NATIONAL ACADEMY OF SCIENCES

JAMES DANIEL HARDY
1904–1985

A Biographical Memoir by

ARTHUR B. DUBOIS

Biographical Memoirs, VOLUME 88

PUBLISHED 2006
NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.

Photograph by Earl Colter

James D. Hardy

JAMES DANIEL HARDY

August 11, 1904–September 6, 1985

BY ARTHUR B. DUBOIS

HARDY CAME FROM A family that was interested in teaching. Born in Georgetown, Texas, in 1904, he attended a Mississippi military school for boys, and from this beginning worked his way up from astrophysicist to admiral. During his career, he swept the underwater mines from Anzio Beach to Normandy, taught astronauts how to fly the space capsule for reentry into Earth's atmosphere, and he calculated the heat load of sunlight on the bright side or of chill of blackness on the dark side of the moon. To reel in bluefish three at a time on Long Island Sound, he used an umbrella rig with a square frame and four lures, one on each corner. His major contributions to science were in finding out how humans regulate their body temperature.

My first encounter with Hardy was as a child watching him play vigorous squash with Harold G. Wolff on the 18th floor of New York Hospital. Each intended to raise the other's core temperature higher than his own. Hardy and Wolff measured pain threshold on each other, and they evaluated the intensity of pain by using my classmates at Cornell Medical School as guinea pigs. The intensity of pain was expressed as a 10-step rating scale, the Dol scale, in which 10 is maximum pain and is experienced by women in labor.

Hardy's life's work seems to have sprung from a physics textbook (Kimball, 1929) that was once on his bookshelf and is now on mine. That textbook formed the basis of his scientific career in that it was like an acorn that would grow into an oak tree. Pin oaks were Hardy's favorite trees, which he planted on his lawn in Woodbridge, Connecticut, and in front of the John B. Pierce Laboratory in New Haven. Those trees would grow straight up as did Hardy's career.

Hardy's grandfather, James Malcolm Daniel, went from upstate New York to Indiana, where he met and married Laura Leonard, and then moved to Overton in East Texas. In 1901 they moved to Georgetown, Texas, where the grandfather became a railroad station agent.

Hardy's father, James Chappel Hardy, had moved from East Texas to Georgetown (the home of Southwestern University) to train for the ministry. There he met and married a student, Lulu Daniel, on November 11, 1903. Hardy's father founded a military academy for boys at Columbia, Tennessee, and subsequently founded the Gulf Coast Military Academy at Gulfport, Mississippi, in 1913.

Jim had a brother, Leonard, and sisters, Jessie, Verona, and Laura. When Jim went to Gulfport High School, his summer job was heavy work loading gravel. He became a football quarterback and was on the track team and debating society. Turning 17, Jim attended Southwestern University, a small Methodist college in Georgetown, Texas, for his freshman and sophomore years. Becoming interested in physics and math, he transferred to the University of Mississippi, where astronomy and physics were his favorite subjects and W. L. Kennon and Vice-Chancellor Alfred Hume were his favorite professors. Since, as he wrote in his autobiographical note for the National Academy of Sciences, he was too small and not strong enough to become competitive in sports, he turned instead to studies, the debating society, and girls. He was given a job as instructor in physics, and at graduation in 1924 was awarded "special distinction" on his degree, awarded magna cum laude. Here his own notes end.

Hardy continued his training in physics, astronomy, and infrared spectroscopy at the University of Mississippi, where he obtained an M.A. degree in 1925 and was an assistant professor from 1925 to 1927. In 1928 he married Augusta Ewing Haugh, of Atlanta, Georgia. He received scholarships at Johns Hopkins University, where he was awarded membership in the Phi Beta Kappa Society and a Ph.D. degree in 1930. His thesis (1930) was "A Theoretical and Experimental Study of the Resonance Radiometer," whose principle he ascribed to A. H. Pfund (1929). In his thesis Hardy used a pendulum to periodically interrupt a light beam that was focused on a thermocouple so that the voltage from the thermocouple would contribute to and amplify the swing of the galvanometer set to have a frequency of oscillation equal to the frequency of the pendulum. This boosted the amplitude 25 times, the way a small periodic push could make a person go higher on a swing. A second light source, bounced off the mirror of the first galvanometer, passed through a grating with bars two mm wide and gaps also two mm in width. The striped beam was focused on two adjacent gratings, separated by a bar's width to make them out of phase with each other, and because the oscillation period of the second galvanometer equaled that of the first galvanometer, the current from the thermocouples periodically kicked the second galvanometer into higher swings up to 2000 times as great as the displacement that would have resulted from the current generated by the first thermocouple. Weak signals of light or infrared from the primary source became strong light and electrical signals from the secondary source thrown periodically onto the second pair of thermocouples and their galvanometer. This maximized the optical signal yet minimized the random noise caused by jiggling of molecules and table tops.

