

HEISENBERG'S UNCERTAINTY PRINCIPLE IN HIGH SCHOOL CURRICULUM

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Abstract

The progress in teaching should be in accord with the progress of science, that's why the subject of teaching must be supplemented by the elements of modern knowledge which permit pupils to understand better what happens around us. For better understanding microworld we must use Heisenberg's uncertainty principle. The beginning of XXI century is characterised by intensification of microworld research, which we deal with in this paper.

”The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa.”

$$\Delta p \Delta x \geq \hbar \quad (1)$$

Δp - accuracy of momentum determination

Δx - accuracy of position determination

From the analysis of physics handbooks and pupils' statements we can say that the principle above is understood incorrectly by them.

There are some reasons why is that (not penetrated in details):
Namely:

- It is a difficult subject relating to the microworld and not available by pupils' observation.
- Some teachers may have some problems with correct presentation of this subject.
- There are many different ways of described principles in handbooks which may cause chaos.
- Lack of clear requirements level in school curriculum and lack of principle used for describing its usage.
- General treatment of this subject by some teachers and handbook authors.

We can ask the question: should the uncertainty principle be in high school curriculum (profile classes)? The answer is affirmative (because of fast nanotechnology developing), but we should strike a happy medium, it means we should arrange a clear way of principle presentation, easily understood by pupils.

Based on curriculum and handbooks analysis we suggest the following track of reasoning.

Description of uncertainty principle on the high school level.

This description should have:

1 Introduction,

which allows pupils to understand the microworld better. It should be linked with the macroworld for better comprehension by pupils and it ought to go to the microworld by analogy. The whole presentation should have examples.

The macroworld is everything occurring around us and we can see or touch it. That is why, the measurements which we take are easier than in the microworld. It happens like that because we can find out that our measurement does not influence on the state of the measured object in the macroworld.

2 Example

We are measuring the height of liquid column by the ruler. We are repeating this activity few times; even though we are getting different results, we know that it depends on inaccuracy of the measurement (instrument or observer). We are conscious that in the macroworld the measurable thing does not change its size after some time (in the same experimental conditions).

But it is not right in the microworld. In the microworld our intuition, which we obtained in the macroworld, starts to let us down. In some physicist's opinion, this quantity has real meaning, which we can measure.

An example from the macroworld and the microworld.

The Moon circles around the Earth, which we can observe due to the sun light, which is reflected to our direction. The light in some way perturbs Moon's movement, but the effect is insignificant.

We have a completely different situation when we think of electron's motion. Even though we are observing some analogy between both configurations, the rules in the microworld are completely different. When we want to see the electron, like the Moon, we must reflect the light or another particle off it. In the electron case; the photon reflection does not leave the configuration without changes as it was in the macroworld. A photon, which will reflect from the electron, will modify electron's motion and the change is not possible to avoid or to measure.

The fact, that we can't in a classical way describe the electron's motions, finds the reflection in Heisenberg uncertainty principle.

3 Subject development

leading out and conceptualization uncertainty principle.

Many interesting conclusions result in the wave theory. Inter alia that, there are no exist bodies with infinitely small sizes, and we cannot pinpoint the momentum of the particle (among others it results from Shannon formula - the fundamental formula of information theory).

From the fundamental formula of quantum theory

$$p = \frac{\hbar}{\lambda} \quad (2)$$

results, that if the value of momentum decreases, the wavelength will increase (the position of particle is fuzzy) and we cannot pinpoint the position of particle. Werner Heisenberg noticed this fact and he formulated uncertainty principle in 1927: "The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa."

$$\Delta p \Delta x \geq \hbar \quad (3)$$

Δp - accuracy of momentum determination

Δx - accuracy of position determination

At first it was though that the measurement of the particle position introduces perturbations in its movement causing velocity and momentum changes. Today we know that uncertainty principle is not the mistake made during measurements. This principle shows some limitations where our classical imagination, for the description of this situation, does not exist.

This principle was confirmed many times by experiments. This is one of these experiments.

Heisenberg's uncertainty principle in high school curriculum

We have the electron beam which moves with some velocity, and then we take one electron and we are trying to measure its position and velocity in x - direction. From the electron beam with momentum p , which is parallel to Oy - axis, we separate electron beam about definite values of the coordinate x by means of the slot with the width Δx .

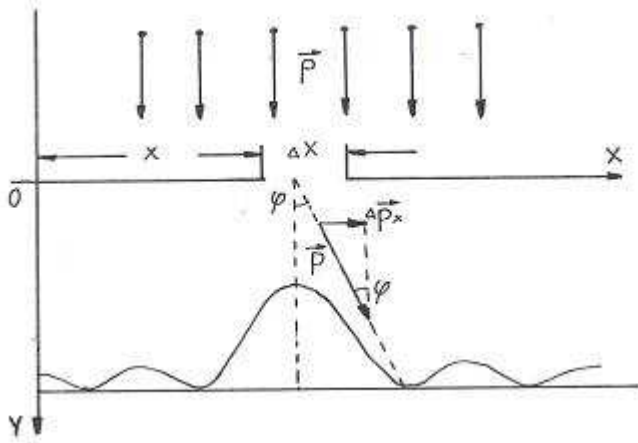


Figure 1: Deflection of electron beam on the single slot

According to de Broglie's hypothesis: electrons have some waves attributes, that is why we can get diffraction image on the screen, which is situated opposite the slot and in long distance from it.

Opposite the slot appears a bright disk which is rounded by dark and bright circles alternately. The direction which is determined by the first minimum makes the angle φ with orthogonal direction to the plane where is the slot. This angle fulfills the condition (analogically like for the light diffraction):

$$\Delta x \sin \varphi = \lambda \quad (4)$$

When we take the de Broglie's formula $\lambda = \frac{h}{p}$ we are receiving:

$$\Delta x p \sin \varphi = h \quad (5)$$



Figure 2: Diffraction image [1]

Diffraction image develops on the screen, because the electrons are getting Δp_x - element of momentum in the $0x$ direction, after going through the slot. As many as 96% of all electrons will be in the first maximum, that is why we can say, that the Δp_x may have a value $p \sin \varphi$.

Taking (5) into account we get the following correlation:

$$\Delta x \Delta p = \hbar \quad (6)$$

When we also take the electrons, which are out of main maximum then (6) we can write:

$$\Delta x \Delta p \geq \hbar \quad (7)$$

The above correlation shows Heisenberg uncertainty principle. After the electrons go through the slot we receive the information about x - coordinate with Δx accuracy, but in return undetermined element of momentum comes into being. From this principle flows that: if we know the position of a moving particle, there is uncertainty in knowing its momentum, and vice versa. Uncertainty principle deals only with the nature of the microworld objects and it does not result from the inaccuracy of the instruments [1]. Measuring instruments enforces additional limitations on the precision of measured values pairs embraced with uncertainty principle (for pairs: x , p or E , t and so on).

4 Summary

Uncertainty principle explains us the nature the wave-particle duality of the light. It results from it that the two opposite aspects cannot appear in the same time and in the same experimental conditions. Therefore, if we check the wave character of the electron, the particle face will be invisible. In turn, during checking the particle character, the wave character will be invisible. Particles and photons we can compare with coins that we can only look at one side at one moment.

Comprehension questions:

- How does Heisenberg's uncertainty principle affect the determination of a particle's location and velocity?
- Where does Heisenberg's uncertainty principle have practical importance?

References

- [1] An Introduction to Physical Science, twelfth edition, J.T. Shipman, J.D. Wilson, A.W. Todd, Houghton Mifflin Company, Boston, New York 2009, page 243, Fig. 9.20(b).