Dielectric Properties of Biological Substances — Tabulated*

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ABSTRACT

The dielectric properties, namely the dielectric constant and the loss factor of biological materials in the frequency range 10 kHz — 10 GHz are tabulated. Also, the composition and permittivity of tissue phantom materials are summarized.

The dielectric properties of tissue and its components are of practical interest in physical sciences and engineering. Recently, an increased interest in the permittivity of biological materials, especially *in-vivo*, is due to further research into the interaction mechanisms of electromagnetic waves in the range of radio and microwave frequencies with biological systems. Also, the knowledge of the dielectric parameters is essential in determining the specific absorption rate and its distribution in simplified models of animals and humans.

A large body of data on the permittivity of biological materials has been accumulated, starting with early work of Cook [10–13], and a mamoth contribution of Schwan and his colleagues [31–33, 35–45]. Very recently, the properties of some tissues in-vivo have also been obtained [5, 49], and special mixtures of various dielectrics have been developed to simulate the electric behaviour of various tissues [9, 13, 20].

The purpose of this paper is to collect all this data, which is scattered in various journals and reports, and present it in such a form that would be convenient for general reference purposes and that would enable to identify the areas where there is a need for measurements to determine the permittivity. It should be underlined, that in very many cases the data shown in the table was interpolated from the graphs (particularly ϵ'') so it is not very accurate.

The permittivity is tabulated in the form

$$\epsilon^* = \epsilon' - j\epsilon'', \tag{1}$$

where ϵ' is the relative dielectric constant and ϵ'' is the relative loss factor. The loss factor shown in the table represents the sum of both the relaxation losses as well as ionic losses and is related to the conductivity and the resistivity of the material through the following equations.

$$\epsilon'' = \frac{\sigma}{\omega \epsilon_o} = \frac{1}{\omega \epsilon_o \varrho} \tag{2}$$

where: σ is the conductivity (including the frequency independent contribution), $\omega = 2\pi f$, f is the frequency, $\epsilon_o = 8.854x10^{-12}$F/m, is the dielectric constant of vacuum, and ϱ is the resistivity.

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	Material	T°C	ε	Frequency (MHz) 10⁻²	10⁻¹	1	10	50	100	200	500	1000	2450	3000	5000	10,000	Ref.	Remarks
ALBUMIN,	Bovine serum	10	ε′		90	83	80.5		79			77.5					1,17	Aqueous solution 80 g/ℓ
			ε″															
		25	ε′	85	85	77	74.5		73.5			72.5						
			ε″															
		23	ε′													1.57-1.75	3	Powder, hydration 0-12%
			ε″													0.02-0.08		
BACTERIA,	E. coli B.	37	ε′	995	600	400	170		50								16,35	in 0.25% sodium chloride
			ε″		3x10⁴	3600	420		63									
		37	ε′		700	500	250		60									in 0.5% sodium chloride
			ε″		8x10⁴	8000	970		130									
	E. coli Cℓ	25	ε′			800	230	80	65	55							7	Effective values
			ε″			900	360	110	59	31								
	Micrococcus	25	ε′			410	340	170	100	80							7	Effective values
			ε″			3600	350	170	110	63								
	M. Lysodeikticus	25	ε′			220	180	120	95	80							8	
			ε″			3200	350	110	65	35								
BLOOD,	"Canine (frozen)"	-10	ε′	450	110	20	10										45	Data given also for -32, -86, -190°C
			ε″															
		-17	ε′	400	45	10.5	8											
			ε″															
	Hemoglobin 15% conc.		ε′						65.5	64.7	64	63*					35	*900 MHz
			ε″															
	Hemoglobin 0-15% conc.	23.6	ε′										60-70*				18	*2 GHz, linear relation ε′ vs Hb conc.
			ε″															
	Hemoglobin 22% conc.	25	ε′				70	65	63.5	63	61.5	60.5					33	Data given for various temp. and conc.
			ε″															
	Human, whole	15	ε′											59.9		42.4*	12	*9.4 GHz; cell conc. 4.9x10⁶/mm³
			ε″											19.9		26.7*		
		25	ε′											57.5		45.5*		
			ε″											17.1		23*		
		35	ε′											56		47.8*		
			ε″											15.9		19.7*		
	Human, serum	23	ε′						69-81	65-73	67-70						52	
			ε″						204-229	94-106	48-51							
	Rabbit	23	ε′	2310	2740	2040	200										37	
			ε″	1.3x10⁶	1.3x10⁵	1.3x10⁴	1000											
BLOOD,	Rat	23	ε′						86	70	63	62	62	62	61	48	5	
			ε″						180	90	35	28	18	19	22.5	33.5		
	whole		ε′					88	75	65	52.9	58	56	55	52	45	41	
			ε″						200	110	46	25.7	15.5	15.5	16.5	22		
BLOOD CELLS,	Red, Bovine	25	ε′					70	56	50							32	
			ε″					150	77	42								
	Red, Human	25	ε′					76.5	60	58							32	
			ε″					173	90	50								
	Red, Sheep	25	ε′			1800	360	75	60	50							6	
			ε″			350	540	180	90	45								
BONE,	Human, in-vitro	21	ε′	7.7	7.0												25	39.8 mg H_2O/g bone
			ε″	0.4	0.2													
		21	ε′	9.1	8.0													52.8 mg H_2O/g bone
			ε″	1.1	0.5													

