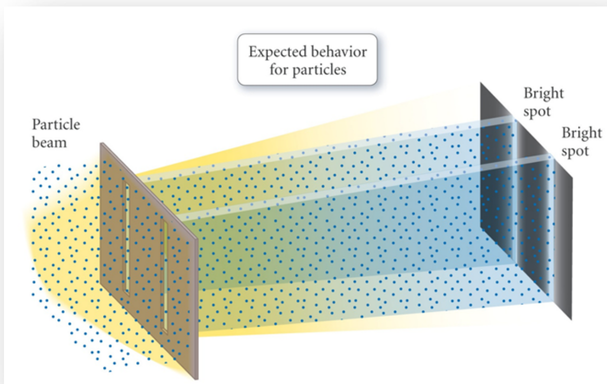
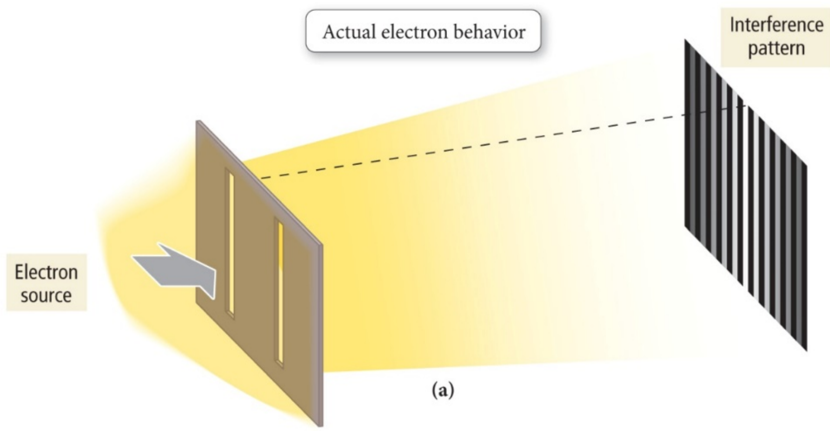
Module-8: Using Modern Quantum Theory

THE DUAL NATURE OF ELECTRONS

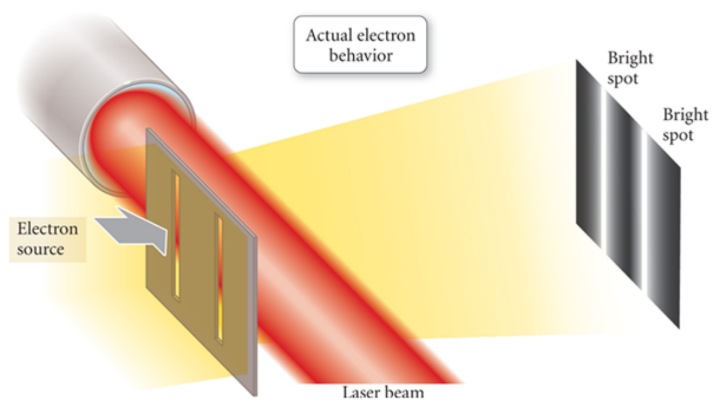
- The French physicist Louis de Broglie proposed that particles could have wave-like character. If electrons were particles two dark lines should be observed right in line with the slits that they pass through.



- However, such a pattern is not observed. Proof that the electrons have wave nature came with the demonstration that a beam of electrons would produce an interference pattern the same as waves do.
- When a beam of electrons goes through two closely spaced slits an interference pattern is created, as if the electrons were waves.



- When you try to observe the wave nature of the electron, you cannot observe its particle nature and vice versa. The following experiment is designed to see through which slit the electron goes, however, under the experimental conditions, the interference pattern disappears in the presence of the laser used to locate the electrons.



