43. EXPOSURE TO NOISE: MAMMALS AND ROACHES

	Animal	Specification	Effect	Reference
10	Man	Nonauditory effects	Respiratory symptoms observed in low-frequency exposures of 60 cycles/sec at 154 db, and 73 cycles/sec at 150 db	12
11			Lung damage at 6 lb/in.^{2} assuming pressure reflection, and at 15 lb/in.^{2} assuming no pressure reflection (based on human accident and animal data)	16
12	Cat	Noise-induced TTS	Cat is more susceptible than man to TTS; exposure must be 18 db greater in energy for man than for cat for approx the same TTS	10
13		Noise-induced PTS	Continuous uninterrupted exposure to 115 db OASPL of broadband noise: Exposure Duration / *Mean Persistent Threshold Shift: 15 min 5.6 db; 30 min 8.5 db; 2 hr 35.0 db; 8 hr 40.6 db. *TTS persisted over several weeks; permanent injury inferred	10
14	Dog, guinea pig	Noise-induced PTS	Injury to organ of Corti, increasing with exposure intensity and duration; at high exposure levels, injury to tympanic membrane and ossicular chain; exposure was to discrete frequencies of 500-100,000 cycles/sec at levels of 115-165 db	4
15	Mouse	Nonauditory effects	Audiogenic seizures in Swiss albino mice at exposures of 110 db in 10,000 cycles/sec sound field	2
16	Mouse, rat	Nonauditory effects	Effects on behavior, blood chemistry, weight of adrenals and other organs: Following continuous exposure to 110 db at 10-20 kcycles/sec, 139 db at 300-4800 cycles/sec, or 140 db at 500-4800 cycles/sec	3
17			After single bursts of 132 db at 2-40 kcycles/sec, or 139 db at 300-4800 cycles/sec	3
18			Death by overheating from absorbed sound energy, 1000-22,000 cycles/sec	5,14
19	Rabbit	Nonauditory effects	Effects on EEG and evoked potentials at exposure to continuous 1000 cycles/sec tone, 100-130 db	11
20	Roach	Nonauditory effects	Death upon exposure to sound fields of 160 db at frequencies near 25,000 cycles/sec	8

Contributors: Nixon, Charles W., and von Gierke, H. E.

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44. PHYSICAL ACOUSTIC PROPERTIES: MAMMALIAN TISSUES

Physical acoustic properties of various tissues can be employed for the determination of certain effects accompanying sound wave propagation, such as the fraction of incident energy reflected at an interface, and the time rate of heat production per unit volume resulting from absorption [5].

	Tissue	Temperature °C	Frequency megacycles	Property	Value	Reference
1	Skull bone of man	(15-25)?	0.6	Amplitude absorption coefficient, cm^{-1}	0.4	7-9
2			0.8	Amplitude absorption coefficient, cm^{-1}	0.9	
3			1.2	Amplitude absorption coefficient, cm^{-1}	1.7	
4			1.6	Amplitude absorption coefficient, cm^{-1}	3.2	
5			1.8	Amplitude absorption coefficient, cm^{-1}	4.2	
6			2.25	Amplitude absorption coefficient, cm^{-1}	5.3	
7			3.5	Amplitude absorption coefficient, cm^{-1}	7.8	
8		37	1.0	Density, g/cm^3	1.7	7,8,10
9				Sound speed, cm/sec	3.36	
10				Acoustic impedance, g/cm^2 sec	6.0	
11				Heat capacity, cal/g °C	0.3	