	Human, mid-tibia	37	ε′											8.35			34	
			ε″											1.32				
	Marrow, in-vitro	37	ε′					6.8-7.7				4.3-7.3		4.2-5.8		4.4-5.4*	35	*8.5 GHz
BRAIN,			ε″					7.2-13				0.8-1.8		0.7-1.35		0.35-1.0*		
	in-vitro	37	ε′					110-114	81-83								35,38	
			ε″					170-190	92-100	129-190								
	Canine, grey matter	22-25**	ε′				300	120	75				50*			40	14	*2 GHz; Equations
			ε″															

	Sheep		ε′			7.7	7.0										52.8 mg H₂O/g bone
BONE,	Human, in-vitro	21	ε′			0.4	0.2										
			ε″			9.1	8.0										
		21	ε′			1.1	0.5										
	Human, mid-tibia	37	ε′											8.35		34	
			ε″											1.32			
	Marrow, in-vitro	37	ε′					6.8-7.7				4.3-7.3		4.2-5.8	4.4-5.4*	35	*8.5 GHz
			ε″					7.2-13				0.8-1.8		0.7-1.35	0.35-1.0*		
BRAIN,		37	ε′					110-114	81-83							35,38	
	in-vitro		ε″					170-190	92-100	129-190							
	Canine, grey matter	22-25**	ε′				300	120	75				50*		40	14	*2 GHz; Equations
			ε″				540	180	105				11*		20		for average per-
		37	ε′				370	150	90			46	49*		39		mittivity between
			ε″				680	210	125			18	12*		17		0.01 and 10 GHz given.
	Canine, white matter	22-25**	ε′				170	75	59				37*		28		**Data below 0.1 GHz
			ε″				400	120	70				8.5*		12.4		at 22°C, above
		37	ε′				200	90	68				37*		30		0.1 GHz
			ε″				505	145	85				8.7*		11.1		at 25°C
	Human, in-vitro	37	ε′										32	33	33*	24	*4 GHz
			ε″										15.5	18	15.8*		
	Human, minced	23	ε′													35	
			ε″			2.6x10³	450	135	69								
	Rat, in vivo	32	ε′						84	69	57.5	55	52.5	52.5	53	42	5
			ε″						145	90	35	21.5	14	13.7	16	18	
	Rat, synaptosomes	25	ε′			185	150	90	75	62						21	0.38 volume fraction
			ε″			9.5x10³	990	230	125	67							in susp. medium
EYE,	Bovine, lens.	32	ε′			100	60	50	40	30						31	Central part
			ε″			3.2x10³	340	150	74	43							
		32	ε′			580	179	77	66	57							Cortical part
			ε″			9.3x10³	1.1x10³	250	130	69							
		32	ε′			200	100	70	60	48							Intermediate part
			ε″			6.1x10³	680	77	40	26							
	Lens		ε′						46	42	36	32	30	30	28	36	
			ε″						72	35	15	9.5	8.0	9.0	10.0	18	
	Vitrous humor		ε′						70	70	70	70	70	70	68	62	36
			ε″						300	150	65	36	20.5	18	20	32	
FAT,	Canine in-situ	37	ε′	2x10⁴												35	
			ε″	5.5x10⁴	6x10³												
	Canine in-vivo	37	ε′				47.5	15.5	14.5	14.2	14.5	14.3	12			5	
			ε″				380	70	38	20	8.6	6.7	5.1				
	Human, in-vitro	37	ε′	2x10³				11-13	8-13	4.5-7.5	4-7	5.3-7.5	5.75	3.9-7.2	4.7	3.5-4.5*	36,35,38 *8.5 GHz
			ε″					14-21	12	2.6-8.6	2.2	1.5-2.7	0.8	0.67-1.36	0.7	0.57-0.88*	43,47
	Human, abdominal wall	37	ε′											4.92		34	
			ε″											1.46			
	Human, breast	37	ε′											3.94		34	
			ε″											0.87			
	Human, faecal fistula	37	ε′											7.0		34	
			ε″											1.75			
G-ACTIN,	Water solution 3.3g/ℓ	4	ε′	91	90.5	88.6										27	Data on pH effect given
			ε″	0.1	0.5	1.65											
HEART,	Human, minced	23	ε′													35	
			ε″			8.6x10³	1.05x10³	215	110								
INSECTS,	Flour beetle	24	ε′					7.8								29	*40 MHz, bulk insects
			ε″					2.2									
	Rice Weevil	24	ε′	14.3	11.8	11.6	8.8		6.2			4.2		41	4.0	28	
			ε″	0.42	0.42	1.4	2.2		2.0			0.42		0.4	0.4		
KIDNEY,	Canine, in-vitro		ε′						80	66.5	55	49.5	47.5	47	43	34	5
			ε″						120	75	25	14.4	13.2	12	14	18	
	Canine in-vivo	37	ε′						78.5	67	57	53	50	49			
			ε″						140	59	30	21.5	20	18			

