Add Glaser

Microwaves and Behavior

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Victor Frankenstein surgically fathered the famous fictional monster, but the fiend was conceptually mothered if not physically spawned by electricity in the form of lightning from the heavens. Perhaps unwittingly, perhaps intuitively, author Mary Shelley (1831) touched a deep truth in the maternal metaphor: Life did originate from electrical discharges into the primeval fog. Indeed, life continues to preserve in all of its earthly forms from the most primitive cell to the most complex organism an elemental dependence on electrical phenomena. Understandably, the curiosity of the scientist about the electrobiological goings-on of the earth's flora and fauna is shared by the layman. A large popular literature is accumulating and embraces experiments and anecdotes that range from the ostensibly respectable to the seemingly bizarre. Recently published texts by Tompkins and Bird (1973) and by Burr (1972, 1973) are not only exemplars of the literature but are rich sources of reference materials. One reads, for example, that plants have nervous systems that yield differing electrical signals on "stimulation" by *kind* or *malevolent thoughts* of human beings (Backster, 1968). One also reads that many Soviet scientists are giving credence and careful study to ESP and related phenomena, not in defiance of Marxian dictates of materialism but quite in keeping with them. The Soviets are championing earlier theoretical notions of Georges Lakhovsky (1934) to the effect that each plant or animal cell is an oscillatory system capable of transmitting and receiving high-frequency electromagnetic energy over a distance. While affirming that electrical events are intimately involved in cellular activity, one must yet wonder from Lakhovsky's perspective why the human central nervous system with its tens of billions of neurons and glial cells does not drown in its own electrical noise. This apparent physical

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complication notwithstanding, the layman's interest in electrobiology is well attested by the substantial volume of the popular literature; but the strange and often conflicting claims that appear are equally an attest to a related truth: Science is sorely lacking in an understanding of basic electrobiological mechanisms. Moreover, the absence of a satisfactory theory of the role of intrinsic electrical events in uni- or multicellular organisms puts a heavy epistemological burden on those who would explain how an organism reacts to electromagnetic fields of extrinsic origin. With the possible exception of mammalian photoreception, which is better understood anyway as a quantum mechanical process than one involving electromagnetic wave activity, there are few basic data on the biological response to exogenous electromagnetic fields. The hard data that do exist—those vindicated by independent experimental confirmations—are without exception correlative or descriptive. Many of the findings are of interest to the psychologist, however, not only because behavior has often been the end point of successful electrobiological experimentation, but also because psychologists have played important roles in these researches, particularly in the development of methodology and instrumentation.

In this essay, I summarize some contributions by experimental psychologists to the biological study of radio-frequency electromagnetic fields, especially the "microwaves." But first the reader should be acquainted with a few fundamentals of wave theory and provided with a synopsis of pertinent historical

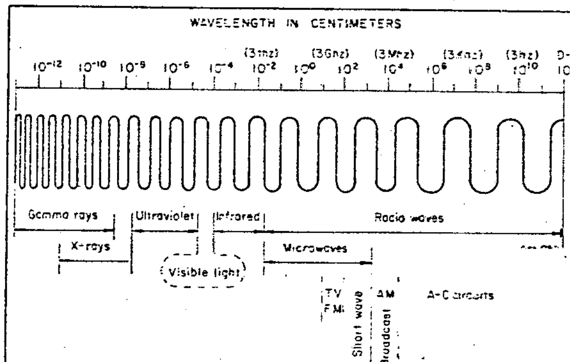

Figure 1. Components of the electromagnetic spectrum. Frequencies in cycles per second (hertz, Hz) are shown in parentheses. (Abbreviations: D-C, direct current or zero Hz; G, giga- = 10^9; K, kilo- = 10^3; M, mega- = 10^6; and t, tera- = 10^{12}.)

developments. The reader who disdains technical discussions may wish to skip the next few paragraphs, but will probably be rewarded by a better understanding of the materials that follow if he or she opts to read them.