continued

44. PHYSICAL ACOUSTIC PROPERTIES: MAMMALIAN TISSUES

	Tissue	Temperature °C	Frequency megacycles	Property	Value	Reference
12	Fat	37	1.0	Density, g/cm³	0.97	2,7,8
13				Sound speed, cm/sec	1.44	
14				Acoustic impedance, g/cm² sec	1.40	
15				Amplitude absorption coefficient[1], cm⁻¹	0.05	
16				Heat capacity, cal/g °C	0.71	
17	Skeletal muscle	37	1.0	Density, g/cm³	1.07	8
18				Sound speed, cm/sec	1.57	
19				Acoustic impedance, g/cm² sec	1.68	
20				Amplitude absorption coefficient[1,2], cm⁻¹	0.13	
21				Heat capacity, cal/g °C	0.82	
22	Central nervous system of cat and rat	37	1.0	Density, g/cm³	1.03	1,6
23				Sound speed, cm/sec	1.51	
24				Acoustic impedance, g/cm² sec	1.56	
25				Amplitude absorption coefficient[1,3], cm⁻¹	0.11	
26	Young mouse (24 hr after birth)	2	1.0	Amplitude absorption coefficient[1,4], cm⁻¹	0.02	3,4
27				Heat capacity, cal/g °C	0.81	
28		10	1.0	Amplitude absorption coefficient[1,4], cm⁻¹	0.05	3,4
29				Heat capacity, cal/g °C	0.81	
30		28	1.0	Amplitude absorption coefficient[1,4], cm⁻¹	0.10	3,4
31				Heat capacity, cal/g °C	0.81	
32		40	1.0	Amplitude absorption coefficient[1,4], cm⁻¹	0.11	4
33				Heat capacity, cal/g °C	0.81	
34		45	1.0	Amplitude absorption coefficient[1,4], cm⁻¹	0.12	4
35				Heat capacity, cal/g °C	0.81	

[1] Absorption coefficient value is proportional to frequency. [2] Absorption coefficient varies with direction of sound propagation relative to fiber orientation. [3] In the cat, the absorption coefficient for white matter is five-ninths that of gray matter. [4] Absorption coefficient is independent of acoustic intensity to at least 200 w/cm².

Contributors: Dunn, Floyd, and Fry, William J.

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45. TISSUE CHANGES IN CENTRAL NERVOUS SYSTEM AFTER EXPOSURE TO ULTRASOUND: CAT

Ultrasound has not been studied as a naturally occurring phenomenon (except for low-frequency, low-intensity emanations of animal origin [3]). Information has been obtained in laboratory environments and almost entirely in animal rather than human experiments. The most comprehensive investigations, with detailed histological studies, have been made on the central nervous system of the cat [7]. (For information on ultrasonic effects on the mouse, consult references 1,4-6,9, and 15; on the frog, references 11 and 12.) The human brain has been modified at localized sites by intense ultrasound, but there has been insufficient material for extensive histological study [10]. However, the dosage conditions employed to induce functional change, and the histological results available, indicate that the effects on the human brain are the same as those observed in the cat. Precisely placed ultrasonic lesions have been produced in a number of deep brain structures in man for treatment and relief of the signs and sensations associated with hyperkinetic, hypertonic, and intractable pain disorders [10,13,18].

High-intensity ultrasound produces physiological changes which are observable immediately [4,6-9], but the effects on tissue structure, at dosages which produce selective irreversible changes, occur at submicroscopic sites [2] and cannot be seen in stained tissue sections until after a time interval of minutes to an hour after exposure. (Acoustically induced cavitation has been eliminated as a primary factor in the development of irreversible changes, by producing lesions as well as motor deficits under a hydrostatic pressure sufficiently great to prevent tension forces from occurring in tissue [12,16,19].) The fact that physiological changes are evident immediately after exposure, but that histological changes do not begin to appear until later, has led to investigations of the possible interaction of intense noncavitating ultrasound and biologically important molecular species in solution. DNA has been shown to

continued

be degraded, principally as backbone scission [14], and enzymatic activity of specific proteins has been found to be reduced [17]. **Changes in Tissue Components**--The following semiquantitative designations apply to the populations of nerve-cell bodies (cytoplasm, membrane, and nucleus) and glia (microglia cells, astrocytes, and oligodendrocytes): very few = 1/10 or less; few = approximately 1/4; some = approximately 1/2; many = approximately 3/4; most = 9/10 or more.

Contributors: Dunn, Floyd, and Fry, William J.

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Part I. SMALL LESIONS IN WHITE MATTER

Data summarize irreversible changes produced in white matter of the central nervous system of 12 cats after single exposure to ultrasound at a frequency of 1 megacycle [2,3]. Ultrasonic exposure conditions: acoustic pressure amplitude, 46-50 atm; acoustic particle velocity, 410-460 cm/sec; exposure duration, 1.0-2.0 sec.

