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(pages in brackets refer to the original)

4 Biological Effects Of Electromagnetic Waves And Their Mechanism

4.1 Effect on the human organism and on other vertebrates

The growing development of the application of radio waves for the most diverse purposes continues to increase the number of individuals who are professionally exposed to this physical factor. Chronic exposure to electromagnetic waves can lead to subjective and objective complaints in persons working both with uhf (21, 81, 101, 117, 119, 126, 184, 224, 225, 274-277, 280) as well as with rf generators (51, 111, 135, 147, 157, 183, 245, 246). The most serious is the effect of the uhf field on the eyes and on the reproductive tissue (in men), since these organs lie close to the body surface and are therefore readily accessible to the effects of electromagnetic waves. Also susceptible are the nervous and cardiovascular systems, which not only lie near the surface of the body but also have conductive properties.

Thermal Effects.
The best known effect of rf energy absorption in biological material is its heating (34). Heating effects result above all from relatively high rf field intensities (193). (Footnote: High intensity: Order of hundreds of volts per meter up to the rf band or hundreds of microwatts per square centimeter in the uhf band. Low intensity: Order of tens of volts per meter up to the rf band or tens of microwatts per square centimeter in the uhf band.) (*According to Marha rf band from 30 kHz to 300 MHz, uhf band from 300 MHz to 3000 GHz*). The most general and easily demonstrated manifestation of these effects is an increase in the total body temperature (228, 245), which increases with increasing intensity and length of irradiation (90, 279, 282). Numerous authors have studied the influence of rf on the temperature of skin and subcutaneous tissue (40, 80, 138), the temperature of muscles (95, 142), and the temperature of the eye. Brief irradiation produces maximum heating at the body surface (skin), often even leading to local superficial burns. The temperature drops with increasing depth. But longer-wave irradiation, on the contrary, generates the highest temperature in deep-lying muscles (195). The temperature of internal organs and of the blood flowing away from the irradiated organ also increases (282). When fields of high intensity (40 to 100 mW/cm²) are applied, blood vessels are seriously injured and there are hemorraghes in the internal organs (40, 283). It is also possible for some organs to be seriously injured without the entire organism being overheated. This phenomenon (*page 30*) arises particularly under those conditions in which some portion of the organism manifest so-called dimensional resonance. If the dimension of some part of the object being irradiated by the electromagnetic waves is comparable with the wavelength (eg an integral multiple of half the wavelength), standing waves may be created in that location. Implanted metal may also cause a concentration of rf energy (165, 195, 209).

Over a certain range of intensities , the thermoregulatory capacity of the organism can restore heat equilibrium (139, 280). At high intensities, the thermoregulation cannot maintain the temperature of the organism within the required limit, leading to overheating of the organism and death (169, 283). Survival times can be substantially affected by the initial temperature of the organism and its cooling during exposure (7, 41). It should be noted that results that rely entirely on animal experiments cannot be readily extrapolated to the effect of the electromagnetic field on man. The somewhat different thermoregulatory system and various coefficients (both thermal and rf absorption) in various organisms must be taken into account (137).

Subjective Complaints of Persons Working in Rf Field.
Workers complain of headaches and eyestrain, together with a flow of tears, of fatigue derived from over-all weakness, and dizziness after prolonged standing. At night their sleep is disturbed and superficial and they are sleepy in daytime. Such persons are moody, frequently irritated, even unsociable. They manifest hypochondriac reactions and a feeling of fear. Sometimes they perceive nervous tension or, on the contrary, mental depression combined with deterioration of intellectial

functions (notably memory impairment). Over a longer period, definite sluggishness and inability to make decisions result. Those affected complain of a pulling sensation in the scalp and on the brow , loss of hair, pain in the muscles and in the heart region. (together with a pounding of the heart), and breathing difficulties. Not infrequently they complain of difficulties in their sex life. It is moreover possible to observe slight trembling of the eyelids, the tongue, the fingers, increased perspiration of the extremities, dermographism (footnote: "Writing on the skin": Hypersensitivity to mechanical stimulation. Repeated mild friction of the skin immediately results in red spots because of local irritation and vascularization. In some persons, such increased irritability is congenital. It is quite common in neurotics.), and brittleness of fingernails. A single irradiation may cause a drop in the resistance of the organism (259, 279). With regard to the dependence of the effect of rf field on sex, women are generally more sensitive to this factor than men (64, 190, 262). Reference has been made to a decrease of lactation in nursing mothers (186, 195). At a certain time after exposure had ended (sometimes as long as several weeks or more) (*page 31*), the organism usually returns to its original physiological state and all subjective and objective complaints vanish. This phenomenon is usually described in the literature as a regeneration (195, 279).

