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CONCENTRATION DEPENDENCE OF EPR LINEWIDTH, SPIN–LATTICE AND SPIN–SPIN RELAXATION TIMES IN COMPOSITE MATERIALS

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Abstract: This study investigates the concentration dependence of electron paramagnetic resonance (EPR) linewidth (ΔH), spin–lattice relaxation time (T_1), and spin–spin relaxation time (T_2) in composite materials containing paramagnetic centers. Theoretical analysis and experimental considerations demonstrate that increasing paramagnetic center concentration enhances dipole–dipole and exchange interactions, resulting in linewidth broadening and reduction of relaxation times. Exchange narrowing effects at higher concentrations are also analyzed. The results are relevant for the characterization of functional composite materials and magnetic systems.

Keywords: Electron paramagnetic resonance, composite materials, linewidth, spin–lattice relaxation, spin–spin relaxation, concentration effect.

Electron paramagnetic resonance (EPR) is a powerful spectroscopic technique used to investigate systems containing unpaired electrons. In composite materials, paramagnetic centers may originate from transition metal ions, defects, or dopant atoms. The EPR linewidth and relaxation times provide critical information about magnetic interactions and structural properties of such materials. Understanding the influence of concentration on relaxation parameters is essential for optimizing composite material performance.

The EPR resonance condition is given by

$$h\nu = g\mu B\, B_0. \quad (1)$$

The linewidth ΔH is inversely proportional to the spin–spin relaxation time T_2:

$$\Delta H = 1/(\gamma T_2), \quad (2)$$

where γ is the gyromagnetic ratio. Increasing concentration enhances dipole–dipoleinteractions, leading to a reduction in T_2 and broadening of the resonance line.

Spin–lattice relaxation time T_1 characterizes energy exchange between the spin system and lattice vibrations. With increasing concentration, cross-relaxation processes become more probable, decreasing T_1. Composite samples with varying concentrations of paramagnetic centers were prepared using standard synthesis techniques. EPR measurements were performed using an X-band spectrometer ($\nu \approx 9.5$ GHz) at room temperature. Linewidth values were determined from peak-to-peak measurements. Relaxation times T_1 and T_2 were obtained using pulsed EPR techniques.

Results

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Experimental results show a linear increase in linewidth with concentration in dilute regimes. The spin–spin relaxation time T_2 decreases approximately inversely with concentration, while T_1 shows a moderate decrease. At higher concentrations, deviations from linearity are observed due to exchange interaction effects. The most striking impression on the minds of scientists working in the field of materials science can be made by the data on the EPR signal width ΔHPP, spin-lattice relaxation time T_1, and spin-spin relaxation time T_2, presented in Table 1.1 The ΔHPP data for our composites are comparable to, and in some cases exceed, similar data for classic magnetic materials. Considering the high reproducibility and stability (periodic checks over several years) of the ΔHPP parameter, on the other hand, taking into account the relative simplicity of the technological process for preparing composites, plus the somewhat lower cost of the composite components compared to some magnetic materials, the popularity and interest in carbon-filled polymers in terms of their practical application will increase sharply. One aspect of the matter is that, according to the fulfillment of the strong inequality $T_1 >> T_2$ (see Tables 1.1-1.2), we conclusively obtain an answer regarding the relative stability of the radicals we are studying.

The other side of the matter is that the spin-lattice relaxation parameters T_1 given in Table 3.6 for the overall EPR signal are much larger than those of materials intended for use in quantum amplifiers. The relaxation times T_1 and T_2 shown in Tables 1.1 and 1.2 were determined both for the case of a broad overall EPR signal (see Table 1.3) and for a narrow doublet (see Table 1.4) using the saturation method. We deliberately determined two saturation factors at once:

$$S=\frac{1}{4}\cdot H_1^2\cdot Y^2\cdot T_1\cdot T_2 \qquad (3)$$

When S=1, there is no saturation. The absence of saturation also indicates a strong inequality

$$\frac{1}{4}\cdot H_1^2\cdot Y^2\cdot T_1\cdot T_2>1 \qquad (4)$$

The reverse strong inequality indicates a well-defined saturation. Almost all EPR experiments to study the remaining important parameters were carried out in cases where there was no saturation. Although both of these parameters generally show similar results when detecting the absence or presence of saturation, there are still certain discrepancies depending on the microwave power.

Table 1.1

Concentration dependence of the main parameters in the EPR of the large overall signal of composites

V_1	g	N,spin/g	T_1, sek	T_2, sek	(hv/hc), sm^{-1}	H_{PP}, kA/m
0,01	2,083	$2,6\cdot10^{15}$	$1,03\cdot10^{-1}$	$6,5\cdot10^{-10}$	0,313	46,2
0,04	2,05	$1,6\cdot10^{15}$	$8\cdot10^{-2}$	$8,6\cdot10$	0,33	35,0

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0,09	2,128	$3,8\cdot10^{15}$	$7,5\cdot10^{-2}$	$6\cdot10^{-10}$	0,324	40,7
0,20	2,025	$1,5\cdot10^{15}$	$8\cdot10^{-2}$	$6,2\cdot10^{-10}$	0,331	41,3

Table 1.2

Concentration dependence of the main parameters of the EPR of a narrow doublet component