	Time after Exposure	Changes in Tissue Components				
		Light Lesion	Medium Lesion		Heavy Lesion	
			Island	Moat	Island	Moat
		Axis Cylinder of Nerve Fiber				
1	10-15 min	Normal	Normal		Normal	Normal
2	1 hr	Normal	Normal		Normal	Few remain; many spheres; much debris
3	2 hr	Some normal; some fragments; some spheres	Normal		Some slightly swollen; few retraction balls & spheres at border	Few normal; some fragments; many spheres
4	6 hr	Many short fragments; many spheres; some retraction bulbs	Normal	Few fragments; many spheres; much debris		
5	12 hr		Many normal; some bulbous	Few fragments; many spheres	Some normal; some swollen; many spheres & refraction balls at border	Few bulbous; many spheres; much debris
6	1 day	Many tortuous fragments with swelling; many spheres	Many normal; some swollen & bulbous; retraction balls at border	Many spheres; much debris	Many swollen; many spheres & retraction balls at border	Few fragments; many spheres; much debris
7	2 days	Few fragments; many spheres; retraction bulbs at border	All fibers slightly swollen; few bulbs & spheres; many retraction balls at border	None left; many broken spheres; much debris	Many swollen; few spheres & bulbs; many retraction balls & spheres at border	Few fragments; many broken spheres; much debris

continued

45. TISSUE CHANGES IN CENTRAL NERVOUS SYSTEM AFTER EXPOSURE TO ULTRASOUND: CAT

Part I. SMALL LESIONS IN WHITE MATTER

	Time after Exposure	Changes in Tissue Components				
		Light Lesion	Medium Lesion		Heavy Lesion	
			Island	Moat	Island	Moat
	Axis Cylinder of Nerve Fiber					
8	4 days		All fragmented; many bulbs & spheres; many retraction balls	Few fragments; many broken spheres; much debris	All swollen; some bulbs; many spheres at border	Very few fragments; some spheres; much debris
9	12 days	Absent				
	Myelin Sheath of Nerve Fiber					
10	10-15 min	Normal			Some swollen	Swollen
11	1 hr	Normal			Some swollen	Some bulbs; some fragments; many spheres
12	2 hr	Many nodal & bulbous; many spheres			Many nodal & bulbous	Few bulbous; few fragments; many spheres
13	6 hr	Few bulbous fragments; many spheres	Some normal; some nodal	Few bulbous fragments; many spheres		
14	12 hr		Many nodal; some spheres	Few bulbous fragments; many spheres	Many nodal & bulbous	Few bulbous fragments; many spheres
15	1 day	All nodal; many spheres	Many nodal & bulbous; some spheres	Few bulbous fragments; many spheres	All nodal & bulbous; few spheres	Few bulbous fragments; many spheres
16	2 days	Some nodal & bulbous fragments; many spheres	Many nodal & bulbous; some spheres	Very few bulbous fragments; many spheres	All nodal & bulbous; some spheres	Few bulbous fragments; many spheres
17	4 days		All nodal & bulbous; many spheres	Very few bulbous fragments; many spheres	All nodal & bulbous; some spheres	Very few fragments; many spheres
18	12 days	Few swollen & bulbous fragments				
	Microglia Cells					
19	10-15 min	Normal			Normal	Normal
20	1 hr	Normal			Normal	Normal
21	2 hr	Normal			Normal	Some gone
22	6 hr	Normal	Normal	Some gone; few pale; very few fragmented		
23	12 hr		Some gone; very few fragmented	Some gone; few fragmented	Some gone; some swollen & fragmented	Many gone; few fragmented
24	1 day	Some gone; rest enlarged	Some gone; some enlarged	Most gone; rest swollen & fragmented	Some gone; some normal	Absent
25	2 days	Double normal population; few gitter cells	Slight population increase; all normal	Double population; few gitter cells	Double population; no gitter cells	Double population; few enlarged
26	4 days		Huge population increase	Huge population increase; many gitter cells	Many gone	Many gone
27	12 days	Huge population increase; many gitter cells				
	Astrocytes					
28	10-15 min	Normal			Few pale	Few nuclei pale stain; few nuclear membranes broken
29	1 hr	Some gone; some swollen & fragmented			Few slightly pale nuclei	Some gone; few pale & broken nuclei; few normal
30	2 hr	Some gone; some broken membranes			Few gone; few pale & broken	Some gone; some pale & broken; few normal