Effect on the Eyes: Experiments on Animals.
The most significant thermal effect of electromagnetic waves is observed in the uhf band, as has been confirmed by research on the heating of the eye as a function of frequency (195) and the distribution of heat inside the eye (39, 142). These tests have shown that the temperature rises more steeply than does the power density (26). Such heating leads to various degrees of eye damage (17, 107, 161, 259), sometimes extending even to cataracts on the lens and on the cornea (215). At a sufficiently high power density, a cataract can appear even after a single exposure, with the exposure time necessary inversely proportional to the power density (137, 227, 269). But even with single exposures at intensities at which the eye is not immediately damaged, a cataract or lens opacity can develop 1 to 60 days after exposure (195, 213). Repeated irradiation at subthreshold intensities can lead to the same damage (14, 26, 27, 30). This is evidence for a cummulative biological effect of uhf (132, 279). From the viewpoint of causing cataracts, a pulsed field is more effective than a continuous field (26, 27). All damage to the eyes results from their direct irradiation. In whole-body irradiation at near-lethal intensities the eyes are not damaged (20, 31, 195), not even with pulsed radiation (142), if the radiation is not aimed at the eyes.

Effects on the Eyes in Man.
No eye damage was found amoung operators of rf installations (21), but a significant percentage of findings where made in persons working in the uhf field, especially radar operators (12, 28, 29). In a number of cases, both unilateral and bilateral cataracts have been described (99, 225, 279, 280). Soviet authors warn that chronic irradiation at intensities of the order of a few milliwatts per square centimeter are sufficient to produce opacities in the human eye (195). In such persons, a flow of tears and eye fatigue is observed first (280), combined with changes in vision, especially a decrease in sensitivity to colored light (especially blue) and defective observation of a white object. In these observations, the authors used a projection perimeter (283). A weak rf field also lowers the threshold of sensitivity to light stimuli in the dark-adapted eye (116). The change in the threshold of sensitivity is the same for pulsed and continuous fields (280). A change in intraocular pressure was also observed to result from chronic exposure to centimetric waves (279). At subthreshold intensities, a lowering in the content of Vitamin C in the lens and in the fluid in the anterior chamber was observed (195). During acute cataract development, a considerable lowering of the activity of adenosintriphosphatase and pyrophosphatase occurs in the lens (37). (*page 32*)

In view of these facts, warnings relating to the therapeutic application of centimetric waves are quite justified, especially where there is eye disease (99, 213). In experiments on models seeking to determine the distribution of heat inside an eye irradiated by a uhf field, materials such as 30% gelatin or polystyrene foam are used (100). Various opinions have been expressed as to the cause of eye damage. At higher intensities the damage is evidently of a thermal nature, connected with a coagulation of the proteins in the lens; at low intensities, there is a disturbance of metabolic processes. An important role in this process has been ascribed to glutathione. Opacities may be also caused by damage to tissue respiration and of the oxidation-reduction systems (195).

Nervous System.
The subjective complaints of persons working in rf fields are predominantly related to the nervous system. For that reason considerable attention has been paid to changes in the central nervous

system under the influence of this factor; the reader will find details in several readily accessible review articles (142, 195, 205, 279, 280, 282, 283). In clinical and laboratory studies (64, 122, 123) of the effects of rf and uhf fields on the human organism, changes in the activity of the central nervous system (CNS) were studied with both large and relatively small field intensities. These changes where determined by an interpretation of EEG of subjects, the majority of whom had worked long periods of time in rf and uhf fields (64, 248). EEG examination is at present the most convenient objective method for determing the early stages of damage to the CNS produced by electromagnetic waves (53, 112, 122-124). The complex of changes in nerve functions caused by damage inflicted on the CNS by low-intensity rf and uhf fields is characterized as a syndrome of the asthenic type (47). In only one case has a severe neurotic syndrome with further functional aberrations been described, in an individual who worked for 10 years in the field of a short-wave generator (35).