The Pfund principle of frequency-dependent, optical-electrical-coupling amplification used by Hardy allowed him to overcome the dimness produced as he spread out the infrared spectrum with a prism to separate closely spaced absorption bands of crystalline versus fused quartz, of helium, of neon, of ammonia, or of hydrogen isotopes. He did these experiments between 1930 and 1932 while he was appointed as a National Research Council fellow at the University of Michigan.

At the time that Hardy was ready to look for a job as an astrophysicist, there was an economic depression, and no such jobs were available. However, on June 7, 1932, he was offered a position as a physicist at the Russell Sage Institute of Pathology under the directorship of Graham Lusk. The letter was signed by my father (Eugene F. DuBois), who was conducting research on body heat production using the Russell Sage calorimeter. In 1948 in his autobiographical note prepared for the National Academy of Sciences, Eugene DuBois wrote (to Hardy's pleasant surprise): "Perhaps my most important service was to bring James D. Hardy, a physicist, into the field of physiology where he could apply his basic training in radiation."

On October 1 of that year, Hardy began the study of the radiation of heat from the human body in the new building of New York Hospital at York Avenue and 68th Street. A series of papers from 1934-1936 on this subject began with: "I. An instrument for measuring the radiation and surface temperature of skin" (1934). He used a portable radiometer to measure radiant energy flux, which he expressed in calories per second per square centimeter of body surface. From this, Hardy used the Stefan-Boltzmann formula to calculate the skin temperature. The formula he used is S =

$S_0(T^4 - T_0^4)$, where S is the radiation emitted in calories per square cm of skin surface per second, S_0 is the Stefan-Boltzmann constant 1.37 x 10^{-12} cal/sec/cm^2, T the absolute temperature of the skin surface (273+ degrees C), and T_0 the absolute temperature of the reference thermocouple at room temperature. At a skin temperature of 27°C the wave length of infrared, calculated from quantum theory using Planck's constant, would be in the range of 5 to 10 or perhaps 5 to 20 microns.

Although shiny surfaces neither absorb nor radiate visible light and infrared light effectively, Hardy found that white skin absorbs and radiates long wavelength infrared just as well as blackened skin. Using a rock-salt prism, he found the absorption and emission wavelength of skin to be 5 to 10 microns, similar to that of a black body, or equal to a Leslie cube held at skin temperature. But the skin had some prominent bands in the absorption spectrum, bands that he attributed to organic compounds in the skin. A Leslie cube is a copper water bath that has a hollow cone, painted flat black inside, inserted into one side with its base facing outward and apex inward. For temperature calibration the spectrometer "looks" at the temperature radiated outward from inside the blackened cone.

When the skin is exposed to visible light, or to infrared of 1-2 microns wavelength, part of the incident energy is reflected by the skin, but part is absorbed and can be sensed as heat. With exposure to wavelengths of 2-10 microns, all the infrared energy is absorbed and may be felt. If the skin is painted with india ink, all the visible and infrared wavelengths are absorbed completely at the skin surface whence the heat may diffuse deeper into the skin. Hardy and Oppel (1937,2) measured the radiant heat from the skin immediately after such an exposure to radiant energy to determine the skin temperature responsible for the threshold for sensation of heat. Later, Hardy would measure the thresholds for warmth, cold, and pain sensations. Between 1937 and 1938 his attention turned to radiant heat loss as compared with convective and evaporative heat loss from the human body at a variety of environmental exposure conditions with or without clothing of subjects while they were enclosed in the Russell Sage whole-body calorimeter. The subject inside would aim the radiometer at designated points on the skin surface while Hardy, standing outside the calorimeter, took galvanometer readings of skin temperature to calculate radiant heat loss (1937,1).

To apply infrared methods in thermal physiology to medicine, Hardy had to understand preclinical and clinical sciences that he had not encountered in college, graduate school, or postgraduate training. Therefore, he took medical school courses in biochemistry, physiology, pharmacology, and neuroanatomy. Hardy maintained an up-to-date reprint file, as well as the latest textbooks.

