinary fields used explanatory models based on constructs that are the basis of the explanation of mechanical systems. Therefore, it is that a phenomenon is explained in mechanical terms.

On the other hand, the physical quantity as speed, mass and strength are as primary to the description of motion of mechanical systems. While physical quantity as momentum, energy, angular momentum are relegated as tools to calculate and solve problems that are difficult to solve since the context of forces [3]. [4]. However, these quantities are differently in modern theories of physics that can quantize, [5] while the magnitudes that are as primary from the classical context not they can be [6] [7]. This shows that the conceptual foundations around the classical scheme are insufficient to provide an adequate description of the systems at the atomic level.

Dirac additionally shows in his treatise [8] the need to abandon the classical ideas because although the classical scheme is elegant and manages to give explanation to a large number of systems on a macroscopic scale, their theoretical predictions atomic level not consistent with the experimental data [8]. Thus suggesting what building a new framework for the description of phenomena at the atomic scale. This new scheme should establish a limit on what is small and large with the need to acquire an absolute size character. To give an absolute meaning to the idea of large and small need a limit to the accuracy of observation instruments, *"limit that should be inherent in the nature of things and it is impossible to overcome although the techniques are perfected or the practiced skill of the observer"* [8].

In this context, the treatment of the atomic phenomena it is related to the idea to the big and small. A system that is not disturbed count oneself large and otherwise, it is as small. The idea of large and small plays a fundamental role in physics, since any system considered large subject to the principle of causality and its movement it is studied by time-dependent differential equations. If the system is small in relation to the disturbance produced, involves establishing an indirect relationship between the result of experiment and theory, i.e., a causal relationship between the conditions of a baseline is set at a given time and conditions another later time through the differential equation. Equations will be indirectly related to the result of observation; since the maximum information theory to calculate the probability of obtaining a particular result to observe [8]. On the other hand, the difference between small and large does not provide elements to construct a quantitative theory, however it shows a new way of looking at nature; form which is characterized by the fact that the observation performed over the system has a degree of uncontrollable disturbance thereon.

2. Classic context

2.1. The notion state

The concept of state plays an important role in the description of the classical systems. On the one hand allows the organization of these, and other, allows a description of its evolution [9]. Additionally, the state of a system can be characterized in relation to a quality; quality that lets you refer to a specific property system. In this regard, the system state is obtained in relation to a specific quality, which can be of motion, thermal, an electric, etc. without the system losing its identity.

In this context, the description of mechanical systems from the can be made perspective of states [9]. A body in a gravitational can be described field fall in free from its state of motion; is defined it as the different ways of being the body in the gravitational field at each instant of time. Furthermore, when a body is cool this state is defines in relation to the thermal quality.

Analyzing the definition given by the Royal Spanish Academy for the word state [10]: "Situation is that someone or something, and especially each its successive modes of being or being" two important elements of the definition are rescued. First, that someone is referred to the system, and second, ways to be or are referred to the various ways in which the system can be found. Therefore, the state of a classic system it defines as different forms of the system characterized by the dynamical variables of position and momentum. The forms of the system are referenced to a specific quality of it. While dynamic variables play the role of observable system and stored a functional relationship with time, which allows knowing the temporal evolution of the system via equation of motion. In addition, the state variables $[r(t)]$, $[p(t)]$ can be measured simultaneously without appreciably disturbing the [9] system.

The state of a system from the context of classical mechanics it specifies by the dynamic variables of position and momentum, which allow determining the further status of the system. Finally, Dirac in his treatise states, "According to classical ideas, you could specify a state giving the numerical value of all coordinates and velocities of the various system components in an instant of time, thus becoming completely determined the movement of all system" [6].

2.2. *Superposition Principle*

The idea superposition means by the sum of the same property and in which there is a link element. Thus, a body in a gravitational field subject to the action of the forces It is characterized by specifying the state of motion from the superposition of the forces [3], [11]. This means that there are both on, as there are both on and so on. On the other hand, when the sum is performed between numbers relationship between the numbers being added and the result of this sum is stable. For example, to add two numbers (5) and (2) superimposing two quantities is giving a new value (7). The components do not lose their identity numbers in the overlay, which means that there is a mixture of numbers and each retains its identity. Thus, overlapping magnitudes is assumed as the relationship between entities without overlapping each of the components lose their identity, as shown in the following expression,

Finally, the overlap in this context it is characterized by not mixing the constituent units, as each of the elements of the combination does not lose its identity and results in a completely deferent state. In this context, the observer does not define the state of the system to observe about it.

