ST. LAWRENCE HIGH SCHOOL

A JESUIT CHRISTIAN MINORITY INSTITUTION

STUDY MATERIAL FOR CHEMISTRY (CLASS-11)

TOPIC- STRUCTURE OF ATOM

SUBTOPIC- QUANTUM NUMBERS

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In chemistry and quantum physics, **quantum numbers** describe values of conserved quantities in the dynamics of a quantum system. In the case of electrons, the quantum numbers can be defined as "*the sets of numerical values which give acceptable solutions to the Schrödinger wave equation for the hydrogen atom*".

How many quantum numbers exist?

A quantum number is a value that is used when describing the energy levels available to atoms and molecules. An electron in an atom or ion has four quantum numbers to describe its state and yield solutions to the Schrödinger wave equation for the hydrogen atom.

There are four quantum numbers:

- n - principal quantum number: describes the energy level
- ℓ - azimuthal or angular momentum quantum number: describes the subshell
- m_ℓ or m - magnetic quantum number: describes the orbital of the subshell
- m_s or s - spin quantum number: describes the spin

QUANTUM NUMBER VALUES

According to the Pauli Exclusion Principle, no two electrons in an atom can have the same set of quantum numbers. Each quantum number is represented by either a half-integer or integer value.

- The principal quantum number is an integer that is the number of the electron's shell. The value is 1 or higher (never 0 or negative).
- The angular momentum quantum number is an integer that is the value of the electron's orbital (for example, s=0, p=1). ℓ is greater than or equal to zero and less than or equal to n-1.
- The magnetic quantum number is the orientation of the orbital with integer values ranging from -ℓ to ℓ. So, for the p orbital, where ℓ=1, m could have values of -1, 0, 1.
- The spin quantum number is a half-integer value that is either -1/2 (called "spin down") or 1/2 (called "spin up").

What are Quantum Numbers?

The set of numbers used to describe the position and energy of the electron in an atom are called quantum numbers. There are four quantum numbers, namely, principal, azimuthal, magnetic and spin quantum numbers.

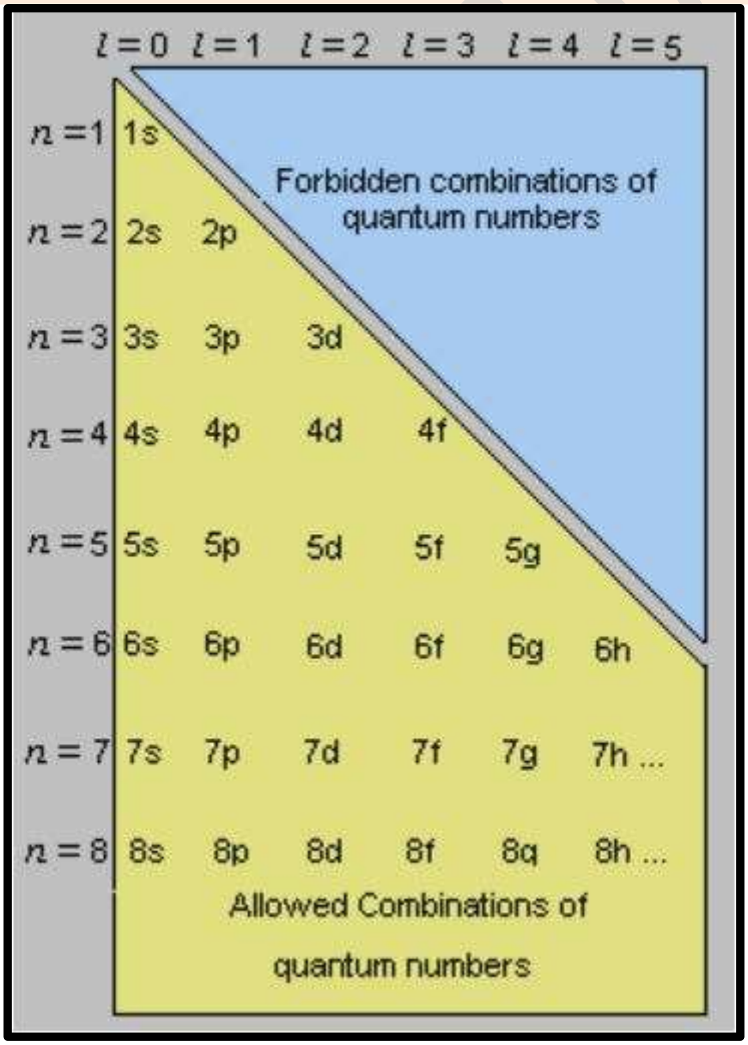
Number	Symbol	Possible Values
Principal Quantum Number	n	$1, 2, 3, 4, \ldots$
Angular Momentum Quantum Number	ℓ	$0, 1, 2, 3, \ldots, (n-1)$
Magnetic Quantum Number	m_l	$-\ell, \ldots, -1, 0, 1, \ldots, \ell$
Spin Quantum Number	m_s	$+1/2, -1/2$