continued

45. TISSUE CHANGES IN CENTRAL NERVOUS SYSTEM AFTER EXPOSURE TO ULTRASOUND: CAT

Part I. SMALL LESIONS IN WHITE MATTER

	Time after Exposure	Changes in Tissue Components				
		Light Lesion	Medium Lesion		Heavy Lesion	
			Island	Moat	Island	Moat
		Astrocytes				
31	6 hr	Some gone; few swollen & pale	Normal	Some gone; some dark stain cytoplasm		
32	12 hr		Few gone; few pale	Many gone; few pale; few fragmented	Few gone; most swollen & fragmented	Many gone; remainder swollen & fragmented
33	1 day	Many gone; rest swollen & fragmented	Many gone; rest swollen & fragmented	Many gone; few swollen	Some gone; some swollen & fragmented	Absent
34	2 days	Many gone; rest normal	Many gone; rest normal	Some gone; few normal; few swollen & fragmented	Some gone; few normal	Many gone; few normal
35	4 days		Many gone; few enlarged; few swollen & fragmented	Many gone; few enlarged; few swollen & fragmented	Many pale; few swollen & fragmented	Many gone; few enlarged
36	12 days	Few present, close to blood vessels				
		Oligodendrocytes				
37	10-15 min				Few pale	Few swollen & fragmented; few pale
38	1 hr	Few gone; few swollen & fragmented			Few swollen; few gone; few pale	Some gone; few swollen & fragmented
39	2 hr	Few gone; few swollen & fragmented			Few gone; few swollen & fragmented	Some gone; rest swollen & fragmented
40	6 hr	Some gone; some swollen & pale; irregular shape	Normal	Many gone; few pale & broken		
41	12 hr		Many gone; rest swollen & fragmented	Many gone; rest swollen & fragmented	Some gone; rest swollen & fragmented	Many gone; rest swollen & fragmented
42	1 day	Most gone; rest swollen & fragmented	Many gone; rest swollen & fragmented	Many gone; rest swollen & fragmented	Many gone; rest swollen & fragmented	Many gone; rest swollen & fragmented
43	2 days	Most gone; rest swollen & fragmented	Many gone; few normal; few swollen & fragmented	Most gone; very few normal	Most gone; few normal	Most gone; few normal
44	4 days		Most gone; rest swollen & fragmented	Most gone; rest swollen & fragmented	Most gone; rest swollen & fragmented	Most gone; few normal
45	12 days	Absent				
		Matrix				
46	10-15 min	Normal			Normal	Slightly pale stain
47	1 hr	Slightly pale stain; few holes			Slightly pale stain	Pale stain; many holes; few clefts
48	2 hr	Pale stain; some holes; few clefts; tendency to island formation			Slightly pale stain; few holes	Pale stain; many holes; few clefts
49	6 hr	Pale stain, few holes	Normal stain; some holes	Pale stain; many holes; many clefts		
50	12 hr		Slightly pale stain; many holes	Pale stain; many holes; few clefts	Slightly pale stain; few holes	Pale stain; many holes; many clefts
51	1 day	Pale stain; many holes; few clefts	Slightly pale stain; some holes	Pale stain; many holes; many clefts	Normal stain; some holes	Pale stain; many holes; some clefts
52	2 days	Pale stain; many holes; few clefts	Slightly pale stain; few holes	Very pale stain; many clefts	Slightly pale stain; few holes	Pale stain; many holes; many clefts
53	4 days		Slightly pale stain; many holes	Pale stain; many holes; some clefts	Slightly pale stain; few holes	Pale stain; many holes; many clefts
54	12 days	Pale stain; many holes				

continued

45. TISSUE CHANGES IN CENTRAL NERVOUS SYSTEM AFTER EXPOSURE TO ULTRASOUND: CAT

Part I. SMALL LESIONS IN WHITE MATTER

	Time after Exposure	Changes in Tissue Components				
		Light Lesion	Medium Lesion		Heavy Lesion	
			Island	Moat	Island	Moat
		Vascular Cuffing[1]				
55	10-15 min	None			None	
56	1 hr	None			None	
57	2 hr	None			None	
58	6 hr	None	None			
59	12 hr		None		Slight perivascular cuffing	
60	1 day	Some perivascular cuffing	Some perivascular cuffing		Slight perivascular cuffing	
61	2 days	Heavy perivascular cuffing	Heavy perivascular cuffing		Some perivascular cuffing	
62	4 days		Heavy perivascular cuffing		Heavy perivascular cuffing	
63	12 days	Residual cuffing				