From 1939 to 1942 Hardy, Wolff, and Goodell published papers on the sensation of warmth and pain resulting from radiant energy focused on blackened human skin. They used a light bulb as the source of heat, and a radiometer as a means of testing the incident rate of heat flux at which the sensation was felt. Sensation (warmth or pain) was dependent on the wavelength of radiation (visible, near infrared = 1-2 microns, or further infrared = 3-10 microns), and on the intensity of radiation (calories per cm^2 per second), the duration of exposure (seconds), skin pigmentation (white or black), skin area exposed (cm^2), and skin location (forehead or forearm). These factors were sorted out by Hardy and Oppel for warmth (1937,2) and cold (1938).

Based on the exploratory findings, Jim Hardy (physicist turned physiologist), Harold G. Wolff (medical neurologist), and Helen Goodell (research fellow in medicine) published a method to determine the pain threshold. They then began to use it to find out how analgesics changed the amount of radiant energy required to reach that pain threshold (1940). The voltage supplied to a 1000 watt lamp was controlled using a rheostat. The light from the lamp was focused by a lens and passed through a shutter that was set to open for exactly three seconds. The light then went through an aperture set to expose 3.5 cm^2 of skin that had been blackened with india ink, for example, on the forehead or forearm. The light intensity was initially set low, but was increased by steps until the subject reported pricking pain, which is distinct from the sensations of warmth or heat. The head or arm was removed from the aperture and replaced by a calibrated thermocouple to measure the radiant heat flux that had been responsible for heating the blackened skin. The heat flux producing threshold pricking pain was found to be 0.23 $cal/cm^2/sec$. Pain reached maximum when the heat flux was more than doubled and the skin blistered.

Various analgesics raised the amount of heat flux required to reach the threshold for pricking pain by about 35 percent above the control threshold (stated previously as 0.23 $cal/cm^2/sec$). These analgesics included acetylsalicylic acid, acetanilide, acetophenetidine, alcohol, barbiturate, and caffeine (1941). The investigators had found that morphine raised the pain threshold 70 percent or even 100 percent, the latter resulting in blistered skin. Codeine raised the threshold about 50 percent, or halfway toward the blistering intensity (1940). In comparison, ethyl alcohol equal to one or two drinks rapidly raised the pain threshold 45 percent for a short time (1942,1).

The reader should note that the concept of pain threshold was based on the radiant heat flux aimed at the blackened skin. At this point the skin temperature at which pain was felt was not being measured. That would have to wait until after World War II.

As Europe was erupting into World War II, Hardy went to the Navy and volunteered his services as a physiologist. The Navy said that it did not need a physiologist, but did need a physicist in mine sweeping, and that Hardy seemed to be suitable. They sent him to England to learn how to defuse unexploded bombs and sweep underwater mines in preparation for an invasion of Europe. As a result, he became the officer in charge of a minesweeping group at the invasion of Tunisia, Sicily, Salerno, Anzio, Normandy, and southern France. He was the mine officer for the Eighth Fleet in 1944 and minesweeping operations officer of the chief of naval operations. He was awarded the Purple Heart and Legion of Merit medals. He returned to inactive duty in February 1946, but continued to train a naval reserve unit and so became commander in June 1948, captain in 1952, and rear admiral in the naval reserves in 1961.

"Isn't it dangerous to try to defuse an unexploded bomb?" I asked.

"Well," Hardy replied, "You have to read the latest bulletins on the newer types of German bombs. Otherwise, when you try to defuse them, they can blow up."

Hardy's helpful nature is revealed by the following anecdote. While under orders to travel from one site to another, he had to wait for a few days until transportation arrived. He reported to the local commander of the post, and rather than do nothing, inquired in what way he might be of some use. The commander suggested that they needed someone to open and censor outgoing letters to make sure that the movement of ships or other operations would not be revealed in the correspondence. Hardy undertook the task until his transportation to the next duty post arrived. He always volunteered his services as a participant in events.

Hardy was bold but cautious, proud but modest, honest about people but always polite concerning them. He loved the South, but preferred to live in the North. These differences coexisted in the same person and put his blood pressure up and down like a yo-yo, also producing a duodenal ulcer that he hardly mentioned while he was directing minesweeping operations in the Atlantic during the war but which later required subtotal gastrectomy.

