1210: The meaning of the uncertainty principle

(Make sure you remember this. The uncertainty relation (principle) can be said to be the starting point for understanding chemical phenomena)

Key words: de Broglie; waves and wave packets, wave interference; wave packets are formed by the combination of waves with many wavelengths; wave momentum; the meaning of the uncertainty relation

The uncertainty principle arises from the wave nature of particles (matter) (even matter has wave properties).

[Wave nature of matter]

The wave nature of electrons was theoretically discovered by de Broglie (L. V., 1892-1987, France) in 1923, and confirmed in 1927 by Davisson (C. J., 1881-1958, USA) through the phenomenon of electron diffraction. Currently, it is recognized that all matters have wave properties, but as the mass of material increases, the wavelength becomes shorter, and wave properties are no longer observed.

[Wave Packet]

Waves generally have a fixed wavelength and spread infinitely without attenuation or increase. Since particles have position, the usual concept of waves cannot be applied. So, the question arises: what kind of wave would a particle have if it had wave properties? If a particle is moving, it is natural to think that the particle's wave exists in its vicinity. In other words, it is a wave that exists only in a certain range of space.

Such a wave is called a wave packet. Waves have positive and negative phases, and when waves of the same phase overlap, they are reinforced, and when waves of different phases overlap, they cancel each other out (this is called wave interference). In fact, a wave packet is formed by the overlap of waves of various wavelengths.

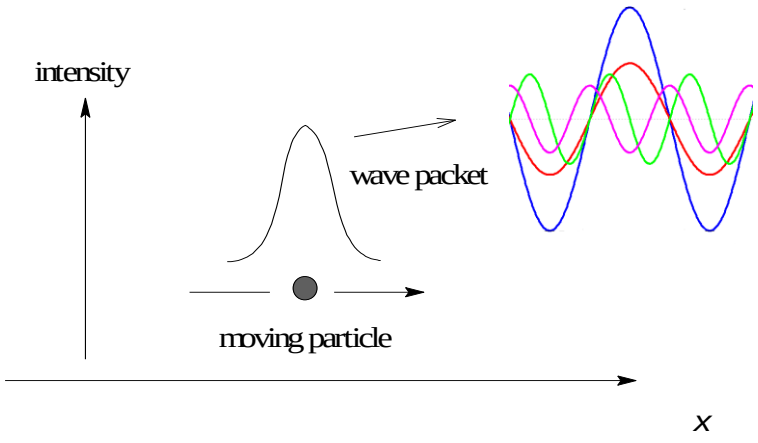

Figure 1. There is a wave packet near a moving particle (the vertical axis is wave intensity). A wave packet is a superposition of waves of multiple wavelengths.

[A wave packet is a superposition of multiple waves]

When we have no idea where a particle is, the particle's wave can be represented by a single wavelength. As the particle's position becomes clearer, the particle's wave takes the form of a narrow wave packet. A wave packet is not a wave of a single wavelength, but a superposition of waves of multiple wavelengths. The narrower the wave packet, the more wavelengths of waves it contains.

[Meaning of the uncertainty relation]

When observing the wavelength of a particle's wave packet, one of many types of waves appears. In some cases, waves with short wavelengths and in other cases with long wavelengths are observed (the observed wavelength varies depending on the measurement (it is not a definite value).

A wave with wavelength λ has momentum h/λ (longer wavelengths have small momentum, and shorter wavelengths have large momentum). Therefore, the wave packet contains waves with various momentums (the value of momentum is not definite and is ambiguous). In other words, when $\Delta x \rightarrow 0$, $\Delta p \rightarrow \infty$, and vice versa, hold. This is the meaning of the uncertainty principle.