Remembering Leo Kadanoff

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Sabyasachi Bhattacharya

Leo Philip Kadanoff, one of the most important theoretical physicists of our time, whose work has profoundly transformed how we perceive collective phenomena in physics, passed away on 26 October 2015 due to post-surgical complications. In his passing, the world of physics has lost a great mind, an educator, a champion of the importance of science in our lives and society, an extraordinary mentor and a master of his trade with a driving passion to develop a unique culture of collaborative research that often unearthed the profound from the commonplace.

Sabyasachi Bhattacharya is a physicist and works on dynamical aspects of disordered condensed matter systems at the Tata Institute of Fundamental Research, Mumbai. Apart from physics, he is interested in higher education policy in India related specially to science and technology research.

Born in New York City in 1937, Kadanoff received his undergraduate education at Harvard University from where he also received his PhD in 1960, with two dissertations under the guidance of Roy Glauber and Paul Martin. In 1962, he co-authored the classic text *Quantum Statistical Mechanics* with Gordon Baym during his postdoctoral work at the Niels Bohr Institute in Copenhagen.

By 1966, while on the faculty at the University of Illinois, Urbana-Champaign, he produced his monumental work on critical phenomena that led to the profound ideas of *universality* and *scaling*. Phase transitions in matter such as solid-to-liquid and liquid-to-vapor, a ferromagnet to a paramagnet or more exotic versions of them, a conventional fluid to a superfluid that has no viscosity or its charge analog – a metal to a superconductor that has no electrical resistance, had been studied extensively over many decades. Paul Ehrenfest categorized them into numbered 'orders' depending on which derivative of the free energy showed an abrupt change at the transition point. A first order transition showed such anomalies in the first order derivatives such as entropy and specific volume (inverse of density), while a second order transition showed such behavior in the second derivatives such as specific heat, compressibility, thermal expansion coefficient, and so on. Experiments however, threw up two major surprises for the second order (often called continuous) transitions. First, these second order derivatives actually diverged as

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the transition was approached instead of being merely discontinuous. Second, disparate groups of systems behaved identically, but differently from other disparate groups in their divergence as seen by distinct sets of critical exponents. Kadanoff's work on scaling, a mathematical form of recursive coarse-graining, provided the key insights that led to the understanding and classification of critical phenomena. For a detailed technical review of the work, see the article in this issue by Srikanth Shastry (p.875). Two seminal papers appeared in quick succession, the first was a single authored paper on the theoretical and mathematical framework. The second, a multi-authored collaborative review, provided a comprehensive status of both theory and experiment at the time. The pattern of reporting a major discovery followed by a comprehensive contextual view of where the field stood would continue throughout his career.

Kadanoff spent nearly a decade thereafter at Brown University. During this period, he became interested in urban planning by recognizing the similarity in the mathematical formalisms in this field with statistical mechanics of condensed matter systems. This work foretold another of Kadanoff's lifelong interest: finding mathematical similarity between physical and more complex systems far afield and bringing the power of analogy to gain meaningful insights to a broader problem, in effect, creating generic if not universal classes of problems. His work in this period was judged important enough for the State of Rhode Island of which he was a resident to formally adopt his recommendations.

Kadanoff's work spanned wide areas, including chaos in simple dynamical systems, onset of turbulence in fluids, mathematical characterization of instability-driven pattern formation and so on.

In 1978, Kadanoff moved to the University of Chicago. It was to be his intellectual home for the rest of his life and many of his extraordinary achievements influencing the course of science in general, and physics in particular, took place here. On an individual level, he continued his work on critical points where the system suddenly changes character. He worked on the onset of chaos in simple dynamical systems, onset of turbulence in fluids, mathematical characterization of instability-driven pattern formation and so on. But he also inspired as well as participated in collaborative research programs, most notably with his colleague Sidney Nagel. Of special note among these enterprises is the by now famous problem of a leaky faucet, the process by which a column of liquid breaks up into droplets.

In Chicago, Kadanoff's role as an extraordinary mentor fully blossomed. His individual accomplishments came very early in life and placed a burden on him to continue producing such path-breaking work. As it became clear in his later-day conversations and interviews, he had wondered about the likelihood of making theoretical breakthroughs comparable to the early ones. He had very consciously taken upon himself the task of building people, programs and a distinct work culture of collaborative research across fields.

Kadanoff was a physicist and mentor par excellence, who championed collaborative research.

I joined the James Franck institute at the University of Chicago as an institute postdoc in 1979, a year after Kadanoff (Leo to all around him) did. For those of us present at Chicago during the early years, it was an extraordinary experience to watch first hand, a style and a culture of physics taking shape even though many of us were unaware of it till years later. Kadanoff had an office strategically located at the south-west corner on the ground floor of the L-shaped low temperature wing of the James Franck Institute. His neighbors included young members of the faculty – John Hertz, Sidney Nagel, Kathy Levin, David Oxtoby, Gene Mazenko and my co-postdocs – Larry Fleishman, Dah-min Hwang and Steve Shenker. A large number of graduate students and postdoctoral fellows from all parts of the building and from across the spiritual divide with the Enrico Fermi Institute for high-energy physics, milled about.

