

## **<sup>1</sup>Charter 16: Emergentism vs. Reductionism 1939-1975**

ROBERT BECKER WAS RAISED in New York, the only child of German immigrants. He was encouraged by his father, a Lutheran minister, and his mother to engage the world and seek an education in whatever area most interested him. He chose medicine, but his premedical studies in collage were interrupted by his service in the Army during the war. By the time he completed college, medical school, and internship, he had answered some questions concerning what his life's work would be, but the answers raised new questions. As a medical student he chafed at the role he saw dogma played in both basic biomedical science and clinical medicine, and he developed a sense of dissatisfaction concerning how physicians were taught to think. Once during a microscopic examination of thin sections of human tissue that had been stained with dyes to enhance various features, he realized that his attention was focused on the appearance of the tissue rather than on thinking about how it had functioned before it died. It occurred to him that making biomedical meaning from what he called painted tombstones was like trying to diagnose a wanderer from footprints left behind. The distinction between structure and function was important to him, and he viewed the failure to appreciate the difference as emblematic of the trend in clinical medicine toward becoming too technologically oriented, treating patients as if they actually were their test results and x-rays.

Other discontents occurred and left their stamps on his character. It seemed to Becker that the determinants of disease were not specific causes that could be controlled by identifying the responsible biochemical reactions, as had been suggested in his pre-clinical biochemistry course in medical school, but rather were multifactorial — habits, mores, and environment continuously introducing new stressors. He distained rigorous biochemical research as mostly irrelevant to actual clinical practice because its primary purpose was to define medical issues in mechanistic terms with scientific accuracy, as if that were the primary consideration.

Becker thought it illusory to believe science would eliminate disease or that scientific rigor was the best path to medical progress. He was dissatisfied with what he thought was an excessive influence of biochemical reasoning, which was presented to him as the norm for the practice of medicine even though it didn't consider the effects on health due to a person's lifestyle, the influence of the environment, or the possibility that disease was a result of maladaptation to change.

For the next seven years, Becker studied pathology, general surgery, and orthopedic surgery, and served as a medical officer in the Army; his experiences shaped and sharpened his perspective on the relation between biomedical science and clinical medicine. One such experience, which occurred while he was an Army ward officer treating soldiers who had fractured bones, was a watershed event. He began to think deeply about the healing process, how the body knew a fracture had occurred, what initiated the healing response, how it was regulated, and what ended it after healing was complete. These questions were largely unstudied even though the final result was something amazing, the growth of new bone that

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<sup>1</sup> This is a preprint of a manuscript that will undergo proof-reading and copy-editing prior to publication.

was indistinguishable from uninjured bone, the exact replacement of what was lost — true tissue regeneration. The more he pondered, the more the questions became salient. Becker recognized the healing process was some kind of a biochemical process as opposed to directly attributing it to what he called the finger of God, but the biochemistry textbooks focused on metabolism and genes, saying nothing about the control and regulation of healing. He wondered how the bone-healing process was initiated by injury with such consistency that it was a surprise when healing didn't occur, and with precise anatomical specificity — invariably, arm bone grew only in the arm and leg bone only in the leg. Equally remarkable was how the healing process ended; it always produced too much bone but the excess simply dissolved, leaving no microscopic or biochemical evidence a fracture had occurred. Some cases of healing he read about were even more remarkable.

Sometimes when a child fractured a femur and the bone was not properly splinted, it healed with an angulation; however, if the child walked on the crooked leg, often bone disappeared on the convex side of the injury site and grew on the concave side, ultimately resulting in a straight leg. No one asked how the synchronized process was controlled or regulated. And some things that were in the medical books did not ring true for him, like the notion healing was brought about by physicians using medicine or surgery rather than something done by the patient based on intrinsic capabilities.

By the end of his medical studies, Becker had developed a sense that the medical profession had become too biochemically oriented and did not encompass some sound and potentially beneficial perspectives, but did embrace some misleading ideas. He decided to devote his life to orthopedic surgery and clinically relevant research aimed at addressing what he saw as shortcomings regarding the medical wisdom he had received. He had never formally studied how to do research, and had a level of training in research well below that of the biochemists who were then shaping the development of biomedicine, but he did not regard that as a limitation because it was the failure of their methodology with regard to medicine that he sought to remedy.

A chance development presented Becker with an opportunity to pursue both of his goals, and he quickly accepted. He was offered the position of Chief of Orthopedic Surgery at the Syracuse, New York Veterans Administration hospital, and a faculty position at the New York Upstate Medical Center. For most physicians, the Veterans Administration position was an unattractive career choice because of the low salary, prohibition on engaging in private practice, and the limited nature of the medical problems that were treated. As an employment perk, the Veterans Administration had a research program that allowed individual hospitals to award staff physicians the time, laboratory space, and funds to perform research, all of which he was promised. In June 1956, the month he finished his orthopedic residency, Becker commenced working at the Syracuse hospital and medical school and continued doing so until 1979, never having worked anywhere else, when he was forced to retire by Philip Handler, who despised Becker because of his research and ideas.

Becker began his research by investigating the clinical problem of muscle weakness, and observed electrical signals on the skin over the affected muscles <sup>2</sup>.

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<sup>2</sup> The electrical response of human skeletal muscle to passive stretch. R.O. BECKER. *Surg. Forum* 10: 828–831, 1960.

He could not relate the signals to the clinical problem, but wondered why they were present. He learned that similar electromagnetic phenomena were reported during the early development of biochemical-based medicine and soon dismissed as unimportant consequences of biochemical reactions. Becker, however, hypothesized the signals he measured arose from purposeful physiological activity and evidenced an internal flow electromagnetic energy. In studies on salamanders, he found similar signals occurred on the skin and formed a pattern corresponding to the anatomic structure of the nervous system, suggesting to him that the signals originated in nerves<sup>3</sup>. In experiments with salamanders, which naturally regenerated missing limbs, and frogs, which did not and served as controls, he found differences between the two species in the characteristics of the signals from animals that had undergone surgical amputations, possibly indicating the electromagnetic energy had a role in limb regeneration<sup>4</sup>. In subsequent experiments, he showed the energy flow along nerves in salamanders could be altered by applying a magnetic field<sup>5</sup>, and by sectioning the nerves<sup>6</sup>, observations consistent with his hypothesis.

Becker found a neural-related pattern of electrical signals on the surface of the human body, paralleling the pattern he had seen in salamanders, and he observed differences in the signals on the head of subjects in particular reduced-attention states including sleep and anesthesia, compared with controls<sup>7</sup>. He reported the signals varied with changes in consciousness induced by hypnosis<sup>8</sup> and raised the possibility the signals were part of the process that controlled the various cognitive states<sup>9</sup>. In studies based on data regarding magnetic storms collected by government agencies, Becker found a statistical correlation between admissions to psychiatric wards and changes in the earth's magnetic field, suggesting the possibility that the geomagnetic field influenced psychiatric hospital admissions<sup>10</sup> and psychiatric ward behaviour<sup>11</sup>. He interpreted the collective results of his studies as evidence of an electromagnetic-based biocybernetic control system — separate from the well-known nerve-impulse system — that controlled and regulated physiological activity and mediated a link between humans and the environment<sup>12</sup>.

Motivated by the then recent work of Albert Szent-Gyorgyi, Becker theorized the existence a biocybernetic control system that governed bone growth, and that it was electromagnetic rather than biochemical because initiation of growth and its subsequent regulation required communication between distant points, a feature not associated with

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<sup>3</sup> The bioelectric field pattern in the salamander and its simulation by electronic analog. R.O. BECKER. *IRE Trans. Med. Electronics* ME-7: 202–208, 1960.

<sup>4</sup> The bioelectric factors in amphibian limb regeneration. R.O. BECKER. *J. Bone Joint Surg.* 43-A: 643–656, 1961.

<sup>5</sup> Search for evidence of axial current flow in peripheral nerves of salamander. R.O. BECKER. *Science* 134: 101–102, 1961.

<sup>6</sup> The longitudinal direct-current gradients of spinal nerves. R.O. BECKER, C.H. Bachman & W. Slaughter. *Nature* 196: 675–676, 1962.

<sup>7</sup> The direct current control system: a link between the environment and the organism. R.O. BECKER, C.H. Bachman & H. Friedman. *N.Y. State J. Med.* 62: 1169–1176, 1962.

<sup>8</sup> Direct current potentials in hypnoanalgesia. H. Friedman, R.O. BECKER & C.H. Bachman. *Arch. Gen. Psychiat.* 7: 193–197, 1962.

<sup>9</sup> The direct current field: a primitive control and communication system related to growth processes. R.O. BECKER. in *Proc. XVI Int. Congress Zool.* 3: 179–184, 1963.

<sup>10</sup> Geomagnetic parameters and psychiatric hospital admissions. H. Friedman, R.O. BECKER & C.H. Bachman. *Nature* 200: 626–628, 1963.

<sup>11</sup> Psychiatric ward behaviour and geophysical parameters. H. Friedman, R.O. BECKER & C.H. Bachman. *Nature* 205: 1050–1055, 1965.