Electromagnetic Wave Theory

The microwave portion of the electromagnetic spectrum includes the emanations of radars, television, and short-wave radio. The microwaves range in frequency from a few to several thousands of megahertz (MHz). In terms of respective ***in vacuo*** wavelengths, the microwaves range from a few meters to about a millimeter. The relation of the microwaves to the other components of the electromagnetic spectrum is shown in Figure 1. My review of data stops short of the radiations of the infrared spectrum and of the solar and cosmic radiations that lie beyond, but I am not drawing an altogether arbitrary line. While absorption of electromagnetic energy of any wavelength translates to and results in an increase of kinetic energy in the biological target, the photon energies of radio-frequency radiations are vanishingly small. Not so of radiations of higher frequency. The ineluctable product of the multiplication of frequency by Planck's universal constant, photon energy, becomes a potent biological factor at higher frequencies. Correlated with the magnitude of photon energy is the probability that a radiation will ionize the atoms of the absorbing target. The displacement of electrons from atoms, the crux of ionization, creates additional electrical charges within and among molecules thereby posing distinct biomolecular hazards—distinct, that is, from the heating of body tissues that results from a moderate increase of kinetic energy. Stated another way, at densities that are low in terms of available kinetic energy, X- and gamma-radiations are like cool but deadly bullets compared to the benign ripples that bathe the organism on exposure to commensurate densities of microwaves and other radio-frequency energy. On the other hand, exposure to high densities of radio-frequency energy is hazardous and can result in excessive heating. Witness the potato that bakes to bursting in a microwave oven in less than four minutes!

A major factor that distinguishes the biological response to radiation by microwaves as opposed to radiation by infrared and ultraviolet energies is that the latter are absorbed or scattered near the surface of a target. Unscattered microwave energy penetrates much more deeply. If 1,000-MHz microwave energy is incident on the head of a human being, a significant portion of the energy will penetrate the skull and be captured by tissues of the brain. One of the hazards of microwave energy is that the warning sensations of warmth so readily produced by infrared energy through stimulation of surface receptors may not occur to exposures to fairly high densities of microwave energy until thermal damage has resulted.

The mechanism of microwave heating of biological materials is fairly well understood and derives from two electrophysical properties of water. First, the molecule of water is polarized; it carries a charge that differs over its surface. The result is an electrical dipole, a molecule that reorients when an external electrical field is impressed on it, even as bits of paper are attracted to or repelled by an electrostatically charged rod. Water's second property is a high molecular viscosity, or what is technically termed a lengthy relaxation time. If its relaxation time is short, a polarized molecule can reorient itself with ease in an oscillating electrical field. Molecules of water are unable to orient and reorient completely in a rapidly oscillating electrical field, and so their high viscosity results in "molecular friction"; much of the microwave energy incident on a biological target can therefore be "lost" or dissipated as heat.

The amount of radio-frequency energy absorbed by a target is a positive function of the target's electrical conductivity, a negative function of its dielectric constant, and to complicate matters, both the conductive and dielectric character of biological materials are frequency- and temperature-dependent. The wave conformation of radiated radio-frequency energy is also a variable that controls absorption; the electric field is at right angles to the magnetic field, and both are at right angles to the line of propagation of the electromagnetic wave. Energy will couple to a biological target either from the electric or from the magnetic field, but the amount coupled will change as functions both of the relative wavelength and of the relative geometry of the target with respect to the vectors of the electric and magnetic fields (see Figure 2).

The quantity of kinetic energy in a propagating electromagnetic field is reckoned by Poynting's vector and is technically termed "power flux density." This density is the quantity of energy that flows in time through a measured plane of space. The quantity of energy is determined by the densitometer and is scaled in terms of watts per square meter (W/m^2) or watts per square centimeter (W/cm^2). A rough rule of thumb for estimating absorption of radio-frequency energy can be applied to the case in which the physical dimensions of a biological target are large with respect to the wavelength of the radio-frequency energy that is incident on it: Approximately half of the energy is absorbed and the remainder is scattered. Another rule of thumb applies when the physical dimensions of a target are much smaller than the wavelength of the incident energy: The target becomes electrically translucent or transparent and little or no energy is absorbed. As the physical dimensions of a biological target approach the wavelength of a radio-frequency radiation, an extremely complex scattering function occurs, a succession of valleys and peaks, and either very little or a great deal of energy is absorbed. Maximum absorption occurs at and defines resonance and may exceed the nominal amount of energy that is incident on the target. At resonance the effective electrical capture surface presented by a "lossy" target of low electrical conductivity may