Everyone gathered at the Monday bag-lunch seminar series Leo started. He was already a celebrity with informal manners and was easily the center of attention, viewed with awe, admiration and a bit of hero worship. Visitors flowed in from all corners of the world and presented bag-lunch seminars in addition to their more formal lecture-duties at the institute colloquia. When there were no outsiders, it was upon one of us to talk about our work. The talks were not always lucid, the central motivation not always apparent, the significance of the results not always clear. In some cases, the speaker would lose the audience within the first few minutes. It was then invariably Leo's task to rescue the situation, which he would achieve by politely asking an innocent sounding question. The answer if given, would unfailingly lift the fog, revealing the shores one is navigating towards, accompanied by a collective knowing sighs and murmurs in the room -"now I see!" Sometimes that would be true of the speaker too. It was some-

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times said that Leo's very presence in the room made everyone else smarter. I later felt that we knew that Leo would be genuinely happy if we did well and not so happy if we did not. Both would be apparent on his face. We wanted to make Leo happy because it was an important marker of how we were doing. He was a master communicator and took this matter seriously. He could communicate the nearly incommunicable: good judgement and good taste. Those of us lucky to be around him, have carried these lessons, to the extent we learned them, throughout our professional lives. He would often make interesting comments about the art of seminar presentations, some of which I pass on to my students even today. Here are two examples: "You cannot underestimate how happy people are if you start by telling them something they already know." And the other: "People do not much care to figure out how smart you are but they are happy if they learn something from your talk."

The emergence of the now famous Chicago school in statistical and soft matter physics took place after I left the University in 1982. Leo's mark on this enterprise was visible in the choice of colleagues he helped recruit and chose to collaborate with and also in the directions of research, both theoretical and experimental that took place there, sometimes quirky, far off the beaten path, but always profound and always beautiful.

Decades later, our professional paths crossed again. For one year, we overlapped on the Council of the American Physical Society – he, as the President and I as the International Councilor. A major controversy broke out over the Society's firm position on global warming. Leo took the society through that difficult period with firm hands, uncompromising on the position based on what he was convinced to be sound science, with a command of its essence and his sense of fairness to those who disagreed. Above all, his core belief that science has a responsibility to society to be honest was apparent to friends and foes alike and carried the day.

Kadanoff was a key figure behind the establishment of the famous Chicago school in statistical and soft matter physics.

Many honors came his way. Among them were the 1977 Buckley Prize, the 1998 Onsager Prize of the American Physical Society, the 1989 Boltzmann Medal of the International Union of Pure and Applied Physics, the 2011 Isaac Newton Medal of the Institute of Physics and the 1999 US National Medal of Science. He also received the Quantrell Award for excellence in undergraduate teaching at the University of Chicago. He shared the 1980 Wolf Prize with Kenneth Wilson and Michael Fisher, widely believed to be the forerunner of the Nobel that was sure to come.

Leo Kadanoff shared the 1980 Wolf Prize with Kenneth Wilson and Michael Fisher.

In October 1982, I was persuaded by colleagues to postpone my departure from Chicago since rumor was rife about the impending announcement of the Critical Phenomena-Nobel Prize that year. There was going to be a grand celebration when that happened and I must not miss it. The announcement came; Leo was inexplicably left out and the prize went to Kenneth Wilson alone. The department was crushed and a pall of gloom hung over the place. We were particularly sad thinking how sad Leo must be. A bag-lunch seminar was scheduled for that day and Leo appeared wearing a jacket and a tie, an unusual attire for him. A colleague, somewhat surprised, asked why he was so well dressed. Leo replied with a smile, " It is not every day that one does not win the Nobel Prize." That led to much laughter and the sense of gloom passed for then. He then proceeded to give a fifteen minute summary of Wilson's achievements and why the work was deserving of the prize without a word on his own contribution. This story, especially that quip, has grown to the status of a legend and is known to many who never met him, and many not even born at the time.

Finally, a personal note. Beyond being a great physicist, mentor, teacher, and a leader, Leo was extremely loyal to his friends. Perhaps more so to those of us who were around in the early days and he stood by us long after we were gone from Chicago. On every trip I made back to the University, he would greet me with the warmth of a homecoming. I gratefully remember all his help and advice in my professional life when stakes were high and mistakes would have been costly. For every change of a job, from academia to industry, from one institution to another, from one continent to another, from an academic role to an administrative one - Leo was there with his firm, impartial and practical advice based on his honest evaluation of my strengths and weaknesses but always concerned about my well-being. To those he knew well, he was always a friend, philosopher and guide. To the world of science he was an inspiration. He will be missed.

Suggested Reading

[1] H Eugene Stanley, *Introduction to phase transitions and critical phenomena*, Oxford University Press, 1971.

[2] John Cardy, *Scaling and renormalization in statistical physics*, Cambridge Lecture Notes, 1996.

[3] Shang-Keng Ma, *Modern Theory of Critical Phenomena*, Perseus Books, 1976.

[4] https://www.nobelprize.org/nobel_prizes/physics/laureates/1982/wilson-lecture.pdf

Address for Correspondence
Sabyasachi Bhattacharya
Tata Institute of Fundamental Research
Homi Bhabha Road,
Mumbai 400 005, India.
Email: shobobh@gmail.com

Videos of Kadanoff

https://www.youtube.com/watch?v=8an6x-NLfIc
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