Report Series in Physics

No A14

INTRODUCTION TO QUANTUM MECHANICS[1]

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1972

A guide for a $2^{nd}/3^{rd}$ year course on atomic physics

29 May 1972

[1] Translation of the original text in Finnish written and distributed for the first time for the spring 1971 course.

1 Introduction to the ideas of the world of atoms

Quantum mechanics is the most central theory of modern physics.

Only with its help it becomes possible to "understand" the structure and the properties of nuclei, atoms and molecules. Thus the present picture of the whole material world is decisively based on quantum mechanics.

However, commonly quantum mechanics is regarded difficult to understand and very abstract – not quite without justification. Therefore, it often carries in public discussion a stamp of unreality and artificialness, which is absolutely wrong. Quantum mechanics is more realistic than classical mechanics, because it is in concordance also with the phenomena of the atomic world – it explains them as is often said somewhat fallaciously –, which are hopelessly outside the range of validity of the classical mechanics. Moreover, quantum mechanics includes classical mechanics as a limiting case.

Classical physics, in this context mainly the Newtonian mechanics and the Maxwellian electrodynamics, is very concrete by nature and as such easily understandable, regardless of some occasionally appearing difficulties of calculation. After classical physics, quantum mechanics means transition into a new way of thinking. To aid adoption of a proper attitude towards the difficulties involved in this transition, it is useful to consider them in the light of general principles.

Actually, it is evident that the transition from macro physics to micro physics inevitably means also transition from concrete concepts to abstract ones. Why, science means, in a large scale, a similar process as perception of sensations is for an individual. Learning to see, hear etc. and understanding of one's sensations is based on certain regularities of the stimuli. Similarly, science is seeking regularities of the natural phenomena and objects. As long as science is studying such phenomena which can be observed by the senses or are, at least, closely coupled to our perceptual world, the regularities and correlations observed scientifically are the same ones, as those on which the human world of ideas and our natural comprehension is based, or, at least, they can be described in terms of concepts which are, in this sense, concretely understandable. It is useful to ponder, how undetachably the natural human world of concepts and comprehension are tied to the perceptual macro world. It is also good to note, that the classical physics is leaning on the concepts of this macro world. This feature is so dominant, that one can take the statement classical physics = concrete physics almost as a definition.

The world of atomic phenomena is, however, very far from the concrete perceptual world, on which our comprehension is based. We thus have a natural lack of comprehension of such concepts, which would be needed for consideration of those phenomena. Or it can be said, at least, that it would reflect a strange poverty of the world of natural phenomena, if the regularities of macro world would be sufficient as the basis of concepts even in this area. If we try to explain the phenomena of the atomic world in terms of the theories of classical physics we are, actually, guilty of circular reasoning. Why, we are trying to explain the structure and phenomena of the macro world by reducing them into the atomic elementary objects and phenomena. Any trials to explain these classically are at bottom attempts to reduce them back into the concepts of the macro world. The only option in view is the abstract mathematical description of the regularities.

Development of an abstract physical theory causes naturally some difficulties for a comprehension based on a concrete world of concepts. It is then necessary to lean emphatically upon general principles of science. Particularly one should pay attention to two principal ideas:

1. Only results of measurement are physically meaningful.
2. Physics is searching for models of the natural phenomena.

Actually, these two statements express rather exhaustively the significances of the experimental research and the theoretical research and their mutual relation.

A quantity is a physical quantity only, if it can be defined in terms of a certain measurement procedure.

A proposition is a physical proposition only, if it can be verified are falsified by measurements.

Thus, a physical proposition can refer to physical quantities only. All other kinds of concepts and propositions belong to the sphere of metaphysics.

Every theory is a model which operates according to definite rules. Certain concepts of the model correspond to certain physical quantities. Therefore the rules of the model can be expressed as if they were mathematical relations between physical quantities.

If a model works in such a way, that it yields correct predictions for measurements concerning phenomena, it is a good theory. We are inclined to call rules of a good theory laws of nature.

When we know the principles of operation of a model, we think to understand the phenomena presented by it. In science understanding = theory.

In this way, the two main principles mentioned, refer the two main target of physics:

1. To present correct statements about the "reality of nature" or to achieve knowledge.
2. To understand the natural phenomena.

The first one requires absolute denial of metaphysics. Correct statements, i.e. physical knowledge can concern only physical quantities, but then, just a list of experimental sets of numbers remains. The second aim, on the other hand, means inevitably identification of a theoretical model with natural objects and phenomena. But a model as such is metaphysics, hence, the target of understanding means always resorting to metaphysics.

The main targets of science are therefore mutually contradictory in a way, which can be called the paradox of physics, if you like.

The experimental results have always priority. Therefore a contradiction between theory and observation is always a fault of theory. Because theory = understanding, experimental results not explained by the theory mean always also a crisis of understanding.

Realisation of this state of affairs has often lead to underrating of the significance of theory. One should note, however, that we are not able to do anything with the pure physical knowledge, as defined, without understanding it somehow. In other words, it is impossible to manage without theory. In fact, we cannot even speak about natural phenomena without some kind of concept formation which already is theory. The independent significance of theory becomes evident particularly emphatically in those innumerable occasions, where it has predicted previously unknown phenomena. This means that something essential about the essence of the reality of nature is hidden in the theory of physics. Still, this something lies beyond the pure physical reality. Here, physics and metaphysics are inseparably intertwined. Here is a drop of mysticism in the nature of science, and this is the basis of its fascination.