In 1946 Hardy returned to Cornell University Medical College where he resumed his studies on pain sensation in collaboration with Wolff and Goodell. Their work is explained in their book *Pain Sensations and Reactions* (1952,1). The first big step leading up to that was the invention of the Dol scale (1947).

Reasoning that pain was a sensation, the authors thought that a just noticeable difference (jnd) in intensity (I = intensity of pain) could be expressed using the Weber law, delta I / I, which Fechner expressed as K, the cumulative function, which is that the sensation is proportional to the natural logarithm of the intensity. Hardy measured the intensities of incident heat flux producing just noticeable differences in pain sensation ranging from threshold to maximum. There were 21 such steps of jnd over the range from threshold heat flux (0.22 cal/ cm^2/sec) to heat flux producing maximum pain (0.68 cal/cm^2/sec). Because it was not usually easy to distinguish less than two jnd steps, the authors decided on a 10-step scale, called the “Dol scale.” They made a graph of the number of Dols (Y axis) versus the stimulus intensity (X axis). The intensity of the stimulus was plotted as increasing linearly rather than logarithmically. The next year they compared the jnd pain scale to estimates of Dols produced by heat as fractions of the heat that had produced 8 Dols. The Dol scale produced by fractionations of 8 Dols equaled the Dol scale built up by summation of jnds. We see Dol scales on the wall of a patient's postoperative recovery room. The patient points to the scale to indicate the intensity of his or her pain as a guide for the doctor to prescribe an analgesic to relieve the pain. Hardy and Javert (1949) used this method to estimate the pain of childbirth, which they found equal to 10 Dols, unless relieved by analgesics.

Hardy, Goodell, and Wolff made a major discovery when they found that the pain threshold depended primarily on skin temperature and only secondarily on the amount of heat flux (1951). Starting in a room at 26°C they measured skin temperature and pain threshold, then moved to a room at 8°C to measure skin temperature and pain threshold on cold skin, then heated the skin to a skin temperature of 43°, each time measuring the heat flux required to produce pricking pain. In each case, pain occurred when the skin had reached 44.9°C, whether initially cold or warm. Reversible tissue damage occurred at that temperature of 44.9°. They concluded: "Thus it is the actual skin temperature level that is critical as regards noxious stimulation of the skin," suggesting that the rate of protein destruction exceeded the rate of protein repair, causing pain.

Alice Stoll and Jim Hardy (1952,2) were influenced by C.-E. A. Winslow and L. P. Herrington (1949), who had examined the heat exchange between a person and the surrounding environment. Stoll and Hardy adapted the thermal radiometer to enable them to measure indoor and outdoor temperatures as a way of examining the way the environment influenced radiant heating or cooling of a person. They could locate hot or cold spots in a wall, or find how Earth radiates to a clear sky at night.

Day and Hardy (1942,2) had constructed a gradient layer calorimeter to measure heat production and heat loss from the body of a premature infant. They placed the infant inside the calorimeter, which consisted of a copper box that had thermocouples inside and outside the box to measure the temperature gradient across the walls (air inside minus air outside). Generation of a measured rate of heat production in the box allowed conversion of thermal gradient to heat flux. The principle behind this early gradient layer calorimeter was used by Lawton, Prouty, and Hardy (1954,1) to construct a gradient layer calorimeter to measure heat loss and heat production in laboratory animals. Air temperature and humidity entering and leaving the chamber were measured at the same time as heat loss through the gradient layer surrounding the animal. Thermal and metabolic responses were complete within six minutes. Hardy needed this apparatus to make measurements on *Cebus* monkeys, cats, and dogs for comparison with earlier measurements on man (1954,2). Surprisingly, temperature regulation in dogs, not monkeys, was closest to that of humans. Hardy used a computer diagram to illustrate how the hypothalamic center seemed to regulate bodily heat loss. Later, he would test this diagram by measurements on the hypothalamus of dogs.

At Johnsville, Lipkin and Hardy gave birth to the first "computer diagnosis" of disease, in this case hematology disorders (1958,1). The computer consisted of punched cards in a shoe box. Diagnostic criteria had been obtained from a hematology textbook and were wedge-punched at the edge of each of 26 cards to match the symptoms and laboratory findings of the 26 blood disorders. Knitting needles were run through the holes that corresponded to the symptoms and laboratory findings of each of 80 patients, matching those to the diagnostic criteria wedge-punched into the edges of the set of 26 hematology cards. Shaking the box made the card whose criteria matched those of the patient drop out of the shoe box to show the diagnosis printed on the hematology card.