A) PRINCIPAL QUANTUM NUMBER:

- ***Principal quantum numbers are denoted by the symbol 'n'. They designate the principal electron shell of the atom.*** Since the most probable distance between the nucleus and the electrons is described by it, a larger value of the principal quantum number implies a greater distance between the electron and the nucleus (which, in turn, implies a greater atomic size).
- The value of the principal quantum number can be any integer with a positive value that is equal to or greater than one. The value n=1 denotes the innermost electron shell of an atom, which corresponds to the lowest energy state (or the ground state) of an electron.
- Thus, it can be understood that the principal quantum number, n, cannot have a negative value or be equal to zero because it is not possible for an atom to have a negative value or no value for a principal shell.
- When a given electron is infused with energy (excited state), it can be observed that the electron jumps from one principle shell to a higher shell, causing an increase in the value of n. Similarly, when electrons lose energy, they jump back into lower shells and the value of n also decreases.
- The increase in the value of n for an electron is called absorption, emphasizing the photons or energy being absorbed by the electron. Similarly, the decrease in the value of n for an electron is called emission, where the electrons emit their energy.

B) AZIMUTHAL QUANTUM NUMBER (ORBITAL ANGULAR MOMENTUM QUANTUM NUMBER):

- The azimuthal (or orbital angular momentum) quantum number describes the shape of a given orbital. It is denoted by the symbol ‘l’ and its value is equal to the total number of angular nodes in the orbital.
- A value of the azimuthal quantum number can indicate either an s, p, d, or f subshell which vary in shapes. This value depends on (and is capped by) the value of the principal quantum number, i.e. the value of the azimuthal quantum number ranges between 0 and (n-1).
- For example, if n =3, the azimuthal quantum number can take on the following values – 0,1, and 2. When l=0, the resulting subshell is an ‘s’ subshell. Similarly, when l=1 and l=2, the resulting subshells are ‘p’ and ‘d’ subshells (respectively). Therefore, when n=3, the three possible subshells are 3s, 3p, and 3d.
- In another example where the value of n is 5, the possible values of l are 0, 1, 2, 3, and 4. If l = 3, then there are a total of three angular nodes in the atom.

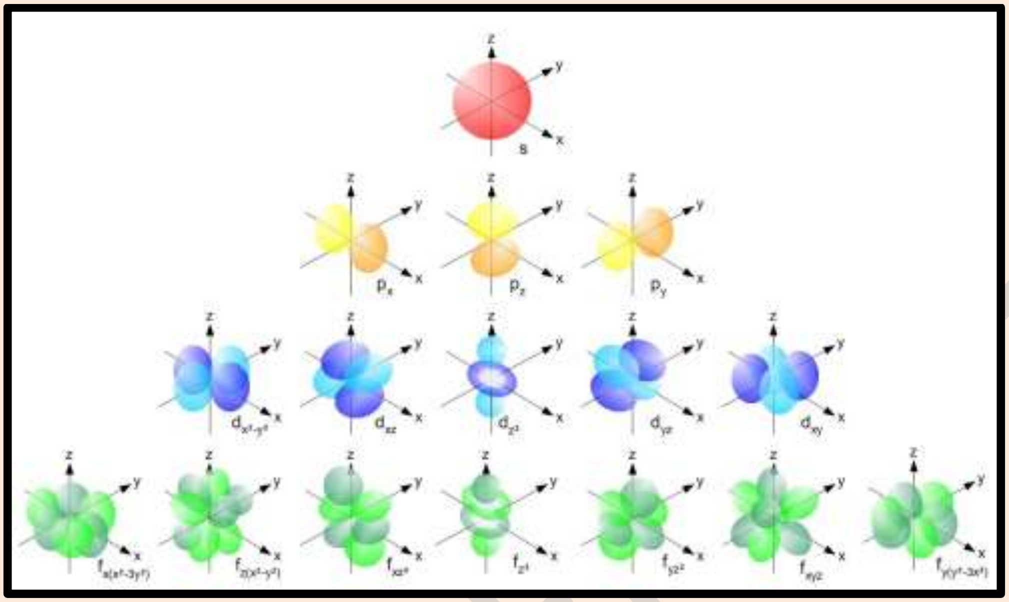


COMBINATIONS OF THE PRINCIPAL AND AZIMUTHAL QUANTUM NUMBERS

The allowed subshells under different combinations of ‘n’ and ‘l’ are listed above. It can be understood that the ‘2d’ orbital cannot exist since the value of ‘l’ is always less than that of ‘n’.

C) MAGNETIC QUANTUM NUMBER:

The total number of orbitals in a subshell and the orientation of these orbitals are determined by the magnetic quantum number. It is denoted by the symbol 'm_l'. This number yields the projection of the angular momentum corresponding to the orbital along a given axis.