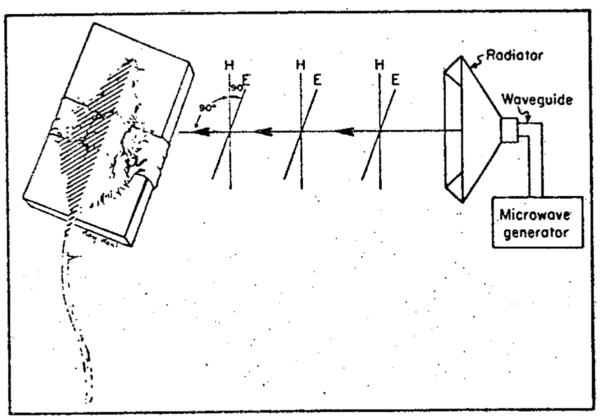

Figure 2. Idealized schematic representation of radiation of a biological target in the open or free field, the traditional method of exposing animals to microwaves. (In practice, the inside surfaces of a laboratory are covered with energy-absorbing material that prevents reflection of energy to the target. The animal is shown in restraint—necessary, unless the subject is anesthetized, because changes of body geometry will alter the capture-surface exposed to radiations. The H and the E, respectively, refer to the magnetic and electric vectors of a plane wave, transverse field; the flow vector [or line of propagation] is depicted by arrows that point to the animal.)

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be greater than its physical capture surface area by an order of magnitude (Anne, Saito, Solati, & Schwan, 1961).

Brief Scientific and Political History of Radio-Frequency Studies

The history of behavioral and biological experimentation on radio-frequency energy is a spotty chronicle that began in the 18th century when Luigi Galvani observed that the isolated leg of a frog would twitch upon brief activation of a remote spark-gap transmitter (see Presman, 1970, p. 3). Much later, a few years before the turn of the 19th century, Jacques d'Arsonval (1893) radiated intact mammals with radio-frequency energy and recorded both physiological and gross behavioral reactions. d'Arsonval's observation of elevated temperatures in his radiated animals marked the beginning of *diathermy*, the medical term for heating of tissues by radio-frequency energy. Nearly half a century passed before the first semblance of concerted investigative activity began—this for the greater part in the Soviet Union, where a number of investigators, many of Pavlovian persuasion, began to probe for behavioral and biological effects of exposure to radio-frequency fields. The researches by Soviet and other Eastern European investigators through 1966 have been well summarized and synthesized by Presman (1970), the distinguished Soviet biophysicist.

The interpretive thrust of the eastern Europeans' studies of animals and of case histories of human beings employed near industrial or military sources of radio-frequency energy is that chronic exposure to microwave radiations results in a *neurasthenic syndrome*. Headache, fatigue, weakness, dizziness, moodiness, and nocturnal insomnia are typically reported symptoms (cf. Marha, 1970; Tolgskaya & Gordon, 1973).

Concerted biological investigations of radio-frequency energy first got underway in the United States during the middle 1950s, largely through the aegis of the Department of Defense. This joint effort by scientists, who were supported by all three military services, faltered and died in the early 1960s for want of sustained funding (cf. Susskind, 1970). The impetus for a renaissance of research activity in the United States occurred in the late 1960s because of political events in the Soviet Union. The interpretation of biological data from the so-called Tri-Service studies (see, e.g., Peyton, 1961) had been at variance with the Soviet's interpretation—American rats and dogs apparently did not develop the neurasthenic syndrome, even after intense radiation by microwaves in the laboratory. Many American servicemen and technicians who worked in proximity to radar and other radio-frequency devices were examined by physicians, but to my knowledge reliable evidence of the syndrome was never reported in the United States. Indeed, the clear implication of the majority of the experimental and case data reported by U.S. investigators has been negative for all but simple heating effects. What triggered a renewed outpouring of support for research on microwaves, once again spearheaded by the Department of Defense, was described by Jack Anderson (1972) in his syndicated column in the *Washington Post*. Reading like the scenario of a novel by Ian Fleming, the column related how the U.S. Embassy in Moscow had been bugged clandestinely for several years by the Soviets, who had presented Ambassador Averell Harriman in 1945 with a handsomely carved Great Seal of the United States. An electronic bug was in the seal, and the seal was in a room where privy conversations among U.S. officials were supposed to take place. These conversations were actually overheard by the Soviets over the next seven years; however, a check by U.S. security experts in 1952 revealed the bug and subsequently brought forth additional experts who made periodic inspections for presence of other electronic eavesdropping devices. During one such sweep in Moscow in the early 1960s, it was discovered that the Soviets were directing beams of microwave energy at the U.S. Embassy.

