63.4: The Heisenberg Uncertainty Principle

The Heisenberg uncertainty principle states that it is fundamentally impossible to simultaneously measure, to arbitrary accuracy, certain pairs of variables. No matter how good the experiment, the fundamental randomness of Nature restricts the accuracy to which it is possible to make these measurements.

The Heisenberg uncertainty principle can be stated mathematically by the following relations:

$$\Delta x \Delta p \geq \hbar/2$$
$$\Delta \phi \Delta L \geq \hbar/2$$
$$\Delta E \Delta t \geq \hbar/2$$

Eq. (60.11) states that we cannot simultaneously measure the position x of a particle and its momentum p to arbitrary accuracy; the product of the uncertainties cannot be less than $\hbar/2$. The more accurately you measure the position, the less accurately you know the momentum. Similarly, Eq. (60.12) states that you cannot simultaneously measure a particle's angular position ϕ and its angular momentum L to arbitrary accuracy. Eq. (60.13) relates the uncertainty in measuring a particle's energy E and the uncertainty in time t required to make that measurement.

Notice that each of these Heisenberg relations involves the product of the uncertainties in a conserved quantity and its so-called conjugate variable.