[1] There is a breakdown of the blood-brain barrier within lesions produced by ultrasound at dosages which leave the vascular system uninterrupted. Trypan blue passes the barrier at the site of lesion if injected soon after ultrasonic exposure, but it does not stain the lesion region if injected later than 72 hours [1].

Contributors: Dunn, Floyd, and Fry, William J.

References: [1] Bakay, L., et al. 1956. Arch. Neurol. Psychiat. 76:457. [2] Barnard, J. W., et al. 1956. Ibid. 75:15. [3] Fry, W. J. 1958. Advan. Biol. Med. Phys. 6:281.

Part II. SMALL LESIONS IN GRAY MATTER

Data summarize the irreversible changes produced in gray matter of the central nervous system of 14 cats exposed to ultrasound at a frequency of 1 megacycle [2,3]. Ultrasonic exposure conditions: acoustic pressure amplitude, 45-50 atm; acoustic particle velocity, 420-470 cm/sec; exposure duration, 1.5-3.0 sec.

	Time after Exposure	Changes in Tissue Components		
		Mild Lesion	Moderate Lesion	Severe Lesion
		Cytoplasm of Nerve Cell		
1	10-15 min	Normal	Some cells hyperchromatic; remainder normal	Some cells swollen with fewer Nissl granules; some cells hyperchromatic & shrunken; a few normal cells
2	1 hr	Normal		All cells Nissl diminished; some cells have vacuoles & are swollen; some have only shredded cytoplasm around nucleus
3	2 hr	Normal	All cells Nissl diminished; many have vacuoles; some pale ghosts	All cells no Nissl; some pale ghosts; some only shredded cytoplasm around nucleus
4	6 hr	No cell loss; many cells have pale cytoplasm, Nissl diminished	All cells Nissl diminished; many have vacuoles	Only few ghost cells left
5	12 hr			Only very few ghost cells left
6	1 day	Some cells lost; remainder have vacuoles & no Nissl.	All cells have no Nissl; many cells gone	Absent
7	2 days			Absent
8	4 & 12 days	Absent	Absent	Absent
		Membrane of Nerve Cell		
9	10-15 min	Normal	Normal	Few ruptured
10	1 hr	Normal		Some normal; some scalloped; some ruptured
11	2 hr	Normal	Few ruptured	Absent

