HEINSENBERG UNCERTAINTY

B.Tech I-SEM

Class Objectives

1. Introduce the concept of uncertainty.
2. Describe an experiment which highlights the uncertainty principle.
3. Explain the reason(s) for the uncertainty.
4. State the principle and give an example of the uncertainty principle.

Heinsenberg (1924 - 25)

- In the period 1924-25 Heinsenberg created theory of Quantum Mechanics.

Heinsenberg (1924 - 25)

- In the period 1924-25 Heinsenberg created theory of Quantum Mechanics.
- It overcame some of the problems with Bohr’s theory.

Heinsenberg (1924 - 25)

- In the period 1924-25 Heinsenberg created theory of Quantum Mechanics.
- It overcame some of the problems with Bohr’s theory.
- It was first developed using noncommuting algebra and then by matrices.

- However this formulism was difficult to apply to problems.

Quantum Mechanics Concepts

The Uncertainty Principle

The Uncertainty Principle

- The contradictions between experimental and theory indicated, that described the phenomena for very small masses at small distances.

The Uncertainty Principle

- We start with the observation of an experiment showing *electron diffraction* (Davisson and Germer 1925).

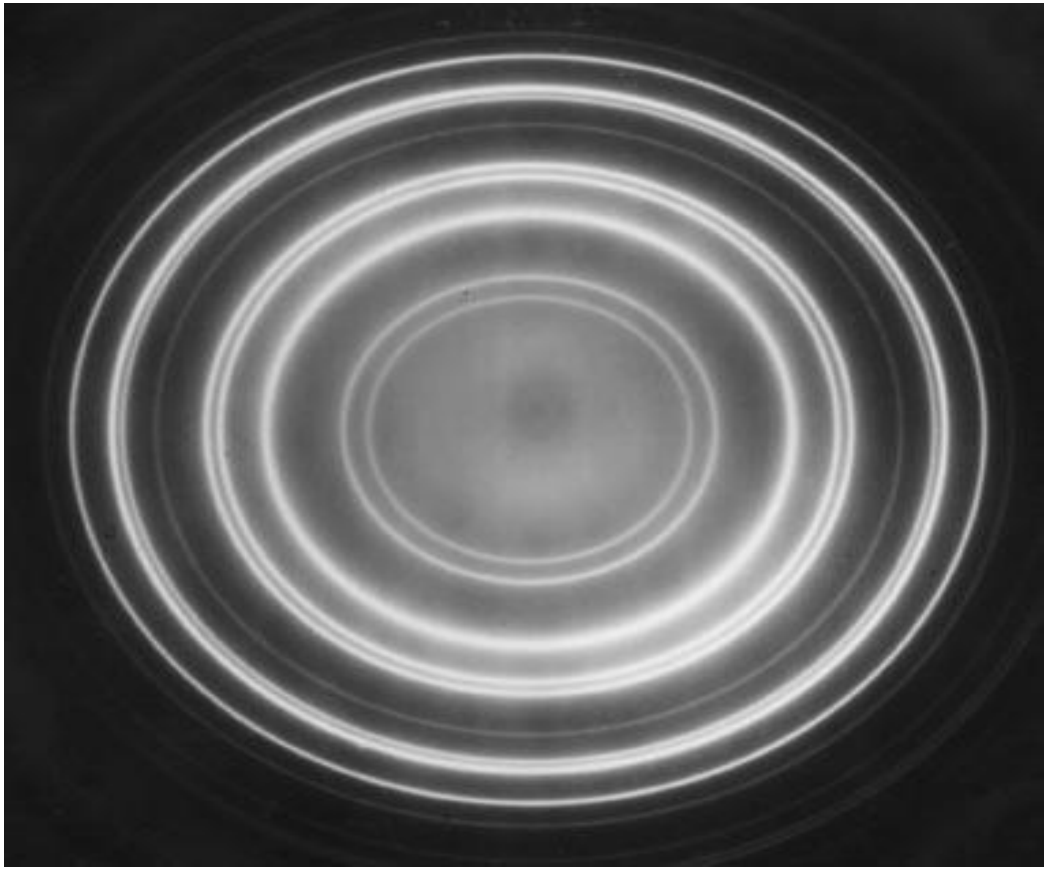
The Uncertainty Principle

- We start with the observation of an experiment showing *electron diffraction* (Davisson and Germer 1925).
- When a beam of electrons passes through a crystal a diffraction pattern similar to what is formed by an EM-wave is produced.