<sup>12</sup> Relationship of geomagnetic environment to human biology. R.O. BECKER. *N.Y. State J. Med.* 63: 2215–2219, 1963.

biochemical reactions. He confirmed bone responded electrically to mechanical stress<sup>13</sup>, and hypothesized bone regeneration was mediated by electromagnetic signals, much as other forms of physiological regulation were effected. Becker's ideas served as the rationale for detailed biophysical studies of how semiconduction, electromechanical forces, negative-feedback systems, and bone growth were related, and as the basis for his proposed negative feedback system for controlling bone growth<sup>14</sup>. The existence of an electron conduction band was supported by his studies using the techniques of electron paramagnetic resonance<sup>15</sup> and photoconductivity<sup>16</sup>, which allowed detection of mobile electrons in bone, flame spectroscopy<sup>17</sup>, which identified trace elements in bone that could account for the origin of mobile charge carriers, and dielectric dispersion<sup>18</sup>, which revealed the presence of water molecules that could account for the ability of charge carriers to enter the conduction band. Becker showed that electromechanical signals in bone originated as a result of the piezoelectric effect exhibited by the protein matrix of bone<sup>19</sup>, and that the signals were probably directly related to bone growth<sup>20</sup>. An important implication of the biophysical studies was the suggestion that the origin of life on earth might have been in a solid rather than in water, as biochemists believed<sup>21</sup>.

Becker reasoned that the physiological control system he had described would be influenced by natural and anthropogenic electromagnetic energy because the control system was electrical in nature<sup>22</sup>. He presented supporting experimental evidence in 1961 at a Massachusetts Institute of Technology symposium on magnetic fields, where he described correlations between changes in the geomagnetic field and admissions to psychiatric hospitals, which he subsequently described more fully<sup>23</sup>.

In a literature review he concluded the lesson of the literature was that the geomagnetic field could be detected by animals and used as a source of information regarding orientation and location, even though the underlying biophysical mechanisms were poorly understood<sup>24</sup>. Following a laboratory study in which he found that artificially modulated magnetic fields altered human reaction times<sup>25</sup>, Becker agreed to a congressional request to provide a report

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<sup>13</sup> Generation of electric potentials by bone in response to mechanical stress. C.A.L. Bassett & R.O. BECKER. *Science* 137: 1063–1064, 1962.

<sup>14</sup> Bioelectrical factors controlling bone structure. R.O. BECKER, C.A.L. Bassett & C.H. Bachman. in *Bone Biodynamics*, H.M. Frost, ed., Little Brown and Co.: Boston, 1964.

<sup>15</sup> Electron paramagnetic resonance in non-irradiated bone. R.O. BECKER. *Nature* 199: 1304–1305, 1963. Evidence for direct physical bonding between the collagen fibers and apatite crystals in bone. A.A. Marino & R.O. BECKER. *Nature* 213: 697–698, 1967.

<sup>16</sup> Photoelectric effects in human bone. R.O. BECKER & F.M. Brown. *Nature* 206: 1325–1328, 1965.

<sup>17</sup> Trace elements of human bone. R.O. BECKER, J.A. Spadaro & E.W. Berg. *J. Bone Joint Surg.* 50-A: 326–334, 1968.

<sup>18</sup> Dielectric determination of bound water of bone. A.A. Marino, R.O. BECKER & C.H. Bachman. *Phys. Med. Biol.* 12: 367–378, 1967.

<sup>19</sup> Origin of the piezoelectric effect in bone. A.A. Marino, R.O. BECKER, & S.C. Soderholm. *Calc. Tiss. Res.* 8: 177–180, 1971.

<sup>20</sup> Piezoelectric effect and growth control in bone. A.A. Marino & R.O. BECKER. *Nature* 228: 473, 1970.

<sup>21</sup> The basic biological data transmission and control system influenced by electrical forces. R.O. BECKER. *Ann. N.Y. Acad. Sci.* 238: 236–241, 1974.

<sup>22</sup> The direct current field: a new data transmission and control system in living organisms. R.O. BECKER & C.H. Bachman. *Digest of the International Conference of Medical Electronics*: 138, 1961. The direct current control system: a link between the environment and the organism. R.O. BECKER, C.H. Bachman & H. Friedman. *N.Y. State J. Med.* 62: 1169–1176, 1962.

<sup>23</sup> Geomagnetic parameters and psychiatric hospital admissions. H. Friedman, R.O. BECKER & C.H. Bachman. *Nature* 200: 626–628, 1963.

<sup>24</sup> The biological effects of magnetic fields: a survey. R.O. BECKER. *Med. Electron. Biol. Eng.* 1: 293–303, 1963.

<sup>25</sup> Effect of magnetic fields on reaction time performance. H. Friedman, R.O. BECKER & C.H. Bachman. *Nature* 213: 949–950, 1967.

regarding a pending bill that would create pre-market safety regulations for exposure to anthropogenic electromagnetic energy emitted by commercial devices. In his report, Becker urged a cautionary approach<sup>26</sup> and presented a supporting report he wrote for the Technical Advisory Committee of the Institute of Electrical and Electronic Engineers<sup>27</sup>. He also delivered a paper at the Institute's annual convention in which, based on considerations regarding the body's cybernetic control system, he warned against "the continuous exposure of the entire North American population to an electromagnetic environment in which is present the possibility of inducing currents or voltages comparable with those now known to exist in biological control systems"<sup>28</sup>.

Becker investigated the question of how fracture healing occurred in frogs by studying the morphological changes that occurred in cells at injury sites in relation to measured electrical changes<sup>29</sup>. The results convinced him that, during healing, some cells dedifferentiate as a consequence of electrical signals that originated in the nervous system, thus becoming cells that can differentiate into the various kinds of cells needed at a healing site. The phenomenon of dedifferentiation became an important focus in Becker's pursuit of the larger question of regeneration in animals and in humans. In 1972 he electrically stimulated partial limb regeneration in a mammal, the rat<sup>30</sup>. Subsequently, he discovered that salamanders could spontaneously regenerate heart muscle and recover cardiac function even after the heart had been cut open and half removed<sup>31</sup>. For reasons of principle, policy, and preference, Handler eschewed any financial support for direct studies of emergent biomedical phenomena including but not limited to limb and organ regulation, bone growth and healing, and the biomedical implications of human detection of natural or anthropogenic electromagnetic energy in the environment.

In the early 1970s, influenced by the axiomatic admonition of respected leaders in orthopedic surgery that "more reliance should be placed upon the primordial power of the human skeleton to regenerate injured and missing substance," Becker explored the clinical implications of the electrical control system with regard to stimulating regenerative healing in man<sup>32</sup>. He viewed the approach as a possible alternative to prosthetic implantation, which was then undergoing a rapid increase in use as the preferred therapy for chronic severe joint pain. Becker's approach to the use of electromagnetic energy for the promotion of healing differed

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<sup>26</sup> Statement to the Subcommittee on Public Health of the U.S. House of Representatives in connection with hearings on H.R. 10790, Radiation Control for Health and Safety Act of 1967. R.O. BECKER. 1967.

<sup>27</sup> The possible hazards of human exposure to magnetic fields. R.O. BECKER. Consultant report for the Joint Technical Advisory Subcommittee 63.1.4, Side Effects of Electromagnetic Energy, 1968. IEEE, New York, 1968.

<sup>28</sup> Electromagnetic forces and life processes. R.O. BECKER. Technol. Rev. (MIT) 75: 32–38, 1972.

<sup>29</sup> A method for producing cellular dedifferentiation by means of very small electrical currents. R.O. BECKER & D.G. Murray. Trans. N.Y. Acad. Sci. 29: 606–615, 1967. The electrical control system regulating fracture healing in amphibians. R.O. BECKER & D.G. Murray. Clin. Orthop. 73: 169–198, 1970.

<sup>30</sup> Electrical stimulation of partial limb regeneration in mammals. R.O. BECKER & J.A. Spadaro. Bull. N.Y. Acad. Med. 48: 627–641, 1972. Stimulation of partial limb regeneration in rats. R.O. BECKER. Nature 235: 109–111, 1972.

<sup>31</sup> Regeneration of the ventricular myocardium in amphibians. R.O. BECKER, S.E. Chapin & R. Sherry. Nature 248: 145–147, 1974.

<sup>32</sup> Augmentation of regenerative healing in man, a possible alternative to prosthetic implantation. R.O. BECKER. Clin. Orthop. 83: 255–262, 1972.

from that of other prominent orthopedists, who he felt were using levels of electromagnetic energy in clinical treatment that had not been tested sufficiently in laboratory and animal studies, and might be too high for purposes of safety<sup>33</sup>. Becker utilized electromagnetic treatment methods that employed energy levels lower than those used by other orthopedists, and he conducted laboratory experiments on animals to evaluate the mechanism of action and safety of his therapeutic methods.

