London Journal of PHYSICS

Volume 3 No 2

The Uncertainty Relation and the Determinacy Relation

N.N. Chavarga

Uzhgorod National University, Ukraine
Email: nikolay.chavarga@gmail.com

July 28, 2026

Abstract

The problem of measuring the energy of a quantum system, the process of emission of an electromagnetic field quantum, and their connection with the provisions of the Heisenberg uncertainty principle are considered. It is shown that the processes of measuring the energy of a quantum system and the time of transition between levels are performed not only simultaneously, but in a single act of measurement, and cannot be fulfilled in another way. This contradicts the physical ideas embedded in the uncertainty principle. As an alternative, the concept of "determinacy relations" is proposed.

1. Introduction

"In principle, it may turn out that quantum theory in its present form is incorrect... If it is ever proved that the uncertainty principle is false, then we should expect a complete restructuring of the physical theory." – J. B. Marion, [1, p. 609].

As is well known, the interpretation of the physical meaning of the uncertainty relation is based on the idea that it is impossible to simultaneously measure certain characteristics of micro-objects, such as the coordinate and momentum of a microparticle, or the energy and the time of the particle's energy measurement, with arbitrarily high precision. Moreover, the most consistent proponents of quantum theory even claim that these characteristics do not exist simultaneously in micro-objects: "*In reality, the situation here is different – the micro-object itself simply cannot simultaneously have both a definite coordinate and a definite corresponding momentum projection,*" [2, p. 35].

The philosophical conclusions drawn from the analysis of the uncertainty relation are of extremely high importance for physics. Already in his first work, in which the uncertainty principle was formulated, Heisenberg asserted as one of the main conclusions that "*quantum mechanics has definitively established the invalidity of the law of causality.*" In his early works, Heisenberg called his relation the "inaccuracy relation" (Ungenauigkeit), and in his later works he changed the name into "uncertainty" (Unbestimmtheit).

In modern literature, the uncertainty relation is given significantly less attention than, for example, the theory of relativity or the probabilistic interpretation of the sense of the ψ-function in the wave equation. In the past, however, claims against the interpretation of the essence of this relation were voiced repeatedly. Somerset Maugham, in his book *The Summing Up* (1927), colorfully characterized the disputes and the positions of opponents: "*Two of the most eminent scientists of our day regard Heisenberg's principle with skepticism. Planck has expressed the opinion that further research will eliminate the apparent anomaly, and Einstein has called the philosophical ideas based on this principle 'literature.' I am afraid that this is only a polite variant of the word 'nonsense'... Schrödinger himself said that no final and exhaustive judgment on this matter is possible at this time,*" [3, p. 179].

All of the above indicates that the issue cannot be considered conclusively resolved. It is evident that if the uncertainty relation was evaluated in such a manner by Planck, Schrödinger, Einstein, de Broglie, and others, then any research on this topic deserves to be presented for the readers' judgment.

2. What is an "Energy Level of a Quantum System" and How is it Measured?

First, let us answer the question: what is a "quantum system" (QS)? The answer: it is a bound state of two or more elementary particles that can change its internal energy only discretely, in leaps (quantum leaps), while emitting or absorbing quanta of electromagnetic energy. The simplest example of a quantum system is the positronium atom, being a bound state of an electron and a positron. This is an unstable system; after several radiative transitions between upper energy levels, the annihilation of the interacting particles occurs, resulting in two quanta of 0.51 MeV each. Stable quantum systems include atomic nuclei, atoms, molecules, ions of atoms and molecules, as well as clusters, which represent the union of quantum systems into a larger-scale system.