American intelligence agents were understandably curious, but they did not want their Soviet counterparts to know that the microwave bombardment had been detected. Enter the Advanced Research Projects Agency (ARPA), an arm of the Executive Office that specializes in getting fast answers to far-out questions that may bear on national security. Agents for ARPA contacted Joseph C. Sharp, former director of research in experimental psychology at the Walter Reed Army Institute of Research, and an electronic engineer, Mark Grove, who began to put together at Walter Reed what is now one of the best equipped laboratories in the United States for studying biopsychological effects of microwave radiations. Additional behavioral, engineering, and medical scientists throughout the United States were also brought into the investigative effort through research contracts. By the early 1970s, ARPA's support of microwave research had largely faded, ostensibly because of the enactment of the Mansfield Amendment. The fiscal slack has since been picked up by the three military services, by the Bureau of Radiological Health of the Food and Drug Administration, and by the Environmental Protection Agency. In spite of much investigative activity supported by these agencies and the recent convening of several international symposia on microwaves (see, e.g., Cleary, 1970; Czerski, 1974; Tyler, 1975), the Soviet's motives in radiating the U.S. Embassy have never been clarified. One speculation is that the Russians were doing it to "bug" the United States, not in the sense of surreptitious surveillance, but to frustrate the U.S. military's curiosity. Jack Anderson suggested that the Soviets may have been trying to induce the neurasthenic syndrome in American embassy officials.[1] I discount this possibility. But it should be noted that Soviet officials voiced suspicions that minions of Bobby Fischer may have bombarded Boris Spassky with microwaves, thereby causing the latter to lose his championship in their famous chess match (Wade, 1972). Recently reported investigations by Soviet scientists (see Czerski, 1974) have convinced me of the sincerity of their belief in the neurasthenic syndrome, but the bases for the differing convictions of Soviet and U.S. scientists about the syndrome and other alleged hazards of low-density microwave radiation are yet to be resolved.

Impact by Psychologists

One of the American pioneers of microwave research is Allan Frey (see, e.g., Frey, 1961, 1965; Frey & Messenger, 1973), a free-lance biophysicist and engineering psychologist. Frey's major accomplishment was discovery or at least confirmation and dissemination of one of the more intriguing data that link microwaves and behavior. Human beings can "hear" microwave energy. The averaged densities of energy necessary for perception of the hisses, clicks, and pops that seem to occur inside the head are quite small, at least an order of magnitude below the current permissible limit in the United States for continuous exposure to microwaves, which is 10 mW/cm^2.

To "hear" microwave energy, it must first be modulated so that it impinges upon the "listener" as a pulse or a series of pulses of high amplitude. At first spurned by most microwave investigators in the United States, the radio-frequency hearing, or Frey effect, was repeatedly dismissed as an artifact until behavioral sensitivity to low densities of microwave energy was demonstrated in rats in an exquisitely controlled study by Nancy King (see King, Justesen, & Clarke, 1971). Shortly after completion of the study and its informal dissemination via the invisible college, the skeptics began to appear in appropriately equipped microwave laboratories in the United States with requests to "listen to the microwaves." A majority was able to "hear" the pulsed microwave energy, thereby belatedly confirming the claims made by Frey for nearly a decade.[2]

Recent work reported by Foster and Finch (1974) suggests that the Frey effect may be a thermohydraulic phenomenon. The authors suspended a microphone in a container of water that was radiated by pulsed microwaves at low-averaged densities of energy. The microphone delivered signals to an amplifier, the audio output of which was not unlike that "heard" by directly radiated human subjects. Since water changes density as its temperature is altered, the minuscule thermalizations produced in it upon absorption of the pulsed microwaves were sufficient to initiate small but detectable changes of hydraulic pressure.

Sonic transduction of pulsed microwaves at low-averaged densities has been demonstrated by Sharp, Grove, and Gandhi (1974) in materials lacking in

[1] Jack Anderson mentioned that the subject of the microwave bombardment of the U.S. Embassy in Moscow was on the agenda when President Lyndon Johnson met Soviet Premier Aleksei Kosygin at the Glassboro Summit Meeting in June 1967. One informant told Anderson that Johnson personally requested Kosygin to order a halt to the radiation of the Embassy.

[2] There is irony here worthy of parenthetical comment. Consider that subspecies of human being, the experimental psychologist, who distrusts introspective data so thoroughly that a proposition based on them is considered highly suspect until corroborating data are observed in lower animals. The irony in the present case is that the demonstration of behavioral sensitivity to microwaves by a dumb animal does not imply that the animal is having an auditory "experience." I was dubious about the Frey effect until I saw rats react to low densities of pulsed radiation; this conversion occurred despite my being one of the sizable minority that cannot hear microwaves under direct radiation. The other side of the coin of paradox is exemplified by a colleague, a confirmed cynic, who, while being irradiated in my presence, said, "Well, I can hear the goddam microwaves, but I still don't believe it!"

water, for example, in carbon-impregnated plastic and in crumpled sheets of aluminum foil. Even subjects who cannot hear microwaves when directly radiated by them can readily perceive clicking sounds when a piece of energy-absorbing material is interposed between the head and a radiator of pulsed microwave energy. Oddly enough, the mass of the interposed material does not seem to be too critical; I successively used smaller and smaller pieces of material as sonic transducers until it was necessary to impale tiny pieces on a toothpick, yet the clicking sounds induced in the material by microwave pulses were clearly audible to me.