Although there were exceptions, Becker's ideas and experimental approach were generally not pursued in other academic research laboratories, largely because of the hegemony Handler exerted over national biomedical funding policy. He deliberately chose not to allow allocation of grants or resources for research in the area of emergent biomedical phenomena. By doing so, he effectively discouraged or marginalized research into broader, system-level biomedical questions, favoring instead reductionist studies of biochemical or molecular mechanisms. It was not just a passive lack of funding but an *active policy choice*: Handler avoided, rejected, or opposed putting money into emergent-level biomedical research, thereby shaping the direction of bioscience by omission. Ironically, although his policy prevented Becker from obtaining grants from the National Institutes of Health for specific research projects, it provided him with significant financial support for his laboratory. Handler had influenced the Congress to support biomedical education as well as research, and Becker received an Institutes' educational grant to support the research efforts of orthopedic residents, medical students, and graduate students in his laboratory. The funds provided equipment and supplies, and supported the addition of new staff members.

Handler effectively achieved his aims by exercising his truly prodigious authority and influence over federal biomedical funding in the 1950s and 1960s to favor reductionistic biochemical studies and exclude other experimental designs of biomedical research. He served on the boards of directors of the National Institutes of Health and the National Science Foundation for many years, and also held other influential positions in both institutions. Handler's influence over military-funded biomedical research was a natural result of a mutually beneficial relationship.

Military advice-seeking contracts provided Handler's National Academy of Sciences the preponderant majority of its annual budget and Handler, in turn, routinely provided the military with science policy reports that used the aegis of the Academy to support the desires and preferences of the military in the specific contractual areas. Handler served as a consultant to the Veterans Administration for almost thirty years — another relationship where mutual benefit took preference over all other considerations. Handler earned money that went into his pocket, and the Veterans Administration used his advice to counter congressional complaints that the Veterans Administration research budget was larded with too many unscientific projects.

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<sup>33</sup> Panel discussion: To what extent can electrical stimulation be used in the treatment of human disorders? C.A.L. Bassett, R.O. BECKER, C.T. Brighton, L. Lavine & B.A. Rowley. Ann. N.Y. Acad. Sci. 238: 586–593, 1974. The current status of electrically stimulated bone growth. R.O. BECKER. ONA J. 2: 35–36, 1975

Philip Handler's father and his mother's parents came from Russia, fleeing a combination of limited economic prospects, systemic antisemitism, and the threat of political unrest and pogroms. Philip, their only son, was born on a farm in New Jersey where his maternal grandparents lived, and raised in a tightly knit Jewish community in New York City. Handler's parents emphasized education as the surest path to advancement and home-schooled him until his early teens. He completed high school at age 15 and entered college as a pre-med student, driven toward academic success as a route to security and social prestige. A biochemistry professor created a vision for Handler of a world where all questions concerning medicine could be answered if they were formulated in the language of biochemistry. While still an emotionally pliable teenager with nothing large to believe in, Handler embraced the proposition that living things were biochemical machines and biochemistry was the highest calling in life.

Graduate school further hardened Handler's ideology. He was taught that physics explained non-living matter but not the unique properties of living matter. Handler adopted the belief of his professors in the existence of yet undiscovered laws, written in the language of biochemistry rather than mathematics, as in physics, that could explain the unique characteristics of living matter as well as how biochemical reactions became imbued with purpose to produce and control life and its characteristics. He became convinced that discovering the laws was the responsibility of biochemists, and he accepted what were presented to him as the seminal rules of the biochemical endeavor — exclusive reliance on the reductive model of life, and experimentation based on chemical energy that excluded electromagnetic energy, which he was taught to regard as vitalist claptrap.

His attitude toward physicians deteriorated greatly. From even before high school, the greatest and most erudite man he knew was the family physician, but by the time he received his PhD in biochemistry, at 21, his attitude toward physicians was marked by scorn for their scientific superficiality. Mostly, he saw physicians as obstacles to truth, necessary functionaries at best, not allies in the quest for biomedical knowledge but rather providers of remedies that weren't proven beneficial by biochemical studies. Handler's gospel was that a true scientist believed only facts and spent his life searching for them, rejecting acceptance of half-truths because they would be insults to his faith in pure science.

Handler's professional career began in 1939 at Duke University, where he was a biochemistry instructor in the medical school and a part-time researcher in the area of nutrition. He began his research with a reductionist worldview and embraced a model of scientific freedom in which the purpose of research was to satisfy scientific curiosity, not to meet societal needs. Funded by philanthropic organizations, Handler's research pattern was to feed rats chemically modified food and observe the results, believing they would help explain the chemical processes by which food was converted into energy. His research reports, however, lacked testable hypotheses and consisted only of verbally complex narratives that reached no generalizable conclusions. He lost his external funding because the philanthropies demanded use-inspired research, which Handler refused to pursue. The Duke administration commenced funding his research provisionally, expecting him to secure external support, but he continued his pattern of disjoint experiments and apocryphal publications in accordance with the pointillist concept of biochemical research he had been taught — the idea that an unlimited number of biochemical publications in a particular area would inevitably coalesce into a comprehensible picture of the biomedical phenomenon being studied.

Although his publications were far below those of the leading biochemists, which included a dozen Nobel prize winners, Handler displayed strengths in other areas that favorably impressed the leaders of the Biochemical Society. He rose in prominence due to his oratorical skill, stylish presentations at annual meetings, organizational competence, and talent for simplifying complex biochemical language for the press. Handler gained a reputation within the Society as an ideal public representative for biochemistry, and was appointed to several important Society committees where he showed an ability to get things done. Even at this early stage of his career, Handler later confessed, he recognized he was a good biochemist at best, but not a great one, and had little enthusiasm for spending his life personally generating individual pointillist publications, believing he was capable of achieving much more.

While pondering his career ambitions, Handler's chronic health problems worsened. Working in a laboratory caused a variety of signs and symptoms that made doing research painful and progressively more difficult. He treated himself because he had little confidence in physicians, but his health only worsened, and in 1948 he became unable to do any laboratory research because of serious allergic reactions to the rats whose nutritional properties he studied. Handler's uncertain long-range goals, medical condition, and lack of external research funds, threatened his academic position, and his hope of securing a position of authority in the Biochemical Society.

The issues, which centered on money, influence, and biomedical education, presented Handler with the problem of how he should manage his career. He decided to change his focus from biochemical research to biomedical policy and, leveraging his popularity within the Biochemical Society, he addressed the issues aggressively.

The National Institutes of Health had recently expanded and begun providing grants for research related to health. Handler was initially unsuccessful in obtaining a grant because the Institutes were legally obligated to fund only research that was linked to health or disease, and Handler was disinterested in use-inspired biochemistry. But he adapted. Friends in the Biochemical Society showed him how to construct averments which conveyed a false impression that the proposed experiments were relevant to disease — transparently contrived lies that satisfied the legal requirement of a foreseeable application to human health. Another development that worked in Handler's favor was the composition of the Institutes' Biochemical Advisory Panel, which had absolute authority to decide who received a research grant. Handler's former mentor in graduate school and several friends were appointed to the Panel.

In 1949, the Panel approved a grant request by Handler for research on how rats metabolized the components of proteins, and over the next two years the Panel approved three additional grant requests from Handler for similar work — money was no longer a problem. He could not actually do the research himself because of his medical problems, but he presented a long-range plan to the Duke administration regarding how he planned to manage the money provided by the Institutes. He envisioned that he would pay for all research expenses, institutional overhead, the tuition and salary of post-graduate students who would work in his laboratory while earning a PhD, post-graduate fellows who would oversee the research of the students, and his salary as the manager of the enterprise. Handler justified the use of public money on the basis that public would be the ultimate beneficiary of the research.

In less than two years, Handler became the best-funded investigator in the biochemistry department, but he had no authority over departmental policy because he was only an associate professor. However the chairman of the biochemistry died suddenly, and Handler immediately applied for the job. He sought and received strong letters of support from prominent members of the Biochemical Society for his candidacy that emphasized his leadership skills.

During interviews with the administration, Handler described his intention to build a federally funded research department focused on training PhDs and expand the department's faculty with essentially no funding by the university. He told the administration his intended expansion plan was based on the one he devised to run his laboratory. The department would focus heavily on research and make teaching PhD students how to do biochemical research its dominant mission.

Teaching biochemistry to first-year medical students would become the secondary mission. He wrote that the "task of developing researchers competent to investigate the edges of knowledge is a terribly expensive and complicated task, but it is imperative for the sake of both the present and future." To pay for the research and education initiatives, he said he would write grant proposals to the Institutes and other federal funding sources similar to what he had already done, and that he expected to be even more successful in the future. He envisioned a departmental faculty five times larger that would be supported completely by federal funds. The administration appointed Handler as chairman and promoted him to full professor. At 32, he became the youngest professor ever at Duke and the youngest biochemistry chairman in the US.

In an effort to simultaneously remedy what he considered to be the deplorable level of scientific training in medical schools, and provide his department with a continuous supply of students who would carry out biochemical research, Handler devoted much time and effort to developing a plan for revamping medical education at Duke, and throughout the country in the U.S. Handler raised several million dollars in grants to design a medical-school curriculum that would extend the traditional curriculum by two years, but would result in the student receiving a medical degree and a PhD in biochemistry. But Handler's prodigious effort to transform physicians into biomedical scientists failed utterly; his plan was rejected by Duke — whose dean called it the worst thing that could happen to medical education — and was not adopted by any U.S. medical school.

