Chapter 5: Developments*

Despite the testimony of industry experts and determined efforts by Handler, novel progressive conceptual and empirical developments in disparate areas of science added legitimacy to the issue of the hazards of electromagnetic energy. 1930–1977

Gold-standard studies were the basis of the decision about health risks in the New York hearing. The Sanguine decision, in contrast, was primarily grounded on Handler's model of biology and his ethos regarding technological progress. He believed that high-voltage powerlines and military antennas were beneficial, even if possibly hazardous, and expected people to adapt to what he regarded as the march of progress; he placed nil emphasis on the consequences for public health or considerations of social justice. Handler's vision went unchallenged because he was not answerable to anyone regarding his reasoning or values. His apoplectic response to the *Saturday Review* article indicated how shocked he was that his actions were called into question, how natural he felt in taking great umbrage when it happened, and how vicious his response could be. Handler's technical judgments regarding Sanguine and Pave-Paws weren't based on relevant scientific knowledge or expertise, but rather on biochemical dogma that questions concerning living systems are properly resolved only through study of their chemical parts, and that electromagnetic energy had no significant system-level role in such questions, and perhaps most of all on the hierarchy of his personal values. Nevertheless, because of his bully pulpit as president of the Academy, his judgments became the law in both cases.

I could not see, back then, how anything good regarding health risks from electromagnetic energy could come about. On one hand there was an ever-increasing rate of published gold-standard studies that collectively were pregnant with the notion of risk to public health from unregulated expansion of environmental levels of man-made electromagnetic energy. On the other hand, nurtured by Handler's enthusiastic commitment to the righteousness of his ideas and constitutional opposition to the validity of biological processes not fully explained in biochemical terms, the sub-specialty of biochemistry had become preeminently exclusive in experimental biology, leaving no room for any other sub-specialty and no governmental funding for biological studies of electromagnetic energy. Moreover, the power industry and the military which, on the grounds of expediency, strongly favored non-regulation of man-made environmental electromagnetic energy, employed their massive financial resources to create an atmosphere of doubt and disdain regarding energy-related health risks. But as it happened, important scientific developments that pointed to the possibility of a way out of the dilemma had already begun in physics, post-reductive biology, biocybernetics, and bioelectromagnetic explorations. At the same time Handler was waging his fight, pioneer investigators asked questions that he

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had ignored or never even imagined. They made assumptions different from his, employed methods he rejected, used mathematics that was beyond his ken, and manifested the ethos of medicine for which he had demonstrated little regard. The collective efforts of the pioneers began to paint a picture of what a more human-oriented science of biology might look like. Becker was the pioneer whom I knew best, but many others also made impressive contributions, especially those whom I will now describe.

Prigogine

The most far-reaching development that occurred in physics was a modification of the second law of thermodynamics by a physicist named Ilya Prigogine. His work was stimulated by observations suggesting that reductionism was not always a sufficient model for inanimate nature, as had been supposed. The first biochemists had modeled biology on the cognitive structure of physics, so Prigogine's work had profound significance for biology including the issue of how electromagnetic energy could cause biological effects. Reliable gold-standard studies based on observations and statistical reasoning had shown empirically that the effects were valid. Prigogine's work validated, at the level of physical theory, the *possibility* of biological effects of electromagnetic energy. Such validation was unnecessary to establish the reliability of the gold-standard studies because that had been proven by means of the scientific method. Nonetheless, Prigogine's work was a significant intellectual achievement that merited the Nobel prize he was awarded, and was a warning to physicists who would purport to tell biologists what biological behavior was or was not possible.

When Prigogine began his studies, physics consisted of a group of deductive mathematical theories confirmed by observation, whereas biology, a subject in which he then had no interest, was a group of systematized observations and induced principles, like evolution. All theories of physics related to cases where the object of study was assumed to be made of independent parts and could be studied individually for purposes of explaining the behavior of the object. Because the theories were invented for objects that could be reduced to parts, the theories always predicted that the behavior of any object was reversible in the sense that its behavior was equally likely to occur regardless of whether time moved forward or backward. There were no theories regarding the behavior of an object that was irreversible in the sense that its behavior always moved in only one direction, forward. But biological processes are inherently and invariably irreversible—there are no observations, as examples, of a chicken turning back into an egg or an adult turning into a child. For that reason, the theories didn't apply to any phenomenon unique to living objects, including life itself, the concept of which was intentionally excluded from the theories of physics. The theories explained everything of interest to physicists but almost nothing that biologists considered truly important.

This fundamental dichotomy between the theoretical focus of physics on reversible processes and the observational focus of biology on irreversible processes historically created chronic low-level antagonism between physicists and biologists, which I saw from the earliest days of my training. The physicists who trained me disdained biology because it had no theories and never deductively explained anything. They were particularly contemptuous of the principle of evolution. The second law of thermodynamics asserted that, left on its own, everything decays—a chair left in a forest eventually turns to dust. In the eyes of physicists, Darwin had effectively claimed not only that dust could spontaneously turn into a chair, dust could even turn into humans—blatant violations of the second law. Physicists did not regard biology as a serious science, and this hubris was what led Schwan to insist that the theories of physics made it virtually impossible for electromagnetic energy to affect animal or humans, regardless of what the biologists thought they observed. A cock-sure Schwan, in turn, emboldened Handler to mock Becker for suggesting the possibility that Sanguine-level electromagnetic energy could be a health risk.

Prigogine created a novel theory that described the behavior of irreversible chemical systems, whether inanimate or animate. In doing so, he explained a *possible* basis for observations such as Darwinian evolution, that under the right circumstances, something manifesting order and structure could emerge spontaneously from nothing recognizable as its antecedent, like dust. Prigogine's research didn't merely involve observations of the phenomenon of spontaneous order—that had already been done by others while studying the behavior of heated water in test-tubes containing dissolved chemicals. He presented a full-fledged theory from which such phenomena were deductive consequences. The right circumstances to permit order to emerge from disorder was that system had to be "far from energy equilibrium," meaning that the system was completely dependent on a continuous supply of energy from external sources—so dependent that if the flow of energy ceased the ordered structure would immediately disappear. Put another way, the system could not be composed of physically separable parts—take away one of the parts and you take away the process itself and the order it produced. Evolution was a perfect instantiation of Prigogine's theory because there was nothing more ordered and structured and farther from energy equilibrium than a human being. His work amounted to formal recognition by physicists that life was possible.

