

Quantum Numbers and Orbitals

What do the four quantum numbers tell you about an electron?

●●○ Intermediate

Atomic Structure & Periodicity

Last reviewed 5 October 2026

Before you start: it helps to understand [Electron Configuration](#) and [Light and Atomic Spectra](#).

What is it?

In quantum mechanics, an electron in an atom is described by an **orbital**: a region of space where the electron is likely to be found. Each orbital, and each electron in it, is labelled by **quantum numbers**, like an address:

Quantum number	Symbol	Allowed values	What it describes
Principal	n	1, 2, 3, ...	The shell: size and main energy level
Angular momentum (azimuthal)	l	0 to $n - 1$	The subshell: shape of the orbital
Magnetic	m_l	$-l$ to $+l$, in steps of 1	The orientation of the orbital in space
Spin	m_s	$+\frac{1}{2}$ or $-\frac{1}{2}$	The spin of the electron

The value of l is usually given as a letter: $l = 0$ is **s**, $l = 1$ is **p**, $l = 2$ is **d** and $l = 3$ is **f**. So $n = 3, l = 1$ is the **3p** subshell.

💡 KEY IDEA

The first three quantum numbers (n, l, m_l) identify an **orbital**; the fourth (m_s) identifies one of the two electrons in it. **Pauli exclusion principle:** no two electrons in an atom can have the same set of all four quantum numbers. That's why each orbital holds at most two electrons, with opposite spins.

Why does it matter?

- **It explains the electron configuration rules.** The number of m_l values gives the number of orbitals per subshell (1, 3, 5, 7), and so the capacities 2, 6, 10 and 14 electrons that build the periodic table.
- **It explains the shape of the periodic table.** The s, p, d and f blocks are 2, 6, 10 and 14 elements wide.

- **Orbital shapes explain bonding.** The directions of p and d orbitals determine bond angles and molecular shapes.

How does it work?

1. Counting orbitals and electrons

For a given l , m_l takes $2l + 1$ values, so there are $2l + 1$ orbitals in the subshell:

Subshell	l	m_l values	Orbitals	Max electrons
s	0	0	1	2
p	1	-1, 0, +1	3	6
d	2	-2, -1, 0, +1, +2	5	10
f	3	-3 to +3	7	14

Shell n contains n subshells, n^2 orbitals and at most $2n^2$ electrons. For example, the $n = 2$ shell has 2s and 2p: 4 orbitals, 8 electrons.

2. Orbital shapes

- **s orbitals** are **spherical**. Larger n gives a larger sphere.
- **p orbitals** have **two lobes** (a dumbbell) on opposite sides of the nucleus, with a nodal plane between them. The three p orbitals point along the x, y and z axes: p_x , p_y , p_z .
- **d orbitals** mostly have **four lobes** (a cloverleaf); one (d_{z^2}) has two lobes and a ring.

3. Nodes

A **node** is a surface where the chance of finding the electron is zero. An orbital has $n - 1$ nodes in total: l of them are **angular** (planes or cones), and $n - l - 1$ are **radial** (spheres).

∞ THINK OF IT LIKE THIS

The quantum numbers are like an address in a city. n is the district (how far from the centre), l is the type of street (its shape), m_l is which way the street points, and m_s is which of the two apartments in the building the electron lives in. No two electrons share the same full address.

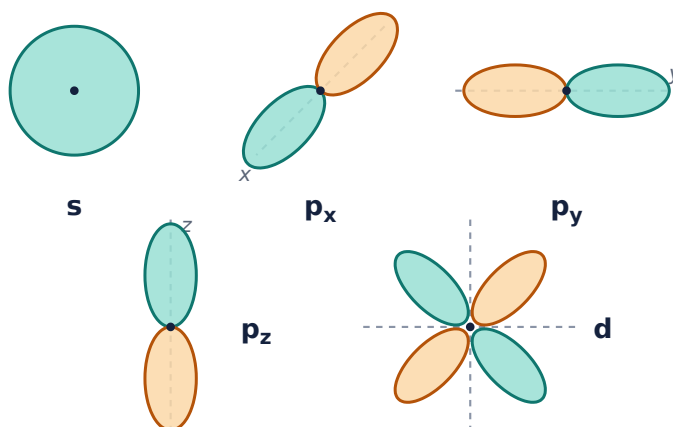
Q MORE PRECISELY

An orbital is a solution of the Schrödinger equation, a **wavefunction**, ψ . The probability of finding the electron is proportional to ψ^2 . The usual drawings are **boundary surfaces** enclosing about 90 % of that probability. In hydrogen all subshells with the same n have the same energy; in many-electron atoms, shielding makes s lower than p, and p lower than d, which leads to the Aufbau filling order. The two lobes of a p orbital have opposite **phases** (signs of ψ), which matters when orbitals overlap to form bonds.