	Material	T°C	ε	Frequency (MHz) 10⁻²	10⁻¹	1	10	50	100	200	500	1000	2450	3000	5000	10,000	Ref.	Remarks
	Canine, saline-perfused	10	ε′					100	78	72	60	59					15	
			ε″					180	100	56	32	18						
	Canine, DMSO-perfused	10	ε′				110	80	58	56	55.5	55						
			ε″				505	110	55	34	22	12.5						
KIDNEY,	Human, in-vitro	37	ε′					119-132	87-92	62	51-54						35	
			ε″					250-400		100								
LIVER,	Canine, in-situ	37	ε′	5x10⁴													35	
			ε″	1.9x10⁵														
	Human, in-vitro	23	ε′			6x10³	865	190	95								35	
			ε″															
		37	ε′	5x10⁴	7-12x10³	1.2-2x10³		88-93	76-79	50-56	43-51	46-47		42-43		34-38*	35,38	*8.5 GHz
			ε″	2x10⁵	3-8x10⁴	4-8.5x10³	700-1000	185-208	100-117	60-82		17-18.4		12-12.2		10.6-12*	43	
	Rat in-vitro	37	ε′				240	100	75								4	
			ε″			5x10³	780	190	110									
LUNG,	Human, in-vitro	23	ε′														35	
			ε″			1.18x10⁴	1.6x10³	360	190									
		37	ε′	3x10⁴						35	35	35					35,43	
			ε″		0.9-1.1x10⁴	1-1.2x10⁴	1.2-1.6x10³	80-140		56	26							
MUSCLE,	in-vitro	25	ε′						72	61	57	55	50.5	50	42	40	42	
			ε″						180	90	36	20	12	12	14	22		
	Barnacle fibers in-vitro	25	ε′				220	105	88			67	60	58	52.5	42.5	53	Data given also for 1°C
			ε″				2430	500	260			39			26.5	27.5		
		37	ε′				300	100	88			66.6	58.5	57	53	44		
			ε″				2500	630	306			43	31	28.7	24	26		
	Canine, in-vivo	34	ε′				223	75	66.5	53	48	47	45				5,49	
			ε″				1.2x10³	300	155	90	35	20	11					
	Frog, in-vitro	25	ε′	9x10⁴	3x10⁴												35	
			ε″															
	Heart, in-vitro	37	ε′							59-63	52-56						35,43	
			ε″							78-94								
	Human, minced	23	ε′														35	
			ε″			1.03x10⁴	1.15x10³	245	120									
	Human, in-vitro	37	ε′	5-9x10⁴	2-3x10⁴	2x10⁴		85-97	71-76	56	52-54	49-52	47.5	45-48	44	40-42*	35,36,43	*8.5 GHz
			ε″	2x10⁵	7.2-10x10⁴	8.6-11x10³	1060-1200	245-320		86-95	41	23-24	13.5	13-14	14	15*	47,48	
	Human, Pectoralis major	37	ε′											50.0			34	
			ε″											17.1				
	Human, Soleus	37	ε′											51.0			34	
			ε″											18.0				
	Rat, in-vivo	31	ε′						80	70.5	63	61	58	56	53	41	5	
			ε″						180	100	40	23.5	17.5	17.3	19.2	23		
PEPTIDES,	Triglycine M/4 H_2O Solution	20	ε′			108		107	108.6	105.5	95	84.7					22	Other temperatures data given
			ε″					3.8	4.9	10.5	16.7	18.3						
		40	ε′			99		99	100	98.3	92	84.5						
			ε″					1.9	3.1	6.8	12.7	16.4						
SKIN,	Goat, Collagen preparation	25	ε′	7.65	7.25												26	Other temperature data given
			ε″	0.23	0.43													
		40	ε′	7.84	7.42													
			ε″	0.21	0.39													
	Human, in-vitro	37	ε′						65	57	46.5	43-46	43	40-45	40.7	36*	35,47	*8.5 GHz
			ε″						130-150	72	26.5	16.4-20	14	12-16	14	15*		