What about the second law? Prigogine provided two possibilities. Retain it as it stood and confine all theorizing in physics to reversible systems, in other words, formally divorce physics from biology. Alternatively, interpret the law to incorporate principles that would make it applicable to irreversible systems, living or otherwise. In other words, change the meaning of the law so that observation of a system that runs backward, from disorganization to organization, isn't illegal.

Prigogine's work had nil practical effect on physics orthodoxers because they were almost exclusively concerned with reversible systems. There was also no dramatic effect on biology. Most research biologists were biochemists, and for them the old ways based on reductionism were good enough. In addition, Prigogine expressed his results in the language of mathematics, which biochemists eschewed. Nevertheless, he supplied the correction that allowed physics to formally recognize the existence of life and the validity of postreductionist biology. Thus, even for physicists, the study of the biological effects of man-made electromagnetic energy, and of the laws that governed the biophysical processes by which the phenomena occurred, were legitimate scientific activities.

Lorenz

About the same time Prigogine established a theoretical basis for undercutting the Handler-Schwan approach to health-risk analysis of electromagnetic energy, a meteorologist and mathematician named Edward Lorenz effectively impeached their arguments in a different way. He was interested in the proportionality between cause and effect in the context of the weather, a natural, inanimate, irreversible chemical system that is far from energy equilibrium. His research involved the use of computers to predict the weather based on mathematical models constructed using the theories of physics—which had been invented to describe reversible systems made of parts. He made the remarkable discovery that the theories of physics contained the latent prediction that weather was dramatically sensitive to infinitesimal changes in climate conditions. Lorenz described the result metaphorically as like the ability of a flap of a butterfly's wings in Brazil to set off a tornado in Texas. Even in his simplest models which contained only three variables, a tiny change in one variable could result in a drastically different prediction.

Schwan had published the results of calculations he said proved to a certainty that the levels of electromagnetic energy from powerlines and the Sanguine antenna were too low to cause biological effects. Handler had adopted Schwan's analysis and independently reached the same conclusion by reasoning from what he believed was a general biological principle—that extremely small levels of all noxious stimuli including heat, chemicals, sound, pressure, light, X-rays, and electromagnetic energy could not possibly produce adverse health effects. Lorenz's work, however, showed they were both wrong because there was no such thing, according to the theories of physics, as a stimulus that was too low to alter the behavior of a system that was far from energy equilibrium. Considering that an actual weather system contained about fifty million variables, Lorenz concluded that, because the weather was so sensitive to extremely small changes in conditions, weather predictions more than about one week in the future could never be more accurate than a guess, a sobering conclusion for those who believed that the natural world was completely predictable if only the right physical theories were utilized, and a clear indication of the limitations of what physics could promise.

Lorenz's work had dramatic implications for the issue of health risks from electro-magnetic energy. If "conclusive" scientific evidence of something relatively simple like the behavior of inanimate matter were impossible, demanding "conclusive" evidence of the reactions of human beings to electromagnetic energy, as Handler had done, was obviously absurd. His mechanical picture of life was dissolving, but he steadfastly remained blind to the developments that were occurring around him. References by him to the work of Prigogine or Lorenz were non-existent in his books, papers, speeches, and letters. Handler not only continued to maintain that the acid test for understanding a living system was the ability to build it from its component parts, he underscored his opinion by predicting that biochemists would someday manufacture cells in a test-tube and then join them together to form an animal. Handler stubbornly ignored the fact that the process Lorenz described, extreme sensitivity to small changes, could physically explain how man-made electromagnetic energy gave rise to legally recognizable health risks inferred from gold-standard studies.

Dubos

Rene Dubos was a biochemist who worked at the Rockefeller University for almost half a century. He originated the line of research that led to the discovery of antibiotics and was elected to the Academy in 1941, a time when there were few members who were not physicists and essentially no members who did medically significant research. During the next two decades, Dubos shifted his focus from test-tube biochemistry to post-reductive experiments in which he tested his theory that susceptibility to infection was influenced by the effects of metabolic products and environmental factors on the host's natural resistance to infection. He concluded from those experiments that biochemistry alone was inherently insufficient to understand who, when, and why someone would develop infectious disease, and developed the viewpoint that the states of health or disease were not biochemical constructs but rather adaptive responses of organisms to environmental challenges. He explained his opinions in an extraordinary series of books, including one that earned him a Pulitzer Prize.

Dubos understood the importance of biochemistry, to which he had contributed substantially, but he rejected as inadequate the strict reductionist view of living processes championed by Handler. Dubos saw life not as a collection of molecules but rather in terms of organization and the ability to adapt to change—the fundamental basis of evolution. But this inroad into the exclusivity of reductionism which Dubos saw as necessary, Handler and his fellow reductionists saw as unwarranted and invalid. They believed biochemistry would someday enable biologists to understand all the basis features of the living state, a belief that Dubos called a utopian "dream of reason." The better view of living things, according to Dubos, was not the Cartesian concept of living things as machines, but rather as things in unstable dynamic equilibrium with their environment—kinetic, not static as demanded by the reductionist outlook.

Dubos regarded the vision of a society in which biochemistry could make everyone healthy and banish disease as an unattainable medical utopia. He believed that the burden of disease on society would never decrease, but rather that disease would assume new forms thereby presenting new challenges to physicians and to society, challenges not amenable to a biochemical approach because they existed above the level of atoms. He made the case that every civilization creates its own diseases, that the continuing advance of medicine produces more problems than it solves, and that the oversimplified mechanistic theory of life entertained by Handler and those like him was an illusion. Dubos reasoned that "some unknown principle runs like a continuous thread through all living forms and governs the organization of their physicochemical properties." A strong candidate for that principle was later identified as information carried by electromagnetic energy, of which Dubos was unaware because the principle was then being discovered by other pioneers in areas other than biochemistry. But he knew enough to identify the painful mistake of always depending upon the analytical method, and never attempting a synthesis and never recognizing the feedback relationship between the organism and its environment.