2.3. *Vertical and Horizontal movement*

A system in a gravitational field that describes a parabolic trajectory can be described, as the linear combination of two movements occurring simultaneously in mutually perpendicular directions. The state of the system status can be represented,

Each of the states of movement components overlap is independent, ie, they do not mix and do not lose their identity. The horizontal movement with constant velocity,

And vertical motion with constant acceleration,
, Result in a parabolic trajectory [3],

The resulting motion state is the sum α of times the state of tilt more β times the state of horizontal movement. Finally, the superposition of the two states of motion is set to a completely different state of motion state components.

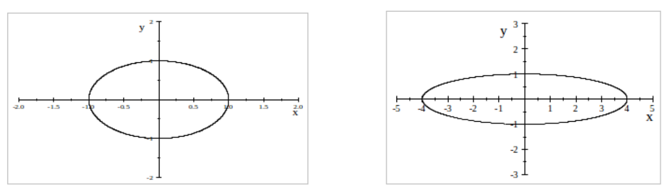
2.4. *Perpendicular oscillations*

A system that is in a state of rotation along the axis (z) with constant motion can be described by a combination of two states of motion perpendicular. The state of motion of the system is described as rotating the rotary projection vector along the horizontal component (x) and the projection of the rotary table along the vertical component (y) [9]. The combination of the two states of one-dimensional harmonic movement is written as,

It is the component states:

With ω_1 and ω_2 oscillation frequencies and δ_1, δ_2 initial stages. Whatever the relationship between the frequencies ω_1, ω_2 and phasesδ_1 y δ_2 state of harmonic motion is obtained as a result a state of motion whose locus is a closed curve contained in a two-dimensional region [9] as shown in figure **1**.

Figure 1: Combination of states of motion with equal frequencies and phases, corresponding to a uniform circular motion b. combining states with equal frequency and phase difference 3/4.



a. b.

Source: own.

Each of the components harmonic motion states do not lose their identity in the overlap resulting two-dimensional very different state of motion.

2.5. *Color Superposition*

When white light is passed through a prism, it is decomposed into a set of colors as shown in Figure **2**.

Figure 2: Spectrum of white light.

Source: [12]

The structure of the spectrum of white light consists of a variety of colors each corresponding to a particular frequency. The variety colors do not lose their identity because if they passed each of the colors by a second prism they do not decompose in other colors, which can be considered as well defined pure states or states [8]. Therefore, overlapping well defined spectral colors states results in a different state of light components, white light.

3. Quantum Context

From the definition of state cited above, *"The situation in which someone or something is, and especially each of its successive modes of being or being"*, [13], It follows two important elements: the person or thing can take different ways of being, and these their states, and the idea of "way of being" is related to the quality. Therefore, the concept of state is the strategy that the subject made to refer to different ways of being a system in relation to a specific quality. Here, the definition made on the state of a system in the classical and quantum context is analogous.

The formalization of the state of a quantum system is related through a space vector kets normalized, i.e. all possible physical state of a system is made to match a normalized ket, having a one to one relationship between normalized vectors and physical states [9]. Therefore, the state of a system at an instant of time is specified by giving the state vector $\psi(r,t) =< r|\psi >$ as a function of the position (r) and the time variable (t) by labeling different state vectors [4], The state is then characterized by the direction of the normalized vector. The formalization of the quantum state of a system does not refer to a dynamic system or observable variable, establishing a distinction between state and observable, which shows a difference from the formalization for a classical system [9]. In this sense, Dirac proposed: *"the state of an atomic system must be characterized by less data or inaccurate data by more than a full set of numerical values of all coordinates and velocities in a particular time instant"* [6].

3.1. An analogy with dice

The state of a system it was considered as the result of the superposition of a series of well-defined ground states is selected. To get an image on the superposition of states in this context, an analogy was made considering a given in a closed box. The mathematical procedure to express the state of the die as a result of the superposition of a set of base states, is done by the possible positions it may have relative to its sides as shown in Figure 3.

Figure 3: Configuring the core states on the sides of the die.