Shapes of Orbitals (as per the corresponding Quantum Numbers)

The value of the magnetic quantum number is dependent on the value of the azimuthal (or orbital angular momentum) quantum number. For a given value of l, the value of m_l ranges between the interval -l to +l. Therefore, it indirectly depends on the value of n.

For example, if n = 4 and l = 3 in an atom, the possible values of the magnetic quantum number are -3, -2, -1, 0, +1, +2, and +3.

Azimuthal Quantum Number Value	**Corresponding Number of Orbitals (2l + 1)**	**Possible Values of m_l**
1) 0 ('s' subshell)	2X0 + 1 = 1	0
2) 1 ('p' subshell)	2X1 + 1 = 3	-1, 0, and 1
3) 2 ('d' subshell)	2X2 + 1 = 5	-2, -1, 0, 1, and 2
4) 3 ('f' subshell)	2X3 + 1 = 7	-3, -2, -1, 0, 1, 2, and 3

The total number of orbitals in a given subshell is a function of the 'l' value of that orbital. It is given by the formula (2l + 1). For example, the '3d' subshell (n=3, l=2) contains 5 orbitals (2X2 +

1). Each orbital can accommodate 2 electrons. Therefore, the 3d subshell can hold a total of 10 electrons.

D) ELECTRON SPIN QUANTUM NUMBER:

- The electron spin quantum number is independent of the values of n, l, and m_l. The value of this number gives insight into the direction in which the electron is spinning, and is denoted by the symbol m_s.
- The value of m_s offers insight into the direction in which the electron is spinning. The possible values of the electron spin quantum number are +½ and -½.
- The positive value of m_s implies an upward spin on the electron which is also called 'spin up' and is denoted by the symbol ↑. If m_s has a negative value, the electron in question is said to have a downward spin, or a 'spin down', which is given by the symbol ↓.
- The value of the electron spin quantum number determines whether the atom in question has the ability to produce a magnetic field. The value of m_s can be generalized to ±½.

SUMMARY

In order to simplify the details of the four different quantum numbers that are related to atomic physics, a tabular column detailing their names, symbols, meanings, and possible values is provided below.

NAME AND SYMBOL	MEANING AND POSSIBLE VALUES
1) Principal quantum number, n	Electron shell, $n \geq 1$
2) Azimuthal quantum number, l	Subshells (s=0, p=1, etc.) , $(n-1) \geq l \geq 0$
3) Magnetic quantum number, m_l	Total number and orientation of orbitals, $l \geq m_l \geq -l$
4) Electron spin quantum number, m_s	The direction of electron spin, $m_s = \pm ½$

SOME IMPORTANT QUESTIONS:

Q.1) What are the Possible Subshells when n = 4? How Many Orbitals are contained by each of these Subshells?

Ans. When n = 4, the possible l values are 0, 1, 2, and 3. This implies that the 4 possible subshells are the 4s, 4p, 4d, and 4f subshells.

- The 4s subshell contains 1 orbital and can hold up to 2 electrons.
- The 4p subshell contains 3 orbitals and can hold up to 6 electrons.
- The 4d subshell contains 5 orbitals and can hold up to 10 electrons.
- The 4f subshell has 7 orbitals and can hold up to 14 electrons.

Thus, a total of 4 subshells are possible for n = 4.

Q.2) What are the Possible m_l values for l = 4?

Ans. Since the value of the magnetic quantum number ranges from -l to l, the possible values of m_l when l = 4 are: -4, -3, -2, -1, 0, 1, 2, 3, and 4.

SOME IMPORTANT QUESTIONS

Q.1) Who proposed the principal quantum number?

Ans. The notion of energy levels and notation has been taken from the atom‘s earlier Bohr model. Schrodinger‘s equation evolved the concept from a two-dimensional flat Bohr atom to a three-dimensional model for wave motion. Where n = 1, 2, 3 is called the main quantity, and h is the constant of Planck.

Q.2) Why are there only 8 electrons in the outer shell?

Ans. The stability of an atom ‘s eight-electrons derives from the stability of the noble gases or the elder term of inert gases, also known as unreactive or noble gases. This law, however, is justified in the periodic table for second row elements whose outermost-shell capacity is 8 electrons.

Q.3) How do you find the principal quantum number?

Ans. The principal quantum number n value is the level of the central electronic shell (central level). All orbitals with the same n value are at the same key stage. All orbitals on the second main stage, for example, have a principal quantity of n=2.

Q.4) What are the principal energy levels?

Ans. In chemistry, an electron’s primary energy level refers to the shell or orbital in which the electron resides relative to the nucleus of the atom. The principal quantum number n denotes this level. Within a time of the periodic table the first element introduces a new key energy level.

Q.5) Which energy level has the least energy?

Ans. There is a single 1s orbital that can accommodate 2 electrons at the lowest energy level, the one nearest to the atomic core. There are four orbitals at the next energy level; a 2s, $2p^1$, $2p^2$ and a $2p^3$. Each of these orbitals can carry 2 electrons, so we can find a total of 8 electrons at this energy level.

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