The demonstration of sonic transduction of microwave energy by materials lacking in water lessens the likelihood that a thermohydraulic principle is operating in human perception of the energy. Nonetheless, some form of thermoacoustic transduction probably underlies perception. If so, it is clear that simple heating as such is not a sufficient basis for the Frey effect; the requirement for pulsing of radiations appears to implicate a thermodynamic principle. Frey and Messenger (1973) demonstrated and Guy, Chou, Lin, and Christensen (1975) confirmed that a microwave pulse with a slow rise time is ineffective in producing an auditory response; only if the rise time is short, resulting in effect in a square wave with respect to the leading edge of the envelope of radiated radio-frequency energy, does the auditory response occur. Thus, the rate of change (the first derivative) of the wave form of the pulse is a critical factor in perception. Given a thermodynamic interpretation, it would follow that information can be encoded in the energy and "communicated" to the "listener." Communication has in fact been demonstrated. A. Guy (Note 1), a skilled telegrapher, arranged for his father, a retired railroad telegrapher, to operate a key, each closure and opening of which resulted in radiation of a pulse of microwave energy. By directing the radiations at his own head, complex messages via the Continental Morse Code were readily received by Guy. Sharp and Grove (Note 2) found that appropriate modulation of microwave energy can result in direct "wireless" and "receiverless" communication of speech. They recorded by voice on tape each of the single-syllable words for digits between 1 and 10. The electrical sine-wave analogs of each word were then processed so that each time a sine wave crossed zero reference in the negative direction, a brief pulse of microwave energy was triggered. By radiating themselves with these "voice-modulated" microwaves, Sharp and Grove were readily able to hear, identify, and distinguish among the 9 words. The sounds heard were not unlike those emitted by persons with artificial larynxes. Communication of more complex words and of sentences was not attempted because the averaged densities of energy required to transmit longer messages would approach the current 10 mW/cm^2 limit of safe exposure. The capability of communicating directly with a human being by "receiverless radio" has obvious potentialities both within and without the clinic. But the hotly debated and unresolved question of how much microwave radiation a human being can safely be exposed to will probably forestall applications within the near future.

The U.S. limit of 10 mW/cm^2 is actually an order of magnitude below the density that many investigators believe to be near the threshold for thermal hazards (Schwan, 1970). There are two camps of investigators in the United States, however, who believe that the limit is not sufficiently stringent. In the first camp of conservatives are those who accept the Soviet's belief that there are hazardous effects unrelated to heating from chronic exposures to fields of low density (< 1 mW/cm^2); some agree with Milton Zaret (1974), a New York ophthalmologist, who holds that severely debilitating subcapsular lesions of the eyes may develop years, even decades, after exposure to weak microwave fields. Others tend to reject the notion that weak microwave fields produce this anomalous cataract, because of lack of substantiating evidence from the clinic or the laboratory (Appleton & Hirsch, 1975). But these conservatives are possessed of a vague unease simply because the Soviet's limit of continuous permissible exposure is three orders of magnitude below that of the United States.[3]

The other camp of conservatives tends to reject the possibility of hazardous nonthermal effects,

[3] The Soviet's exposure limit of 10 $\mu W/cm^2$ is three orders of magnitude below the exposure limit in the United States, but a different, that is, *emission,* limit holds for microwave ovens purchased for use in the American kitchen. In the United States at the present time, a newly purchased microwave oven may not emit radiation at a density greater than 5 mW/cm^2 as measured at a distance of 5 cm from the oven's surface. A user who stands 1 m from an oven that emits energy at the maximum permissible quantity would probably be exposed to a density of only a few microwatts per square centimeter—this is because electromagnetic energy when radiated from a point source attenuates markedly as it propagates through space.

Laboratories, took the lead in squeezing the last eliminable error from the determination of energy dosing. Hunt and his colleagues (see, e.g., Hunt, King, & Phillips, 1975; Phillips et al., 1975) developed a special twin-well calorimeter (Figure 4) into which suitable models or carcasses of a control and an irradiated animal are placed immediately after microwave treatments. Differential calorimetry is then used to measure the amount of energy absorbed by the radiated target, either in the multimode cavity or in the free field. When quantities of absorbed energy at high dosing levels were subsequently equilibrated for live animals in the cavity and in the free field, Hunt and his colleagues observed that death rates were much higher from exposures in the free field. One would expect this difference because the animal in the cavity is absorbing energy that is incident from all angles while the animal in the free field is illuminated unidirectionally (calling to mind the discomfiture of the naked child in a cold room as he stands in front of an overheated potbelly stove).

