Close Encounters with Heisenberg

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Abstract. The Uncertainty Principle is one of the milestones marking the break-up with former theories describing reality at macroscopic level. Its physical meaning has been deeply discussed and currently various approaches have not yet come to a common description. The exploration of its physical meaning is probably the best ground where to bring students to a more conscious understanding of Quantum Mechanics and of Physics as well. A didactic proposal, based on the acoustic analysis of a musical theme form the Steven Spielberg's movie "Close Encounters", is proposed as a starting point to introduce, via analogy, the Heisenberg Principle to secondary school students.

1 The Uncertainty Principle teaching

Heisenberg uncertainty principle (UP) can be taught in many different ways. One of them is through a "gedanken experiment" method to demonstrate that even with a 'perfect' apparatus it is impossible in principle to determine simultaneously the position of a particle and its momentum with arbitrary accuracy (the 'Heisenberg's Microscope' [1, 2]). Another, is to use single-slit diffraction to demonstrate the effects of the Heisenberg uncertainty principle [3]. However, these approaches can lead to misunderstandings. A common one is considering uncertainty as a problem related to measurement processes [4]. An alternative way, we believe can lead to a better understanding of the UP as an intrinsic quantum aspect, is to underline that uncertainties are related to dispersions of quantum states, a common aspect also present in more familiar phenomena like sound. This brings a bridge that, via analogy, allows a much more natural approach to the nature of uncertainty in quantum mechanics.

2 The Uncertainty Principle and the Fourier Transform: Acoustic analogy and a zero cost experiment for secondary school students.

The UP concerning quantum systems arises from the Schrödinger equation and in particular from its linearity and homogeneity. Both this features lead to the validity of the superposition principle and to the possibility to place side by side two functions related by a Fourier Transform,

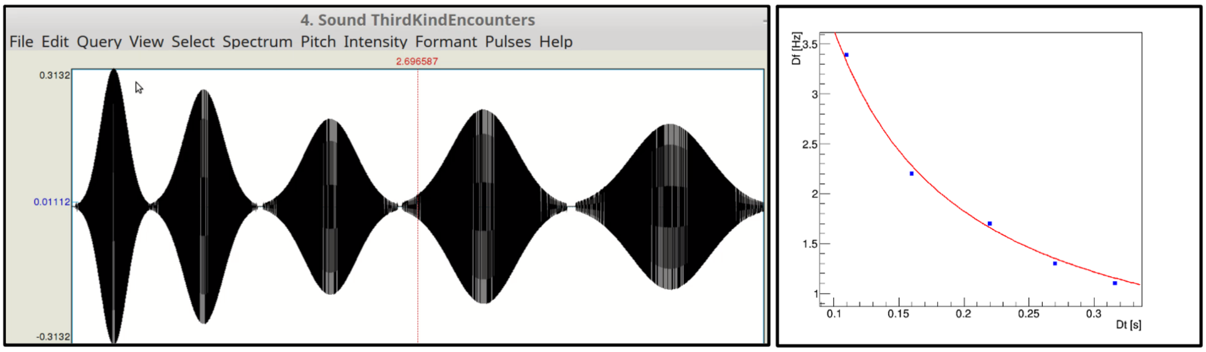

Fig. 1 The five-tone theme from "Close Encounters" (Left) and the plot showing the uncertainty relation (Right).

$\Psi(x)$ and $\hat{\Psi}(k)$. If we consider a quantum system confined in a finite region of space (bound state), performing a Fourier Transform we can show that its space dispersion, Δx, is related to its momentum dispersion, Δk, by an uncertainty relation $\Delta x \Delta k \geqslant const.$ Since in acoustics we have a similar scenario (sounds in the time domain, $\Psi(t)$, related by a Fourier Transform to functions in the frequency domain, $\hat{\Psi}(f)$), we propose to carry out simple experiments with sound to address typical issues with a direct counterpart in quantum mechanics.

The activity proposed does not require the purchase of expensive devices: a personal computer and a loudspeaker will be enough to carry out the experiment and get in touch with the uncertainty relation. The sound we have chosen is the five-tone theme used by humans to communicate with extra-terrestrial intelligences in the Spielberg's movie "*Close Encounters of the third kind*". A slight modification has been introduced: each of the five pure tones has been modulated in time with a Gaussian function and mathematically "synthesized" with the software Mathematica (see Fig. 1-left). Computing the spectrum of each tone and measuring each frequency dispersion Δf and the time dispersion Δt, we get a set of five data pairs showing the uncertainty relation $\Delta f \cdot \Delta t \simeq const.$ (blue points in Fig. 1-Right). The plot shows the typical inverse proportionality between the two dispersions. This is the starting point from which via analogy we develop the uncertainty concept at quantum level.

3 Conclusion

The didactic approach to the UP based on the acoustic analogy allows to introduce the Heisenberg Principle without connections with errors in the experimental measure process, opening the possibility to explore new meanings of the principle itself.

References

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