The internal energy of a QS is quantitatively characterized by the energy that can be converted into electromagnetic radiation (EMR). If a QS is at an excited level E_2, under certain conditions it can be transformed into energy $E_2=m_2c^2$ – this is the physical meaning of the statement that the system is at the energy level E_2. Being at a lower level E_1, the quantum system has an internal energy $E_1=m_1c^2$. During a transition from higher levels to lower ones, the QS emits quanta of electromagnetic radiation, and the energy of the system decreases by

$$\Delta E = E_2 - E_1 = m_2c^2 - m_1c^2 = \Delta m\, c^2 \tag{2.1}$$

In this case, the mass of the QS decreases by the value Δm (mass defect), which is true for any quantum system – from a heavy atomic nucleus to the transitions of excited atoms between levels, including the lightest atom in the nature, positronium. There is a common legend in the literature stating that we can measure the energy of a quantum system with arbitrarily high precision, even infinite, provided that the measurement is conducted for a very long time [4]. Neither the method of measurement nor the instrument by which such measurements could be performed is specified.

In reality, we have no possibility of direct measuring either the energy of the QS or its changes. We lack a sophisticated "energymeter" whose probes could be applied to an atom or a nucleus to measure the energy contained within. The most we are capable of is registering an EMR quantum during the system's transition from a higher level to a lower one. In this process, the quantum must be directed onto a dispersing element (a prism or a diffraction grating) to measure the angle φ by which the quantum deviates from its original direction of motion. This is all that we can perform when attempting to measure changes in the energy of a QS.

The quantum emitted by the system (the product of the system's transformation) is directed onto a diffraction grating, which deflects the quantum from its motion direction. The instrument's scale in degrees can be calibrated in wavelengths according to:

$$d \sin\varphi = k\,\lambda$$

allowing us to determine the wavelength of the quantum. Furthermore, using the known wavelength and the velocity of the quantum, we can find its oscillation period T and frequency ν, and from there, the energy E_k , carried away by the quantum:

$$E_k = h\nu$$

Based on the well-founded assumption that the energy conservation law is carried out during the emission process (and with very high precision), we conclude that the QS has changed its energy ΔE by the amount of the photon's energy, E_k.

$$\Delta E = E_k$$

If the energy conservation law is strictly carried out in such processes, it implies that all photons emitted by quantum systems during a specific transition will be deflected by the instrument at strictly the same angle. Consequently, we obtain an extremely narrow line in the emission spectrum, which is broadened only by the imperfections of the instrument (the apparatus function) and the conditions of emission (the Doppler effect, the influence of neighboring particles at the moment of emission, etc.). Experiment clearly demonstrates that during the emission of a photon by a quantum system, the energy conservation law in the microworld is strictly obeyed.

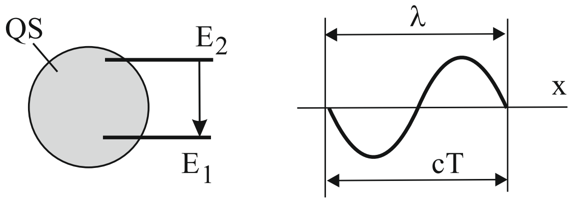

Fig.1

Let us consider a scheme illustrating the process of photon emission by a quantum system. Suppose we have an atom at an excited level E_2, Fig. 1. Upon transitioning to level E_1, it emits a quantum:

$$E = h\nu \ = \frac{h}{T} \tag{2.2}$$

Or:

$$E\,T = \ h \tag{2.3}$$

This result means that for all quanta of the electromagnetic field, the product of the energy E concentrated within them and the oscillation period T is equal to the same value – Planck's constant. Why this is so, no one yet knows, but it is an experimental fact. The quantities E, T, and h are characteristics of the quantum, and we already know that they are all measured in a single act of measuring the deflection angle. **They are not measured simultaneously by different instruments, but in one measurement act, using the same instrument.**

It is quite logical to expect that a similar equation should also describe the process of energy change in a quantum system. The energy loss ΔE corresponds to the energy E as to the photon's energy, in the QS; therefore, we already know the value of one of the quantities for the future equation with high precision, even though we did not apply "energymeter" probes to the system or touch it at all. What do we currently know about the period T of a quantum? There are already lasers that produce ultrashort pulses, so short (attoseconds) that the pulse length in space is equal to the wavelength of the photons. From this, we can draw a definitive conclusion: a photon is generated over a duration equal to the period T, and in the longitudinal direction, quanta have a size equal to their wavelength. This conclusion is a simple consequence of causality holding true not only in the macroworld but also in the quantum world.