The Uncertainty Principle

- We start with the observation of an experiment showing *electron diffraction* (Davisson and Germer 1925).
- When a beam of electrons passes through a crystal a diffraction pattern similar to what is formed by an EM-wave is produced.
- That is a series of maxima and minima.

The Uncertainty Principle



The Uncertainty Principle

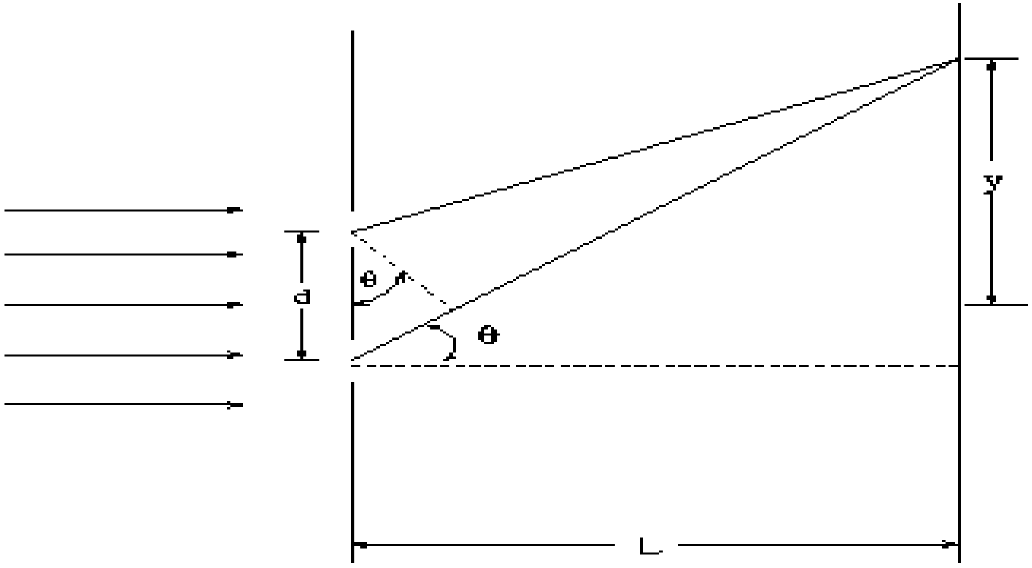
- Consider the following thought experiment.

The Uncertainty Principle

- Consider the following thought experiment.
- Take the set up for Young’s double slit experiment.

The Uncertainty Principle

- Consider the following thought experiment.
- Take the set up for Young's double slit experiment.



The Uncertainty Principle

- If we observe a beam of electrons through one slit with the other closed we get some intensity pattern.

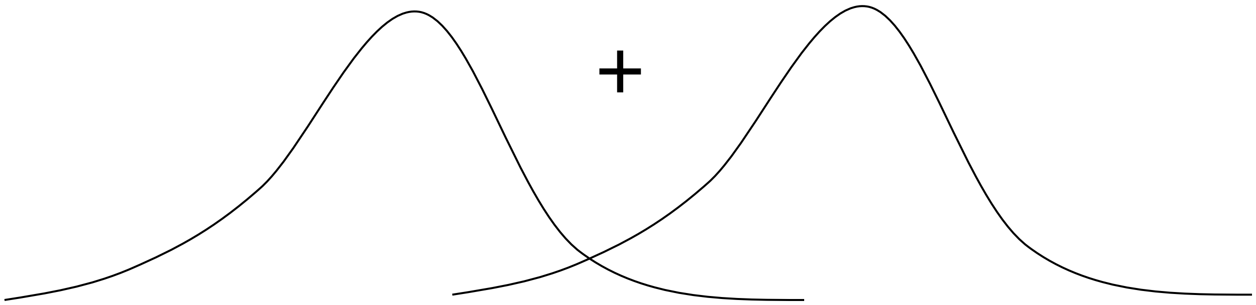
The Uncertainty Principle

- If we observe a beam of electrons through one slit with the other closed we get some intensity pattern.
- Similarly if we now open that slit and cover the other a similar pattern is observed.

The Uncertainty Principle

- If we observe a beam of electrons through one slit with the other closed we get some intensity pattern.
- Similarly if we now open that slit and cover the other a similar pattern is observed.
- Classically, if both slits are open a pattern formed by a superposition should be the result.

The Uncertainty Principle



The Uncertainty Principle

- However no such pattern is obtained.

The Uncertainty Principle

- However no such pattern is obtained.
- In order to understand this phenomenon the idea that a particle has a distinct path must be discarded.