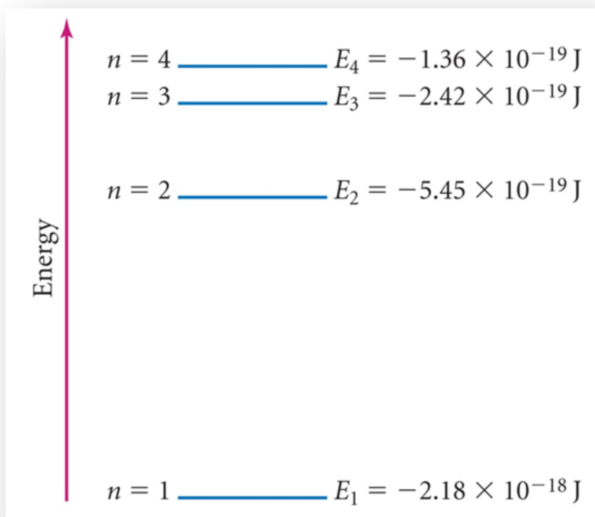
- This experiment proves the uncertainty, that, we cannot locate the electrons and observe the wave nature simultaneously.

THE QUANTUM NUMBERS

- The discussions here are purely qualitative without the use of the mathematics involved in arriving at the following conclusions.
- There are four different quantum numbers that are associated with each electron in an atom, they are,

The Principal Quantum Number	n
The Angular Momentum Quantum Number	l
The Magnetic Quantum Number	m_l
The Spin Quantum Number	m_s

- The principal quantum numbers '*n*' represents the different energy levels in an atom, with $n = 1$ at the lowest energy level. The principal quantum numbers are also called as the main or primary shells. The maximum number of electrons that can occupy a primary shell is given by the formula, $2n^2$.



The '*n*' values are whole numbers, among the known elements the '*n*' values do not exceed the number '7'.

- The next quantum number, namely, the *angular momentum quantum number* (*l*) is an integer that *determines the shape of the orbital*.

  The *angular momentum quantum number* (*l*) can be seen as the subdivision of the principal quantum number or simply subshells. The possible values of '*l*' are 0, 1, 2 … and *l* can have integer values from 0 to $(n – 1)$.

  Each value of *l* is represented by a particular letter that designates the shape of the orbital.

Value of l	Letter Designation
$l = 0$	s
$l = 1$	p
$l = 2$	d
$l = 3$	f

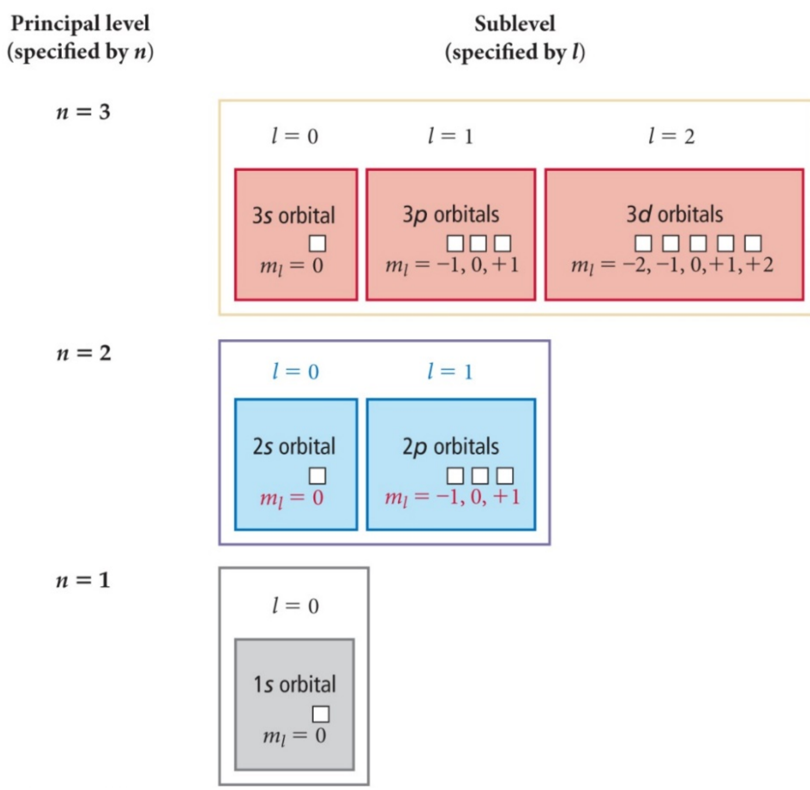
Note: for the shapes of different orbitals refer the textbook.