continued

45. TISSUE CHANGES IN CENTRAL NERVOUS SYSTEM AFTER EXPOSURE TO ULTRASOUND: CAT

Part II. SMALL LESIONS IN GRAY MATTER

Time after Exposure	Changes in Tissue Components		
	Mild Lesion	Moderate Lesion	Severe Lesion
	Membrane of Nerve Cell		
6 hr	Few normal; many scalloped; some ruptured	Many ruptured	Absent
12 hr			Absent
1 day	All indistinct or absent	All indistinct or absent	Absent
2 days			Absent
4 & 12 days	Absent	Absent	Absent
	Nucleus of Nerve Cell		
10-15 min	Normal	Normal	Some nucleoli pale
1 hr	Normal		Many pale nucleoli; nuclear membranes normal
2 hr	Normal	Nucleoli pale or absent; all nuclear membranes sharp	Nucleoli pale or absent; all nuclear membranes sharp
6 hr	All hyperchromatic with indistinct nucleoli; all nuclear membranes sharp	Nucleoli pale or absent; all nuclear membranes sharp	Nucleoli pale or absent; all nuclear membranes sharp but pale
12 hr			Very few nuclei left; no nucleoli
1 day	Few pale nuclei left; nucleoli pale or absent; nuclear membrane sharp	Few pale nuclei left; nucleoli pale or absent; most nuclear membranes indistinct	Very few nuclei left
2 days			Absent
4 & 12 days	Absent	Absent	Absent
	Axis Cylinder of Nerve Fiber		
10-15 min	Normal	Many stain spottily; some gone	Many gone; remainder stain spottily & are bulbous
1 hr	Normal		Few remain; fragmented & bulbous
2 hr	Normal	Few bulbous remain	Absent
6 hr	Only few bulbous remain	Absent	Absent
12 hr		Absent	Absent
1, 2, 4, & 12 days	Absent	Absent	Absent
	Myelin Sheath of Nerve Fiber		
10-15 min	Normal	Many normal; some bulbous	Many swollen & bulbous; few spheres
1 hr	Normal		All bulbous & swollen
2 hr	Normal	Few remain; all bulbous; some spheres	No sheaths; few spheres
6 hr	Few remain; all bulbous; some spheres	Few remain; all bulbous; few spheres	Few spheres
12 hr			Few spheres
1 day	No sheaths; few spheres	No sheaths, few spheres	Absent
2, 4, & 12 days	Absent	Absent	Absent
	Microglia Cells		
10-15 min	Normal	Normal	Normal
1 hr	Normal		Few pale
2 hr	Normal	Few gone; few pale	Some gone; rest pale
6 hr	Few gone; few pale	Many gone; few pale	Most gone
12 hr			Absent
1 day	Slight population increase (macrophagic stage)	Some in early macrophagic stage; most gone	Few in early machrophagic stage
2 days			Few gitter cells
4 days	Huge population gitter cells		
14 days		Huge population gitter cells	Huge population gitter cells
	Astrocytes		
10-15 min	Normal	Normal	Some pale
1 hr	Normal		Some gone; some pale; very few fragmented
2 hr	Normal	Some gone; few pale & fragmented	Some gone; rest swollen & fragmented

continued

45. TISSUE CHANGES IN CENTRAL NERVOUS SYSTEM AFTER EXPOSURE TO ULTRASOUND: CAT

Part II. SMALL LESIONS IN GRAY MATTER

	Time after Exposure	Changes in Tissue Components		
		Mild Lesion	Moderate Lesion	Severe Lesion
		Astrocytes		
50	6 hr	Many gone; few swollen & fragmented	Many gone; few swollen & fragmented	Most gone; rest swollen & fra
51	12 hr			Absent
52	1 day	Many gone	Absent	Absent
53	2 days			Absent
54	4 days	Moderate increase above normal		
55	12 days		Numerous	Numerous
		Oligodendrocytes		
56	10-15 min	Normal	Normal	Some pale
57	1 hr	Normal		Few gone; few swollen & frag
58	2 hr	Normal	Some gone; few swollen & fragmented	Some gone; rest swollen & fra mented
59	6 hr	Some gone; few swollen & fragmented	Some gone; few swollen & fragmented	Many gone; rest swollen & fra mented
60	12 hr			Many gone; rest swollen & fra mented
61	1 day	Most gone; rest swollen & fragmented	Most gone; rest swollen & fragmented	Most gone; rest swollen & fra mented
62	2 days			Absent
63	4 days	Most gone		Absent
64	12 days		Absent	Absent
		Matrix		
65	10-15 min	Normal	Pale stained	Pale stained
66	1 hr	Normal		Pale stained; some holes; sm perineuronal spaces
67	2 hr	Normal	Pale stained; some holes; some small perineuronal spaces	Pale stained; clefts
68	6 hr	Pale stained; medium perineuronal spaces	Pale stained; medium perineuronal spaces; some holes	Pale stained; clefts
69	12 hr			Pale stained; clefts
70	1 day	Pale stained; some holes; medium perineuronal spaces	Pale stained; some holes (large); large perineuronal spaces	Pale stained; clefts
71	2 days			Pale stained; clefts
72	4 days	Pale stained		
73	12 days		Pale stained	Pale stained
		Vascular Cuffing[1]		
74	10-15 min	None	None	None
75	1 hr	None		None
76	2 hr		None	None
77	6 hr	None	None	None
78	12 hr			None
79	1 day	Slight	Some	Some
80	2 days			Some
81	4 days	Much		
82	12 days		Residual	Residual

[1] There is a breakdown of the blood-brain barrier within lesions produced by ultrasound at dosages which le vascular system uninterrupted. Trypan blue passes the barrier at the site of lesion if injected soon after ul exposure, but it does not stain the lesion region if injected later than 72 hours [1].

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