	Human, breast	37	ε′											40.0			34	
			ε″											12.3				
	Human, faecal fistula	37	ε′											51.1			34	
			ε″											15.2				
	Human, sole of foot	37	ε′											42.4			34	
			ε″											13.1				
	Stratum		ε′	1100	1005	450												

	Human, breast	37	ϵ'							40.0		34			
			ϵ''							12.3					
	Human, faecal fistula	37	ϵ'							51.1		34			
			ϵ''							15.2					
	Human, sole of foot	37	ϵ'							42.4		34			
			ϵ''							13.1					
	Stratum corneum		ϵ'	1100	1005	450						51			
			ϵ''	220	160	360									
SPLEEN,	Human, minced	23	ϵ'									35			
			ϵ''			6.8×10^3	1100	270	140						
	in-vitro	37	ϵ'					135-140	100-101			35			
			ϵ''					240-280							
TENDON,	Bovine, in-vitro	25	ϵ'	6.7	6.2							23	10.9% water content		
			ϵ''	0.02	0.005										
		25	ϵ'	7.8	6.4								16.9% water content		
			ϵ''	0.04	0.03										
YEAST,	Cell suspension	15	ϵ'	950	815	250						46	Volume fraction 0.34		
			ϵ''												
	Kell preparation		ϵ'	0.23	0.49										
		40	ϵ''	0.71	0.39										
	Human, in-vitro	37	ϵ'				65	57	40.5	43 46	43	40-45	40.7	36'	35,47 *18.3 GHz
			ϵ''				130-150	72	26.5	16.4-20	14	12-16	14	15*	

Tissue Phantom Materials

Tissue	f(MHz)	T(°C)	Permittivity ϵ'	Permittivity ϵ''	REF.	Composition
Bone and Fat	30		19	16.8	2	79% Laminac 4110, 20.72% Aℓ powder, 0.28% Acetylene Black, 3.5 cm^3/kg. MEK Peroxide
(Phantom)	915	22	5.6	1.3	13,20	85.2% Laminac 4110, 14.5% Aℓ powder
	2450	22	4.5	0.84		0.24% Acetylene Black, 3.75 g/kg MEK Peroxide
	8,500	20	3.8-6	0.3-1.3	9	Laminac 4110, Aℓ powder, Acetylene Black;
	10,000	20	3.8-5.7	0.3-1.3		several different examples and equations given
Brain	915	22	34.4	15.2	13,20	62.61% H_2O, 0.5823% NaCℓ, 29.8% Polyethylene powder, 7.01% super stuff
(Phantom)	2450	22	33.6	9.1		
	2450	22	42	19	30	59% H_2O, 1% NaCℓ, 40% gelatine
Muscle	10	22	65.8	2.1×10^3	49	75.5% H_2O, 0.9% NaCℓ, 15.2% Polyethylene powder,
(Phantom)	50	22	44.1	430		8.4% super stuff
	100	22	44.8	215		
	30		110	390	2	76.57% H_2O, 0.153% NaCℓ, 13.78% Aℓ powder 9.495% super stuff
	915	22	50.6	26.6	13,20	75.44% H_2O, 0.907% NaCℓ, 15.2% Polyethylene
	2450	22	49.6	16.5		powder, 8.45% super stuff
	2450	22	50	16	30	69% H_2O, 30 gelatine, 1% NaCℓ
	8,500	20	34-48	9.5-15	9	H_2O, NaCℓ, Polyethylene and super stuff;
	10,000	20	30-45	10-15		several different examples and equations given
Skin (Phantom)	2450	22	43		30	60% H_2O, 1% NaCℓ, 39% cellulose paper

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