The scientific and ethical contrasts between Handler and Dubos could not have been starker. They both began as orthodox biochemists, but along the way Dubos came to see that biology was far more than biochemistry, it was also a matter of human judgment regarding what we want life to be—the collective values of society, not a scientific fact, as Handler argued. Dubos was the long-time editor of the *Journal of Experimental Medicine*, and explained his scientific reasoning in thoughtful books that were unprecedented in their clarity, reliability, scientific basis, and ethical dimension. Handler wrote nothing other than a contribution to an elementary textbook. He always remained aloof, as if on a throne, and recognized no responsibility to explain or rationalize his philosophy of science or explicitly defend the biochemical creed. He never spoke publicly about Dubos, never appointed him to an Academy panel, and never accepted any invitation to review any of Dubos' books. Nothing Dubos said and no evidence he produced provoked Handler into an explicit defense of his position, so the two men simply talked past one another. Dubos famously said, "A society that blindly accepts the decisions of experts is a sick society." He argued, "It is essential that scientists discuss more thoroughly in public the implications of their findings with regard not only to the practical applications of science but also to its influence on the concepts of man's place in the order of things." Handler held diametrically opposite opinions. He believed that that the views of the experts he appointed to his panels were value-free and should be blindly accepted. He called scientists who spoke publicly "prophets of doom" and condemned their "overly emotional and irrational imaginings of future catastrophe." He was a man who knew the function of every type of molecule in the body but the value of none.

Wolff

Harold Wolff was a physician, a president of the American Neurological Association, and perhaps the most outstanding neurologist of the last century. He was also an accomplished medical investigator, a relative novelty in a time when medical research was dominated by PhD biochemists. He was the editor of the *Archives of Neurology* and wrote hundreds of papers and many textbooks dealing with the forms of human pathology and disease that stemmed from dysregulation of the nervous system. Wolff brought to basic medical research the component of human compassion that is unique in those who treat the sick and see their suffering first-hand, but alien to those who never leave the laboratory and pursue knowledge for knowledge's sake.

The common denominator in Wolff's clinical and scientific work was his attention to the role of the nervous system as the master organizer of the complex reactions inside a human being that occur in connection with changes in the internal and external environments. He presented extensive clinical evidence showing that an unidentified but indubitably real regulatory system protected the individual despite continuous changes occurring inside the body and the presence of diverse time-dependent factors in the environment. The external stimuli consisted of infectious agents and chemicals, and also of neurogenic factors resulting from involvement with other people that resulted in fear, anger, and/or threat. When the limits of the normal adaptive reaction pattern controlled by the body's regulatory system were exceeded, the body responded with a reaction that was self-destructive, as manifested in common maladies such as peptic ulcer, hypertension, colitis, and migraine headaches. This idea that both somatic and neurogenic stresses of life incite bodily disease was Wolff's best-known contribution to medicine. The idea unified human pathology by emphasizing that the pathological reactions occurring in man depended on goals, purposes, aspirations, and values, as well as on physical agents.

Wolff also studied headache pain and developed a theory that the primary source of the pain was a disturbance in the brain's regulation of cerebral blood vessels—tension caused vasoconstriction and fatigue caused vasodilation—as a reaction to the inability of the patient's body to cope with the stresses of life. Wolff's investigations of the relationship between the stresses encountered in life and bodily disease profoundly influenced the modern concept of diseases and helped explain them as outcomes of attempts at adaptation. He saw human pathology as a failure of biological regulation, and recognized a clinical responsibility to treat it and a scientific obligation to identify its causes with the aim of preventing it. The scientific method he developed, cause-effect associations manifested at the system level, was perfectly suited to his objectives. But in Handler's perspective, the method was inferior because it was not reductive, and was motivated by teleological principles which Handler believed had no place in biology.

Selye

Hans Selye was a physician and biochemist who Worked at McGill University and the University of Montreal. His work laid a physiological foundation for the understanding of the role of system biology in medicine, and a scientific foundation for the legal admissibility of evidence regarding public-health impacts of environmental pollutants including but not limited to electromagnetic energy. He was probably the most important heterodoxer of the pre-Becker era.

Early in his career, Selye observed that patients with diverse chronic illnesses displayed a common set of symptoms. At that time, the practice of medicine was based on the identification of symptoms that were specific for each disease, a procedure then regarded as necessary and sufficient for diagnosis and treatment. Contrary-wise, Selye believed that understanding the reasons patients with diverse diseases exhibited similar symptoms was also important, and that such knowledge might improve treatment of all diseases. Throughout the 1930s, he pursued his interest in different-causes/same-effects biophenomena by exposing animals to a diverse range of agents that he collectively called "stressors"—heat or cold, toxic chemicals, trauma, too much or too little exercise—and observed that they caused a common pattern of system-level responses. Orthodox biochemists, the originators of the one-disease/one-symptom theory, believed that every physical agent had a specific biochemical effect, and that the purpose of research was to identify the responsible biochemical entities. But the orthodoxers were strict reductionists and recognized no scientific method other than test-tube studies, whereas effects and symptoms occur only at the system level. Selye's chief told him that studying common effects was a waste of time, like "studying the effects of dirt," and advised him to begin another line of research. Selye persisted anyway, recognizing, I suppose, that research pertinent to human health often best begins with system-level studies in humans and animals. Funded by philanthropic groups, he performed animal studies and discovered the extraordinary fact that the effects of stressors were mediated biochemically by a small group of hormones produced by the brain and the adrenal gland. He proved that the hormones brought about the common effects by regulating the immune system and nervous systems, and that the complex interactions were all orchestrated by the brain. That was the first time in biological modernity that specific agents were identified as the cause of non-specific system-level effects.

During further research, Selye observed that the same hormones triggered by somatic stressors—heat or cold, toxic chemicals, trauma, too much or too little exercise—were also triggered by psychological factors like fear, anger, and anxiety, indicating that psychological factors could also be stressors. Descartes had postulated that a human being was composed of a "machine" body and an ethereal principle he called a "soul" but which later became called a "mind." Selye's work showed that the mind and the body were essentially the same thing in the sense that both somatic and neurogenic stressors elicited identical biochemical responses.

