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ORIGINAL PAPERS

BIOLOGICAL ACCOUNTS EMERGING FROM SOME KINDS OF ELECTROMAGNETIC WAVES IN THE ENVIRONMENT*

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Abstract. Industrial use of induction heaters generating electromagnetic energy of frequencies below 9 kHz makes an exposure of their operators to magnetic field H of high intensity and to electric field E of relatively low intensity. The operators of such heaters have suffered repeatedly from infections in the upper respiratory tract and in the skin of the forearm. The experimental exposure of rats to E or H fields of frequencies of 10 Hz, 50 Hz or 1–45 kHz induced changes in growth rate of exposed animals and weight changes in the pituitary-adrenal glands. These results support the suggestion about the involvement of the endocrine system in the biological reaction to incident electromagnetic fields of VLF and ELF.

INTRODUCTION

In Radio Regulations of International Telecommunication Union (ITU) of 1986 (9) frequencies below 9 kHz are not allocated for radiocommunication purposes. Till recently, there was practically no standard for electromagnetic (EM) fields below 9 kHz. Thus, it was an open way for development of industrial devices using frequencies below 9 kHz, mainly of various types of the induction heaters which may be the sources of electromagnetic contamination in environment.

Another environmental contamination with EM energy derives from facilities for special long-distance link. Such facilities use exremely low frequencies (ELF), e.g. 45 Hz to 76 Hz. Experimental exposure of animals, including Primates, to the fields of such frequencies indicate functional changes in the neural and endocrine regulatory systems (3).

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There also is possible, at least theoretically, that an emission of the time varying (pulsing) waves of 2–7 Hz is regestired which may influence the behaviour of the biological objects including man (7).

The above mentioned bands of EM frequencies are among emerging needs for medical and experimental studies, and for environmental monitoring of such unfavourable agents.

MATERIALS AND METHODS

I. Investigation into the occupational environment

With the meter MEH-1a equipped with dipol and frame probes (manufactured in Wroclaw Technical University, Poland) the intensity of E and H fields was measured on the work post at 30 induction heaters using frequencies from 2.4 kHz to 10 kHz. The selected results of periodic medical examinations within five years of 126 workers employed at these induction heaters and of 54 workers exmployed at other work places in the same factories were obtained from the industrial health registers in medical centers at these factories.

II. Experimental investigations

Immature or adult male and female Imp-DAK rats in groups of 10 animals were kept in plastic cages with perforated aluminium cover and were housed in standard conditions (12 hours light – 12 hours dark cycle, temperature 22 ± 2°C relative humidity 50–60%, murigran food and degased tap water). The animals were not accustomed to experimental environment because of chronic actual experimental procedure. However, there was always similar handling of control and exposed rats. Every day, the experimental and control rats in groups of 10, were moved to perforated plastic cages and the cages with experimental animals were placed in homogenous E or H field. The cages with control animals were put in Faraday chamber nearby. The experimental and control animals were exposed between 7.00 and 12.00 a.m. and during that period they had no access to food and water. The applied electric (E) and magnetic (H) fields are specified in Tables and Figures containing the results. After termination of exposure the animals were moved back to cages in the vivarium. At the start of the experiment and on every Monday after termination of exposure the animals were weighed. After termination of the last exposure both control and experimental animals were weighed and autopsied, and respective tissues were excised for further assays. The numerical results in exposed and control animals were compared with "t" test for a small number of data.

III. Checking of extremely low frequency of EM signals

The set including the sensitive voltmeter (UNIPAN, Poland) and the special probe i.e. ,"coil model of man" (4) was used for checking 4 Hz electromagnetic events (intensity fluctuations and pulses). These events were checked every day (excluding holidays) between 7.30 and 8.00 a.m. No attempts were undertaken to identify the observed EM events.

RESULTS

I. On the work posts at 30 induction heaters working with frequencies from 2.4 kHz to 10 kHz the intensity of E field was from below 1 V/m to 60 V/m and of H field from below 1 A/m to 500 A/m. General periodic medical examinations of 126 operators of these induction heaters did not reveal specific changes in their health state in comparison to 54 workers of the control group. However, these operators suffered very often from infections in the upper respiratory tract, and from furunculosis in the skin of forearms (Table 1). They also reported neurological and circulatory symptoms (not included).