During Hardy's appointment in 1953 as research director of the Aviation Medical Acceleration Laboratory, U.S. Naval Air Development Center, in Johnsville, Pennsylvania, Hardy was in charge of the human centrifuge. He was also professor of physiology at the University of Pennsylvania, where he was in charge of the Ph.D. program for students in physiology, under John Brobeck, chairman of physiology.

At Johnsville, Hardy tested G tolerance of astronauts for the space program and tested equipment that would be flown in the Gemini and Apollo space flight missions of the National Aeronautics and Space Administration. Since astronauts would have to be protected against thermal stress of solar radiation, or dark sky, in orbit or on the Moon, rats and other animals as well as humans were used to assess the effect of thermal radiation on the skin. Re-entry from space into Earth's atmosphere would produce seven to ten G force on the body as the space capsule decelerated. Protection against these G forces could be tested using the human centrifuge (1959,1). To simulate various phases of space flight, the person riding in a capsule mounted on the arm of the centrifuge could control the roll, pitch, and yaw of the capsule, enabling astronauts to practice in advance how to control the rocket during its exit from and reentry into the atmosphere (1959,2). This way, Hardy taught the astronauts how to fly the space capsule.

A major step in understanding pain threshold came when Hendler, Crosbie, and Hardy (1958,2) devised a method to alternate between exposure of the skin to infrared radiation and the measurement of the resultant skin temperature. The trick was to use fan blades separated by open sectors that exposed the skin first to the heat source and then to the radiometer, which measured the skin temperature as the fan rotated at 12 revolutions per second. The method would be used to relate temperature sensation to skin temperature.

After studying the heat production and heat loss in the dog (1958,3), Hammel, Hardy, and Wyndam surgically implanted thermode tubes and thermocouples into the hypothalamus of the dog brain. The tubes would conduct hot or cold water deep into the brain substance to locate neural receptors and control centers sensitive to heat or cold (1960; 1961,1). Hardy's thinking on thermoregulation is best summarized in "The Physiology of Temperature Regulation" in *Physiological Reviews* (1961,2).

In 1961, at the age of almost 59, Hardy, who was under the stress of two simultaneous full-time jobs, or three if you include his being in charge of a naval reserve training unit, welcomed an offer to become director of the John B. Pierce Foundation Laboratory, in New Haven, so named for the benefactor who had endowed the New York Foundation in his will of 1916 to do research and teaching for the benefit of human comfort and hygiene (i.e., health) in the fields of heating, ventilating, and sanitation. The trustees of the Pierce Foundation of New York had established a laboratory building in New Haven in 1934 to provide Charles-Edward Amory Winslow, who was a Yale professor of public health, with a place where he could oversee research in indoor air quality and climate, which were among his interests. The initial staff under Winslow had been Lovic P. Herrington and A. Pharo Gagge. The trustees had also established a facility in New Jersey to design and test prefabricated houses suitable for families, and to test modular buildings for farms or factories. Hardy persuaded the trustees to focus the resources of the trust fund on physiology rather than on architecture. Hardy was appointed professor of physiology at Yale Medical School and later professor of public health. He negotiated an affiliation agreement with Yale to work jointly on teaching and research in areas of common interest to the foundation and Yale. This agreement attracted capable staff members to the laboratory, many of whom received academic appointments at Yale, where they taught without pay. Hardy began to supplement the annual budget with research grants from outside the foundation, such as those from the National Institutes of Health. This way he set aside enough endowment money received from the trustees to enable further construction of new laboratory space.

Scientists are promoted to administrative positions because of their achievements in science and often lack training in administration. But Hardy had learned administration first by working in several departments (medicine at Cornell Medical School, physiology at the University of Pennsylvania, the Navy aboard ship, and then in the Civil Service at the Naval Medical Acceleration Research Laboratory, in Johnsville). As civilian director of the Johnsville facility, Hardy supervised employees by using Civil Service guidelines. When he came to the Pierce Laboratory, Hardy had these systems of administration in his background, first academic, second military, and third Civil Service. His dealings with Yale and with the trustees, and his management of the laboratory were based on this experience.