Source: [12]

Each of the sides of the die is considered as a pure state or well defined, as each of these cannot be decomposed in terms of the other sides. The state of the die can then be written as a linear combination of the possible states (sides) which may be,

When an observation on the die is made (open box) know the state in which it is. Therefore, the observer defines the resultant state of the die after observation.

3.2. Superposition principle

The idea of linearity plays an important role in the description of the systems at the atomic level, and that every set of states can overlap to lead to another system status [6]. When a system is in an arbitrary state, this can be written as the linear combination of numbers (in general complex) representing amplitudes probability of finding the system in each of the basis states (well defined states), i.e., system status can be seen as the result of being at once in each of the basis states is selected [8].

The overlap is then a relationship between the constituent states on a given quality so that the resulting state is determined by the relative weights of the states that overlap. On the other hand, when making a comment on this system, this state is given in relation to the observation. Therefore, the formalization of quantum superposition principle plays a different role compared to the classic context since the observer disturbs the system leaving an uncontrollable way the system in one component states overlap when observed. The following examples illustrate specific instances in relation to the superposition principle of quantum states from context.

3.3. *Orientation of a coin*

System is considered as a coin whose sides are heads or tails. The coin has two opportunities to be, i.e., has two possible states given in their respective sides, as shown in Figure 4.

Figure 4: C Possible base currency states.

Source: [15]

Considering the currency within a closed box can describe their status as a linear combination of the possible states based $|heads>$ and $|tails>$,

The state of the currency in the box is considered as the result of the superposition of states $|heads>$ and $|tails>$ in which the coin is partially. Until the case is no and the state of the currency note, both heads or tails occur simultaneously. Only when the viewer decides to see what state is the system (the currency), you can fully define their status, that is, the state of orientation of the coin.

3.4. *Live and dead cat*

The linear combination of states taking as an example a cat in a box with a sardine set. Considering the cat in the box and next to it a poisoned sardine can describe the state of the system, once unopened, by two possible situations. The cat eats the sardine and dies and the cat does not eat the sardine and lives. We say that the cat is in the state when it is alive and is in the state when it is dead. Taking the states and the set of states based on the combination,

and until they open the box and the final state of the cat is observed, both possibilities occur at the same time, the cat is in a superposition state of live and dead to the observer. When the observer make a comment on this system defines the final state of the cat. Therefore, the most information you can get on one of the components of the superposition states is the probability that the system is in that state [15].

3.5. *The double-slit*

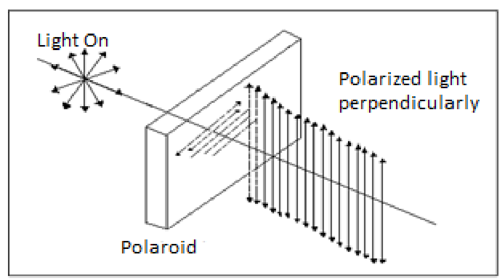
When an electron beam is sent through two slits it is expected that electrons pass by or passes through the other slit and two strips occurs on the photographic plate [8]. However, in the experiment an interference pattern is observed as generated a wave passing through the double slit. Each electron leaves as a particle; it becomes a wave of possibilities and passes through both slits and interferes with itself until it hits a particle detector [8]. This can be written as the superposition of two states, the electron passes through and the electron passes through,

occurring both possibilities simultaneously, i.e., the electron is partially in each of the two component states. At the time of observation through which the electron interference pattern is destroyed, which means that the observer uncontrollably disturb the system and also decides what state is [8]. The act of observing through which the electron results in a well-defined state component of superposition.

3.6. *A monochromatic wave*

When a light beam is passed through a polarizer, it is polarized in one direction called polarization plane as shown in Figure 5.

Figure 5: Polarization of a light beam.



Source: [14]

Each photon beam is in a polarization state well defined and if passed again by a second polarizer photon will be absorbed. Therefore, each state of the photon can be expressed as a parallel polarization state, state or as a polarization state perpendicular to the optical axis status. The polarization states and forming a base and satisfy the relationship orthonormality.

When the photon beam is polarized obliquely to the optical axis, the resultant state of the photon can be written from the superposition of two component states, one parallel to the direction of wave propagation and the other perpendicular to the direction propagation [8],

This means that the photon is both partly in the state of polarization parallel to the optical axis and in the polarization state perpendicular to the optical axis,

When the viewer decides what state is the photon, which forces them to be in a state of polarization parallel or in a perpendicular polarization state,

with the probability for each case of 50 %.

