



Microwave Surfing

Light-Bulb Moments

■ Rajeev Bansal

Scientists, intent on categorizing everything around them, sometimes divide themselves into the lumpers and the splitters. The lumpers, many of whom flock to the unifying field of theoretical physics, search for hidden laws uniting the most seemingly diverse phenomena: Blur your vision a little and lightning bolts and static cling are really the same thing. The splitters, often drawn to the biological sciences, are more taken with diversity, reveling in the 34,000 variations on the theme spider, or the 550 species of coniferous trees.

G. Johnson in *The New York Times*, 1999 [1]

In what way is a person like a 100-watt light bulb? Before you rack your brain for the punch line, let me hasten to add that my question is not a joke but a serious scientific matter. I first came across it over 40 years ago while doing a literature review during my graduate work on the absorption



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of radio frequency (RF) radiation by the human body. Some of the earliest work on establishing safety standards in this area was done by H.P. Schwan in the 1950s and 1960s. He explained the rationale for his 10-mW/cm^2 (100-W/m^2) safe-exposure limit (IEEE Standard C95.1-1966) in a 1971 article [2]: “We assume one side of the human body completely illuminated, i.e., an

exposed area of about 1 m^2 . Thus the total thermal load is about 100 W .” This figure of 100 W was, by Schwan’s reckoning [3], equal to “the amount of heat the body dissipates under normal conditions.” How did he estimate that? If a person consumes $2,000\text{ kcal/d}$, it will represent roughly $8.4 \times 10^6\text{ J}$ of energy over a period of $86,400\text{ s}$. That is a rate of around 100 J/s ; hence the figure of 100 W used by Schwan. He reasoned that an extra-thermal load (from the RF radiation) of the same magnitude should not pose a thermal challenge for the human body, which can dissipate much more heat during vigorous exercise.

Recently I came across the same (approximate) 100-W figure for the base metabolic rate for human beings in a very different context in a book [4] by the physicist Geoffrey West. In 1993, West was in charge of the high-energy physics program at the Los Alamos National Laboratory and was involved with the design and development of the Superconducting Super Collider. When later that year, the U.S. Congress abruptly pulled the funding from the project, West decided to team up with two biologists from the University of New Mexico to focus on the life sciences, bringing a physicist’s search

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for a unifying theoretical framework to biological problems. The successful collaboration resulted in papers in *Science* and *Nature* in the late 1990s and, more recently, in a book [4] on biological scaling laws.

As West notes [4], Metabolic rate is the fundamental rate of biology, setting the pace of life for almost everything an organism does. . . . The basal metabolic rate of the average human being is only about 90 watts, corresponding to a typical incandescent light bulb and equivalent to the approximately 2,000 food [kilo]calories you eat every day.

How does this metabolic rate change with the size of an organism? The Swiss physiologist Max Kleiber had already observed in 1932 that “the metabolic rate scales as a power law whose exponent is very close to the number $\frac{3}{4}$ ” [4]. For example, an animal twice the size of another one requires only 75% more food and energy each day, rather than 100% more. This scaling law

was found to be valid across all taxonomic groups and all sizes from mice to elephants. West and his colleagues developed a quantitative framework to explain this scaling law “rooted in the universal mathematical, dynamical, and organizational properties of the multiple networks that distribute energy, materials, and information to local microscopic sites that permeate organisms” [4]. Amazingly, according to West, the same scaling law applies even to the growth of cities and companies!

As sophisticated computer simulations and laboratory data have become available, the IEEE RF safe exposure standard C95.1 has also continued to evolve since the days of Schwan’s heuristic analysis based on the base metabolic rate. More research, especially in the millimeter-wave frequency bands now being used for 5G, is still needed. The D.C. Circuit Court noted in a recent ruling that although “it takes no position in the scientific debate over the health and environmental effects of RF radiation” [5], the Federal Communica-

tions Commission needs “to explain why its current guidelines [dating to 1996] adequately protect against the harmful consequences of exposure to radio frequency (RF) radiation unrelated to cancer” [5].

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