In 1953, economic and management problems within the Biochemical Society provided Handler an opportunity to efficiently obtain the Institutes' funds he needed to fulfill his promises to grow his department and enrich the University. Handler agreed to accept a leadership position in the Society, and to house and pay for some of its administrative tasks and find a home for the Society and its journal — emoluments he had the power to do using funds provided by the Institutes and made available to him through the Duke administration. In return, Handler asked the Society to recommend to the Institutes that he be appointed to the Biochemical Advisory Panel. In due course, Handler became the chief operating officer of the Society, and was appointed to the Panel and soon thereafter became its chairman. As the Society's de facto executive leader, Handler advanced its interests at a national level — opposing political interference in the research endeavor, shaping national biomedical policy, and cementing federal support for biochemistry.

Handler's assent to a dominant role on the Panel and to the position of managing officer of the Society gave him the opportunity to influence the evolution of U.S. biomedical research according to his image. He later described the developments as pivotal in his career decision to concentrate on the organization of biomedical science, its role in society, and its relationship to government. Handler had continuous access to the federal dollars budgeted by the Congress for biochemical research. Equally important to him, his position on the Panel empowered him to throw shade on funding of grant applications whose experimental designs did not conform to his philosophy of biomedical research. Handler shaped the member-selection process to his liking, thereby facilitating implementation of his policies. Wearing his Society leadership hat, Handler successfully organized major national and international biochemistry meetings, appointed a new editor for the Society's journal, and spoke at national forums where his aggressively advanced its views regarding the importance of increased funding of biochemical research.

Handler's influence within the Society and on the Biochemical Advisory Panel was the smaller part of his impact in the areas of biomedical and public health policy, and funding policies for biochemical research. Over a period of about a decade, Handler served on the board of directors of the two main federal science agencies —including a period as the chair of one of the agencies. Further, he was a member of the science advisory board to four Presidents and functioned as a consultant to the Veterans Administration and the Department of Defense. He also acted as an advisor to the Congress, testifying about science policy more than fifty times.

From the time Handler received his first research grant from the Institutes in 1949 until he was elected leader of the National Academy of Sciences in 1969 he functioned as a veritable financial frontman for the biochemistry department at Duke. He did no research and, at most, managed the research of others during the first decade. During the second decade he essentially lived in Washington, not Durham, where he pursued a national role in the politics of science, and his participation in affairs at Duke became nil. Nevertheless, the university paid him a salary, using pass-through funds from Institutes grants to Handler — which were administered by Duke — even though he had essentially no role in the ongoing research within the department, of which he was the titular chairman. Throughout his career, Handler never received regular paychecks from any source except Duke and the Academy.

Handler's role as a frontman at Duke was a metaphor of his work in Washington that resulted in his legacy — the institutionalization of biochemical reductionism in U.S. science policy. In the first decade, his role as frontman was visibility without substantive research engagement. He remained the department's outward face and drew a salary via grant pass-throughs funds, but his efforts were primarily devoted toward managing and growing the national biochemical society. During the second decade, Handler's participation at Duke became nil, although the salary continued

In many ways, the pattern of appearance substituting for substance Handler displayed at Duke was a metaphor for his activities in Washington where he rose to national leadership and carried out his broad policy project. First, Handler's role as the figurehead at Duke became transformed into his role as the gatekeeper of biomedical science in Washington. The same logic was scaled up —projecting scientific authority while relocating the real work elsewhere. Handler presented reductionist biochemistry as the sole science behind biomedical research, while

pushing alternative, emergent approaches to the periphery through denial of funding, arbitrary review norms, and propaganda for his agenda. The front became an institutional facade — a narrow program packaged and misleadingly displayed as neutral science. Second, the pattern of appearance substituting for substance was manifested again when Handler presented front as infrastructure. He devised a series of mechanisms that turned appearances in the Institutes' review process and the Academy's advisory process into infrastructure. Handler considered every biomedical problem a molecular problem, which simplified the tasks of his committees and made molecular reasoning a proxy for scientific merit. He adopted editorial and review conventions that privileged reductionist framings as the baseline of rigor. He relied on an idiosyncratic series of methods, metrics, and problem choice, that instantiated his ideology as the facade of how bioscience was done. Third, Handler acted as a representative figurehead for Duke's biochemistry department, projecting authority and status while the actual research work was being conducted by others, thus serving as a rhetorical shield that legitimized what was essentially a dishonest scheme because his name and position at Duke had cash value when it appeared on grant applications. In policy-speech advocating for reductionism, Handler similarly resorted to rhetorical shielding, using words such as "unscientific," "inconclusive," and "unsupported" indiscriminately, thus hiding trade-offs and functioning as ideological narrowing. Fourth, Handler's facade had strong negative consequences for research that was not based on Handlerian reductionism. Systems-level and electromagnetic-oriented biomedical research were cast as speculative or soft, resulting in the denial of federal funds, thereby compressing the permissible agenda to reductionistic studies. Once the denials were discussed in reviews and budgets, the facade became self-reinforcing.

The front Handler developed at Duke prefigured his policy legacy where reductionism's image of rigor was installed as the governing template for what counted as biomedical science — essentially, the front became the framework.

Handler, who had a proclivity to conflate personal opinion with scientific truth, used his position as leader of the Academy to reinforce biochemistry as the foundation of U.S. biomedical research, and to oppose any lines of inquiry that could not be reduced to molecular experiments. He defended federal science budgets, but only on reductionist terms; he opposed expanding Institutes' support for holistic or environmental health approaches. Handler contended they lacked biochemical rigor but was blinkered by his refusal to acknowledge the limitations of biochemical reductionism. He institutionalized his highly exclusionary model of biomedicine and public health, dismissed emergent phenomena, denied a role for electromagnetic energy, and discouraged alternative conceptions of life and healing. Handler established reductionism as U.S. science policy and made the Institutes and the Academy gatekeepers for that molecular view of life.

There was a philosophical clash between Becker and Handler regarding what biomedical science was and the basic model that should be used when conducting investigations and experiments. He regarded biomedical science as the effort to discover the organizing principles that made living systems work. Handler believed it was more than biochemical facts because

they could not yield a causal account of what occurred — for example, why the right bone regrew in the right place with reliable endpoints. Handler, in contrast, saw biomedical science as an indiscriminate accumulation of biochemical facts that hopefully would coalesce into something perceivable and useful in clinical medicine. Becker had a medical perspective and recognized the necessity of an emergent way of thinking about living systems — health-related phenomena cannot be fully grasped by molecular analysis alone, but require systemic, contextual explanations. Handler had an extreme ideological perspective that was embodied in his uncompromising model of biochemical reductionism — an insistence that truth resides in molecular experiments, and that life does not demand system-level models of understanding because it is fully reducible to chemistry.

Becker developed an emergent model of biomedical science during his medical education. In his clinical experiences he saw that physiological systems, disease dynamics, and human health could not always be reduced to molecular explanations. He wrestled with the problem of the complexity of growth and healing, how it unfolded in ways that suggested regulation at levels beyond chemistry alone. Although Becker was initially trained in the biochemical tradition of biomedical science during his basic-science years in medical school, during his clinical years he increasingly recognized its limitations when confronted with the complexity of his patients' medical problems. Through clinical experience, he edged toward a recognition that system-level explanations were necessary for a coherent understanding of health and disease—even if they could not be reduced to molecular pathways, as in metabolism and genetics. Becker's evolving vantage point became sympathetic to an emergent model — that while molecules are fundamental, system-level interactions shaped outcomes in ways irreducible to what can be observed in test-tube studies. He came to believe that a reductionist framework was incomplete for addressing clinical questions and challenges, and that coherent explanations required attention to system-level interactions, constraints, and contexts.

Handler embraced a reductionist model of biomedical science during his academic education. In graduate school, he learned the practice of isolating of chemical species from homogenized tissues, and was taught how to study the physical properties of the isolate. He was trained by his professors — who were part of the first generation of biochemists — that studies of isolates would lead to an understanding of life, the only area of science not already explained by physics. As an inexperienced, impressionable teenager, Handler accepted the words and ideas of his mentors, that an understanding of the complex world of clinical medicine and public health laid in isolating causal mechanisms at the biochemical level. He comprehended the goal of biomedical science as uncovering molecular truths about life, no matter how small or seemingly unimportant an individual truths might be — curing disease and serving immediate social ends were benefits, not goals. Handler became deeply skeptical of any framework that diluted the purity of reductionist inquiry, especially direct explanations of emergent biomedical phenomena, which he considered vague and imprecise speculation that compromised the rigor of true biomedical science. His credo was undiluted biochemical reductionism — knowledge advanced by isolating variables and pinning causal chains to their molecular mechanisms.

Handler never conducted nor even considered conducting direct studies of emerging systems. On the other hand, doing so was Becker's principal objective. He adopted the then-developing idea that to understand life one must go beyond simple molecular interactions and consider system-level explanations. He framed healing as an information-based process consisting of detecting injury, orchestrating the biochemical activity of many types of cells, controlling the salutary activity, and terminating it at the proper time — all system-level activities. Becker wanted to know how the organism's internal signaling architecture achieved the right result in the right place at the right time, and was profoundly skeptical simply cataloging of molecules could explain these activities. He regarded the patient's intrinsic healing capacities as primary — physicians assisted but healing was fundamentally the system's performance — so the scientific task was to uncover the architecture that enabled the performance. In short, Becker affirmed a systems model because it considered organization, context, and control, and he rejected Handlerian reductionism because it did not.