Table 1. Some symptoms revealed in the operators of the induction heaters using 2.4–4 kHz EM energy

Groups of operators: Period of exposure	(age in years)	n	Intensity of H field at work posts, A/m	Total incidence of: infections in the upper respiratory tract	furunculosis in the skin of the forearm
I. 1) up to 1 year	(25–39)	4	0.5–53	2	–
2) over 1 year	(26–54)	14	0.5–53	105	–
3) controls	(30–51)	12	–	48	–
II. 1) up to 1 year	(19–55)	18	2.0–50	3	–
2) over 1 year	(24–46)	29	2.0–50	23	1
3) controls	(21–57)	28	–	11	–
III. 1) up to 1 year	(23–49)	9	0.8–7.6	3	–
2a) over 1 year	(20–54)	38	0.8–21	219	22
2b) over 1 year	(23–51)	14	7.6–430	63	13
3) controls	(36–52)	14	–	36	7

n – number of persons

Explanations. The infections, especially in the upper respiratory tract, were observed among the operators repeatedly (up to 13 times) within the period of five years of exposure.

Figures I, II and III denote three different factories and subclasses relate to period of exposure or to the difference of magnetic field intensity (2a and 2b).

II. The slowing growth rate, weight changes in the anterior pituitary gland, adrenals, and testicles were found in animals exposed to E or H field of 1–45 kHz (Tables 2, 3, 4 and Figs 1, 2, 3).

Table 2. Biological indices in control rats and in rats exposed (Ea and Eb) 4 hrs/daily to 10 kHz E field of 320 V/m (55 exposures) or of 3000 V/m (45 exposures). Ten male rats per group. Figures denote $\bar{X} \pm$ S.D

Biological indices	Control rats	320 V/m, Ea	4 hrs/daily Eb	Control rats	3000 V/m, Ea	4 hrs/daily Eb
Body weight (g):						
initial	101±7	104±8	111±9	115±14	119±14	119±11
final	278±25	268±19	274±15	299±21	291±28	293±17
(gain per cent)	(275)	(258)	(248)	(260)	(245)	(246)
Anterior pituitary	^{a}8.5±1.1	^{b}7.0±0.6	^{c}7.4±1.2	7.6±1.3	7.1±1.0	7.3±1.2
Adrenal glands (mg)	^{x}57.0±5.5	^{y}50.4±7.8	^{z}52.4±2.9	51.5±7.6	50.8±7.1	47.3±5.1

Explanations. Ea and Eb denote two parallel exposed groups of rats.

Statistical differences: a : b $t = 3.66$ and $p < 0.01$

a : c $t = 2.06$ and $p < 0.05$

x : y $t = 2.15$ and $p < 0.05$

x : z $t = 2.23$ and $p < 0.05$

Table 3. Macroscopic indices in control (C) and in exposed rats to E or H field. There are some differences in final body weight and in weight of the anterior pituitary and adrenal glands. Ten male rats per group. Figures denote $\bar{X} \pm$ S.D

Experimental procedure	Biological indices	Groups of animals		
		Controls	Exposed to E field	Exposed to H field
Exposure of male rats	Body weight (g):			
4 hrs/daily for 22 days	initial	73±5	89±6	85±4
in 45 kHz:	final	217±21	242±15	226±9
E field of 9000 V/m or				
H field of 70 A/m	(gain per cent)	(297)	(272)	(266)
	Anterior pituitary gland (mg)	6.0±0.8	6.9±0.9	6.5±0.4
	Adrenal glands (mg)	^{x}41.8±8	^{y}50.9±9	^{z}47.7±4
Exposure of male rats	Body weight (g):			
4 hrs/daily for 28 days	initial	114±9.5	118±10	125±6
in 41 kHz:	final	247±14	248±22	255±21
E field of 9000 V/m or				
H field of 210 A/m	(gain per cent)	(216)	(210)	(203)
	Anterior pituitary gland (mg)	7.0±0.6	7.0±0.7	7.3±0.8
	Adrenal glands (mg)	^{a}49.0±3	^{b}44.8±9.5	^{c}39.7±6

