John King (1925-2014)

The Zen of Physics Lab

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September 8, 2014

1 Introduction

> **"There is no substitute for hands-on fooling around with real stuff."** [1]

John King's death has taken from us someone who fervently believed this. But "fooling around" does no justice to his striking ability to see the physics in simple everyday things — the glug-glug of water pouring from a jug, the sound of tearing paper, the burn-out of a lightbulb — and his remarkable ability to imagine and construct ingenious apparatus for exploring that physics.

This ability was manifest in all parts of his life whether setting up a generator system at his summer place in Maine, fixing the washing machine at home, devising a way to detect radiation emissions from a neighboring power plant, looking for a dipole moment of the electron or the spontaneous creation of protons, or generating microwaves with a spark-gap assembled from thumbtacks and a clothespin.

The pleasure and satisfaction that he got from devising simple apparatus to study everyday phenomena energized a life-long effort to get students, friends, colleagues, or passers-by to observe and explore the physical world around them. To him "hands-on fooling around with real stuff" was as natural as breathing. He wanted the rest of the world to learn to breathe as he did.

He did his "fooling around" with an acute understanding of physics and a remarkable detailed knowledge about how things are made, what they are made of, and how they work. "Things" included automobiles, motorcycles, laboratory instruments, electronic components, pumps, plumbing parts, and household

[1] Quoted by Curt Gabrielson (MIT S.B. '93) in *Tinkering*, p. 23, MakerMedia, Sebastopol, CA 2013. Alternatively, **"There's no substitute for hands-on fooling with real stuff."** "Observation, Experiment, and the Future of Physics – John G. King's acceptance speech for the 2000 Oersted Medal presented by the American Association of Physics Teachers, 18 January 2000", Am. J. Phys. **69**, 12 (2001).

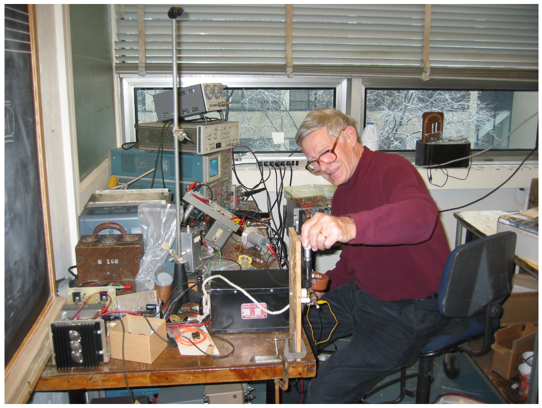

Figure 1: John King in 2004 fooling around with real stuff. He is working on a corridor lab apparatus to measure the speed of light. By this time corridor labs were no longer used by the physics department, but John was helping MIT's Edgerton Center build some corridor-lab boxes to engage and instruct people walking by the Edgerton Center. Photo by Ed Moriarty.

hardware and appliances of all sorts. He particularly enjoyed solving laboratory problems with unexpected uses of equipment, as when he created a high-voltage pulse by briefly closing a circuit by firing a .22 bullet through a wedge of two angle irons mounted on a block of 2 x 4. A telephone book caught the bullet. [2]

John liked to tell stories about his projects. His stories show how his"hands-on fooling around with real stuff" evolved into a philosophy of physics education. The stories also exhibit an element of Zen in his fusion of imagination, understanding of physics, and feeling for material detail. And, although John would reject the idea emphatically, I think they show him becoming a Zen master of physics experimentation, conveying insights by example to his apprentices.

2 Unrooted childhood

John attributed some of his ability with apparatus to his unusual childhood. He was born in London in 1925. His parents divorced when he was two. His mother married a Frenchman. Before John was eleven he attended five different schools in three different languages. His first school was a one-room country school in France's Basque region where he learned French and arithmetic. In 1936 he came to the U. S. and attended school in Mesa, Arizona, in Santa Barbara, California, and in Palm Springs, California (where one of his class mates was

[2]CHH interview with John King: "Well, one night in my house in Dover, Massachusetts, I took a 2 by 4 and mounted two angle irons on it like this and fired a .22 bullet from my childhood single-shot .22 rifle through it, and that bullet squeezed in and became a switch. Sort of closed the circuit between the two..."

Shirley Temple). In 1937 his mother went back to Europe and John went to a German-speaking school in Zuoz, Switzerland. After they returned to the U.S. in 1938, he spent a year at the Fessenden School in Newton and in 1939 he entered Phillips Exeter Academy.