At high intensities of rf and uhf fields, the asthenic syndrome is accompanied most often by disturbances of the cardiovascular vegetative regulation (61, 102). Functional changes, even though sporadic, have been described in individuals systematically irradiated by an rf field at wavelengths of tens and hundreds of meters (183, 194, 228). Here, too, the neurotic symptoms are the most frequent, described as "short-wave nausea" (51, 64). Interesting, though drastic, are experiments that describe brain activity during irradiation of the head by a strong transmitter (115). When the experimental subject was emotionally disturbed or absorbed in creative work, changes in brainwave parameters occurred. At the same time it was noted that a strong rf field can even elicit hallucinations. Other authors noted involuntary motor reactions when the cerebrum of healthy subjects was irradiated (142). The functional changes mentioned (*page 33*) above are usually reversible: after removal of the source-that is, the effect of the rf field-a normal state is restored; in more serious cases, considerable improvement of the over-all condition can be obtained by appropriate treatment (35). Only in a few individual cases may the changes be of a progressive character (46, 195). Under the effects of electromagnetic fields, animal behavior can also be significantly changed. It is possible to observe agitation (180), excitement, and increased motor activity (142), sometimes going as far as turning tranquil animals into aggressive ones (116). At low intensities, animals may be observed to become sleepy. Exposure of a hen´s head to rf field leads to stiffness; the animal accepts neither water nor food, and when made to stand remains standing until it falls down exhausted.

Also interesting are experiments in which the effects of rf field on the reflex activities of animals were studied. At intensities too low to disturb the animal, both conditioned and unconditioned reflexes were evoked in dogs (142, 208). However, at higher intensities, conditioned-reflex activity is significantly decreased or extinguished, or else the period of time required to develop the reflex is prolonged; in some cases it is necessary to use a stronger stimulus before the reflex action takes place (11, 79, 159, 208). For example, we observed the loss of all obedience training in a dog taught in a police school after the animal had moved about for about six months in a space subjected to a strong rf field. But these results are not unambiguous, since some dogs conditioned to have simultaneous taste and defense reflexes preserved the defense reflexes under irradiation (14). The EEG was used both in animals and in human subjects to detect changes in the electrical activity of the brain during irradiation by an rf field (276). The effect of both single and chronic irradiation of the organism by an rf field on reflex activity is probably due to changes in interneural connections (143, 168, 279, 283). It is possible to observe degeneration of neurons in the cerebral cortex and the basal ganglia, the pons, the medulla oblongata, and in some cases even the cerebellum, as well as histological and chemical changes in the vicinity of nerve fibers (20, 143, 228).

Effects similar to those produced by centimetric waves are caused also at substantially lower frequencies (12). The reaction of the cortex to an rf field is the same as that evoked by bromides and caffein (142). Studies have also been made of the functional state and changes in the excitability of neuro-muscular preparations of rf fields (39), and of the effect of an rf field on the rheobase and chronaxy in both animal and human subjects; and there are descriptions of differences between the results of a continuous and a pulsed field, and of the effects of bromides and caffein on the results.

The reactivity of the entire nervous system of an animal is disturbed by an rf field. For example, sensitivity to touch and (*page 34*) the threshold of pain are both reduced (223, 228). The analgesic effects of the rf field are explained by a reduction in the conductivity of the affected nerve. Several papers examine the effect of the rf field on the threshold of sensibility and on the latent period of medullar nerves (142). As mentioned previously, the visual analyzer is also affected by an rf field (51, 116, 225). When the auditory analyzer is subjected to an rf field, even low intensities serve to reduce

excitability and at the same time prolong the latent period. However, auditory acuity may be somewhat increased at such low intensities. Irradiation of the human cerebellum may manifest itself by a short-term change in spatial sound perception without a change in the threshold of sensibility. Sensitivity also decreases (ie the level of threshold of sensibility increases) when the olfactory analyzer is subjected to an rf field. (225). This decrease in the sensitivity of smell can serve as one of the earliest symptoms of the effect of centimetric waves on healthy subjects working with rf installations (279). In cold-blooded animals (a shark) the ability to "scent" or otherwise find the prey deteriorates under the effect of rf fields (287), The effect of high intensity uhf fields may lead to damage of the interoreceptor apparatus.