Talented scientists joined or visited the lab between 1961 and 1965, for example, Jan A. J. Stolwijk, A. Pharo Gagge, H. Ted Hammel, T. Nakayama, Harold T. Andersen, Joseph Eisenman, R .F. Hellon, and Don C. Jackson. George Rapp and Robert Rawson and later Michel Cabanac took part. Women scientists initially included Dorothy Murgatroyd, Kerstin Southerland, and Dorothy Cunningham. Hans

Graichen built much of the equipment, and James Casby wrote the computer programs to collect and analyze laboratory data. Linc Dotlo managed the lab, and Gloria Trapkauskas was the secretary.

Hardy's interests during this time continued to focus on the internal mechanisms for regulation of body temperature not only in man (1966,1,2) but also in monkeys (1971), dogs (1960), rats (1974), and even such animals as lizards (1967), which although generally considered cold blooded, sought warm spots if they were infected with bacteria. Their hyperthermia seemed to be a substitute for the fever in mammals. John T. Stitt would explore the febrile response to endotoxin in rats (1974).

Hardy now had an opportunity to examine how man responded to changes in the thermal environment. He built specialized chambers in which the environment could be controlled and changed quickly. Partitional calorimetry was carried out within an all-weather chamber using different indoor climates where the temperature, humidity, wind velocity, and radiant heat load could be varied (1965). The respiratory oxygen uptake, skin temperature, and sweat rate would be monitored with a computer, and the comfort vote and thermal sensation would be recorded. People at rest or exercising on a bicycle ergometer would rate the comfort of the conditions while their core temperature, skin temperature, and sweat rate were measured. The effect of clothing on comfort was measured. Such measurements of subjects at rest or during exercise, with summer or winter clothing, were of use in defining the comfort zone.

From all this, Hardy and Stolwijk (1966) sketched out a heat transfer model of the passive temperature control system, and then added to this the body's temperature control system. A. P. Gagge translated these into comfort zones delineating acceptable conditions for people at rest or working in built environments, such as office buildings, factories, or vehicles. Such data are used by architects and heating and ventilating engineers as criteria to be met in designing buildings. The thermal physiology field was summarized in a collection of articles (1970,1) resulting from an international symposium held in New Haven in 1968.

As director, and even as director emeritus at age 70, Hardy kept up certain traditions. One was lunch club. At noon, Hardy would sit down at the head of the table, with his top senior on his right, next senior on his left, and so forth, alternating sides until reaching the junior person near the end. A local person, Rose, came in and prepared soup and sandwiches. Conversation usually included experiences and events, with war stories sprinkled among them. Lunch kept the group cohesive and informed.

Another tradition was the annual bluefishing expedition. From the dock at New London a select crew consisting of the head of technical services, two janitors, the business administrator, and Hardy would board the party boat to go fishing. Out in "the Race" the rods would be rigged and the lures deployed in the tide rip over a shoal. There may be some parallel between catching fish, getting research grants, and writing manuscripts. Hardy was good at all of these.

There was the tradition of the annual Christmas party. Mrs. Hardy (Augusta) would invite most of the laboratory members and their spouses to dinner at the Hardy house in Woodbridge, Connecticut. Someone would play the piano and lead the Christmas carols. People would sit around and chat. After dinner everyone would help clean up. Several days later Augusta would load the ironing board into the trunk of the Cadillac and the Hardys would head for their condominium in Winter Park, Florida, near Jim's brother, Leonard, who was a magistrate judge in Orlando.

There was the annual summer outing at a country site for hire. All the scientific and maintenance staff would attend with wives and children. The picnic grounds had wide lawns, tennis, volley ball, grills for hot dogs and hamburgers, beer, ice cream, and a lawn for playing bocce ball. Hardy and the janitors would roll the bocce balls to see who could get closest to the white ball used as a target. The janitors usually won at this game. Younger athletic scientists competed at volley ball. The children swam in the pool while the wives watched them for safety.

Hardy added other specialists to the staff in the fields of assessment of air quality, and of psychophysics to assess how the human senses respond to environmental changes. Eleanor R. Adair would extend Hardy's earlier studies on microwave absorption to include thermal responses to microwaves in monkeys trained to control their environment by adding cool or warm air as they sensed a need (Adair et al., 1970, cited in Hardy and Stitt [1971]). There were two conclusions. One was that microwaves could heat up body tissues while bypassing the skin's sensors, posing a thermal threat; the other was that behavior of trained animals could be used to judge their feeling of temperature. Hardy's lab became a center for visiting scientists from Great Britain, Europe, Canada, and Japan.