The comparisons by Hunt and his colleagues involved mice and rats in restraint under irradiation by moderate to high densities of microwave energy. The bodily restraint, which is used in the free field to maintain constancy of energy dosing, can interact as a stressor with microwave-induced hyperthermia to increase morbidity and mortality (cf. Justesen, Levinson, Clarke, & King, 1971; Justesen et al., 1974). Comparisons of cavity and free-field exposures of restrained subjects at lower densities of energy would be desirable on two grounds: first, if the energy incident upon an animal in the free field is not too intense, the gradient of temperature between exposed and unexposed areas of the body will be reduced by convective dispersion of heat by the blood stream; and second, the study of operant and respondent behaviors can best be realized in animals undebilitated by excessive heating. The appropriate comparison of behaviors of subjects under low to moderate densities of microwave energy has been undertaken by Lin, who trained rats to accept restraint in a body holder (Lin, Guy, & Caldwell, Note 6). Slight movement of the head of a restrained subject was possible, and it was this movement that Lin used as an operant response. During pretraining, a restrained animal was reinforced with a food pellet each time its head interrupted a photoelectric beam until responding during short daily sessions had stabilized. Then Lin et al. irradiated the animals with 918-MHz microwaves in the free field, first at low densities and then at successively increased densities until the head-moving operant extinguished. The absorbed-energy dosing rate at the threshold of extinction was near 8 mW/g, a value that agrees closely with that reported for comparable measures on rats exposed in the multimode cavity by Justesen and King (1970) and by Hunt et al. (1975). One may surmise, at least tentatively, that the behavioral and biological response to exposures in the cavity and in free field are more likely to be comparable at low densities of radiation and increasingly divergent at increasingly higher densities. One may also surmise that free-field exposures to microwave energy, insofar as they produce unevenness of heating in an experimental animal, are much more likely to be thermally stressing in the psychological sense. The quintessential characteristic of psychologically adequate stimulation is change either temporally or spatially. In the absence of change, or in the stead of change that occurs too slowly, even intense energy may not be behaviorally stimulating. Scripture (1899, p. 300) recounted how a frog never so much as twitched, as the water in which it was immersed was slowly brought from body temperature to the boiling point. King (1969) recounted a similar experience with rats long inured of exposures in the multimode cavity to mildly thermalizing radiation. During radiation treatments the animals became immobile and appeared to go to sleep. I thought her animals were displaying the neurasthenic syndrome until she measured their body temperatures and found they were suffering from something akin to heat prostration!

Epilogue

Focused as it was on methodology and instrumentation, this article has skirted much information that relates psychology and psychologists to the biological study of electromagnetic fields. Among the omissions is the special concern for behavioral variables manifested by most basic and medical scientists currently working "in the microwave field." Much of this concern is actually homage to the reliability with which behavioral effects have been demonstrated and duplicated in the radiobiological laboratory. Behavior has become a major "handle" or end point in attempts of scientists to get a purchase on the biophysical and physiological events that occur in the radiated organism. What these scientists have discovered is that the central nervous system is a biological amplifier whose output as manifested in behavior provides a highly sensitive litmus of reactivity to electromagnetic energy. This sensitivity, particularly the demonstration of the Frey effect, will inevitably give rise to the question, Are there substantive implications here for paranormal phenomena, especially from the vantage of the Soviet scientist for whom ESP means "electrosensory" (not extrasensory) perception? I am not prepared to answer beyond this caveat: Under optimal experimental conditions, the quantity of microwave energy that is necessary for direct transfer of information to a human being is many orders of magnitude greater, say, than the photic or acoustic energy associated with a threshold response to visual or auditory stimulation. Perhaps there are electromagnetic receptor systems in us as yet undiscovered with sensitivities comparable to or even greater than that of the visual and auditory systems. This possibility, however, is bankrupt of operational meaning without a corollary demonstration of specific electromagnetic radiation by the human organism. Without a transmitter, a receiver is useless. Except for an incoherent flux of infrared energies that are broadcast from our bodies as the residue of metabolism, there are no known electromagnetic emissions of sufficient energy to warrant more than the most guarded of speculations. Not at all a cynic, but very much the skeptic, I conclude:

ElectroMagnetic receivers we are.
A light-wave we can see;
As E-M emitters our wave fronts are weak,
Hardly enough for ESP.