From the start of their careers, Becker and Handler headed in different intellectual and professional directions. Becker began with a focus on holism and bioelectromagnetism. As an orthopedic surgeon and researcher, he studied regeneration, healing, and the role of electromagnetic energy in coordinating physiological processes — questions reductionist molecular biology ignored or dismissed. Becker saw the biomedical complexity manifested in growth, healing, regeneration, disease, and in the consequences of exposure to anthropogenic agents in the environment as something emergent that required high-order coordination that could not be produced by biochemistry alone. Handler began with — and increasingly committed himself to — a reductionist worldview. He saw putative biomedical complexity as something that could be resolved by breaking it into simpler, experimentally tractable parts, each explored by means of innumerable pointillist studies that would ultimately self-assemble to explain the part, and the parts could then self-assemble to deductively explain high-order coordination, if it existed. For several years he conducted pointillist studies of nutrition in rats, hoping to but failing to find results that summed to explanations pertinent to human nutrition.

For 23 years, Becker worked as a surgeon, directed and conducted research in his laboratory and in the clinic, and taught medicine and surgery, all in the context of a hospital and medical school. His research on the physiology and biophysics of bone growth, regeneration, and electromagnetic signaling was published in important national and international journal, but marginalized and sometimes actively suppressed. Handler taught biochemistry at Duke for about 22 years and did laboratory research during the first decade. He then ceased doing research for health reasons and began specializing in advocacy regarding issues pertinent to biomedical policy. He emphasized the need of federal support for reductionistic studies to produce the knowledge needed to explain the whole of human medicine. Subsequently, he managed the research projects of others at the university, the business affairs of the biochemical society, and the funding practices of the National Institutes of Health.

During the 7 years thereafter, he rose to positions of national leadership in matters of bioscience policy. He functioned as a leader of the two main federal science agencies, served on the science advisory board to three Presidents, worked as a consultant to the Veterans Administration and the Department of Defense, testified about science

policy before the Congress more than 30 times, and became the leader of the National Academy of Sciences.

Becker's model of emergence differed from Handler's model of reductionism in many ways, the most salient of which was Becker's adoption of pluralism.

He regarded biochemical knowledge as collection of known biochemical reactions, but insisted on the need to also recognize that a coherent overall understanding of emergent biomedical phenomena demanded system-level explanations and interventions, which cannot be derived from molecular interactions because biomedical explanations characteristically include context, control, and regulation.

Handler's reductionistic model, in stark contrast, was exclusionary. He contended that the only thing that counted as an explanation was molecular cause. In its absence, according to his ideology, knowledge claims regarding the control and regulation of emergent biomedical phenomena, or the role of an anthropogenic factor in the production of disease could never be accepted as scientific knowledge. He dismissed assertions of the existence of electromagnetic regulatory systems as no more than vitalists claims that were overcome years ago, during the development of biochemistry.

Other differences between the models embraced by Becker and Handler were related to the purpose, function, and manner of implemented of the models. Becker rejected the necessity of the conclusive causal inferences demanded by biochemical reductionism and believed oppositely — that they were impossible, at least in the context of emergent biomedical phenomena, electromagnetic regulation, and electromagnetic-related health risks. Handler's attitude toward reductionism was that of a holy man defending his religion. He regarded anything less as the pursuit of half-truths and derided scientists who labeled an explanation as scientific before its molecular basis was established. Becker viewed the biomedical system — control, regulation, action-at-a-distance, nonlinear interactions, individual genetic influences, environmental influences, previous exposure history — as part of the thing to be explained. Handler derided what he called system talk and asserted that, without biochemical anchoring, it wasn't science but only a guess at what the science was, and must be excluded in favor of analyses of molecular processes. Becker considered animal studies a prerequisite to the understanding of the biomedical mechanisms that undergirded emergent biophenomena and determinations of human health risks of anthropogenic environmental agents. Handler regarded animal studies as irrelevant and inapplicable to humans, and demanded reliance on a molecular reductionism criterion for understanding biophenomena and positing the existence of danger to health. Becker regarded bedside research as an important and sometimes best form of biomedical research because the most acceptable explanations for healing come from observations in humans. Handler criticized clinical research of the type carried out by because it never produced conclusive results.

Handler routinely dismissed grant applications not predicated on the basis of reductionism, and particularly objected to Becker's research model because of its cybernetic aspect — the system-wide flow of electromagnetic energy carrying information that controlled and regulated physiological functions. Handler analogized the suggestion of a biomedical role for electromagnetic energy to vitalism — a discredited 19th century bogeyman of biochemists — the doctrine that the functions of a living organism were due to a metaphysical principle

distinct from physicochemical forces. Handler acquired his deep prejudice against the notion of biomedical electromagnetism when he was in graduate school, which was not unusual because it was a rule in the canon of biochemistry, and he was in a policy position to enforce it. He denied financial support for electromagnetic research to many investigators including Becker, who Handler first encountered in the mid-1960s when the government consulted them regarding the biomedical implications of exposure to anthropogenic electromagnetic energy in the context of the Moscow signal.

Handler's claim that Becker's research model was a reincarnation of vitalism was the opposite of the truth. Becker approached the study of emergent biomedical phenomena through physics physiology, biochemistry, and anatomy. Handler's accusation was not a genuine assessment of Becker's scientific model but rather a misleading rhetorical move designed to discredit Becker without engaging with the real scientific and policy questions — namely, whether alternative, non-reductionist models might expand biomedical understanding. Handler regarded his model as a postulate, something immune to experiment, whereas Becker used experiments to develop his model. He never relied on a special essence to explain emergent biophenomena, as Handler implied, but rather regarded them as what, tissues, biochemicals, anatomic structures, electromagnetic energy, and nonlinearity do in the context of individual genetic composition, previous exposure history, and environmental natural and anthropogenic agents.

Becker explicitly embraced physics-grounded concepts and experimental methodologies to rationalize the cybernetic aspect of his model for biomedical science, which differed fundamentally from Handler's model of mass-action chemical kinetics. Becker's publications provided reproducible evidence of measurements of the physical properties and electromagnetic behavior of living tissues and of excised tissues that were studied as intact solids, thus preserving their anatomical structure, which was a key factor in the flow of cybernetic signals. In Handler's reductionist model, not only was living tissue not directly studied, the dead tissue studied was a homogenized slurry that had no anatomic or sub-anatomic structure, which he assumed was unimportant. Becker made the opposite assumption — that structural organization of tissue was the key to an understanding the dynamics of cybernetics.

Becker's research program produced scientific evidence for an electromagnetic control system that governed and regulated emergent biophenomena. He began his research career with a clinical puzzle — muscle weakness. In patients, he detected weak electromagnetic signals on the skin above the weakened muscles. Conventional medicine regarded such signals as meaningless by-products of biochemical processes, but Becker proposed a radical idea—that these signals reflected purposeful physiological activity, part of an internal electromagnetic communication system.

Becker's most influential early research involved salamanders, animals capable of regenerating lost limbs. He discovered that electromagnetic patterns appeared on their skin corresponding to the structure of the nervous system, and that the patterns changed after limb amputation. Salamanders showed distinctive signal changes compared to frogs, which cannot regenerate limbs, suggesting that the signal in salamanders to initiate limb regeneration was

lost during amphibian evolution as if it were a tradeoff — salamanders conserving more of the ancestral amphibian body plan, frogs surrendering the ability to regenerate in return for specializations in body form and locomotion. Becker wondered whether the difference in the electromagnetic signals could be isolated and simulated by modern technology to guide regeneration in evolutionarily advanced but non-regenerative species, especially humans. Further experiments showed that applying magnetic fields or cutting nerves could alter the signals, strengthening the case that they were transmitting functionally important information. Ultimately, Becker demonstrated in the laboratory that partial limb regeneration could be induced even in mammals, such as rats, using electrical stimulation. He also showed that salamanders could regenerate heart tissue after severe injury—findings that underscored the possibility of a broader regenerative capacity in vertebrates.

Becker extended his studies to humans, finding patterned electrical activity on the skin that mirrored his animal results. The signals shifted depending on states of consciousness such as sleep, anesthesia, or hypnosis, suggesting they might be involved in regulating awareness. Looking outward to the environment, Becker analyzed data on geomagnetic storms and found statistical correlations with psychiatric hospital admissions, suggesting that natural magnetic fluctuations could affect human behavior. He later confirmed in laboratory studies that artificially modulated magnetic fields could influence human reaction times. Such findings implied that the body's control systems were sensitive to external electromagnetic conditions.