Looking at Fig. 1, we understand that the process of the QS transition begins simultaneously with the start of the photon's birth – the beginning of the photon's "expulsion" by the system – and ends at the moment when the photon is fully formed and begins to detach from the system. Otherwise (if causality did not hold), it might happen that the system's energy begins to decrease toward an unknown destination without being spent on the birth of a photon; or the photon has already departed while the system is still "transitioning"; or, finally, the system has long since completed the transition, but the photon has not yet left, sitting nearby and waiting for something. Thus, the duration of the system's transition Δt must be equal to the period T, that is:

$$\Delta t = T \tag{2.4}$$

2.1. A simple analogy from the macroscopic world

Taking into account the importance of the issue, for vividness of the argumentation and to clearly reinforce the conclusions drawn, let us employ a familiar analogy from everyday practice. Suppose a young beautiful woman named Mary, during her visit to a market, finds 5 apples added to each of her three baskets. We can write an "equation for the increase in her material well-being": 3x5=15 apples. This is a determinacy relation for apples and baskets.

According to the "law of conservation of the number of apples," they must have been subtracted from someone else. We guess that they were taken from three containers belonging to a young man John, who, out of personal motives, transferred them to Mary’s possession. Based on the information about the number of Mary's apples, we can write an "equation for the decrease in well-being" for John, even if we have never seen his containers: 3x5=15 apples. We also understand that, in accordance with the law of causality, the moment and duration of the apples' departure from John will perfectly coincide with the moment they begin to arrive in Mary's possession. This means that the moments these processes conclude also coincide.

And what can be said about the precision of the apple emission equations written above? The question is rather strange, for the precision of the calculations is determined by our ability to count at least to 15, and our confidence in the equations is determined by our trust in the multiplication table. In other words, the precision with which we define such certainties as the number of baskets, apples, and containers is absolute, and the very question of precision seems strange at the very least. Note that in these calculations, we are not interested in the absolute number of apples in John's containers; for our purposes, it plays no role whatsoever. Even if these were his last apples (a close analogue to annihilation, as in the case of positronium), it does not affect the level of our confidence in the recorded equations.

From what has been said above about atoms, photons, baskets, and apples, it becomes absolutely clear that for a quantum system, instead of equation (2.3) for a quantum, we have the right to write a similar equation for the quantum system itself:

$$\Delta E\, \Delta t = h \tag{2.5}$$

Both physical quantities presented in this expression, as characteristics of a quantum system, cannot be measured directly – neither sequentially nor simultaneously. Therefore, the question of what happens to the system or how the transition time from level to level changes while we measure the transition energy (or vice versa) cannot be raised. We have measured both of these quantities indirectly in a single act of measuring the quantum's deflection angle by a dispersing system. The precision of measuring these QS characteristics completely coincides with the precision of measuring the angle φ, and there is, in fact, nothing more to discuss here.

It is obvious that we cannot call the relation (2.5) the uncertainty relation – all the quantities included therein have a clear definition, and the expression as a whole is a strict equality. In other words, we cannot replace the equals sign in (2.5) with the symbols "≥" or "≤" to turn it into an uncertainty relation. **Furthermore, we cannot alter the physical meaning of the quantities within this equation.** Taking the above-mentioned into consideration, we propose to call (2.5) the "determinacy relation."

Another unexpected nuance: we recall that (2.5) was derived based on the assumption of the energy conservation law, $\Delta E = E$, and the principle of causality, the fulfillment of which leads to the result $\Delta t = T$. In this regard, there remains a feeling that (2.5) contains a deeper meaning, such as representing the combined action of the law of conservation and causality, or something of that nature. All of classical physics is built upon three basic concepts: space, time, and matter. Equation (2.5) represents the "product of matter and time," the product of the "law of conservation of matter and the principle of causality"...