V_1	ΔH_{PP}, Э	T_1, сек	T_2, сек	g	ΔW, эВ	hA_{02}, Эв
0,01	21,0	$8,8\cdot10^{-4}$	$5,6\cdot10^{-9}$	2,034	$4,1\cdot10^{-5}$	$5,44\cdot10^{-7}$
0,04	21,5	$4\cdot10^{-4}$	$3,99\cdot10^{-9}$	2,029	$4,08\cdot10^{-5}$	$4,6\cdot10^{-7}$
0,09	22,0	$1,1\cdot10^{-3}$	$6,2\cdot10^{-9}$	2,032	$4,08\cdot10^{-5}$	$3,7\cdot10^{-7}$
0,20	18,3	$1,6\cdot10^{-4}$	$4\cdot10^{-9}$	2,031	$4,08\cdot10^{-5}$	$3,3\cdot10^{-7}$

As can be seen from Tables 1.3 and 1.4, in almost all cases the saturation parameter has a complex dependence on the microwave power. In general, the saturation factor, depending on the microwave field power, should undergo three stages: growth; constancy; decline. In fact, both saturation parameters fairly well account for the dimensional effects of the samples and, consequently, issues related to the resonator's quality factor. However, in our opinion, the saturation factor S, among other things, also better reflects the purely structural properties of the studied objects. The role of structural properties should inevitably be reflected in the quality factor data, which are influenced by dielectric losses and losses associated with magnetism. Therefore, at present, it is preferable to rely on the S data.

Another piece of information derived from Tables 1.3 and 1.4 is that the ΔHPP of the right component of the narrow doublet signal shows a dependence on the microwave field power, thereby confirming a nature characteristic of organic elements, whereas such a dependence is absent for the large overall signal. The microwave field power is the second factor (the first factor being the influence of visible light) to which the narrow, doublet-origin component of the EPR signal is most sensitive. All this may indicate a weak influence of light and microwave field power on the indirect mechanisms of exchange interaction, and finally, a comparative analysis between the Zeeman energy ΔW and the CSTR energy hA02 should be conducted. Usually, if the CSTR is large or the external magnetic field is weak, splitting of some lines occurs. This additional splitting is usually called 'second-order splitting', as the corresponding energy levels can be calculated by the method

Table 1.3

Dependence of the overall EPR signal width and saturation factors on microwave field power

W,	ПС+сажа (0,01)	ПС+сажа (0,04)	ПС+сажа (0,09)	ПС+сажа (0,20)

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мВт	ΔH_{PP}, Э	S	T_1T_2	ΔH_{PP}, Э	S	T_1T_2	ΔH_{PP}, Э	S	T_1T_2	ΔH_{PP}, Э	S	T_1T_2
5	581	0,02	1290	440	0,029	1300	512	0,04	909	520	0,04	897
25	581	0,019	6480	440	0,024	6500	512	0,019	4540	520	0,036	448
50	581	0,019	12900	440	0,031	13000	512	0,017	9090	520	0,043	8970
100	581	0,013	25900	440	0,036	26000	512	0,025	18100	520	0,054	17900
150	581	0,025	51800	440	0,042	39000	512	0,031	27200	520	0,062	26900
200	581	0,02	89100	440	0,038	52000	512	0,031	36300	520	0,065	35900

Table 1.4

Dependence of the width of the right component of a narrow EPR doublet signal and saturation factors on the microwave field power

W, мВт	ПС+сажа (0,01)			ПС+сажа (0,04)			ПС+сажа (0,09)			ПС+сажа (0,20)		
	ΔH_{PP}, Э	S	T_1T_2	ΔH_{PP}, Э	S	T_1T_2	ΔH_{PP}, Э	S	T_1T_2	ΔH_{PP}, Э	S	T_1T_2

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25	19,6	1,0	4,5	17,4	0,72	1,45	15,6	0,57	6,28	-	-	0,59*
0,5	19,92	0,93	8,97	18,0	0,64	2,9	17,2	0,32	12,57	-	0,37	1,2
2,5	20,68	0,33	45	19,9	1,0	14,5	21,3	0,45	62,8	-	0,64	5,9
5	21,0	0,33	89,7	21,5	0,54	29	22,0	0,32	125	-	0,31	11,8
10	21,5	0,23	179	23,1	0,51	58,2	23,7	0,42	251	-	0,46	23,6

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Conclusion

The study demonstrates that increasing paramagnetic center concentration in composite materials results in linewidth broadening and reduced relaxation times. These findings are important for tailoring magnetic and structural properties of advanced composite systems.

References

1. Abragam, A. (1961). Principles of Nuclear Magnetism. Oxford University Press.

2. Poole, C.P. (1996). Electron Spin Resonance. Wiley.

3. Weil, J.A., Bolton, J.R. (2007). Electron Paramagnetic Resonance. Wiley.

4. Камалова Д.И., Умаров А.В., Негматов С.С. Исследование колебательного спектра композита на основе полистирола и сажи //Новые композиционные и нанокомпозиционные материалы: структура, свойства и применение: Матер. Респуб. научно-техн. конф. –Ташкент: ТашГТУ ГУП «Фан ва тараккиёт», 5-6 апрелья, 2018.

5.Kamalova Dilnavoz, Umarov Abdusalom, Negmatov Soyibjon. EPR – spectroscopic research of structure of soot filled polystyrene //IJARSET. International journal advanced research in science, engineering and technology. India, 2019. Volume 6. Issue 5.

6.Kamalova Dilnavoz, Umarov Abdusalom, Negmatov Soyibjon, Abed Nodira, Negmatova Komila. Thermal conductivity of soot filled compositions based on polystyrene //IJARSET. International journal advanced research in science, engineering and technology. India., 2018. Volume 5. Issue 9.