Statistical differences: x : y at $p<0.1$ (not significant)
x : z at $p>0.1$ (not significant)
a : b at $p>0.1$ (not significant)
a : c at $p<0.01$ (not significant)

Table 4. The final body weight of animals in per cent of their initial body weight accepted as 100%, after prolonged exposure to E or H field

General experimental procedure	Average final body weight in % in groups of 10 rats		
	Controls	Exposed to E field	Exposed to H field
1. Exposure 4 hrs/daily for 50 days to E field of 1 kHz at 200 V/m	251	a) 261 b) 251	–
2. Exposure 4 hrs/daily for 55 days to E field of 10 kHz at 320 V/m	275	a) 258 b) 248	–
3. Exposure 4 hrs/daily for 45 days to E field of 25 kHz at 320 V/m	318	298	–
4. Exposure 4 hrs/daily for 45 days to E field of 10 kHz at 3000 V/m	260	a) 245 b) 246	–
5. Exposure 4 hrs/daily for 38 days to E field of 25 kHz at 3000 V/m	320	278	–
6. Exposure 4 hrs/daily for 20 days to 8 kHz: E field at 9000 V/m or H field at 210 A/m	155	156	153
7. Exposure 4 hrs/daily for 22 days to 45 kHz: E field at 9000 V/m or H field at 70 A/m	297	272	266

a) and b) denote two parallel exposed groups of rats.

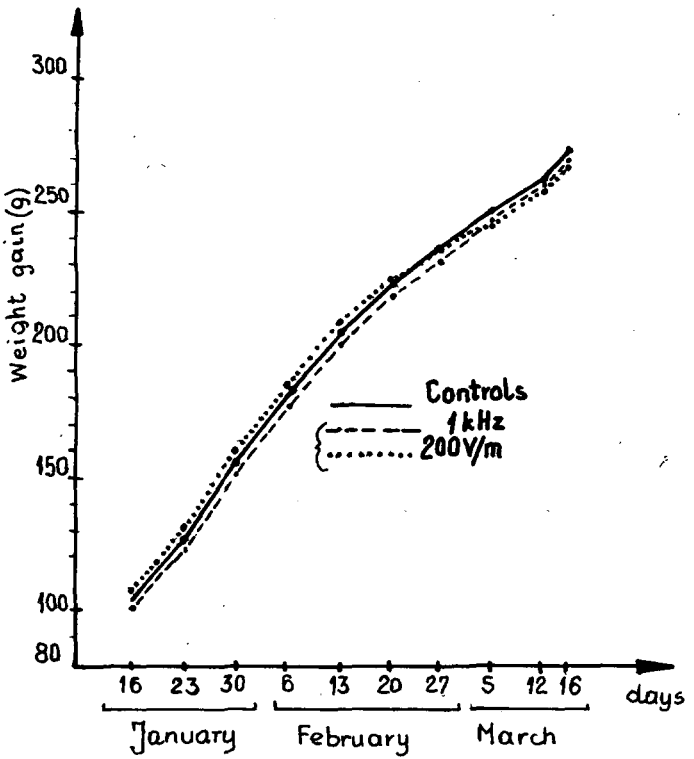

Fig. 1. Growth rate of immature male rats exposed 4/daily to E field of 1 kHz at 200 V/m. There was no difference in growth rate between control (————) and exposed (– – – – – and . . . . . .) rats.