Reproductive Tissue.
Besides the eyes and the nervous systems, the genital organs are the most susceptible to rf fields. Perceptible changes occur mainly at high field intensities in the centimeter-wave region (17, 30, 82, 113, 137), At these intensities, the main effect is thermal damage to the reproductive tissue. An increase in the temperature of male or female gonads results in morphological changes (83) and possible degenerative processes in these organs. The changes are similar to those produced by thermal trauma (82). Thus the walls of the blood vessels that supply the reproductive organs may contract, or else there may be direct damage to the ovaries and the testes. Histological examinations have revealed interruption of spermatogenesis in several phases of the process (282). These morphological changes may then manifest themselves in changes of the reproductive cycle, in a decrease in the number of offspring, in the sterility of the offspring (79), or in the increase in the number of females born.

No decrease in fertility was noted in persons working in rf fields (12, 36, 280), but as far as the number of children born is concerned, girls distinctly predominate. The results of a study of the effect of rf and uhf fields on the menstrual cycles of women subjects are not uniform. Disturbance of the menstrual cycle is mentioned as one of the symptoms of the effect of electromagnetic fields on organisms (182), even though the results of some studies of women who have worked from 3 to 11 years in a uhf field have not confirmed this effect (24, 186). It appears that rf irradiation of pregnant women and female animals increases the percentage of miscarriages (222). The offspring (*page 35*) of female rabbits subjected to the effects of an rf field showed definite functional aberrations and higher mortality when compared with individuals from a control litter (30). The literature contains a case of embryopathy in the fetus of a mother treated by a shortwave diathermy at the beginning of pregnancy. When the child was born, it exhibited changes in the upper and lower extremities: the upper extremities lacked ossification centers (30). Other authors have also reported that the rf field definitely impairs embryogenesis in both humans and animals, particularly in the beginning stages. The development of the fetus is retarded, congenital defects appear, and the life expectancy of the infant is reduced. The effect is cumulative and the thermal effect also plays a definite role (160).

Circulatory System.
Periodic exposure to a high intensity rf field leads to changes in the circulatory system (195, 279, 280, 283). Disturbances in blood circulation have been described (80), evidenced by a change in blood flow (216). In general it is an increase in blood flow that is described, proportional to both the intensity and duration of exposure (214); except that in the denervated extremities, a decrease is observed. These phenomena depend on vasodilation. Clearly, a change in the blood flow and vasodilation produces a change in blood pressure (262). At first, blood pressure rises moderately and then it drops (5, 11, 98, 224). The drop can be very pronounced and may persist for several weeks after exposure. However, negative results in radar personnel have also been reported (224).; the heart rate also changes (141). Depending on which part of the body is exposed, the rate may be either accelerated or retarded (11, 198, 199). The EKG is used for objective study of changes in cardiac activity. Rf fields reduce the conductivity of the coronary circulatory system, which are then manifested as changes in the EKG, characterized as changes of the sinusoidal bradycardia type sometimes combined with sinusoidal arhythmia (245). Further observations include aberrations in vascular reactions; for instance, oscillations of the vascular tonus (61).

Soviet authors (279) divide symptoms of chronic exposure to centimetric waves (at the level of vasometer disturbances) into three stages: (1) the initial, compensated stage; (2) the stage of moderate changes; (3) the state of clearly discernible changes. The degree of change depends on the intensity and the duration of exposure to the uhf fields. The above changes in circulatory functions are

reversible, but a case has also been described in which the change in the EKG continued after the effect of the field has been removed, even though other functions returned to normal (280).

Changes in the Blood Picture.
A number of authors note that the blood picture is not noticeably affected by the effect of an rf field (12, 36, 143, 195). But other authors have found changes (105, 107, 224, 276), both in the white (79, 95, 98, 156, 200, 225, 279) (*page 36*) and in the red blood picture (104, 224), and a drop in hemoglobin content (79). The osmotic resistance of erythrocytes is perceptibly negatively affected (195). When centimetric waves act on a suspension of erythrocytes, both their volume and shape change and continued exposure may even lead to hemolysis (73, 245). Cell walls obtained in this way have electrical properties different from those of walls obtained by conventional osmotic hemolysis. After exposure to an rf field, coagulation time is decreased (195). The prothrombin time, according to Quick, is reduced (229). Increased coagulability, combined with the changes in the vessels, may even give rise to thrombosis. Some authors have also studied the effect of microwave radiation on the hematopoetic organs (42, 121).