"...because I was by myself so much of the time, the foreigner, I had hobbies such as taking apart old radios, and I spent summers in Vermont and built public address systems using push-pull 6L6s in the output stage. So I was quite sharp in electronics. I built regenerative radios. I was a radio ham..."[3] From his French stepfather John also learned to work on motorcycles and automobiles.

At Phillips Exeter his precocious ability to design, build, and use apparatus was apparent. As one of several projects, he built a Cavendish balance and measured G, the constant of proportionality in Newton's Law of Universal Gravitation. For the necessary weights, he melted lead pipe; for the suspension he used the bronze filament unwound from the bass string of a guitar. "What I wanted to do was a method that I had read about in the Journal of the Bureau of Standards...not to look for a static deflection but to observe the change in period when the two masses are [moved from one position to another]..."[4]

John entered MIT in the summer of 1943. Hoping to avoid the draft he took a job in Harvard's Underwater Sound Laboratory where his prowess with apparatus was quickly recognized. In 1944 he was drafted, but the lab needed his skills.

"...I worked on acoustic torpedoes, built a chassis with 30 vacuum tubes..., so it was "Get that kid back here'. " The lab had him transferred from the Army to the Navy and then detailed back to the Harvard Lab, where he worked until 1946.

3 Rooted at MIT

In 1946 he enrolled as a freshman in MIT. In 1948 he became acquainted with Professor Jerrold Zacharias, who ran an extra-curricular seminar for outstanding physics students. King's grades were not outstanding, but his ability in the lab was already widely recognized at MIT. He talked his way into Zacharias' seminar; he also did a senior thesis and then his PhD thesis with him. Although Zacharias was something of an absentee mentor — he seldom came to the lab because he was often away in Washington or off leading some government sponsored study — but he was a powerful and influential member of the physics faculty, and he made John his protégé. Zacharias saw that John got into graduate school, that he was appointed to the faculty, that he advanced steadily through the ranks, that he got good consulting jobs, and that he was not poached away from MIT. John soon became the de facto head and then the official head of Zacharias' molecular beams lab. He retired from the faculty in 1996, but remained closely associated with MIT until his death.

[3] Zimmerman AIP interview

[4] CHH interview; sitting 2, pg. 2

Figure 2: The car in the PSSC movie "Straight Line Kinematics" was John's 1928 Type 35B GP Bugatti. He bought it for $4000 and sold it for $8000. (It later sold for $2.5 million.)

3.1 PSSC Movies

Zacharias also drew John into physics education. In 1956 Zacharias started PSSC (Physical Sciences Study Commission), a large-scale, generously funded effort to modernize high-school physics. The project produced a text, a series of movies, a series of topical books, demonstration set-ups, and an array of simple experiments that used low-cost apparatus. The ripple tank is probably PSSC's best-known demonstration apparatus.

Zacharias brought John into the PSSC enterprise, and John made or appeared in eight movies. Figure 2 shows him in 1959 sitting in his 1928 Type 35B GP Bugatti as he prepares to demonstrate linear kinematics by accelerating to 120 mph on a stretch of the as yet unopened Massachusetts Turnpike.

> I can't remember how the notion that I should make a movie came up, but in late 1957 I was working on one of the early ones: "Time and Clocks." After working up the script and demonstrations over a few weeks I would go to the studio from 8 to 5 for a week or ten days with all the business of film-making: multiple takes, scene by scene, from which the final version could be assembled. Occasionally a whole sequence would work, uninterrupted by apparatus troubles, misstatements, buzzing flies, etc. Later I went on to make "Photons,"

"Interference of Photons," "Size of Atoms from an Atomic Beam Experiment," "Velocity Distribution of Atoms in a Beam," and I helped with shorter pieces: "Momentum of Electrons," "Angular Momentum of Circularly Polarized Radiation" and a 30 second intro to "Straight Line Kinematics" featuring a 1928 Type 35B GP Bugatti. The last one, "Velocity of Atoms," was made in 1964. They were all based on stuff that I had been or was involved with: lecture demos, teaching lab apparatus, senior theses, the early cesium atomic clock, and a vintage racing car.[5]

3.2 Frank O'Brien on John King

John did his research in the Molecular Beams Lab. He had a particular taste for null experiments and provided experimental projects for undergraduate and graduate students. The physics of this work is interesting, but it is not the focus of this recollection. However, the energy and enthusiasm that were part of all his work in physics are nicely captured by Frank O'Brien.