Selye developed a theory to explicate the medical significance of his work. He asserted that humans had evolved multiple defenses to defend against harmful agents, and consequently that most diseases had multiple causes in the sense that more than one of the body's defenses must be weakened for disease to occur. The hormones he had identified, he said, mediated the system-wide process for adapting to stressors. The system served the teleological purpose of maintaining normal homeostasis, a system-level state synonymous with health, by initiating and controlling appropriate responses to stressors; in response to a cold stressor, for example, the system would initiate a shiver response and in response to a heat stressor the system would initiate perspiration. By continuously altering the balance and effects of the hormones, the adaptive process mitigated damage from the totality of the stressors to which a subject was exposed.

For each individual, according to Selye, the unique set of stressors in the external environment, taken together with stressors in the subject's internal environment that reflected past behavior including food, drugs, and previous diseases determined whether homeostasis was successfully maintained. If a maladapted state developed, the unique mix of stressors would determine the particular pathological result. Selye developed a unique vocabulary to communicate his ideas. He used "resistance" to describe the body's tendency to resist changes in homeostatic levels, and "stress" to describe the internal force tending to bring about the changes. In most instances he used the term with a negative valence, particularly so beginning during the Second World War, when clinical diagnoses of "combat stress" became common after it turned out that combat stress activated the same set of hormones that Selye had identified in connection with adaption to temperature changes, toxic chemicals, trauma, poor exercise, or psychological factors. Thus, in Selye's language, a "stressor" caused "stress" by taxing "resistance." The respective corresponding observables were identifiable physical agents or circumstances, changes in symptoms or behavior, and increased rates of disease. Stress could produce the feeling of wellness and happiness, but it became significant in medicine because of its links to symptoms and disease.

Selye vigorously promoted medical and popular awareness of "stress," and intractable opposition from orthodoxers developed immediately. Selye's "stress" was purely a system-level phenomenon, like health or homeostasis or life or disease or healing or consciousness. Consequently, if "stress" were to be studied scientifically, the studies perforce had to be system-level studies—"stress" had no unique biochemical definition. But the orthodoxers recognized only knowledge that was generated in test-tube studies based on the philosophy of using reductionism. Thus the interests and approaches of Selye and the reductionists were incommensurate.

The result of adaptation was observable in the individual but was actually composed of highly individualized specific biochemical responses to a unique mix of stressors. The biochemical changes, taken together, created the state of stress, but no method was possible to measure all the individual changes in individual patients. This principle regarding "stress" was as final and certain a statement about biology as the uncertainty principle was about physics.

The symptoms of stress were general musculoskeletal pain, headache, lethargy, and mood changes such as anxiety and depression. The state of stress could be proven in two-stressor gold-standard studies, but such studies were expensive, time-consuming, of no importance in the eyes of the orthodoxers, and of no use diagnosing stress in a specific patient. Unsurprisingly, few double-stressor studies were performed. The essential subjectivity of the symptoms of biological stress in a specific person on the one hand, and the unremitting antagonism of biochemical orthodoxy that demanded any “real” disease could be rationalized only by means of a blood, tissue, or DNA test, guaranteed that the progress in recognizing and treating stress could be won only slowly.

Selye was widely recognized for his discoveries. He published well over a thousand papers and about fifty books and was frequently nominated for a Nobel Prize. But he failed to overcome the hostility of orthodoxers, who monopolized the peer-review committees that dispensed the funds he needed for his research and denied him recognition in their textbooks. He survived by attracting funds from charities, companies, and the U.S. and Canadian governments. He focused his research to appeal to the concerns of patient consumers for relief from chronic symptoms and anxiety neuroses, which he interpreted as the clinical manifestations of stress. He recommended anxiolytic and adrenocortical medications, and achieved validation for stress in the medical marketplace. He counseled that willpower and self-awareness were the most effective therapeutic methods for dealing with stress, and insisted that individuals must identify their own unique stressors and develop personal therapeutic strategies; his suggestions included reading a book, taking a walk, listening to music, or smoking a cigarette.

Selye’s diagnostic method involved identifying the patient’s symptoms and conducting a detailed history to assess the known stressors experienced by the patient; a treatment plan of drugs and specific avoidance was then formulated. Selye always began with a symptomatic patient—he never considered the possible adverse physiological consequences of a stressor that didn’t cause symptoms. A patient who was healthy one day and diagnosed with cancer the next day, therefore, fell outside Selye’s clinical stress paradigm. But under that paradigm, any agent that activated the hormonal system he had discovered could be a stressor. And any stressor could be a but-for cause of cancer or any other disease because all stressors taxed body resistance. The first observations that I know about which suggested man-made electromagnetic energy was a biological stressor were made by Barnothy and by Becker in the 1960s. Becker and co-workers reported that exposure to environmental electromagnetic energy was correlated with admissions to psychiatric hospitals, and that laboratory electromagnetic energy altered human reaction times, contributed to pathological changes in rabbit brains, and altered the stress hormones in monkeys. Although Selye’s work generated the insight that led them to perform their studies, Selye himself never publicly recognized the possibility that electromagnetic energy was a stressor.

After Becker’s research had become well known I asked Selye why he had not publicly acknowledged that his research was an obvious basis for explaining the link between electromagnetic energy and disease. In the end I got no clear answer but gained the impression that his decision was motivated by a desire to protect his business model. He had survived for many years despite hostility to his experimental methods and the scientific questions he pursued, and by the time I knew him his research days had ended and he had settled into a comfortable clinical niche. I thought that he had decided he didn’t need additional overt hostility from the interests that Becker had antagonized. I came away from our contact with the impression that he was a great man who, after a half century of conflict with orthodoxers and granting agencies, had grown weary and wanted to remain in the shadows. The only public statement he ever made about man-made electromagnetic energy was to tell the author of the *Saturday Review* article about Handler that the expert on stress induced by electromagnetic energy was Becker, not him.

Szent-Gyorgyi

Selye's research on stress and adaption laid a biological foundation for explaining how man-made electromagnetic energy could lead to disease. Like Dubos and Wolff, Selye used post-reductive experimental designs to study health and disease directly, without the necessity of first studying biochemical entities in test-tubes. Albert Szent-Gyorgyi, a prominent orthodoxer who became an advocate of the idea of system biology late in his career, followed the opposite research path, grounding his research into the biological consequences of electromagnetic energy on ultra-reductive experimental designs.