On the other hand, to conclude this discussion, it is worth emphasizing a fact that, for some reason, has remained unnoticed in physics for a hundred years: the problems of measuring anything (whether methodological, technical, material, or related to the professional level of the researchers, etc.) cannot be presented as laws of nature. Theory (and mathematics as its tool) does not concern itself with the problems of real instruments and real measurements, including the problem of measurement precision. If we state that we have a coordinate frame, we do not ask where or with what funds we obtained it, especially with axes of infinite length. We do not ask who placed the marks on the axes and the numbers next to them, or with what precision those marks were placed. Equations are written under the assumption that all quantities considered in the theory are known with absolute precision.

Regarding time, the situation is exactly the same as concerning space. If we declare that all chronometers in this frame are synchronized, then we, as the authors of the theory, do not answer the question: "How can this be really done?", because these are problems of experimentalists. Thus, we have a simple conclusion: if the problems of synchronizations form the basis of any theory, then such a theory becomes incorrect automatically. In all theories where equations of motion for material points are used, the synchronization of time-measuring instruments is postulated, at least, it should be postulated. It is a different matter if a theory raises the question of the rate at which physical processes occur depending on their state of motion. In that case, the synchronization of all possible chronometers is postulated, as the primary position of the theory, and regarding the rates of physical processes, hypotheses are put forward for experimental verification.

We cannot help noting one more rather unpleasant fact connected with the uncertainty relation. Assume that we managed to make up an "energymeter", we connected the energymeter probes with the quantum systems in an excited state, and then we measure the loss of energy in the system during its transition from level to level, E_2

→ E_1. Assume then that we obtained a very accurate value of ΔE. It is found out that it is not for us to parallelly measure the duration of this transition by means of a chronometer, – it is sufficient to insert the obtained value of ΔE into the uncertainty relation, so that it turns into the relation with one unknown quantity Δt, then we can find the same Δt with the same accuracy, with which we measured ΔE. However, if we attribute the sense of the measurements' inaccuracy to the quantity ΔE, as Heisenberg himself asserted it, then it is the problem of experimentalists, and we already know that it cannot be raised to the rank of a physics law.

3. Conclusion

An elementary analysis of the process of photon emission by a quantum system has shown that measuring the change in the energy of a QS and measuring the time of its transition from level to level are performed not only simultaneously and with identical precision, but even in a single act of measurement – specifically, when measuring the deflection angle of a photon by an optical dispersion system. Such a result allows for a radically another, but within common sense, consideration of a series of elementary processes in the physics of the microworld. It also significantly clarifies the image of a quantum as an electromagnetic object whose longitudinal size is equal to its wavelength. This model will require a revision of the available explanations for several phenomena, such as photon interference in a Michelson interferometer and others, but that is a topic for another conversation.

Nature is always simple, and always
consonant to itself (Newton).

4. Copyright Notice

This article is published by the Author under a Creative Commons CC-BY 4.0 license. The Author retains full copyright, with the first publication right granted to the London Journal of Physics.

References

1. Marion, J.B. *Physics and the Physical World.* Moscow: Mir, 1975. 624 pp.
2. Tarasov, L.V. *Fundamentals of Quantum Mechanics.* Moscow: Nauka, 1978. 287 pp.
3. Podolny, R. *Something Called Nothing.* Moscow: Znanie, 1983. 191 pp.
4. Landau, L.D., Lifshitz, E.M. *Quantum Mechanics.* Moscow: Nauka, 1974. 752 pp.
5. Lorentz, G.A. *Old and New Problems of Physics.* Moscow: Nauka, 1970. 370 pp.
6. Schrödinger, E. *New Paths in Physics.* Moscow: Nauka, 1971. 428 pp.

 DOI 10.69710/ljp.v3i2.17423