Why History Matters

Lessons to be learned from the life of Enrico Fermi

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The Arguments Against History:

- We can learn the science without recourse to how it developed.
- An historical approach focuses on people rather than the science itself.
- Why clutter the minds of students who already have enough to learn without having to learn some history as well?

The Arguments FOR History

- Your understanding of the science will be richer if you know the history.
- You can learn from knowing how the great physicists approached problems.
- You can learn mistakes great physicists have made.
- Scientific progress does not happen in a vacuum. Understanding how past discoveries were made leads to a deeper understanding of the current issues in the field.
- Scientific progress reflects the state of the field at any given moment. We learn much about how to approach the problems of our own era when we look back and understand the historical-scientific context of historical discoveries.

Key Points of Fermi's Life

- Born in 1901 in Rome, died in 1954 in Chicago.
- Certainly one of the most prolific and important physicists of the 20th century.
- Recognized as a child prodigy in his early teens, and trained to master physics early on.
- Contributions include Fermi-Dirac statistics, theory of beta decay, discovery of the slow neutron effect, creation of the first controlled and sustained nuclear fission reaction and the associated invention of the nuclear reactor, conducting the first computer simulation of a physical process.
- Mistakes include his failure to recognize that his 1934 experiments bombarding elements with neutrons had resulted in the fission of the uranium nucleus, and the failure to anticipate Xenon-135 poisoning at the first plutonium production reactor at Hanford.
- He came of age during the golden age of the development of quantum mechanics, and was recognized as one of the greatest physicists of his generation well before WWII broke out.
- He also worked in two very different socio-political environments, Italy 1922-1938 and the United States 1939 – 1954.

Fermi As Child Prodigy

- Mentored from age 13 onward.
- Systematically trained from ground up.
- Built most solid foundation imaginable. No short cuts, step by step, slow.
- Habit of mind: SLOW, thorough, and systematic acquisition of knowledge.
- Habit of mind: seeing relationships between all branches of physics.

Fermi-Dirac Statistics (1925)

- The problem: Is there a quantum mechanical expression of entropy?
- The solution: found in Pauli's work on the anomalous Zeeman effect, and the idea of the exclusion principle.
- The use of Pauli's exclusion principle in an entirely different context.
- Habit of mind: using a tool developed in one context to solve a problem in another context.

Theory of Beta Decay (1933)

- The problem: how does an electron and a neutrino get created in the process of beta decay?
- The solution: use Pauli's invention of the neutrino and Dirac's theory of quantum electrodynamics (and quantum fields) to describe the interaction.
- Habit of mind: using a concept developed in one context to solve a problem in a completely different context. (Are we seeing a pattern here?!)

Slow Neutrons (1934)

- Neutron irradiation a direct result of hearing about Curies' experiments with alpha particles.
- (Relatively) systematic exploration of each element in the periodic table.
- Accidental discovery of the slow neutron effect.
- Habit of mind: An irresistible impulse to explore an unexpected physical phenomenon.
- Habit of mind: An instinctive search for a theory.

Nuclear Fission

• Problem: After the news of the Hahn/Meitner/Strassman work in Jan 1939 was a chain reaction possible?

• Fermi and Szilard begin work on what was to become CP-1.

• By December 1942 experiments prove successful.

• Habit of mind: the thorough, slow, methodical experiments of 1935-1937 on neutron diffusion by Fermi and Amaldi made Fermi the best in the world to conduct the CP-1 experiment.

Computer Simulation of Vibrating String

• Fermi, Pasta, Tsingou, Ulam paper of 1953 describes one of the first computer simulations of a physical process.
• Results were surprising – instead of an ergodic process it turned out to have very complex patterns.
• Historical note: beginning of non-linear physics/chaos.
• Habit of mind: Fermi had always been interested in how to describe the vibrating string, as evidenced by his application exam for SNS. He was also fascinated by the potential of the development of computers for analyzing physics problems.

Mistake #1

- Failure to see nuclear fission in 1934.
- Setup of experiments led to failure.
- Stopping the search for byproducts at lead also contributed
- Bigger problem: no theory to predict/explain it. (Ida Nodack did not have the theory either!)
- Took another four years or so to discover and explain.

MISTAKE #2

- Failure to Predict Xenon-135 Poisoning in Reactor B
- Xenon-135 was KNOWN as a fission byproduct.
- The analysis that Wheeler did after the fact could have been done before the fact.
- Fermi should have directed a team to look at neutron cross sections of all fission byproducts.
- Problem: By this time enormous pressures to get the project done quickly.

Ideas Originating with Fermi that Have Relevance Today

- Fermi-Dirac statistics still used every day by physicists across many fields, well beyond the initial purpose of describing a monatomic gas.
- Theory of beta decay basically unchanged, and hinted at electro-weak unification.
- Are Mesons Fundamental Particles?
- Ergodic and Non-ergodic Processes.

Fermi's Time vs. Ours

- Key problems in QM: Zeeman effect, beta decay.
- The first use of high energy accelerators.
- The first use of computers.
- Observation: he lived in an incredibly fruitful period for science. Would he have become a physicist in today's world?

Historical-Scientific Context

- Small Science vs. Big Science
- Private Science vs. Government Science
- Fascist Science vs. Democratic Science
- Role of Individual vs. Role of Team

Final Thoughts: Fermi's Style

- Use of Innovations Developed in One Context to Solve Problems in Different Context
- Extremely – Perhaps Frighteningly – Deep Foundational Knowledge from Youth
- SLOW AND STEADY. Never short cuts.