Szent-Gyorgyi had made ground-breaking discoveries regarding the biochemistry of muscles, won a Nobel Prize for his biochemical research of vitamins, and once told me he should have won a second Prize, the one Krebs got for metabolic studies that had so impressed the young Philip Handler and which Szent-Gyorgyi said had been done in his lab. He reflected on what he and other biochemists had accomplished and concluded there was something wrong with biochemistry because it had failed completely to explain what life is, or how or its principle attributes such as growth and healing were regulated. He expressed this view many times, most poignantly in a story he told one evening during a dinner. He held his hands palms up and said I should imagine he was holding a live rat in one hand and a dead rat in the other, and then he asked what the difference was between the two rats. I told him I didn't know, and he said it couldn't be biochemical agents because they were the same in the two rats, so it had to be some form of electromagnetic energy. But even though Szent-Gyorgyi became a post-reductive thinker, he remained a reductive doer. He and his co-workers used concepts and imagery from solid-state physics in many experiments designed to prove his theory of how the flow of electromagnetic energy was related to cancer.

Weiner

The ideas of "control" and how it was "communicated" to various parts of the body were central in the research of Dubos, Wolff, Selye, and Szent-Gyorgyi. A mathematician named Norbert Wiener was a key figure in the development of a new area, which he named "cybernetics" and defined as the study of the principles that governed control and communications in *any* system, human or computer. According to cybernetics, a system was not the atoms or biochemicals that it contained, but rather its organization and the internal movement of "information" that permitted the system to respond to stimuli, adapt to changes, and communicate with other systems. A living system, for example, was not conceptualized as water and biochemicals but rather as its three-dimensional dynamically changing structure, and the internal movement of the "information" that permitted the system to respond to stimuli, adapt to environmental changes, heal, grow, and age. The dynamical changes and information flow weren't envisioned as "parts"—they *were* the system.

The objective of cybernetics was to identify the principles by which information flow controlled the organization and function of a system. The physical basis of the information could be electromagnetic or chemical energy. The information itself, however, was not energy but something that had not previously been recognized as a fundamental scientific entity. By means of cybernetics, the mysterious stuff that moved through nerves, reverberated in the brain, produced homeostasis, regulated growth, mediated health and disease, and was coded into genes by evolution became objectified.

Wiener recognized that if information regulated structure and function, as he supposed, then it must in some sense be a scalable variable capable of specifying this or that structure or function, or no structure or function. He identified the lack of information as a kind of randomness akin to static or noise in a telephone signal and assumed that all nonrandom signals contained some information. He also introduced the cybernetic concept of circular causality—when communicated information produced a change in structure or function, the resulting change itself became a source of information that modified the consequences of the earlier informational signal. Wiener and co-workers-built machines that modeled living systems wherein a cause produced an effect that, in turn, became the cause of an information-bearing signal that modified the original effect.

The central nervous system was no longer conceived as a self-contained organ receiving signals from the senses and activating muscles. On the contrary, some of its most characteristic activities were explainable only as circular processes in which information travels throughout the body in a continuous cycle of cause and effect that never ceases until death. Thus in a cybernetics approach, human beings were viewed as integrated wholes that functioned by means of the constant flow of information-bearing electromagnetic and chemical energy. The approach was a perfect cognitive structure on which to base interpretations of the gold-standard studies in relation to health risks, but cybernetics was irreconcilable with the orthodox exclusively biochemical vision of human biology.

Shannon

Cybernetics was a conceptual advance but had the severe limitation that "information," its core variable, apparently was incommensurable. In contrast to matter and energy, there was no information-meter, information scale, or information standard in a vault in Paris. But then an engineer in the informal group of scientists who were creating the science of cybernetics, Claude Shannon, invented a method for measuring information in one well-defined situation—the content of a telephone message. Employing a mathematical representation of the voltage signal that passed through the wire, he counted the number of zeros or ones—a measurement unit he called a "bit"—that was needed to represent the information in a message, and proved that the number of bits was a reliable measure of the amount of information in the message. Shannon's method of measuring information did not permit him to say anything about the meaning of the message. "There is a fire" and "there is no fire" could not be distinguished by counting bits. Moreover, the units of "bits" were not directly applicable to biological cybernetic information such as the signals that regulated homeostasis, or communicated the stress response, or provided feedback control of bone growth, or carried information to the brain from receptors in the body that electromagnetic energy had been detected. Even so, the idea of measuring information was revolutionary. Before Shannon, the term "information" had been used in science only metaphorically, as when biochemists asserted that DNA in a bottle contained "genetic information." He showed that information was a measurable scientific construct, like matter and energy.

The lack of a biological-information meter that could measure biological information in standardized units was an existential limitation on the benefits that post-reductive biological research could yield. But that limitation was only an empirical problem that could, in principle, be overcome by future investigators. What was certain, because of the work of Wiener and Shannon, was that there were three measurable entities in science: matter, energy, and information. In a biological context, information was fundamentally and indubitably a post-reductive entity—a sobering development for Handler and other orthodoxers who believed in a strictly reductive biology.

Burr

Electromagnetic energy had been ignored assiduously by biochemists in favor of chemical energy and had entered biology only in an engineering perspective, as when Schwan employed the model of a copper sphere exposed to electromagnetic energy to explain how it affected living systems. The first person who seriously addressed the possibility that electromagnetic energy might be an intrinsic element of living systems was a neuroanatomy professor at Yale named Harold Burr.

Burr was interested in the question of how a salamander egg developed into a fully formed salamander. At that time, the biochemists viewed questions regarding biological control or regulation as essentially philosophic or religious rather than scientific. According to their wisdom, embryonic development was simply a condition of the world, like gravity, not something to be investigated beyond resolving the problem of identifying the relevant biochemical entities. Nevertheless Burr sought a scientific explanation for a specific aspect of salamander development—his observation that the rates of cell division in one area of the embryo were always temporally coordinated with the growth of specific nerves in another area of the embryo. Recognizing that causal behavior occurring at a distance was an inherent property of electromagnetic energy, he developed the theory that information-bearing electromagnetic energy in the embryo coordinated the two processes. With financial support from philanthropic organizations and his department at Yale, Burr invented instruments capable of measuring the extraordinarily small levels of energy that he supposed existed, and he discovered that they were present everywhere in the embryo throughout the entire period of its development, as he had supposed.