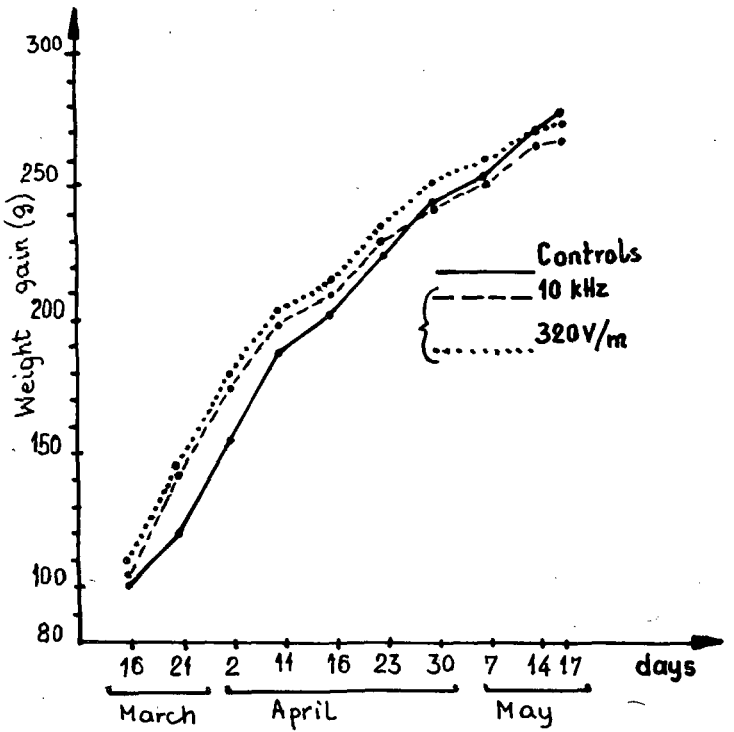

Fig. 2. Growth rate of immature male rats exposed 4 h/daily to E field of 10 kHz at 320 V/m. There was no difference in growth rate between control (————) and exposed (– – – – – and . . . . . .) rats.

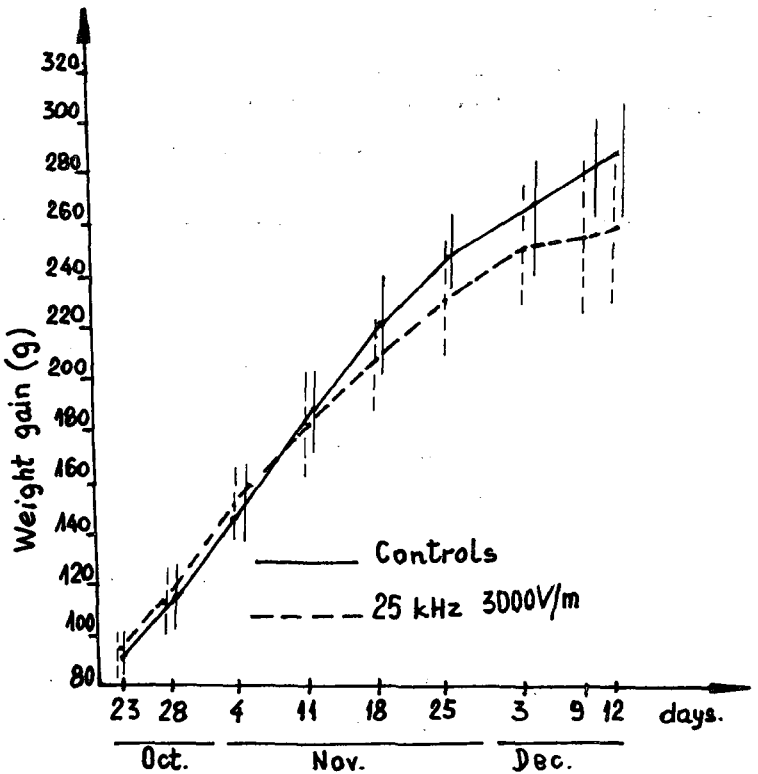

Fig. 3. Growth rate of immature rats exposed 4 h/daily to E field of 25 kHz and 3000 V/m. There was retardation of growth rate in exposed rats after 14 days of exposure. The final body weight of control and exposed rats was different at $t = 2.68$ and $p < 0.02$.