O'Brien started in 1946 as a young technician to the Molecular Beams Lab. In time he became the lab's senior engineer, and he played major roles both as a source of technical expertise and as a mentor and teacher of post-docs and graduate students; he supplied important social glue. There was a high degree of mutual respect between King and O'Brien, and his charming characterization captures the essence of John's "ferocious vigor" at work or play.

> "...As you may know, in the many conversations you have had with him, his mind is always four or five phrases ahead of his tongue. What you may not know is his mode of apparatus building is exactly the same.
>
> His mind is way ahead of his hands. When working on an experiment of his own, and you are working along with him, as I have many times, as a certain component is being built up, his mind is clicking away a mile a minute. A constant flow of 3 dimensional thought-talk keeps coming out as you are both rushing about trying to keep up with design changes. For instance, on the lathe for 3 minutes, make a change, jump off the lathe onto the milling machine, another two changes 1 1/2 minutes. Off the miller onto the soldering bench, 3 more changes in 2 1/2 minutes, throw the piece away! Now a new concept altogether. On the lathe again, off the lathe onto the miller. Then into the pipe bender, copper this time not brass. We'll slide the assembly instead of rotating it. Let's use a "C" clamp for a micro manipulator. We'll tie a lead weight here for a constant force. Let's

[5] "Personal views of the beginnings of PSSC and my film experiences," http://www.compadre.org/portal/pssc/docs/King.pdf

spring-load the opposite end for a restoring force. Then voila!! It's finished.

You have a feeling you have been following a hurricane around. In your wake lays a welter of tools, materials, chips, bits & pieces and a TENSE gut! You wonder how long you could have kept up with him. He could foresee mistakes and hang-ups then correct for them before putting the component into use on the apparatus. Of course many times things did not work out perfectly and they had to be changed. However fewer changes had to be made fewer times when compared to other experiments.

The chief advantage to his operating this way was you had the opportunity to try more things faster. Why take three months to do a weekend job."[6]

4 Does away with introductory physics labs

With his remarkable ability to do laboratory work, it is not surprising that John came to be in charge of the laboratories of MIT's undergraduate physics program. It is perhaps surprising that he got rid of them.

> " . . . I was in charge of the freshman lab. When I reached a certain level of authority and was in charge of all undergraduate labs at MIT in the Physics Department, I did something. I decided that the freshman labs and sophomore labs were doing more harm than good. That is, for a tiny percentage of the students like me, they found interesting things in it, but for most people they were finessing it; it was 10-15% of the grade; it was monotonous; not well done. There would be a room with 16 identical set ups. Not good. Cookbook. So I used my authority to get rid of it."[7]

4.1 Search for Better Lab Experiences

It is somewhat ironic that getting rid of freshman physics labs left John with a life-long mission of creating substitute lab experiences that would do more good than harm. This mission evolved into an aspiration to provide laboratory experiences for everyone, for people of all ages, in all walks of life. To this end he created and installed corridor labs; he developed and taught Physics Project

[6]Frank O'Brien, "A Casual History of the MIT Molecular Beams Laboratory 1946-1973." This copy of O'Brien's 1973 seminars and a collection of pictures was presented to John King when he retired in the year 2000. The quotation is from pp. 8-9.

[7]¶49, "Interview of John G. King by George O. Zimmerman on November 18, 2009 at Boston University," Niels Bohr Library & Archives, American Institute of Physics, College Park, MD USA, (http://www.aip.org/history/ohilist/33499.html)

Figure 3: This picture from 1995 shows a stretch of corridor with lab boxes along its wall. They did not catch on as elements of regular courses of instruction, in part because the level of maintenance required was more than could be provided.

Lab; he devised kits that students in MIT's introductory physics used to do experiments in their living units; and when John Belcher introduced studio physics to MIT, John King and his son Ben supplied ideas and apparatus for student experiments. He strenuously advocated installing in public spaces stations of equipment with which passers-by could experience physics; and he proposed that every child at birth be given a set of toys that would introduce basic physical principles, the sets to be upgraded as the child grew. He was distressed by how little contact modern American children have with "real stuff."