During a long series of published experiments, he generalized his cybernetic concept into a system that controlled the entire process of embryonic growth so that the successive developmental stages followed each other in regular order. According to his theory, each stage was guided by, contributed to, and modified the flow of the electromagnetic energy, which he regarded as the unifying principle responsible for integrating myriad local biochemical processes that produced regulated growth and development, resulting in new animals that always looked more or less as expected.

Burr discovered that the electromagnetic energy was present everywhere on the skin of the salamanders, and on the skin of animals and humans. He conducted many human and animal experiments aimed at understanding where the electromagnetic energy came from, how it controlled biological processes, how measurements could be used for diagnostic purposes, and how desirable processes could be trigged by the application of man-made electromagnetic energy. He proved that the energy levels changed in relation to growth and after pharmacologic or surgical interventions, as would be expected if the electromagnetic energy were part of a cybernetic system.

Brown

Frank Brown was a biology professor at Northwestern University who sought to understand the natural behavior of animals that lived in the intertidal zone of the seacoast. Fiddler crabs could change their skin color, and he discovered that they did so by means of hormones rather than neural regulation, as had been supposed. He was especially interested in what regulated the color rhythm and an activity rhythm that the crabs also exhibited. The crabs changed their skin color from dark to light in synchrony with the 24-hour cycle caused by the earth's rotation; the clock hours when the skin was the darkest and lightest advanced fifty minutes each day, matching the rhythm of the tides. The crabs also displayed a tidal rhythm in activity; at each low tide they scuttled from their burrows onto the beach that had been exposed by the receding tide and then returned as high tide approached.

Funded by the government and the military, Brown found that the color rhythms persisted after the crabs were housed in a laboratory under constant illumination, indicating that they could kept tract of time even without environmental light signals. In the laboratory, the rhythms were no longer precisely 24 hours but rather a few minutes longer or shorter depending on the animal. He suspected that crabs had a genetically-determined clock that measured time, and genetically-determined rhythms of approximately 24 hours whose precise timing between the peaks and valleys of the rhythms was determined by the natural signals in the environment. He verified his discovery of an animal clock when he flew some crabs from the east to the west coast and showed that their rhythms never drifted three hours but rather remained the same as the crabs on the east coast, meaning that the ability of the crabs to measure time did not depend on the rotation of the earth.

Light was the obvious timing signal for hormonal regulation of the skin-color rhythm, ensuring that it was exactly 24 hours. However the timing signal for the activity rhythm was unobvious; high and low tides occurred twice daily, but the crabs could not see the ebb and flow of the sea. Based on experiments, Brown eliminated the possibility than any natural geophysical signals known capable of affecting animals could be responsible for synchronizing their innate activity rhythm with the local 24-hour clock. He recognized that the putative signal had to have unique physical properties: exhibit two cycles each 24-hour period at every location on earth; easily passed through the walls of a laboratory; exist during the evolution of life, allowing ample opportunity for the rhythm to become encoded in the genes of the crabs. Brown rejected advice that he concentrate on the problem of identifying the biochemical oscillators that created the genetic clock which the crabs used to measure time. Instead, he asked a question that had broader implications— the nature of the environmental signal that allowed the crabs to synchronize their rhythms with the cycle of the tides. He adopted the startling hypothesis that the timing signal was electromagnetic energy, in particular the geomagnetic field, because it alone had the necessary physical properties.

Brown knew that oysters in the sea off the east coast opened and closed their shells in synchrony with the tides, and he confirmed that they maintained the rhythm when housed in a laboratory under constant illumination. When he transported some oysters 1000 miles westerly, to the Northwestern campus, he found that they gradually adjusted their open-close cycle to coincide with the tidal pattern that would exist if Northwestern were located on a seacoast rather than 1000 miles inland, supporting his hypothesis that the local geomagnetic field was the timing signal which allowed the oysters to synchronize their activity with local environmental changes. In actuality, Brown had uncovered the first evidence that animals had a sensory system in addition to the eye for detecting natural electromagnetic energy and transferring information in the detected signal to the brain, permitting it to orchestrate appropriate behavioral responses.

Using snails from the intertidal zone, Brown directly tested the theory that animals could detect changes in the electromagnetic energy contained in the earth's magnetic field. He placed snails in a box with an exit facing magnetic south and verified that they displayed a tidal activity rhythm identical to that of the free-living snails, turning westward early in the morning as they came out of the exit, eastward at noon, and then westward again in the early evening. When Brown positioned a bar magnet beneath the exit and oriented the magnet to increase the natural field, the angle of the snails' turns increased. Rotating the magnet, which had the effect of altering the extent to which the natural magnetic field was changed, also changed the angle at which the snails exited the box, showing that that the snails had the capability of detecting electromagnetic energy, as Brown had supposed.

In further studies of the effects of electromagnetic energy on the responsiveness of animals, Brown proved that snails, flatworms, and Paramecium were extraordinarily sensitive to natural levels of the energy, as evidenced by changes in their behavior in response to small changes he made in their local electromagnetic environment. Characteristically, the animals did not respond until enough time had elapsed to allow them to accommodate to the new energy level that he imposed on them in the laboratory; when he made unnaturally large changes in the energy level, the organisms did not respond at all. He found that animals could differentiate the natural periods of change of electromagnetic energy in the atmosphere from the small fluctuations that occurred in association with changes in in longitude and latitude, an ability that could enable organisms to use the earth's field as a compass.

Brown's research showed that animals had inborn clocks, inborn rhythms, and inborn sensory systems, three related but different things, and that the sensory systems detected not only light but also natural and man-made electromagnetic energy. His discovery of an animal electromagnetic sense had a dramatic effect on natural biologists, resulting in field and laboratory studies by many investigators that showed birds, insects, fish, bacteria, and even the platypus, a mammal, were sensitive to environmental electromagnetic energy, and employed the information in the detected signal for purposes of migration, orientation, and prey-location. However, from among the multiplicity of questions that Brown's novel insight raised, the only question that seriously interested biochemists involved the biochemical nature of the clock and the rhythm, which they mistakenly assumed were the same thing. The biochemists accepted the existence of biological clocks but denied the possibility that external information other than light signals was needed for the clock to function. A heritable system of biochemical oscillators that measures time and facilitates rhythmic physiological activity was eventually discovered in the brain, but otherwise, Brown's work had nil effect on reductive biochemists. From their viewpoint, whatever a living organism did was determined solely by its chemical properties, not something in the environment; electromagnetic energy was especially objectionable for reasons of historical bias and because there was no proven detecting organ except in the platypus, fish, and bacteria, which the orthodoxers regarding as irrelevant to human biology.