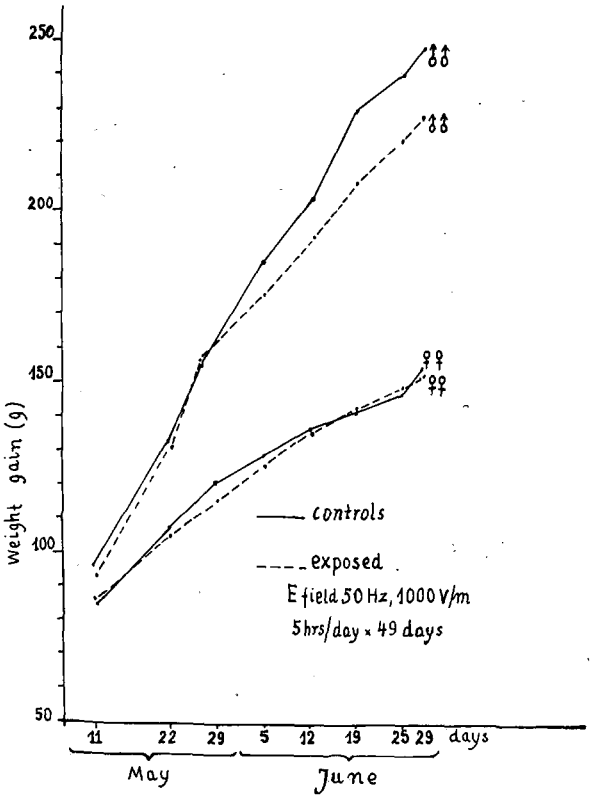

Fig. 4. Growth rate of control rats (————) and of rats exposed to E field of 50 Hz at 1000 V/m (– – – – – – –). Retardation of growth rate is seen in male rats but not in female rats. The difference of final body weight of control and exposed male rats was at $t = 1.68$ and $p < 0.1$ (not significant).

The growth rate of immature male rats was enhanced by 50 V/m and slowed by 500 V/m and 1000 V/m of 50 Hz field. No effects of 1000 V/m were found on growth rate of female inmmature rats (Fig. 4). There was no detectable influence of 10 Hz E field at 10 V/m on growth rate but nonsignificant weight changes in pituitary – adrenal glands in male rats during long term exposure were observed (Table 5).

Table 5. Some biological indices in control and in exposed male rats to E field. Ten male rats per group. Figures denote $\bar{X} \pm S.D$

Experimental procedure	Biological indices			
	Body weight (g) initial	Body weight (g) final	Anterior pituitary gland (mg)	Adrenal glands (mg)
I. Exposure 4 hrs/daily for 58 days in E field of 10 Hz at 10 V/m	a) 196±7	311±16	9.0±0.6	49.4±3.5
	b) 196±11	316±20	8.8±0.9	47.7±5.1
Control animals	205±10	309±20	8.5±0.8	45.9±4.4
II. Exposure 4 hrs/daily for 42 days in E field of 10 Hz at 10 V/m	181±7	304±23	7.5±1.0	48.9±6.1
Control animals	178±4	300±21	7.9±1.0	54.3±6.2

a) and b) denote two parallel exposed groups of rats.

III. The results presented in this subchapter should be believed as the preliminary results. At the time of observation between 7.30 and 8.00 a.m. the 4 Hz electromagnetic events in the form of intensity fluctuations and pulses were checked. The intensity of fluctuations was within 0–50 μV and within 60 μV to over 300 μV for pulses of short duration, which appeared irregularly within tens of seconds to a couple of minutes. The origin of these 4 Hz electromagnetic events remains unknown.

DISCUSSION

The described investigations concern the biological effects of extremely low frequency (ELF) and very low frequency (VLF) electromagnetic fields. Present contamination of the environment with EM energy results from innumerable telecommunication, military, industrial, medical, and domestic appliances which emit time-varying EM energy of frequencies ranging from ELF to EHF (extremely high frequency). One may even speak about an electromagnetic chaos which makes a permanent negative impact on all living organisms. The above described results were obtained in original investigations and some of them look to be more or less compatible with the results presented in the publications discussed below.

The frequent infections in the upper respiratory tract and in the skin of the forearm (furunculosis) in workers employed at induction heaters could be related to the adverse influence of magnetic field of relatively higher intensity than the intensity

of electric field. The susceptibility to such infections could be related to state of immunity in the exposed workers. Such supposition is confirmed by the described experimental results which showed an involvement of the pituitary-adrenal system in animals exposed to E or H field of frequencies from 1 kHz to 45 kHz. Moreover, it should be stressed that the described changes are more pronounced under the influence of H than of E field despite the fact that the intensity of applied H field was lower by about two orders of magnitude than the intensity of applied E field (5) (like in the impedance of free space where $E/H = 377\ \Omega$).