- The third quantum number, the *magnetic quantum number* (m_l), is an integer that specifies the orientation of a given orbital.

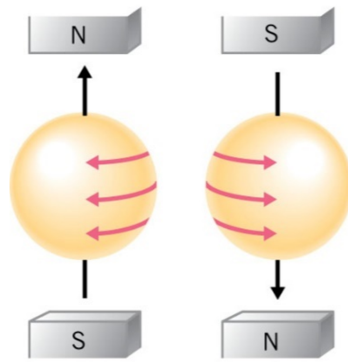
  From the magnetic quantum number, we can find out how many subshells are there and how are they orientated.

  The values magnetic quantum number (m_l) range from $-l$ to $+l$, including zero.

  For example, when $l = 2$, the values of m_l are −2, −1, 0, +1, +2, which means there are five orbitals with $l = 2$



- The fourth quantum number is the spin quantum number, m_s, Electrons can spin in either direction in the presence of an external magnetic field. This gives rise to the spin quantum number, m_s with allowed values of + ½ (spin "up") or – ½ (spin "down").



- The following table summarizes the above discussions

Allowed Combinations of Quantum Numbers *n, l*, and m_l for the First Four Shells

n	l	m_l	Orbital Notation	Number of Orbitals in Subshell	Number of Orbitals in Shell
1	0	0	1*s*	1	1
2	0	0	2*s*	1	4
	1	−1, 0, +1	2*p*	3	
3	0	0	3*s*	1	9
	1	−1, 0, +1	3*p*	3	
	2	−2, −1, 0, +1, +2	3*d*	5	
4	0	0	4*s*	1	16
	1	−1, 0, +1	4*p*	3	
	2	−2, −1, 0, +1, +2	4*d*	5	
	3	−3, −2, −1, 0, +1, +2, +3	4*f*	7	

Practice Problems

1. Which quantum number distinguishes the different shapes of the orbitals?

(A) n (B) m_l (C) l (D) m_s

2. The angular momentum quantum number is best associated with the

(A) shape of the orbital.
(B) number of orbitals in a subshell.
(C) energy of the orbital.
(D) orientation in space of an orbital

3. A possible value of the magnetic quantum number m_l for a 5p electron is

(A) 1 (B) −3 (C) −5 (D) 5

4. Which of the following sets of quantum numbers (n, l, m_l, m_s) refers to a 3d orbital?

	n	l	m_l	m_s
(A)	3	1	0	+ ½
(B)	3	4	3	+ ½
(C)	4	2	1	– ½
(D)	3	2	1	– ½

5. All the following statements about the quantum numbers are true <u>except</u>

(A) m_l has $2l + 1$ possible values

(B) m_l may take integral values of $+l$ to $-l$, including zero

(C) l may take integral values from 1 to $n - 1$

(D) m_s may take only the values of +½ and −½.

6. How many values are there for the magnetic quantum number when the value of the angular momentum quantum number is 4?

(A) 9 (B) 16 (C) 8 (D) 32

7. An orbital with the quantum numbers $n = 3$, $l = 2$, $m_l = -1$ may be found in which subshell?

(A) 3*s* (B) 3*p* (C) 3*d* (D) 3*f*

8. Which of the following sets of quantum numbers (n, l, m_l, m_s) is <u>not</u> permissible?

	n	l	m_l	m_s
(A)	3	3	– 3	+ ½
(B)	2	1	– 1	+ ½
(C)	1	0	0	+ ½
(D)	4	0	0	– ½

9. Which of the following combinations of quantum numbers is permissible?

	n	l	m_l	m_s
(A)	1	2	0	– ½
(B)	3	2	1	+ ½
(C)	1	1	0	+ ½
(D)	1	1	–1	0

10. What is the total number of <u>orbitals</u> found in the $n = 4$ shell?

(A) 8 (B) 32 (C) 18 (D) 16