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but holds that there are thermal hazards even in microwave fields of low-measured density. To understand the qualms of these conservatives, the reader needs be informed that the data used to establish the current U.S. limit were for the greater part gathered under highly controlled conditions in the laboratory with simulated biological targets (see Anne et al., 1961). Hollow glass spheres containing mixtures of fluids that duplicated the net electrical characteristics of the contents of the human head were radiated in what is technically termed the "free field," that is, under conditions in which no reflected energy illuminates the target, only that radiated by the source. Under actual conditions where microwave radiations at fairly high densities are encountered by human beings, for example, aboard ships, in or about aircraft, or near ground-based radars, there are nearly always reflective surfaces that could reflect additional energy on a biological target. Unfortunately, additional concentrations of reflected energy may not be detected by densitometers because of their high directional sensitivity. A radio-frequency field that measures low in density may actually contain significant levels of energy. Such was the finding in a collaborative investigative venture by the engineer Arthur Guy and psychologist Susan Korbel.

Guy and Korbel (Note 3) radiated models of rats in a 500-MHz microwave field that, as carefully measured by several densitometers, appeared to have an incident density near 1 mW/cm². Activity levels of radiated rats had earlier been found to differ reliably from levels of controls after exposures at this low density (cf. Korbel, 1970; Korbel-Eakin & Thompson, 1965). Guy and Korbel were aware that the exposures had taken place in an electrically shielded enclosure. Since the shielding created the possibility of undetected reflections and concentrations of energy within the enclosure, thermographic studies were performed on radiated models. Extremely high concentrations of thermalized energy were found, some of sufficient density that they would result in focal burns in the heads and extremities of live animals. The hot spots observed in the models would be less severe in a live animal because of partial thermal equilibration by the circulatory system; of major interest is that the total amount of energy absorbed by the models was often much higher than what would be predicted from the measured density of the microwave field. Guy and Korbel's data are a clear vindication of suspicions by other investigators that the exclusive use of field density as the independent variable in biological studies of microwave irradiation is an egregious shortcoming (cf. Johnson & Guy, 1972; Justesen & King, 1970).

In 1967, Nancy King and I sought to resolve the problem of accurate scaling and dosing of microwave energy in laboratory studies by two means. The first was to use the multimode cavity, now widely in domestic use as the "microwave oven," as the medium for exposing experimental subjects. The quantity of microwave energy absorbed by an animal in such a cavity can be closely metered and controlled (Justesen, Pendleton, & Porter, 1961; Justesen & Pendleton, Note 4). Justesen, Levinson, Clarke, and King (1971) transformed the cavity (a Tappan microwave oven)

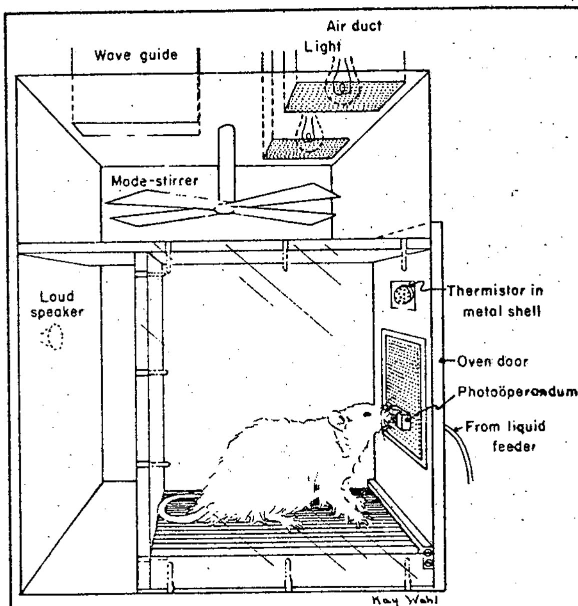

Figure 3. Plexiglas conditioning chamber located in a multimode cavity. (Microwave energy enters the cavity from the wave guide and is mixed by a slowly rotating mode stirrer so that it impinges on the animal in the chamber from all angles. A photodetector of the licking response, a liquid feeder, and a special grid for presenting electrical shocks to the feet provide for operant and/or respondent conditioning of an animal during radiation. A steady stream of cooled air flows from an air duct into the cavity and the chamber and out of small holes in the door of the cavity. Temperature in the chamber is monitored via an electrically shielded thermistor.)

into an operant and respondent conditioning chamber that permits radiation during behavioral testing. The achievement of controllable energy dosing of animals in behavioral experiments was something of a challenge because we had to design and incorporate a special response-detection and payoff system for operant conditioning that would not interact with the microwave fields inside the cavity's conditioning chamber (King, Justesen, & Simpson, 1970). A similar challenge, that of providing a noninteractive source of aversive electrical stimulation for Pavlovian conditioning, was met by the design and incorporation of a faradic shocking device (Justesen, King, & Clarke, 1971).