Effect of Rf Fields on Other Organs.
The effects on the circulatory system lead to observed acceleration (sometimes retardation) of the breathing rate (11, 195). Further more, hemorrhaging and bleeding can occur in some internal organs (20, 195). A number of authors have studied the effects on the kidneys, the adrenal glands, and the liver (20, 92, 195). They found decreased filtration in the renal tubules, perhaps caused by degeneration of the epithelial cells in the distal and proximal renal tubules. In addition, there was increased activity of the adrenal cortex, hemorrhaging in the liver, and degeneration of hepatic cells. Persons working in rf fields, particularly women, exhibited enlargement of the thyroid gland, though without an accompanying clinical picture of hyperthyroidism. Increased incorporation of radioactive iodine was detected in studies of the functioning of the thyroid (190, 262, 279, 280).

Since the dimensions of some portions of the organisms may lead to resonances, partial injury to organs may occur-for instance the intestinal necrosis (20, 224). Rf irradiation does not cause histological changes in bone marrow or changes in the incorporation of tracer calcium and phosphorus into irradiated bones (56, 106, 250). Some histological changes in muscle following chronic irradiation have been described (158). At the higher intensities, morphological changes are produced not only within the organism, but also in the paws and ears of experimental animals (195, 259). No histological changes were found after a single exposure (282).

Biochemical Changes.
The effects of electromagnetic fields are manifested by metabolic changes in the most diverse tissues (251). A series of experiments were made on sections of the cerebral cortex (8, 93). Under the influence of a pulsating field, the glucose level falls and the oxygen consumption rises (133, 154). Simultaneously, there is an increase in CO_2 content, in lactic acid content, and in the inorganic phosphate level, whereas the content of macroergic structures decreases. Considerable aerobic glycolysis thus takes place. Changes in the alkaline reserve and in the blood ph have also been noted (33, 127). In (*page 37*) unanesthetized rabbits, the activity of succinodehydrogenase and cytochromoxidase changes slightly; in anesthetized rabbits (whose basal metabolism is lower), the rf field raises the activity of tissue respiration almost to normal levels (118). A study has ben made of the effect of the rf field on oxidation processes in man (22).

Even at relatively low intensities, the activity of cholinesterase in the blood and in other organs is reduced (279). We may thus assume that the rf field causes a rise in the level of acetylcholine in some parts of the organism, which may be of great significance in the development of vegetative changes. Several changes in the composition of blood plasma have also been described (18, 252). A number of authors have noted a decrease in total proteins, with a simultaneous decline in the ratio of albumin to globulin (9, 82, 280). The change in this ratio is most probably caused by a substantial increase in gamma globulin (62, 82, 224, 279), which may in turn be related to a change in the decomposition of tissue proteins. However, this observation is more of an exception than the rule. In some cases a rise in the histamine level of the blood was detected (97, 200, 280) and with it an increase in the resistance to ionizing radiation. The rf field also affects the glycemic curve (195, 229, 279) and glycogen breakdown in the liver (82, 116). In healthy individuals, only slight changes have been observed in the levels of sugar, cholesterol, and blood lipids, but there was a pronounced decrease in all three

components and in improvement in subjective complaints when rf was applied to diabetics (92). It is likely that changes in sugar and phosphorus found in the blood of rabbits are caused by a disruption of sugar metabolism (195).

A drop in the level of ribonucleic acid (RNA) in the spleen (and after continued irradiation, in the liver and in the brain as well) of rats was observed after chronic irradiation by microwaves. The content of desoxyribonucleic acid (DNA) remained unchanged (283, 195). Other authors report that a single irradiation of rats led to a reduction of the activity of both ribonuclease and desoxyribonuclease, ie an increase in the level of both nucleic acids, and especially of RNA (282). In skin cells and dermatic derivatives, a single irradiation led to an increase in the activity in both enzymes (283). An increase in the RNA level was also observed in the lymphocytes of rf generator personnel, which corresponds in the blood picture to an increase in the number of monocytes, which contain the great majority of RNA (young cells) (245). Also affected is fibrinolytic activity, which increases in young individuals after irradiation but is more likely to decrease in older subjects (15), although it is otherwise the same in both groups. The effect on the activity of other enzymes was also studied (91).

On the basis of biological changes (mainly in sugar metabolism) under the influence of rf fields, several authors have proposed that research in this direction might point the way toward (page 38) a successful cancer cure (19, 116). Effects of rf fields on cancer patients have been actually studied (60, 164). A group of French scientists has reported a successful cure of cancer in rats that had been subjected to short-time exposures of rf fields at various frequencies (217, 218, 219). (However, this report was received with certain reservations by specialists in oncology.) The authors conclude from experiments made to date that rf fields cause changes in the metabolism of tumorous tissues (179), not only retarding the growth of primary sarcomas but also inhibiting the growth of secondary tumors and the production of metastases.