> Looking at our built world, most physicists see order where many others see magic. This view of order should be available to all.... We need to supplement people's experiences in ways that are applicable to different groups, from physics majors to people without formal education."[8]

4.2 Corridor Labs

To provide physics students with a laboratory experience, in the 1970s John devised, built, and had installed on the wall of the corridor near the physics

[8]He described these ideas fully in an article based on his speech accepting the Oersted Medal from AAPT in January 2001: "Observation, Experiment, and the Future of Physics John G. Kings acceptance speech for the 2000 Oersted Medal presented by the American Association of Physics Teachers, 18 January 2000, *Am. J. Phys.* **69**, 11-21 (2001)

Figure 4: John King in 1995 standing by an Edgerton Center corridor lab at which you measure your electrical capacitance.

department a series of stations where students could work through some measurements or examine some interesting phenomenon. Under heavy use these installations required more maintenance than budget allowed. Their instructional effectiveness was never measured. The photograph in Fig. 3 shows the boxes still on the walls in 1995, a couple of decades after the program was launched.

Descendants of John's corridor labs still exist. He worked with the Edgerton Center to install versions of corridor labs on the walls of "strobe alley" on the fourth floor of Building 4. They are in use today and are mentioned in websites describing cheap entertainments in the Boston area. One of the favorites is the set-up for measuring your electrical capacitance (shown in Fig. 4). You can see that John's preferred box for these installations is a fire-alarm box repainted blue.

4.3 Take-Home Labs

In the late 1980s John tried another way to attach "real stuff" to MIT's introductory physics course. Working with Philip and Phyllis Morrison, he designed take-home experiments for students who opted to take the special King-Morrison section of freshman physics. Each student acquired a tool kit (see Fig. 5) and as the course progressed received kits of parts from which they built such things as a low-voltage power supply, a current balance, a high-voltage supply, and a fairly sensitive electrometer. With these they studied Ohm's law, electrolysis,

Figure 5: This is my Physics 8.02x tool kit from 1989, along with the low-voltage power supply that I built and a copy of *ZAP!* the laboratory manual that was published in 1991 to accompany kits commercially available from the Carolina Biological Supply Co.

forces between currents, and magnetic fields. The culminating experiment was to build a sparkgap microwave generator, produce standing waves, and measure their wavelength. As Fig. 6 shows, the sparkgap was built from a spring-loaded clothespin with thumb tacks as electrodes; it is typical of John's ingenuity. During that first run-through of the course in the winter term of 1989, I sat in on the lectures – mostly by King – and at night, in my apartment, I did all the experiments.[9] After developing and trying out experiments for the freshman electricity and magnetism course, John, working with Tony French, applied the approach to mechanics.

These special sections with their take-home experiments continued for more than fifteen years. You can see them as 8.02X and 8.01X on the MIT Open Courseware site `http://ocw.mit.edu/courses/physics/`. The special sections ended around 2006 when the department moved to teaching introductory physics students in studio mode. The special sections went away, but John King's experiments did not. They are an important part of the set of experiments that all students now perform in groups of three at their tables in the studio-mode classroom; students still work with a sparkgap made from a spring-loaded clothespin. The King heritage is alive in today's MIT general physics course.

[9] It was great fun, but doing the experiments took me many more hours than the estimates the faculty provided to the students!

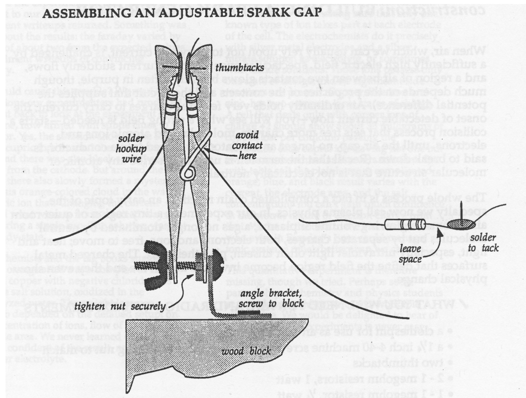

Figure 6: The clothespin sparkgap microwave generator

4.4 Physics Project Labs

John's favorite mode of physics teaching was the project lab. For him this was the ideal way to engage students with physics. He would work with pairs of students to find some physical phenomenon that interested them – maybe based on a hobby, a sport, or a musical inclination. Or, perhaps, the project would be based on some everyday physical event like the tearing of paper or water pouring from a jug. Then the students would begin to ask questions about their topic and look for experimental ways to find answers. It was, in short, real research. He proposed and described this approach in his talk on the occasion of receiving the AAPT Robert A. Millikan award.[10]