Visualise it

Orbital shapes

Boundary surfaces (schematic). Colours show the phases.



Boundary surfaces of s, p and d orbitals (schematic). The two colours show the opposite phases of the lobes.

Worked example

WORKED EXAMPLE: Allowed values in a shell

Question: List the allowed values of l and m_l for $n = 3$. How many orbitals and electrons can the shell hold?

Step 1 $l = 0, 1, 2$ (3s, 3p, 3d).

Step 2 m_l : for $l = 0$: 0; for $l = 1$: -1, 0, +1; for $l = 2$: -2, -1, 0, +1, +2.

Step 3 Orbitals: $1 + 3 + 5 = 9 = 3^2$. Electrons: $2 \times 9 = 18 = 2 \times 3^2$.

 WORKED EXAMPLE: Which sets are allowed?

Question: Which of these sets (n, l, m_l, m_s) are allowed? (a) $(2, 1, 0, +\frac{1}{2})$ (b) $(2, 2, 0, +\frac{1}{2})$ (c) $(3, 1, -2, -\frac{1}{2})$ (d) $(4, 0, 0, 0)$

Step 1 (a) **Allowed:** l is below n , m_l lies between $-l$ and $+l$: a 2p electron.

Step 2 (b) **Not allowed:** l must be at most $n - 1 = 1$.

Step 3 (c) **Not allowed:** for $l = 1$, m_l can only be $-1, 0$ or $+1$.

Step 4 (d) **Not allowed:** m_s must be $+\frac{1}{2}$ or $-\frac{1}{2}$.

 WORKED EXAMPLE: Naming a subshell

Question: Name the subshell with $n = 4$, $l = 2$, and state how many electrons it can hold.

$l = 2$ is d, so this is **4d**. It has $2l + 1 = 5$ orbitals, holding **10** electrons.

 WORKED EXAMPLE: Quantum numbers of a valence electron

Question: Give a possible set of quantum numbers for the outermost electron of sodium ($1s^2 2s^2 2p^6 3s^1$).

The electron is in 3s: $n = 3$, $l = 0$, $m_l = 0$, $m_s = +\frac{1}{2}$ (or $-\frac{1}{2}$).

 WORKED EXAMPLE: Counting nodes

Question: How many nodes of each kind does a 3p orbital have?

Total = $n - 1 = 2$. Angular = $l = 1$ (a nodal plane). Radial = $n - l - 1 = 1$ (a nodal sphere).

Common mistake

 COMMON MISTAKE: Letting l equal n

l runs from 0 to $n - 1$. There is no 1p or 2d subshell: the first p subshell is 2p and the first d subshell is 3d.

 COMMON MISTAKE: Confusing orbitals with electrons

A p subshell has **3 orbitals** but holds up to **6 electrons**. Always check whether a question asks for orbitals or electrons.

 COMMON MISTAKE: Thinking an orbital is a path

An orbital is not an orbit the electron travels around. It is a region of probability; the electron has no definite path.

 NOTATION NOTE

- l is a lower-case L; some books write it ℓ .
- A subshell is written number + letter (3p), and its electron count as a superscript ($3p^4$).

Remember this

 REMEMBER THIS

- $n = 1, 2, 3, \dots$; $l = 0$ to $n - 1$ (s, p, d, f); $m_l = -l$ to $+l$; $m_s = \pm \frac{1}{2}$.
- Orbitals per subshell: $2l + 1$ (1, 3, 5, 7). Per shell: n^2 orbitals, $2n^2$ electrons.
- Pauli: no two electrons have the same four quantum numbers, so 2 electrons per orbital.
- s spherical, p two lobes (x, y, z), d mostly four lobes.
- Nodes: $n - 1$ total; l angular; $n - l - 1$ radial.

References

1. Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

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