4.2 Effect on other organisms
(...) (S.40ff) *Dependence of Biological Effects upon Field Parameters*

From the brief discussion above regarding the effects and action of electromagnetic fields on living organisms, and even after a detailed study of the works in the bibliography, it is still impossible to come up with a concise and (so far as is possible) unambiguous conclusion. If we keep in mind the fact that the biological effects of radio waves depend on an number of factors (the most important being intensity of the field, its nature, and the exposure time), it becomes clear that not even the final results will be unambiguous and will vary more or less (or even be contradictory), as is frequently the case even in the above summary. From the sections that follow, which describe several important factors depending on the field parameters, it is possible to gain some idea of difficulty of getting a correct and objective appraisal of the end effect.

The frequency dependence of the biological effects may vary according to the above-mentioned partial mechanism of the effects. It appears that the complex biological effect of electromagnetic waves at a relatively low field intensity is not too dependent on frequency, provided the energy acting on the organism is always (*page 41*) of the same magnitude, although the individual active mechanisms may exhibit a pronounced frequency dependence. There are thus basically two types of effects: thermal and nonthermal. It must be emphasized that nonthermal effects cannot be seperated from the thermal, which predominate at high intensities and depend upon the energy transmitted. Thermal effects increase sharply with increasing frequency and are therefore most important in the range of the so-called microwaves. Owing to the small depth of penetration of microwaves, caused by their considerable damping in tissues, the eyes and (in men) reproductive organs are most seriously endangered. Nonthermal effects depend primarily on the istantaneous amplitude of rf radiation. Their significance increases with repeated exposure to relatively low-intensity irradiation, especially by pulsed fields, in which the total transmitted power is relatively low but the instantaneous amplitude is quite high.

In this situation, nonthermal effects tend to predominate over the thermal. On the basis of our present knowledge of the primary biophysical mechanisms of the nonthermal effects of electromagnetic waves, we can say that the primary effects involve above all the macromolecular and cellular levels. It

is mainly a question of influencing the colloidal structure of the cellular contents and other colloids in the body, and also affecting the electrical conductivity of the cell, which may be significant above all for the function of the central nervous system. The frequency dependence of each of these two partial mechanisms need to be the same and our present knowledge of them is still very incomplete. We do know, however, from experiments on the effects of electromagnetic waves on isolated colloidal components, that the frequencies and intensities at which they are affected depend on the composition of the colloids.

The frequency dependence of the biological effects of rf and uhf fields has been studied by many authors (17, 279). As far as the thermal effects are concerned (41, 195, 210), the dependence is determined by the fact that the electrical characteristics of individual tissues vary with frequency (240). This change is monotonic, ie it proceeds without any maxima or minima. For the body as a whole, however, there is a certain optimal range of frequencies at which heating reaches a maximum (69, 235). This range is due to the finite dimensions of the body, which is not a homogeneous structure, and the frequency dependence of the dielectric constant (the so-called dispersion) of many tissues. The frequencies for maximum heating of the human body lie in the range of very short and centimeter waves. However, it may be said in general that tissue heating increases with frequency. Many other effects are also more pronounced at the higher frequencies. Thus, retardation of visual motor reaction is greater at 75 MHz than at 0,3 MHz, just as are changes in the central nervous system (280). Changes in the growth of bacteria as a function of frequency have also been described (63). As far as the circulation of the blood is concerned, it has been found to (*page 42*) increase in the centimetric-wave region and contrariwise to fall below normal at substantially lower frequencies (195). In that case, however, it was more likely a matter of the effect of two different field intensities. The same assumption may be made in the previously described difference in sensitivity of the auditory analyzer between the 10 and 3 cm wavelengths, since there is no difference in the effect of these waves on the endocrine system nor on the central nervous system (279).

Far more significant than the frequency dependence is the effect of the nature of the emitted signal. The latter may be either unmodulated, so that the electromagnetic field is continuous, with a more or less constant amplitude (cw operation), or modulated. A boundary case of an amplitude-modulated signal is pulse modulation.