Becker also explored the role of electromagnetic energy in bone. Building on Albert Szent-Györgyi's ideas, he proposed that bone growth and repair depended not solely on biochemical cues but also on electromagnetic signals. He showed that bone tissue produced electromagnetic signals when mechanically stressed — a property previously thought to exist only in mineral crystals such as quartz — and argued the signals directed bone remodeling and healing. Using refined experimental techniques normally employed by physicists to study the electrical properties of solids, especially semiconductors, Becker presented evidence that mobile electrons facilitated the flow of electromagnetic energy in bone, and he studied the physical properties of bone that could affect the energy flow. His research led him to hypothesize that the skeleton itself operated as an electrically responsive system capable of self-repair. These insights inspired development of the use of applied electromagnetic energy as a potential therapy for fractures and degenerative joint disease.

Taken together, Becker interpreted his results as evidence of a secondary, electromagnetic cybernetic control system operating in the central and peripheral nervous system alongside the well-known and nerve-impulse systems that mediate sensory perception and muscle control. The cybernetic system, he theorized, mediated emergent phenomena such as regeneration, healing, and consciousness, and life itself, and linked organisms to the natural and man-made electromagnetic environment.

Such a framework implied that human health could be vulnerable not only to chemical pollutants but also to electromagnetic pollution, which might interfere with the body's electromagnetic regulatory system. He suggested the issue merited consideration because of the post-war proliferation of TV and radio antennas, radars, and powerlines.

Becker's studies were published in the most respected scientific and medical journals of his day, both nationally and internationally. His work on the solid-state electrical properties of tissues, the role of electromagnetic energy in bone growth and regeneration, the existence of

an electromagnetic control and regulatory system, and its possible link to environmental electromagnetic energy appeared in peer-review journals, demonstrating that the broader scientific community judged his methods and findings as credible. Becker's research was not simply tolerated at the margins, it was part of mainstream scientific discourse. Yet despite this validation, his program was marginalized at the policy level by Handler, whose opposition was not grounded in experimental critique but in ideological conviction. Handler contended that all biomedical phenomena must ultimately be explained in biochemical terms, and therefore rejected Becker's non-reductionist framework outright. From this position, no degree of empirical success could alter his judgment, because Becker's findings violated the reductionist boundary that defined what Handler called true science

Consequently, the legitimacy of Becker's peer-recognized research was rejected on ideological grounds and he was denied financial support by the main federal science-funding agencies — over which Handler exercised broad influence — not on evidentiary grounds but because Becker's research threatened the dominance of biochemical reductionism.

Becker's research spanned regeneration biology, consciousness studies, bone physiology, and environmental health. His unifying goal was to demonstrate the existence of an evolutionary-conditioned electromagnetic communication system that mediated the occurrence of emergent biomedical phenomena, including life itself.

While many in the scientific community accepted Becker's findings as valid contributions, Handler and the institutions he controlled or influenced rejected them on ideological grounds. The clash between Becker's emergent framework and Handler's reductionist dogma underscored a larger struggle in twentieth-century science — whether life and health can be fully understood through biochemistry alone, or whether new models of systemic electromagnetic communication must also be embraced.

In September 1973, the New York Academy of Sciences sponsored the first international conference on electromagnetically mediated growth and healing, a field that Becker had essentially invented. Details of ongoing research in his laboratory that involved the effects of electromagnetic energy on wound healing, cartilage regeneration, infection control, and side-effects were presented in talks by his staff, which included me. Becker delivered the keynote lecture on the electromagnetic nature of the basic biological data transmission and control system. He pointed to the spectrum of interactions between electromagnetic energy and living organisms that he and others had reported — effects on levels of consciousness, spatial orientation, biorhythms, growth, healing, and regeneration — and addressed the issue why the effects occurred. He asked the audience to imagine, starting from lifeless material, how one might go about building an object that was alive and could react to electromagnetic energy in the manner demonstrated in reported experiments. Starting from the time there was no life on earth, he argued that reflection revealed inanimate material could not be endowed with all the properties of living systems simultaneously because the nervous system, for example, could not have developed until after life had been created. But even though the first living object could not have had a nervous system, it must have had some kind of primitive capability to modify its behavior in response to environmental factors, to self-organize and thereby survive. He said that in the absence of such a capability we could not regard the object as alive, and asked how the object could be endowed with this primitive capability. One possibility, based on biochemistry,

postulates the development of complex molecules in an aqueous solution, and their subsequent sequestration from the environment by some kind of membrane. But a better explanation, Becker contended, was the development of solid-state properties such as semiconductivity, photoconductivity, and piezoelectricity, all of which operate by means of a flow of electromagnetic energy. A solid-state origin of life was far more likely to have occurred in response to natural forces, compared with a biochemical origin wherein one is forced to assume that proteins, DNA, and cell membranes all developed simultaneously and spontaneously. He thus arrived at the idea that the proto-cell, the original living thing, must have been some kind of a self-organizing solid-state object whose activity was controlled and regulated by electromagnetic energy. Then, by means of biochemical reactions, evolution produced continuously increasing complexity. However, Becker emphasized, the original solid-state electromagnetic control system was not eliminated, but rather became commingled with the water-based biochemical system. Thinking this way, he concluded, there were two communications systems in the body. The earlier solid-based system that was anatomically linked to the nervous system, and mediated the functions that he studied — consciousness, orientation, biological rhythms, growth, healing — and the later-developing water-based nervous system. He concluded that, at least in principle, both systems could be affected — for good or evil — by anthropogenic electromagnetic energy, depending on the circumstances. When he finished his presentation almost everyone in the audience stood up and a long sustained applause ensued, one that the moderator of the session could not curtail despite his incessant thumping on the microphone. The next speaker prefaced his talk by telling the audience, “we have just heard one of the most important talks in biology ever given.”

Becker was criticized by scientists working in his area who accepted his model of emergent biophenomena, to one degree or another, in a manner that was typical of what occurred in normal scientific discourse. Andrew Bassett, an orthopedist at Columbia University and partner with Becker in his early studies of the role of electromagnetic energy in controlling and regulating bone growth and healing in animals. With the help of venture capitalists, Bassett formed a company and began treating patients with electromagnetic energy, produced using external coils, for the purpose of accelerating fracture healing. Their joint research ended because Becker believed human application of the technique was premature because the extensive animal studies needed to ensure that the energy would not cause cancer had not been done. Bassett believed the work he had done was sufficient to show that the applied energy would cause healing without causing cancer and, within a decade, his company became the most profitable new business in America. Carl Brighton, an orthopedist at the University of Pennsylvania, with the support of the Navy and investors began treating patients whose fractures had failed to heal, using a form of electromagnetic energy that required the use of implanted wires. Brighton rejected Becker’s model as the basis for his clinical success and adopted Handler’s reductionistic model instead. Brighton contended that the bone healing he observed was due to chemical changes at the negative electrode that produced high oxygen levels which caused the healing.

Sitting around a table, each with a PhD from their staffs sitting to their left, Becker, Bassett, and Brighton discussed the use of electromagnetic to cause bone healing. Bassett told Becker that the breadth of his perspective on biology and

medicine was impressive, except for one point.

“You have said that the electromagnetic energy we are applying to our patients might cause cancer. But there is no evidence of that. Your fear is unwarranted and will likely be an incubus on progress in this field.”

“By progress,” Dr. Becker replied, “do you mean commercial progress?”

“I do,” Bassett said, “but more. Electrotherapy may revolutionize medicine. If it can grow bone, why not cartilage and joints, or nerves? I think that in 20 years electrotherapy will be a standard tool in the armamentarium of the physician.”

“You may be right, but you may also be wrong,” replied Dr. Becker. “People will likely think that if Columbia University and the University of Pennsylvania say that the method is safe, then it must be safe. They will know nothing of the thinking that created the method, but their eyes will be glazed over by your promises.”

The taciturn Brighton spoke, saying, “Scientific medicine proceeds step by step, by evolution not by revolution. Oxygen is the key to life. It is not surprising that electricity, which affects oxygen, should also affect growth.”

“Are you saying that oxygen causes cancer?” the sarcastic Jonathen Black, Brighton’s PhD said to Becker who responded only with a disdainful look.

At this point the voluble Arthur Pilla, Bassett’s PhD exclaimed, “Our method has nothing whatever to do with oxygen levels. Our method sends specific messages to particular kinds of cells telling the cells what to do.”

“So your message to bone cells will be to build bone but not to cause cancer,” Dr. Becker asked, and Pilla replied, “Exactly,” oblivious to Dr. Becker’s irony.

Becker liked Pilla’s thinking because it came from the perspective of communicating directly with cells, which could happen only if electromagnetic energy were the language of cells. However, Becker did not like the plan of Bassett and Pilla to rush headlong toward commercialization.

Becker said to Pilla, “The basic principle is that electrical signals control the activity of cells. This capability can be exploited for therapeutic purposes, but it would be foolish to ignore the possibility that it could also cause disease. How can you be sure that you are always sending a beneficial message?”

“Nothing is perfect,” said Bassett. “As physicians, we must always balance the risks against the benefits.”

“On that we can agree,” said Dr. Becker. “But is the risk of cancer worth the benefit of mobilizing a fracture patient one or two weeks earlier?”

“Bob, there is no risk whatsoever of cancer,” said Bassett. “You invented it. You have no evidence. On the other hand the benefits are enormous. Millions of dollars would be saved and people would be returned to work sooner than would be expected.”