4. Conclusions

The conclusions from reflection above, are show in Tables 1 and 2: the comparing the notion of state and the superposition principle from the classical and quantum context.

Tabla 1: The state and observable

Classic context	Quantum context
• The state is defined as the different ways of being the system in an instant of time without losing their identity. • The shape of the system being referred to a quality; quality that can be move, thermal, electrical, polarization, etc. • The state of a system is characterized by the dynamic variables of position $[r(t)]$ and momentum $[p(t)]$. • The position and momentum variables bear a functional relationship with time, which allows knowing the temporal evolution of the system via equation of motion. • The dynamic variables of position $[r(t)]$ and momentum $[p(t)]$ are observable system, which can be measured simultaneously (switch) without significantly disrupting the system. • Dynamic variables that are functions of the position and momentum $\psi = (r(t), p(t))$, are also observable system. • The system status is identified with the observable $[r(t), p(t)]$ physical, meaning that both the state and the observables depend explicitly on time. • No distinction between the mathematical representation of an observable and values is made. • The measure of a classical observable is a physical operation, which is considered a value approximately, zero experimental uncertainty (ideal size). • By specifying the function $H = H(r, p)$ Hamilton, the time evolution of the system via equations of motion and initial conditions $[r(0), p(0)]$ is determined. • The system state is not disturbed when you make a comment on it.	• The physical state is defined as the different ways of being the system in a moment of time and in a position without losing its identity. • The way to be referred to a quality; quality that may be, thermal, electrical, polarization, spin etc. • The state of a quantum system is characterized by a space vector kets, called state vector. • All possible physical state corresponds to a normalized space vector kets. Having a two-way relationship between normalized vectors and physical states. The formalization of the state of a system at a point in time is specified by giving the state vector $\psi(r, t) =< r\|\psi >$ as defined by the position function, which means that the position variable is a dummy variable and not dependent on the time variable (t). Therefore, the physical state is a function of the position (r) as the time variable label the different state vectors in the space of kets. •The linearly dependent vectors correspond to the same physical condition as they are always standardized. Therefore, the state vector is defined except for a phase factor.A distinction between the mathematical representation of an observable and their values is made. • The definition of the quantum state does not deal with the dynamics, observable variables of the system, thus establishing a distinction between state and observable. • A linear Hermitian operator with a complete set of orthonormal eigenvectors and a set of real eigenvalues represents a physical observable mathematically. • The observable spectrum may be discrete or continuous or a combination of the two. • The state of a system is altered uncontrollably when a measurement of the observable, that is, if the system is in an arbitrary state before the measurement is made, immediately thereafter the system is in one of the corresponding eigenstates to eigenvalue measured observable. • Specification operator H = H (r, p) Hamilton, the time evolution of the system $\psi(r, t) =< r\|\psi >$ via equation of motion and initial condition $\psi(r, 0)$ it is determined.

Source: own

Tabla 2: Principle of superposition of states.

Classic context	Quantum context
• The overlay is an additive operation, considering that there is a relationship between the elements overlap. • System states can be written as a linear combination of basis vectors of the space. .• The superposition of two or more states results in a completely different state to the component states. • It is considered a classic observable always has a value, and a measurement of the observable value is obtained without significantly disturbing the system. In general, it is assumed that the value of the measured observable when there is not performed independently or measure. • The act of observing the system (measuring observable) did not significantly disrupt or define its final state.	• The overlay is an additive operation, considering that there is a relationship between the elements overlap. • All ket status can be written as a linear combination of the eigenvectors of the observable, which form a basis of the space. • Each system state is written as a linear combination of numbers (usually complex) representing the amplitudes of probability of finding t he system in each of the courtrooms basis of some set is selected. • When the system status is given as a linear combination of basis states, measurement may give any observable observable own value. Therefore, the measure will not only not predictable. The most that can predict the outcome is likely to far a proper value of the measured observable. In this sense, the act of observing the system disturbs appreciable uncontrollable way. • Most information about the state of a system is achieved immediately after a measurement. Immediately before measuring system status it is unknown. Therefore, when measuring the observable results in knowing with some precision the system state, but ignorance of what their state prior to measurement arises. • The act of making a measurement on the system results in the preparation of system status and not comment on it. The observer because a measurement of the observable prepares the system in a proper state of the measured observable.

Source: own

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