We sought to cope with the energy-scaling problem by using calorimetric dosimetry; whereas the densitometer measures energy in proximity to a target, the calorimetric technique provides estimates of the amount of energy actually absorbed by a biological target (cf. Justesen & King, 1970; Justesen, Levinson, Clarke, & King, 1971; Justesen, Levinson, & Justesen, 1974). Taking our lead from the ionizing radiobiologists, we proposed a convention based on absorbed energy per gram unit of mass. Because of the high-photon energies of X- and gamma-rays, the rad—the standard unit of absorbed dose of ionizing radiation—is couched in relatively minuscule terms of only 100 ergs per gram. For the microwaves with their low-photon energies, we proposed that 10^7 ergs or one joule per gram (J/g) serve as the dosing unit of total absorbed energy. Since the joule per second is the time-complexed quantity of energy that defines the watt, we also proposed that the watt per gram (W/g) serve as the basic unit of rate of dosing.

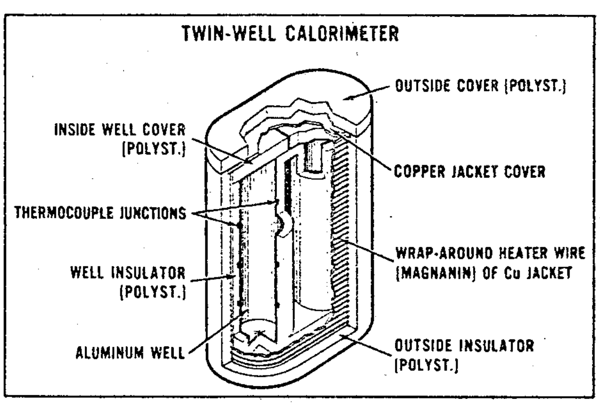

Figure 4. Schematic diagram of a twin-well difference-calorimeter developed at the Battelle Laboratories. (Highly precise measurements are made of the quantity of microwave energy absorbed by models or bodies of radiated animals. A reference or nonirradiated target is placed in one well, a radiated target in the other well; the difference in thermal loading is then detected by sensitive thermocouples.)

To estimate the amount of energy absorbed by an animal in a microwave field, we employ simple thermometry, the measurement of elevation of temperature (Δt) in phantom models by precision electronic thermometers. In the multimode cavity, the Δts of cylindrical models of water can provide an estimate within 10% of the energy actually absorbed by small animals of equivalent mass (Phillips, Hunt, & King, 1975). The quantity of energy in watts is readily calculated from the Δts and is then divided by the animal's weight in grams to yield the rate of dosing. A 300-g rat under pulsed 2,450-MHz radiations has a dosing-rate threshold of perception near .5 mW/g (King et al., 1971). To place this value in a meaningful perspective, one can compare it to the rat's ambient rate of energy production through metabolism, which is near 10 mW/g in a standard environment. A 60-sec exposure of a 300-g animal that is absorbing microwave energy at a rate of .5 mW/g would maximally increase its averaged body temperature by .01° C.[4]

The calorimetric dosing method is a substantial improvement for experimental purposes over the traditional scaling technique in which the measured density of energy as incident upon an animal is used directly as the independent variable or else to estimate (via rough rules of thumb) the deposition of energy in the animal. Where errors of measurement greater than an order of magnitude are possible and, indeed, probable, with the traditional, densitometric methods of scaling, the calorimetric technique reduced the error to less than 10%. A psychologist, E. Hunt of the Battelle

[4] The maximal rise of temperature is stipulated for the anesthetized animal. The awake, physiologically intact animal that is experimentally naive to radiation at detectable densities may exhibit an elevation of body temperature that is greater than that solely attributable to heating by microwaves. Apparently, the emotional activation induced by novel (or noxious) stimulation is associated with metabolic activation, and thus concomitant endogenous heating, which adds to the total thermal loading of a radiated animal (Justesen, Note 5). Unless there is a compensatory rise in rate of heat dissipation, an emotionally stressed animal may succumb from hyperthermia during radiation treatments that are not mortal for an habituated, unstressed, or anesthetized animal (Justesen, Levinson, Clarke, & King, 1971; Justesen et al., 1974).

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