“I agree with that,” said Brighton.

Becker looked at Bassett, then Brighton, and then back to Bassett and said, “You both have your companies, and your patents. Are you speaking now as physicians or businessmen?”

“Bob, you sound like a spent force, afraid of the future that you helped create. Electrotherapy is coming, even if it is not perfect,” Bassett replied.

I said nothing.

Lionel Jaffe was a biochemist at Purdue University who conducted laboratory studies of seaweeds. He had the same worldview as his friend Philip Handler — that all biophenomena should be understood as a result of biochemical reactions rather than as emergent processes mediated by electromagnetic energy as described by Becker.

Shortly after Becker first reported the existence of electromagnetic signals on the skin of salamanders, frogs, and humans, Jaffe received federal funding, through Handler’s intervention, to study whether seaweeds produced similar signals. In 1966, Jaffe reported that fertilized seaweed eggs produced electromagnetic signals that caused the eggs to develop into mature organisms, showing that local dynamic adjustments could control emergent biophenomena. He distinguished his report as the first to show biochemical reactions could produce electromagnetic signals that governed an emergent biophenomenon. Jaffe was dissatisfied, however, with the primitive method he used to measure the signal produced by the eggs because it could not be extended to the study of mammals. Again with Handler’s help, Jaffe secured a federal grant to construct a voltmeter that could be used in any study of emergent biophenomena, including Becker’s studies of limb regeneration and bone growth.

Jaffe was invited to present his research at the 1973 New York conference on electromagnetically mediated growth. During his talk, Jaffe said he discovered that seaweed eggs generated electromagnetic signals in the form of ion flows, and that he measured them using a novel voltmeter he invented; he speculated that the signals caused the eggs to develop toward becoming mature organisms. In his model of the system he studied, the processes of control and regulation were collapsed into ionic regulation, contrasting to the Becker’s model of emergent biophenomena, which distinguished between them and was a main theme of the conference. The few attendees who heard Jaffe expressed surprise at his hostility toward electromagnetically-based bone research, which was another conference theme.

Jaffe claimed that the bone growth stimulated by electromagnetic energy was an electrode artifact, and continued to defend his contention even after he was told that such growth occurred even when the electromagnetic energy was applied in the absence of electrodes.

At that time, Jaffe was the only U.S. biochemist who studied the role electromagnetic energy based on a reductionistic model of a living system.

He continually failed to prove that the electromagnetic signals he measured were a genuine mechanism, not merely a by-product of biochemical activity that was causally unrelated to the emergent biophenomena. Essentially, Jaffe's experiments were only exercises in measuring electromagnetic signals, which he found everywhere he looked. Jaffe measured only the omnipresent electromagnetic signals, so each experiment was more or less the same, as if his voltmeter were a hammer and every system-level process were a nail. From Handler's viewpoint, however, Jaffe's work was useful because it provided a sense of openness regarding permissible experimental designs but no sense of fear the canon of biochemistry excluding reliance on electromagnetic energy would be violated. Handler repeatedly supported Jaffe's work with grants from the National Science Foundation and the National Institutes of Health.

Becker largely ignored Jaffe's studies, believing they offered no possibility of understanding development or any other emergent biophenomena. Becker regarded *control* as a directive — top-level initiation and coordination that tells the system what to do and when. He viewed *regulation* as dynamic adjustments through feedback mechanisms that maintained balance and precision, and ensured the response was correct, proportionate, and consistent with system-wide harmony. His research supported his hypothesis that *control* was fundamentally electromagnetic and *regulation* was biochemical and electromagnetic. Becker contended that without recognizing a cybernetic role for electromagnetic energy, the system-level coherence manifested in emergent biophenomena could not be explained

The contrast between Jaffe and Becker was a doppelganger for that between Handler and Becker. Becker was a physician and orthopedic surgeon whose primary motivation was to improve understanding of health, growth, injury, regeneration, and susceptibility to side-effects of anthropogenic agents for the benefit of the public. His background framed biomedicine in terms of systems-level function — how tissues coordinate, repair, and restore order. For Becker, the biochemical reactions within cells were necessary but insufficient to explain such emergent biophenomena because biochemical reactions followed the blind laws of chemistry without reference to higher purposes. Only by means of studies at the level of emergent biophenomena and feedback regulation could one make sense of phenomena like fracture healing, limb regeneration, wound healing, and health consequences of environmental pollution.

Jaffe was a biochemist with an interest in how cells that generated electromagnetic signals in an aqueous environment affected their own physiological function or that of the organism of which they were a part. His ambition was not therapeutic but explanatory within a reductionist program — identifying molecular mechanisms and cellular processes in simple, tractable models such as seaweed eggs.

Jaffe invented a voltmeter to help calculate ionic currents that spontaneously flowed in the water in which the eggs were immersed, and interpreted the currents as mechanistic drivers of the developmental changes that occurred in the eggs. Unlike Becker, Jaffe did not confront the large question of how the laws of physics could account for the emergent developmental changes that occurred in the eggs. Jaffe just assumed the laws could do so, and confined his efforts to measuring the signals that occurred near the eggs.

Jaffe was interested in how biochemical reactions produced ion fluxes during development. His goal was to explain, within a reductionist framework, the molecular details of how the fluxes caused development. Becker was interested in whether and how electromagnetic signals governed growth and repair. His goal was to explain, within a system-level framework, how the signals controlled and regulated system-level biophenomena. By *control* he meant the ability of the signals to specify what form growth would take, and by *regulation* he meant their ability to maintain or restrain growth. In his view, *control* and *regulation* were not reducible to ionic currents, but rather were emergent properties of organized systems, analogous to governance not chemistry. Becker was less concerned with molecular details than Jaffe but, ironically, published many reports in this area, whereas Jaffe published none.

Jaffe favored reductionism and sought to integrate ionic fluxes into a molecular paradigm for developmental biology, thereby explaining an emergent biophenomenon on the basis of a reductionistic model. Becker favored emergentism and proposed a biomedical model in which control and regulation were irreducible to biochemical reactions sans the involvement of electromagnetic energy. Becker recognized biochemistry lacked purpose but believed that, somehow, emergentism intrinsically provided something akin to purpose, because emergent biophenomena existed.

Unknown to him at the time, Edward Lorenz proved, on the basis of the laws of physics, that certain classes of nonlinear systems — as distinguished from linear systems like reductionistic models — exhibited emergent behaviors. Because living systems are a preeminent example of Lorenzian nonlinear systems, it followed that emergent biophenomena, and life itself, are predicted by the established physical laws. In teleological language, the nonlinear nature of living systems provides what functionally amounts to purpose, as Becker believed. The objective of Jaffe and Handler — to refine reductionist explanations by extending them into the domain of emergent biophenomena — was unachievable essentially because it was a physical impossibility. In contrast, Becker's objective — to transcend reductionism by recognizing explanations of health, healing, development, and health reactions to anthropogenic environmental agents require mediative control and regulatory systems — was a physical necessity

Jaffe ingratiated himself to Handler by structuring his laboratory practice within the narrow bounds of molecular biochemistry that Handler championed. By casting his studies of extracellular ion fluxes and cellular dynamics in the idiom of molecular mechanisms and chemical pathways, Jaffe signaled loyalty to the reigning reductionist creed and thereby won Handler's approval. Handler had said that "the progress of medicine lies in deeper penetration

into molecular events”, and Jaffe’s program fit seamlessly into this vision. Handler’s model could absorb Jaffe’s conclusion that electromagnetic signals in the form of ionic fluxes were the mechanism responsible for observed cellular changes in seaweed eggs. Becker’s system-level model — that electromagnetic signals were cybernetic, as distinct from molecularly causal — incorporated the idea that electromagnetic signals had an indispensable role in understanding health and disease, and life itself. He contended that the electromagnetic signals system “is not an epiphenomenon but a true control system... essential for growth and repair.” The same empirical events — weak electromagnetic signals — appeared in both Becker’s and Handler’s models, but their significance and meaning could be and was twisted by Jaffe and Handler to fit their ideological belief in the sufficiency of biochemistry to explain all emergent biophenomena. Whereas Jaffe prospered under Handler’s protection by affirming the reductionist orthodoxy, Becker incurred Handler’s hostility by openly defying it. The irony was that the same empirical events, electromagnetic signals, occurred in both men’s research. For Jaffe, they were mere molecular fluxes reducible to ionic gradients; for Becker, they were evidence of a higher-order regulatory system irreducible to chemistry. The fact that the same phenomena could be enrolled in radically different scientific worldviews, evidenced the profound influence of ideology on the definition of legitimate biomedical inquiry.