No contemporary biochemist made an attempt to repeat Brown's experiments involving electromagnetic energy, apparently believing that the experiments were wrong on their face because electromagnetic energy was biologically insignificant. Brown's most vociferous critic was J. Woodland Hastings. He regarded the clock and the rhythm as the same thing, and argued that the clock was a completely self-contained timer, not a forced response to a geophysical agent but a self-regulating property of the biochemical activity inside animals and humans, plants, and plankton. Repeatedly, in print and at meetings, Hastings claimed that Brown's work on energy biosensitivity was unsound and that "the property of being sensitive to a hypothesized exogenous geophysical cue whose putative effect is that of providing time information of some sort is not supported by evidence." Hastings faulted Brown for failing to explain the biophysical nature of the clock mechanism that was sensitive to geophysical factors, and urged that "the hypothesis should be viewed with the greatest skepticism."

Handler appointed Hastings to a panel that organized a symposium on biological rhythms sponsored by the Academy, and Hastings invited all the leading rhythm researchers in the world, except Brown. A few years later, after Handler had appointed Hastings as head of the Sanguine panel, I asked him why he hadn't invited Brown and Hastings told me that "the focus was on mathematical theories, and biochemical systems, and the effects of light, not on some kind of factor-X in the environment."

Brown's research inextricably linked animals with nature and obviated the possibility of a rigid distinction between the metabolically maintained electromagnetic energy inside an animal and that of its geophysical environment. From the standpoint of the health-risk issue, and its legal implications, Brown opened Pandora's box.

Wever

Brown's theory concerning detection of electromagnetic energy was tested on humans by a German physicist named Rutger Wever. With funds from the German government, he built an elaborate underground bunker where his research subjects lived for more than a month while he studied their biological rhythms and determined whether they were affected by electromagnetic energy. When he measured the periods of the body-temperature and activity rhythms and compared the results between subjects who lived in a room that was shielded to block the geomagnetic field with the results from subjects who lived in an unshielded room, he found that the shielding persistently lengthened the daily rhythms by about 45 minutes, indicating that the subjects had detected the geomagnetic field. In his next experiment, he applied artificial electromagnetic energy to the volunteers in the shielded room and made the dramatic observation that periods returned to normal, effectively reversing the effect of the shielding in every volunteer he studied.

Wever ended his work on electromagnetic energy in 1969 because it had a much weaker impact on human rhythms, his primary research interest, than did light or social interactions. Nevertheless, using optimal experimental designs, he clearly demonstrated that both natural and man-made electromagnetic energy could alter the function of the human body, and both Becker and I cited his research to support our opinions regarding health risks from unregulated exposure to powerline electromagnetic energy. But under crossexamination, Herman Schwan harshly criticized Wever's research, claiming it was invalid because Wever failed to consider the consequences of naps or the electromagnetic energy in the illumination, and he accused Wever of hiding data unfavorable to his conclusion. I sent Schwan's verbatim comments to Wever and he replied that the naps were irrelevant, all pertinent data had been published, and that the experimental design used made it impossible to explain the reported effect as an artifact. Wever said, "I have the feeling that the objections interposed against my work are unfounded," and he reiterated his conclusion that "even weak electromagnetic fields can produce measurable effects in human beings."

Barnothy

Shortly after the end of the second world war, Madelaine and Jeno Barnothy, both astrophysicists, studied the ways that, according to basic physical laws, electromagnetic energy from strong magnets affected ordinary matter. The Barnothys speculated that at least ten of the physical processes they identified could theoretically occur in living matter and result in slowing the rate of cell division, which would make electromagnetic energy a potential tool for treating cancer. With funding from a philanthropy, they continuously exposed mice to a magnetic field ten thousand times stronger than that used by Brown and reported that the mice exhibited an abrupt weight loss during the second day of exposure, followed by a gradual return to a more normal body weight during continued exposure. The Barnothys recognized that the effect of the energy on the mice had one of the characteristics of a response to a non-specific stressor as described by Selye—an alarm reaction followed by a process of adaption. When they directly tested the stress hypothesis by examining the tissues of mice that had received prolonged exposure to magnetic energy, they found that the tissues exhibited abnormal changes identical to those Selye had described in maladapted animals exposed to stressors, an interpretation with which Selye agreed.

The Barnothys were unsuccessful in their attempt to identify the process that deductively explained the stress effect and to find a method for treating cancer, and they returned to research in astrophysics. Nevertheless, their biological experiments were far more important than was recognized at that time—the biological equivalent of the Michelson-Morley experiment. The discovery by the Barnothys that electromagnetic energy was a biological stressor encouraged other investigators to conduct more detailed studies, crucial steps toward understanding the process by which electromagnetic energy can cause cancer. Moreover, their work contributed significantly to the narrative first fully developed by Aleksandr Presman, that deductive explanations of energy-induced system-level biophenomena were impossible because the cause and its effect existed at two different levels of reality.

Presman

In the Soviet Union, the brand of orthodox biochemistry that prevailed in the U.S. never achieve a similar hegemony over Soviet biological research, which had been dominated by an equally dogmatic structure, Lysenkoism. After it passed away, Soviet research into the biological and medical consequences of natural and man-made electromagnetic energy flourished, unimpeded by anti-electromagnetic prejudice in the U.S. and other Western countries. Many post-reductive studies appeared in Soviet journals, including the studies of Aleksandr Presman, who worked at the Soviet Academy of Medical Sciences and taught at Moscow University. In 1970, he published a book in English, *Electromagnetic Fields and Life,* the first comprehensive review and analysis of the literature in the area, including the Soviet work which had not previously been generally available in the

West.