The enhancement of growth rate of immature rats under the influence of 50 Hz E field at 50 V/m and the retardation of growth rate of immature rats under the influence of 50 Hz E field at 500 V/m and 1000 V/m idicate opposite biological changes as a result of exposure to EM fields of low and high intensity. Most of the experimental results in this paper indicate an involvement of general and/or of organ growth in the animals subjected to EM fields. It points the involvement of the endocrine regulatory system in the response of the animals to electromagnetic energy.

Since 1970 a number of papers have been published on the biological effects of electric and magnetic field of ELF communication systems. The attention has been called to humans, behavioral effects, physiological changes, genetic consequences, growth and development, and general ecology (3). The author (3) informs that two groups of scientists have been charged to asssess a real significance of existing publications and to evaluate the probability of biological risk of the functioning of ELF communication systems. Clear and decisive conclusions have not been drawn, however, results from experiments on animals, including Primates, indicated that the behavioral, neurological, and endocrine changes could be possible. Among others, the Rhesus monkeys were exposed for more than three years, and in exposed males but not in exposed females, the enhanced growth rate was observed. Since that time new experiments have been carried out but their results are not available for the authors of this paper.

There are two possible ways, at least, to generate ELF waves (0 – 300 Hz) in the ionosphere. One way depends on the modulation of one strong high frequency wave (2 – 30 MHz) and the other could be accomplished by beating two strong radiowaves characterized by frequency difference Δf laying in the ELF band. The already generated ELF waves return to the earth surface and could be registered (2). This author (2) also mentioned that experimental generation and registration of pulses in the band of 3 Hz to 5 Hz had been successfully achieved. It seems to be possible to direct such ELF waves to desirable areas of the earth surface. Such assumption does not mean that the registered 4 Hz electromagnetic signals, described in this paper, are of such origin.

The results of very recent investigations indicate favourable effect of H field within frequency range of theta waves (3 – 7 Hz) in the prevention of the seizures in patients with epilepsy (1), and unfavourable effect of 5 Hz magnetic field on the memory and learning abilities in adults (7).

Circadiane rhythms of temperature and of other indices were changed in men living in conditions without access to natural EM field of 10 Hz (8). In our experiments there was no detectable influence of 10 Hz E field at 10 V/m on growth rate and on weight of pituitary – adrenal system in male rats during a long term exposure in the natural terrestrial environment.

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REFERENCES

1. Annions PA, Tsagas N, Sandyk R. Derpapas K. Magnetic stimulation in the treatment of parietal seizures. Intern J Neurosci 60: 141–171, 1991.
2. Ganguly S. Experimental observation of ultralow-frequency waves generated in the ionosphere. Nature (London) 320: 511–513, 1986.
3. Grisset JD. Biological effects of elecrtic and magnetic fields associated with ELF communication systems. Proc IEEE 68: 98–104, 1980.
4. Kameduła M, Kameduła T. Testing of EM energy in a specified volume of space. Proc. of the Eleventh International Wroclaw Symposium on Electromagnetic Compatibility, September 2–4, 1992. Eds JM Janiszewski, W Moroń, W Sęga. Technical University of Wroclaw, 50-370 Wroclaw, Poland. Part 1, 80–81, 1992.
5. Mikołajczyk H, Kameduła M. Biological effects related to E and H vectors of electromagnetic fields. Proc. of the 9th International Wroclaw Symposium on Electromagnetic Compatibility, June 28–30, 1988. Eds JM Janiszewski, W Moroń, W Sęga. Technical University of Wroclaw, 50-370 Wroclaw, Poland. Part 1, 427–431, 1988.
6. Mikołajczyk H. Electromagnetic hazards for biological systems and strategy of electromagnetic compatibility control. Proc. of the 10th International Wroclaw Symposium on Electromagnetic Compatibility, June 26–29, 1990. Eds JM Janiszewski, W Moroń, W Sęga. Technical University of Wroclaw, 50-370 Wroclaw, Poland. Part 1, 185–187, 1990.
7. Persinger MA, Nolan M. Partial amnesia for a narrative following application of theta frequency electromagnetic fields? J Bioelectricity 4: 481–494, 1985.
8. Wever R. Einfluss schwacher elektromagnetischer Felder auf die circadiane Periodik des Menschen. Naturwissenschaften 55: 29–30, 1968.
9. Radio Regulations. Ed. of 1982, rev. in 1985 and 1986. International Telecommunication Union. Geneve.

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