Jaffe was careful to accommodate the notion of biochemical mechanisms and not disturb the broader architecture of biochemistry. Becker, in contrast, reconfigured of biomedical theory around emergent control systems — an approach that required new institutions, funding streams, and criteria of scientific legitimacy, as well as the rejection of Handler’s ideological principle that the language of biochemistry was both necessary and sufficient to explain all biophenomena. Handler’s influence and authority made it politically expedient for officials in federal agencies that funded biomedical research to support research like Jaffe’s and reject proposals based on emergentist models as unscientific or vitalistic. Handler’s national position of authority in matters of science policy allowed him to channel research funds, define credible science, and consolidate reductionism as the governing framework of biomedical research. Consequently electromagnetic signals could be institutionally validated when framed as ionic mechanisms, yet delegitimized when framed as emergent control — a duality that revealed the political dimensions of entrenched reductionism. [Great](#)

The contest between Handler’s biochemical reductionism and Becker’s emergent electromagnetic model of biophenomena was never resolved by evidence alone. Instead, it was shaped in the crucible of mid-twentieth-century U.S. science policy, which Handler dominated as a leader of both federal agencies that funded biomedical research — The National Science Foundation and the National Institutes of Health — a witness who testified about science policy before congressional committees almost a hundred times during his career, a science advisor to three U.S. Presidents, a consultant to Defense Department and the Veterans Administration, and head of the National Academy of Sciences. Handler used his positions of power and authority to establish the molecular program developed by biochemists as the definition of legitimate bioscience. He created the conditions in which certain kinds of research involving electromagnetic signals, such as Jaffe’s work on seaweed eggs, could be accepted as extensions

of biochemical reductionism, while other research like Becker's work on salamanders, frogs, rats, and humans was marginalized or condemned.

Creation of the National Institute of General Medical Sciences, which the Congress authorized as a direct result of a two-year lobbying campaign by Handler, was a decisive moment in his campaign to privilege reductionism. In his congressional advocacy, Handler consistently framed biomedical progress as a matter of deepening biochemical knowledge. In testimony before the Senate Subcommittee on Health, he declared, "The great frontier of biology is molecular in nature. What we need most urgently is more knowledge of the chemical basis of life processes." In testimony before Congress, Handler routinely insisted that the federal government's responsibility was to fund basic biochemical research that would uncover what he said was "the chemical basis of life processes." He framed health and disease as fundamentally molecular phenomena, to be solved by dissecting enzymes, DNA, and metabolic pathways, a position that defined the research agenda in terms of molecular causation and biochemical analysis.

Handler's program provided a conceptual home for laboratory studies like Jaffe's that extended biochemical reductionism into cellular physiology by exploring ionic currents and localized feedback mechanisms. Handler's definition of biochemical science was expansive enough to include ion currents in the context of cellular development, a process he called "molecular physiology," a simple extension of "molecular biology," which Handler christened as a new name for "biochemistry." For Handler, Jaffe's work fit comfortably within the reductionist paradigm: ion currents were still biochemical, and entirely compatible with the molecular machinery of ion channels, ion pumps, and the microstructure of cells.

In contrast, Becker's work on bone growth, salamander limb regeneration, and the safety of anthropogenic electromagnetic agents, pointed in an entirely different direction and differed fundamentally excluded from a reductionist framework, and was therefore excluded from scientific acceptability. His experiments showed that internal electromagnetic signals were not mere byproducts of biochemical changes but functioned as regulators of regenerative growth and other emergent biomedical phenomena. To Becker, this implied that control and regulation were properties of complex living systems, not reducible to the purposeless chemistry of molecules. He asserted that the electromagnetic signals he measured were not epiphenomena but a true control system that was essential for growth and repair. According to Becker, biochemical reactions cannot explain such regulation because they follow the laws of chemistry blindly, without purpose. But within the funding model of the National Institutes of Health installed by Handler, nonreductionistic experimental designs were excluded from consideration because they lacked molecular grounding and implied that new explanatory frameworks beyond biochemistry were required. Handler's influence ensured that such lines of inquiry would not be institutionally supported because, although they recognized that biochemistry was necessary for providing an understanding of biomedical phenomena, they implicitly denied it was sufficient for doing so. For Handler, such a possibility fell outside the boundaries of credible science.

As the head of the National Academy of Sciences, Handler reinforced this boundary, using his authority to appoint every Academy committee and edit every report to advance his ideology as a priority for federal research funding. In an Academy report he described concepts such as Becker's electromagnetic cybernetics as "heuristic metaphors" that "must be reduced to

the molecular and biochemical terms that alone constitute scientific explanation.” This boundary-drawing reflected Handler’s institutional goal, that only molecular frameworks would be considered legitimate. Academy reports consistently emphasized biochemistry as the sole scientific foundation of medicine and biology. Concepts like control, regulation, and electromagnetic cybernetics were relegated to the status of heuristic constructs, awaiting mechanistic reduction, or dismissed altogether. In effect, the Academy reports institutionalized the view that emergent biophenomena would ultimately be explained by the localization of molecules, with no need to consider a role for electromagnetic energy — chemical energy was deemed to be necessary and sufficient.

One of Handler’s most effective rhetorical devices for supporting his ideology was the invocation of “vitalism.” By the mid-twentieth century, “vitalism” had become a term of scientific disrepute, a label for pre-modern speculation about life forces. Handler and his allies strategically weaponized the term to discredit approaches that emphasized emergence or system-level properties and delegitimize arguments that supported such approaches. In an Academy symposium he sponsored, Handler said, “Science cannot afford to return to old metaphors about forces of life. We must reduce, not mystify, and we must always remember that every phenomenon will yield to molecular analysis.”

Becker, whose clinical findings suggested that electromagnetic energy regulated growth and repair, became a particular target of Handler. Even though Becker explicitly rejected metaphysical notions, had three PhD physicists on his staff, and published many reports dealing with the solid-state properties of tissues pertinent to electromagnetic energy, Handler’s network sought to stigmatize Becker’s research as vitalistic and therefore unscientific. Jaffe’s work was never threatened with such dismissal. Although he studied the same empirical class of phenomena — electromagnetic energy — he did so in a way that preserved reductionist assumptions.

By framing ionic fluxes as mechanistic extensions of biochemistry, Jaffe avoided the taint of vitalism and ensured his work was institutionally acceptable. Thus, although Jaffe and Becker worked on electromagnetic energy in living systems they received radically different receptions from Handler, not because of the quality of their observations, but because of the frameworks in which they were interpreted.

The essential difference between reductionism and emergentism lay in the living system that was chosen for study. Jaffe was concerned with molecular and cellular processes in lower life forms such as seaweeds. Becker, in contrast, was focused on control and regulation in higher life forms such as mammals, and the determination of how they healed grew, developed diseases, and responded to natural and anthropogenic agents in the environment. His interest was in the system-level signals that that could guide growth, restrain it, or redirect it after injury. For Handler, whose worldview was anchored in the reductionist conviction that all biology must eventually be explained solely in terms of molecular mechanisms, Jaffe’s program was acceptable and even useful. Becker’s ideas were not merely unacceptable but dangerous, because they implied that reductionism was insufficient and emergent explanatory models were needed — an outcome Handler worked tirelessly to prevent.

Handler, through speeches, congressional testimonies, authority over federal research agencies, and Academy reports, institutionalized reductionism by controlling the purse strings of research, not on the basis of scientific evidence. He said in a 1974 Academy speech, “The power of molecular biology lies not only in its past successes but in its promise to explain every aspect of life. To turn elsewhere would be to abandon the only rational course.” But the so-called promise was a figment of Handler’s ideology. Despite the enormous research funds he essentially controlled, no evidence whatsoever was ever produced indicating biochemistry was both necessary and sufficient for explaining “every aspect of life,” nor was there any evidence that abandoning his ideology was irrational. Becker, who insisted control and regulation were irreducible to molecular process, was far closer to the truth than Handler, at least with regard to emergent biophenomena and emergent health risks. The reality was that chemical energy alone was insufficient to explain any aspect of life — electromagnetic energy was also needed. In what amounted to a contest between David and Goliath, Becker made this point on the basis of research funded at an infinitesimal level compared with what Handler spent to advance his ideology.

Handler embraced Jaffe’s reductionist-compatible program regarding electromagnetic signaling and funded it for many years. Becker’s program, in contrast, was marginalized by the federal agencies Handler influenced. His research laboratory enjoyed a stable, slender existence because the Veterans Administration research program in orthopedics was beyond Handler’s teeth throughout the 1960s and most of the 1970s. In this way, a class of phenomena — electromagnetic signals — was institutionally split, with one stream absorbed into biochemistry and the other cast into disrepute.

Handler positions of authority and influence enabled him to ensure that reductionism was the official and exclusive language of American biomedicine. Jaffe’s ionic studies were acceptable because they remained molecular in character. However, Becker’s emergent electromagnetic cybernetics, which spoke in terms of control and regulation beyond chemistry, was excluded as metaphysics. The institutional entrenchment of reductionism was not a reflection of scientific evidence but rather a product of deliberate strategy for implementing Handler’s ideology — supporting research that reinforced biochemical orthodoxy while discrediting work that challenged it. The institutional entrenchment of reductionism was not a reflection of scientific evidence but rather a mark of the success of Handler’s strategy — supporting research that reinforced biochemical orthodoxy while discrediting work that challenged it. The strategy narrowed of what counted as legitimate science. Electromagnetic energy was validated in one guise and marginalized in another, depending on whether the guise could be reconciled with the reductionist worldview Handler was determined to preserve.