Hardy reached the age of 70 in 1974 and became Professor Emeritus at Yale and Director Emeritus of the John B. Pierce Laboratory. I, who had known and respected him since 1932 at Cornell Medical School and then while at the University of Pennsylvania, became director. Hardy continued for 10 more years as a consultant whose advice was of the utmost value in continuing the traditions of the Pierce laboratory.

Hardy received many awards for his work. Among these were the Eric Liljancrantz Medal of the Aerospace Medical

Association in 1960; Meritorious Civilian Service Award by the U.S. Navy in 1961; honorary doctor of science, Kansas City College of Osteopathy and Surgery, 1966; honorary doctor of science, Southwestern University, 1967; doctor honoris causa of the Faculty of Medicine and Pharmacy, University of Lyon, France, 1970; fellow of the American Academy of Arts and Sciences, 1970; member of the National Academy of Sciences, 1970; William F. Peterson Medal for Human Biometeorology in 1972; and Distinguished Alumnus Award, University of Mississippi, 1976. He was an invited speaker at many international conferences, traveled abroad with his wife, played golf, and as he passed 70 in 1974 continued to do all these things and advise the younger members when they asked him. Despite hypertension and some angina, which were controlled with pills, he continued to be active and greatly admired by everyone in the thermal field.

Hardy retired from his Navy career as line officer with the rank of rear admiral. On Navy Day, he would appear at the lab resplendent in full uniform with the gold stripe on his sleeve. Despite coronary arteriosclerosis, he lived to the age of 81. Highly respected, well liked, he and his wife were buried in Arlington National Cemetery with an 18-gun salute. He was survived by a sister, Laura Crites of Annandale, Virginia; a brother, Leonard, of Orlando, Florida; son James Daniel Hardy Jr., of Baton Rouge, Louisiana; and son George Frederick Hardy, of Pelham Manor, New York.

NOTE

A literature search for publications of James Daniel Hardy yielded a second author with the same name. Both authors are honored graduates of Ole Miss. Ours was a physiologist who lived in Woodbridge, Connecticut, whose publications originated in institutions on the East

Coast, whereas the other was a cardiovascular surgeon who lived and published in Jackson, Mississippi. They wrote about different subjects.

REFERENCES

Kimball, A. L. 1929. *College Physics* (4th ed. revised by A. L. Kimball Jr.) New York: Henry Holt.

Pfund, A. H. 1929. Resonance radiometry. *Science* 69:71-72.

Winslow, C.-E. A., and L. P. Herrington. 1949. *Temperature and Human Life*. Princeton, N.J.: Princeton University Press.

(Obituary information can be found in Adair, E. R. 1985. *Bioelectromag. Soc. Newsl.* 62; LaMotte, R. H. 1986. *Pain* 27:127-130; and Stitt, J. T. 1986. *Yale J. Biol. Med.* 59:83-84.)

SELECTED BIBLIOGRAPHY

1930

A theoretical and experimental study of the resonance radiometer. Dissertation. *Rev. Sci. Instrum.* 1:429-448.

1934

The radiation of heat from the human body. I. An instrument for measuring the radiation and surface temperature of skin. *J. Clin. Invest.* 13:593-604.

1937

With E. F. DuBois. Regulation of heat loss from the human body. *Proc. Natl. Acad. Sci. U. S. A.* 23:624-631.

With T. W. Oppel. Studies in temperature sensation. III. The sensitivity of the body to heat and the spatial summation of the end organ responses. *J. Clin. Invest.* 16:533-540.

1938

With T. W. Oppel. Studies in temperature sensation. IV. Stimulation of cold sensation by radiation. *J. Clin. Invest.* 17:771-778.

1940

With H. G. Wolff and H. Goodell. Studies on pain. Measurement of the effect of morphine, codeine and other opiates on the pain threshold and analysis of their relation to the pain experience. *J. Clin. Invest.* 19:659-680.

1941

With H. G. Wolff and H. Goodell. Measurement of the effect on the pain threshold of acetylsalicylic acid, acetanilid, acetophenetidin, aminopyrine, ethyl alcohol, trichlorethylene, a barbiturate, quinine, ergotamine tartrate and caffeine: An analysis of their relation to the pain experience. *J. Clin. Invest.* 20:63-80.

1942

With H. G. Wolff and H. Goodell. Studies on pain. Measurement of the effect of ethyl alcohol on the pain threshold and the "alarm" reaction. *J. Pharmacol. Exp. Ther.* 75:38-49.