Presman described the theoretical arguments of Rajewsky, Schwan, and Michaelson that indicated high-strength electromagnetic energy had significant biological effects due to its conversion to heat, and then described a plethora of experimental and theoretical studies done at sub-thermal levels of electromagnetic energy. The sub-thermal studies included the work of the Western scientists Adey, Brown, Becker, Barnothy, Beischer, Szent Gyorgyi, Wever, which I have mentioned, and that of Audus, Baranski, Becker G., Deichmann, Dijkgraaf, Frey, Gordon D., Lissman, Maletto, Marha K., Prausnitz, Reiter, and Ren which I didn't mention. Presman also evaluated the work of numerous Soviet investigators including Amineev, Baranski, Fukalova, Gordon, Gorodetskaya, Kamenskii, Kholodov, Kitsovskaya, Konchalovskaya, Levitina, Lobanova, Nikogosyan, Nikonova, Novitskii, Orlova, Petrov, Sadchikova, Sazonova, Skurikhina, Smirnova, Sokolov, Solov'ev, Tolgskaya, and Toroptsev.

Presman identified three classes of sub-thermal reports: effects of natural environmental electromagnetic energy on the regulation of vital processes; the role of natural internal electromagnetic energy in the organism in the coordination of physiological processes; and health-related effects of man-made electromagnetic energy. He described experimental demonstrations that humans and a diverse species of animals down to the level of unicellular organisms behaved as highly sensitive receptive systems for all forms of electromagnetic energy over a broad and diverse range of values and parameters used to characterize the energy—strength, frequency, vector direction, pulse structure.

Following the second world war, Schwan had asserted that how much and how quickly electromagnetic energy heated tissue was the only possible process through which the energy could affect the vital activity of humans and animals. He invoked the simple ideas of dielectric constants and ionic conductivity as the exclusive basis for explaining how electromagnetic energy affected living systems. Presman broke sharply from that perspective. He interpreted the empirical evidence to necessitate a scientific perspective not limited by the ultra-reductive assumption initiated by Schwan that became fashionable in the West. Presman proposed a model in which nonthermal levels of electromagnetic energy was transduced into information that was then conveyed within the organism and employed to coordinate and integrate biochemical reactions occurring in the nervous, endocrine, and immune systems. He concluded that coordination and integration of biochemical reactions were emergent phenomena that existed only at the level of the organism as whole and were not present in comparable form at the molecular level.

Essentially every published independently conducted study fit Presman's theory of the informational nature of the biological effects of electromagnetic fields. The theory had been adumbrated by Wiener, Burr, Brown, and Becker, but with minimal impact on the biochemical orthodoxers. By the time Presman expressed it, however, and cited the supporting research of many Soviet investigators, the tide began to turn in the West, not dramatically, but slowly and relentlessly, in the face of staunch opposition from industry and military stakeholders, who benefited hugely from the previously existing state of affairs.

Heterodoxy

Prigogine and Lorenz necessitated a change in how the relationship between physics and biology was perceived. Their work revealed that physics was only a first step toward a scientific understanding of complex nonlinear systems, of which life itself and its processes were the most outstanding examples. Dubos, Wolf and Selye showed that understanding biology was inherently a post-reductive project—physics could help, but only at the margins. They were among the first biological researchers to recognize that post-reductive knowledge was far more important to humanity than academic reductive detail. Their writings were suffused with concern regarding the seeming indifference of the biological research establishment to the needs of the public. Weiner and Shannon made plain that information was a scientific concept equally fundamental and unique as the concepts of matter and energy. Because of them, the concept of measurable biological information became respectable—Hastings' "factor X" could exist inside the body in transduced form and act independently of Schwan's "biophysical principles."

Burr was the trailblazer in modern energy-related biology. From the standpoint of the biochemists of his day, from whose leadership in biological research methods he departed, neither the question he asked nor the theory he proposed had any merit. Handler expressed this point of view when he said that Burr's theory was merely an attempt to resurrect the long-discredited Cartesian concept that human beings were animated by a soul. In Burr's day, the key elements of modern biological hypothesis-testing—gold-standard experimental designs and statistics-based decision-making—had not yet been developed. Consequently the progress he could make was capped. But succeeding energy heterodoxers used post-reductive methods to study the relationship between electromagnetic energy and life from a biological perspective, and new vistas appeared. Notable among these pioneers were Brown who discovered animal sensitivity to natural electromagnetic energy, Wever who discovered that humans were no exception, and the Barnothys who discovered that man-made electromagnetic energy was a biological stressor, culminating in the remarkably insightful work of Presman. He integrated all earlier energy studies, natural and man-made, human and animal, and provided the first coherent rationale for the point of view that the assumption a human being was a sphere of copper was a grossly inadequate way to begin a scientific evaluation of the question of health risks from electromagnetic energy. He marshaled the evidence, as of 1970, and documented that a substantial, rapidly increasing number of studies from many laboratories and countries clearly established that the truly significant biological effects of electromagnetic energy were independent of the theoretically predictable, ultra-simplistic thermal effects.

The heterodoxers introduced the ideas of irreversibility, nonlinearity, post-reductionism, cybernetics, information, and electromagnetic energy into modern biological research, developments that are certain to have profound effects on our concepts of life, health, disease, and risk. Their work legitimized the post-reductive studies of Burr, Brown, Presman, and Becker and narrowed the range of opposition to counterarguments like those made by Schwan, Michaelson, and Miller and to perspectives based on blind prejudice like those of Handler and Hastings. The narrowing was real and substantial progress, because prior to the heterodoxers the notion of even studying the relationship between electromagnetic energy and biology, much less claiming such a relationship actually existed, had been dismissed as arrant nonsense. Historically, heterodoxers invariably endure continuing criticism of their work, and those I described were no exceptions. Classically, new ideas gain acceptance when enough people replicate the novel observations, a theory develops that can account for the observations, and the proponents of the old ideas die.

The situation I saw in the late 1970s was something new—unprecedented and sobering. On one hand, sophistical arguments like those of Schwan, Michaelson, and Miller and judgments by ignorant and prejudiced authorities like Handler and Starr were so unethical and unjust, it seemed impossible that they could continue to prevail. On the other hand, the military and industrial powers that created and sustained the false arguments and judgments were everyday facts of life, and how they could be overcome was not clear.