

## Electron Paramagnetic Resonance (EPR) Spectroscopy



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Electron Paramagnetic Resonance (EPR) Spectroscopy, also known as Electron Spin Resonance (ESR) Spectroscopy, is an effective analytical technique for studying materials having unpaired electrons. It is particularly important in the domains of chemistry, physics, biology, and materials research because of its unique capacity to provide extensive information about the electronic structure and surroundings of paramagnetic species. One of the principal uses of EPR spectroscopy is to detect and characterise free radicals, which are molecules or atoms with unpaired electrons. Free radicals serve important roles in many chemical and biological processes, such as oxidation, polymerisation, and ageing. EPR can directly detect these species and offer information on their concentration, structure, and behaviour. Many transition metal ions, such as  $\text{Cu}^{2+}$ ,  $\text{Fe}^{3+}$ , and  $\text{Mn}^{2+}$ , have unpaired electrons and show EPR spectra. EPR spectroscopy is useful for assessing the oxidation states, coordination environment, and electronic characteristics of metal ions in complex biological systems and catalysts. EPR spectroscopy is a non-destructive procedure, making it perfect for investigating sensitive samples that may have been damaged or deteriorated by other analytical techniques. Its high sensitivity allows it to detect even tiny levels of paramagnetic molecules, making it ideal for studying low concentrations of radicals or transition metal complexes in complex mixtures or biological systems.

The EPR spectrum describes the hyperfine interactions between the unpaired electron and adjacent atomic nuclei, such as hydrogen, nitrogen, or oxygen. This hyperfine coupling gives information about the local environment, as well as the distances between interacting species. For example, EPR can differentiate between various radical species and determine the structure of complicated chemical molecules or coordination compounds. EPR can also provide insights into reaction mechanisms by measuring the generation and decay of free radicals. This is especially useful for investigating the kinetics of radical-based polymerisation reactions, oxidation processes, and the involvement of reactive oxygen species in biological systems.

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In biological research, EPR spectroscopy is used to explore the function of free radicals in oxidative stress, a condition linked to a variety of diseases, including cancer, cardiovascular problems, and neurodegenerative diseases (such as Parkinson's and Alzheimer's). EPR can detect these radicals in biological samples, allowing researchers to better understand how they contribute to disease progression. Furthermore, EPR imaging techniques, which combine spectroscopy and spatial localisation, are employed in medical research to map the distribution of free radicals or paramagnetic probes in tissues, yielding information on biological functions and diseases.

In materials science, EPR spectroscopy is used to investigate the flaws, impurities, and electrical characteristics of many materials, including semiconductors, polymers, and nanomaterials. For example, it aids in characterising paramagnetic flaws in silicon-based semiconductors, which can affect their performance in electronic devices. In the study of catalysis, EPR is used to explore catalyst active sites and understand their interactions with reactants. This information is critical for optimising catalyst design and increasing chemical process efficiencies.

Because of its unique ability to detect and analyse paramagnetic substances, EPR spectroscopy is a must-have instrument in many scientific areas. Its extreme sensitivity, non-destructive nature, and thorough understanding of molecular structure and dynamics make it ideal for researching chemical reactions, biological processes, and material qualities. As research advances, the importance of EPR spectroscopy in revealing complicated phenomena is projected to expand, confirming its position as a critical analytical technique in both basic and applied sciences.