Let us imagine an experiment in which we have two generators operating at the same fundamental frequency, one unmodulated and the other in pulsed operation. If the average radiated power of the two devices is comparable, there is no difference in the thermal response of the organism to these different fields (279). Nevertheless, we can detect different effects. In the single exposure of rats to radiation at a power density of approximately 200 mW/cm² in the 10 cm-range, cw operation of a generator does not produce any visible effect on the experimental animal even after 30 min, whereas pulsed operation (pulse width 1 μs, repetition frequency 1000 Hz) kills the rat after 3 to 4 min (151). Postmortem examination reveals only considerable enlargement of the spleen; the histological appearance of the principal organs (including the brain) is normal. In addition, the response of an experimental animal to pulsed-wave radiation is characteristic from the very beginning and indicates the dominant influence of electromagnetic waves on the central nervous system. A pulsed field is thus biologically more effective than a cw field. This conclusion has been reached independently in the USSR, the USA, and Czechoslovakia (118, 145, 151, 254).

It may be assumed that the greater biological activity of pulsed fields is caused by nonthermal effects (118). Mention has already been made of the difference between the effects of unmodulated and pulsed fields on the development of cataracts (26, 27, 215), morphological changes in the links between neurons (280), and on the rheobase and chronaxy (142). The wavelengths used in these experiments were centimetric, which are usually used in pulsed operation. But even at metric wavelengths, a greater biological effect of the pulsed field has been demonstrated, for instance on oxidation processes in tissue (118). With increasing average power density of the field, the difference between the effects of continuous and pulsed fields washes out, since the thermal effect begins to predominate (20).

It has already been stressed that the rf field, in its different manifestations, may have either a stimulatory or a damping effect; moreover either direction may be associated with a given frequency and field characteristics. It depends on its intensity (*page 43*) and period of exposure. At high powers,

the effect is governed by the field intensity and period of exposure, whereas at low intensities or brief exposures the effect may oscillate.

Many parameters thus affect the biological effects of an rf field. In this respect, it is evidently unimportant how the field is produced. Besided man-made rf generators, there are fields that are derived from natural sources. One such powerful source is the sun; in addition to heat and light rays, it emits radio waves over the entire width of the spectrum. The intensity of this radiation can under certain circumstances reach values that are sufficient to evoke biological effects (6). In addition, the sun emits corpuscular radiation which, when it reaches the upper layers of the atmosphere, can produce short rf pulses in the range from 10 to 50 kHz (50). Similarily, large air movements (mainly fronts with unstable moist boundaries) under certain conditions become rf field sources in the same frequency range. Many papers are available at present that deal with the biological effects of this range of frequencies (51, 187, 188, 288). It is interesting that statistically significant evidence has been presented regarding the effect of such fields on the mortality rate of the population (51), the birth rate, traffic mishaps, and industrial accidents (6).

Laser Radiation. Following the invention of lasers, sources of coherent electromagnetic radiation in the visible region, studies of the biological effects of these rays were begun (49, 256, 284). It was found that laser radiation, like low-frequency electromagnetic waves, has both thermal and nonthermal biological effects and has its greatest effect on biologically complex macromolecules (proteins) (62). When pulsed laser radiation is applied to the eye, ultrasonic waves are generated in the skull, which produce vibration of the brain, the cerebrospinal fluid, and the bones of the cranium; piezoelectric recordings can be made from the bones at the base of the skull (2, 43).
Comparison with the effect of classical monochromatic light sources (whose radiation is not coherent and which can thus produce only thermal effects in practice) shows that laser radiation has specific chemical and electrochemical effects of a nonthermal origin (260). The hypothesis has been put forward that the mechanism of this effect is similar to that of radio waves.

Simultaneous Action of Electromagnetic Waves and Other Factors. In the operation of rf generators, high-voltage power supplies are used to run the vacuum tubes in the final stages. Above approximately 20 kV, flow of anode current gives rise to X radiation (145). Measurements made on various uhf generators have shown that peak values up to 50 r/min can occur. The effect of the combined influence of an rf field and of X radiation was therefore studied; it was found that in such a case the damage to a biological object is more serious than when each factor acts (*page 44*) independently (195, 264). A reinforcement of the effect was also found for successive exposure to an rf field and ultraviolet radiation (114), as well as gamma sources (200). The combined action of fields at different frequencies likewise appears to be most dangerous (76). Irradiation of an organism in an rf field can also significantly affect the known effects of certain chemical substances, such as medicines, so that the effects are increased or disturbed (116).