The Uncertainty Principle

- However no such pattern is obtained.
- In order to understand this phenomenon the idea that a particle has a distinct path must be discarded.

The Uncertainty Principle

- There is no such concept as the path of a particle.

The Uncertainty Principle

- There is no such concept as the path of a particle.
- This forms the content of what is called the uncertainty principle.

The Uncertainty Principle

- The fact that an electron has no definite path means it also has no characteristics (quantities defining the motion).

The Uncertainty Principle

- Only when the electron interacts with a classical object can its characteristics be defined.

The Uncertainty Principle

- The interaction between a classical object and a quantum particle is called a measurement.

The Uncertainty Principle

- The interaction between a classical object and a quantum particle is called a measurement.
- The classical object is called the apparatus.

The Uncertainty Principle

- The measuring process in QM always effects the subjected quantum particle.

The Uncertainty Principle

- The measuring process in QM always effects the subjected quantum particle.
- The more exact the measurement the greater the effect.

The Uncertainty Principle

- The measuring process in QM always effects the subjected quantum particle.
- The more exact the measurement the greater the effect.
- Reducing the accuracy reduces the effect on the particle.

The Uncertainty Principle

- The measuring process in QM always effects the subjected quantum particle.
- The more exact the measurement the greater the effect.
- Reducing the accuracy reduces the effect on the particle.
- It is impossible in principle to make the effect arbitrarily small.

Heisenberg Uncertainty Principle

Effect of taking a measurement

Heisenberg Uncertainty Principle

- The uncertainty principle may be stated as:

Heisenberg Uncertainty Principle

- The uncertainty principle may be stated as:

  If a measurement of position of made with precision Δx and a simultaneously measurement of momentum is made with precision Δp, then the product of the uncertainties can not be smaller than the order of $\hbar$.

Heisenberg Uncertainty Principle

$\Delta x \Delta p \geq \hbar$ (The uncertainty principle)

Heisenberg Uncertainty Principle

- Example: Location an Electron.

Heisenberg Uncertainty Principle

- Example: Location an Electron.
- The speed of an electron is measured to have a value of $5 \times 10^3 m/s$ to an accuracy of 0.003% . Find the uncertainty in determining the position of this electron.

Heisenberg Uncertainty Principle

- The momentum of the electron is

$$p = mv$$

Heisenberg Uncertainty Principle

- The momentum of the electron is

$$p = mv = (9.11 \times 10^{-31} kg) \cdot (5 \times 10^{3} m/s)$$

Heisenberg Uncertainty Principle

- The momentum of the electron is

$$p = mv = (9.11\times10^{-31} kg)\cdot(5\times10^{3} m/s)$$

$$= 4.56\times10^{-27} kgm/s$$

Heisenberg Uncertainty Principle

- The momentum of the electron is

$$p = mv = (9.11\times10^{-31}kg)\cdot(5\times10^{3}m/s)$$

$$= 4.56\times10^{-27}kgm/s$$

- Since the uncertainty is 0.003% we get

$$\Delta p = 0.00003p$$

Heisenberg Uncertainty Principle

- The momentum of the electron is
  $$p = mv = (9.11 \times 10^{-31} kg) \cdot (5 \times 10^{3} m/s)$$
  $$= 4.56 \times 10^{-27} kgm/s$$
- Since the uncertainty is 0.003% we get
  $$\Delta p = 0.00003 p = 1.37 \times 10^{-31} kgm/s$$

Heisenberg Uncertainty Principle

- From the uncertainty principle $\Delta x \Delta p \geq \hbar$

Heisenberg Uncertainty Principle

- From the uncertainty principle $\Delta x \Delta p \geq \hbar$

$$\therefore \Delta x \geq \frac{h}{2\pi \Delta p}$$

Heisenberg Uncertainty Principle

- From the uncertainty principle $\Delta x \Delta p \geq \hbar$

$$\therefore \Delta x \geq \frac{h}{2\pi\Delta p} = \frac{6.63\times10^{-34}\,J\cdot s}{2\pi(1.37\times10^{-31}kgm/s)}$$

Heisenberg Uncertainty Principle

- From the uncertainty principle $\Delta x \Delta p \geq \hbar$

$$\therefore \Delta x \geq \frac{h}{2\pi \Delta p} = \frac{6.63 \times 10^{-34} J \cdot s}{2\pi (1.37 \times 10^{-31} kgm/s)}$$

$$= 0.77 \times 10^{-3} m$$

Heisenberg Uncertainty Principle

- From the uncertainty principle it can be shown that $\Delta E \Delta t \geq \hbar$.