With R. L. Day. Respiratory metabolism in infancy and childhood. *Am. J. Dis. Child.* 63:1086-1095.

1947

With H. G. Wolff and H. Goodell. Studies on pain: Discrimination of differences in intensity of a pain stimulus as a basis of a scale of pain intensity. *J. Clin. Invest.* 26:1152-1158.

1949

With C. T Javert. Studies on pain: Measurement of pain intensity in childbirth. *J. Clin. Invest.* 28:153-162.

1951

With H. Goodell and H. G. Wolff. The influence of skin temperature upon the pain threshold as evoked by thermal radiation. *Science* 114:149-150

1952

With H. G. Wolff and H. Goodell. *Pain Sensations and Reactions.* Baltimore: Williams and Wilkins.

With A. M. Stoll. A method for measuring radiant temperatures of the environment. *J. Appl. Physiol.* 5:117.

1954

With R. W. Lawton and L. R. Prouty. A calorimeter for rapid determination of heat loss and heat production in laboratory animals. *Rev. Sci. Instrum.* 25:370-377.

Summary review of heat loss and heat production in physiologic temperature regulation. Report No. NADC-MA-5413, 1-46, Oct. 14. Johnsville, Pa.: Bureau of Medicine and Bureau of Surgery.

1958

With M. Lipkin. Mechanical correlation of data in differential diagnosis of hemotological diseases. *J. Am. Med. Assoc.*166:113-125.

With E. Hendler and R. Crosbie. Measurement of heating of the skin during exposure to infrared radiation. *J. Appl. Physiol.* 12:177-185.

With H. T. Hammel and C. H. Wyndam. Heat production and heat loss in the dog at 8-36°C environmental temperature. *Am. J. Physiol.* 194:99-108.

1959

Acceleration problems in space flight. In *Proceedings of the XXI International Congress of Physiological Sciences.* Symposia 1-12, Buenos Aires, August 9-15, Buenos Aires: Congreso International de Ciencias Fisiológicas.

With C. C. Clark. The development of dynamic flight simulation. *Aerospace Eng.* 18:48-52.

1960

With H. T. Hammel and M. Fusco. Thermoregulatory responses to hypothalamic cooling in unanesthetized dogs. *Am. J. Physiol.* 198:481-486.

1961

With T. Nakayama and J. S. Eisenman. Single unit activity of anterior hypothalamus during local heating. *Science.* 134:560-561.

The physiology of temperature regulation. *Physiol. Rev.* 41(3):521-605.

1965

With A. P. Gagge and J. A. J. Stolwijk. A novel approach to measurement of man's heat exchange with a complex radiant environment. *Aerospace Med.* 36:431-435.

1966

With J. A. J. Stolwijk. Partitional calorimetric studies of man during exposures to thermal transients. *J. Appl. Physiol.* 21:1799-1806.

With J. A. J. Stolwijk. Temperature regulation in man—a theoretical study. *Pfluger's Arch.* 291:129-162.

1967

With M. Cabanac and T. Hammel. *Tiliqua Scincoides*: Temperature sensitive units in lizard brain. *Science* 158:1050-1051.

1970

With A. P. Gagge and J. A. J. Stolwijk, eds. *Physiological and Behavioral Temperature Regulation.* Springfield, Ill.: Charles C. Thomas.

With J. D. Guieu. Effects of preoptic and spinal cord temperature in control of thermal polypnea. *J. Appl. Physiol.* 28:540-542.

1971

With J. T. Stitt. Thermoregulation in the squirrel monkey (*Saimiri sciureus*). *J. Appl. Physiol.* 31:48-54, citing E. R. Adair, J. U. Casby, and J. A. J. Stolwijk. Behavioral temperature regulation in the squirrel monkey: Changes induced by shifts in hypothalamic temperature. *J. Comp. Physiol. Psychol.* 72(1970):17-27.

1972

With W. Wunnenberg. Response of single units of the posterior hypothalamus to thermal stimulation. *J. Appl. Physiol.* 33:547-552.

1974

With J. T. Stitt and J. A. J. Stolwijk. PGE_1 fever: Its effect on thermoregulation at different low ambient temperatures. *Am. J. Physiol.* 227:622-629.

1975

With R. L. Day, L. M. Kitahata, F. F. Kao, and E. K. Motoyama. Evaluation of acupuncture anesthesia: A psychophysical study. *Anesthesiology* 43:507-517.