Originally he imagined that every MIT student would take a project lab in one discipline or another. This would truly replace the sterile lab experience that he had eliminated. As it turned out, MIT did not make project labs a general institute requirement, but John taught his own project lab course for over twenty years to some 2000 students. John always made little of his contribution to the choice of project and to the experimental ingenuity with which students answered their questions, but his students recognized that they were working in a unique way with a unique individual. Some, like Fred Dylla and Sam Cohen, went on to do PhDs with John. Others took the essence of John's message out to a broader public. Curt Gabrielson has made a life's work of teaching by doing; in his book *Tinkering* he cites working with John and John's ideas as major motivators for his own work.[11]

Some of the work inspired John. A student project in 1965 to study the lifetime of incandescent bulbs aroused his interest, and years later he and Paul Gluck

[10] "On Physics Project Laboratories," *Am. J. Phys.* **34**, 1058-1062 (1966).
[11] Curt Gabrielson, *Tinkering* Maker Media, Sebastapol, CA, p. 22 et seq. (2013).

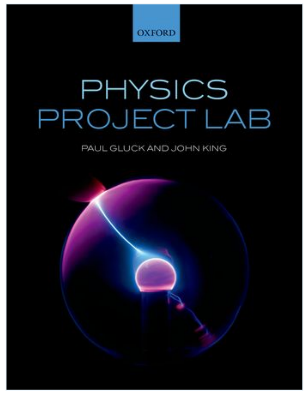

Figure 7: A book that is the summary of a lifetime of enthusiasm, imagination, insight, and love of laboratory physics.

published an article in *The Physics Teacher* explaining the interesting behavior of such bulbs and pointing the way to further projects with them.[12]

The imaginations of John and his students ranged widely. The table shows just a small sample of project topics. Their variety and accessibility is evident.

Examples of Project Topics	
pulse speed in falling dominoes	physics of rubber bands and cords
physics of incandescent lamps	Doppler effect
Johnson noise	physics with loudspeakers
vortex physics	saltwater oscillator
birefringence in cellulose tape	the drinking bird

John's enthusiasm for project labs is apparent in the book that Paul Gluck and he have written. In many ways the book is a summary of laboratory skills and insights acquired over a lifetime. It is also a cogent justification of educational efficacy of project labs and a source of tips, techniques, and ideas useful and inspiring for all who want to teach their students in a collaborative, research mode. The book, *Physics Project Lab*, is in preparation with Oxford University Press and is due out in December. It is sad that John did not live to see it published.

5 Epitaph

There's more to John King's life than physics and laboratory. Others will describe his research work — work that he continued in retirement in a laboratory

[12] Paul Gluck and John King, "Physics of incandescent lamp burnout," The Phys. Teach. 46, 29-35 (2008) doi: 10.1119/1.2823997

that he built in an old semi-tractor trailer on his land in Maine — or tell about the parts of his life shared with his first wife Betty King and their eight children; or about the more than thirty years with his second wife Jane Williams. He had a deep appreciation of classical music, French wines, and activities outside the physics laboratory. A complete account of John King should include these.

John kept a little notebook in his pocket in which he put ideas and observations as they occurred to him. He also kept a list of the names and email addresses of people he liked to have lunch with. I had the good fortune to be on that list, and for the past ten years John and I lunched together roughly every six weeks. It was always fun and informative. He was a digressive conversationalist; so am I. Our talk would happily wander over physics, physicists, technology, how to get people to appreciate science, how to fix stuff, getting old, and anecdotes of all sorts. He — more than I — could usually remember the point of our conversation and get us back to it. And, always when we were done and received the luncheon bill with our 20% AARP discount, he would carefully refigure the amount so that the savings of the discount went to the waitress as an extra tip.

John sometimes expressed regrets: the amount of time he spent in the lab was hard on his family; he missed opportunities because he was so much the protégé of Zacharias; he lacked perspective because his career was so entirely at MIT; with more self-discipline or a different mentor he could have done more significant research.

Regrets or not, he knew his life had been fortunate and satisfying. As he said in 2000 at an event celebrating him and his career,

"Fundamentally, I had a hell of a good time and lots of fun."[13]

[13] Quoted in *MIT Tech Talk*, April 12, 2000.