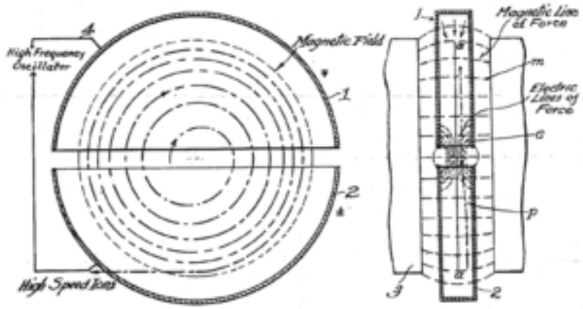
Brief History of Nuclear Physics

1896: discovery of radioactivity by Becquerel
1898: separation of Radium by Maria and Pierre Curie; discovery of α, β, γ rays
1911: nucleus as a central part of an atom – Rutherford
1913: Soddy and Richards elucidate the concept of nuclear mass: isotopes are born
1919: Rutherford carries out first transmutation (He+N $\rightarrow$ p+O)
1923: Georg von Hevesy uses radioactive tracers in biology
1928: theory of alpha decay by Gamow
1929: cyclotron (Ernest Lawrence); Rasetti discovers spin J=1 for ^{14}N
1930: Pauli predicts neutrino; Dirac predicts antimatter
1932: discovery of the neutron by Chadwick; discovery of positrons by Anderson
1934: Fermi theory of beta decay; Baade and Zwicky predict neutron stars
1935: nuclear (strong) force through meson exchange – Yukawa
1936: John Lawrence treats leukemia with ^{32}P
1938: stars are powered by nuclear fusion (Gamow, von Weizsäcker, Bethe): pp, CNO
1939: nuclear fission (Hahn, Strassman, Meitner, Frisch); Bohr, Wheeler explain fission
1940: McMillan and Abelson produce a new element (n+$^{238}U \rightarrow {}^{239}U \rightarrow {}^{239}Np \rightarrow {}^{239}Pu$)
1942: first self-sustaining fission reaction (Fermi); Manhattan project (Oppenheimer)
1945: atomic bomb
1947: pi meson discovered in Bristol (by studying cosmic ray tracks)
1948: Big Bang nucleosynthesis (Alpher, Bethe, Gamow)
Electricity generated at the X-10 Graphite Reactor in Oak Ridge

1949: nuclear shell model (Mayer, Jensen)
1951: nuclear collective model (Bohr, Mottelson, Rainwater)
1952: hydrogen bomb (Teller, Ulam); Hoyle resonance predicted
1954: proton therapy at Berkeley
1956: experimental evidence for antineutrino (Reines, Cowan)
prediction and discovery of parity violation (Lee, Yang, Wu)
1957: stellar nucleosynthesis (Burbidge, Burbidge, Fowler, Hoyle)
1958: nuclear superconductivity (Bohr, Mottelson, Pines)
1961: first PET scan at Brookhaven
1964: quarks proposed (Gell-Mann, Zweig)
1967: discovery of neutron stars (Hewish, Shklovsky, Bell)
1969: intrinsic structure of the proton (SLAC)
1972: color charge and quantum chromodynamics (Fritsch, Gell-Mann)
1978: discovery of the gluon (DESY)
1982: chiral symmetry on the lattice (Ginsparg, Wilson)
1983: discovery of W and Z intermediate vector bosons (CERN)
1995: top quark discovered (Fermilab)
1999: discovery of particle stability of ^{31}F (RIKEN)
2001: neutrino oscillations (Super-Kamiokande, SNO)
2002: element Z=118 produced in Dubna
2005: quark–gluon liquid of very low viscosity discovered at RHIC
2008: discovery of ^{40}Mg at MSU https://www.youtube.com/watch?v=tJsam4z715c

Ernest and John Lawrence



John Lawrence was a physicist and physician, a pioneer of nuclear medicine. He discovered treatments for leukemia and polycythemia by injecting infected mice with radioactive phosphorus derived from the cyclotron invented by his brother

In the summer of 1935, John came to Berkeley to conduct research on the medical applications of radiation. He injected some leukemic mice with radioactive phosphorus produced by the cyclotron and then went fishing; when he returned he found the mice improved. It was the beginning of medical physics at Berkeley. John was also more aware than were the physicists in the laboratory of the dangers of exposure to radiation, so he insisted that they undertake some experiments with the radiation produced by the cyclotron. He conducted an experiment that he described, years later, in this way:

One of the first animals that we exposed - I'm not sure that it wasn't the first one - we … placed within the cyclotron between the two poles of the magnet near the beryllium target which was being struck with alpha particles. So Paul and I told Ernest to turn off the cyclotron because we wanted to go back and see how the rat was. Well, the rat was dead. That scared everybody because it had only been exposed for about a minute and the dose was very low. We were very scared and we then recommended increasing the shielding around the cyclotron*. Later we found that the rat died of suffocation but not radiation.*

None of these achievements however was as important and satisfying as that which occurred in 1937. Within months of John's arrival in Berkeley, he and Ernest learned that their mother was diagnosed with uterine cancer; she went to the Mayo Clinic for treatment. John went to Mayo immediately. Mother Lawrence was told that she had only three months to live. John tells the story in his oral history, in the archives at Berkeley:

> So then I got on the phone with Ernest. I said, "They don't want to treat her here with radiation. How about my bringing her out and we'll talk to Dr. Stone?" We did talk to Dr. Stone and he said, "Sure, I'll take her." So I took her on the train, wheeled her across the station in Omaha. (…) She was about 67 or 68 years old then…. They started treating her through four fields…. *To make a long story short, this massive tumor just started evaporating.* At the end of ten years my mother finally agreed that she must be cured. It took me about ten years to convince her and she died at 83 and had the best years of her life…. It was really, really a fantastic result.

HW#1: The “Brief History” ends in 2008. What milestones would you add to the list?

(The more the merrier)

Subfields of nuclear physics

- nuclear structure, whose goal is to build a coherent framework for explaining all properties of nuclei and nuclear matter and how they interact
- nuclear astrophysics, which explores those events and objects in the universe shaped by nuclear reactions
- hot QCD, or relativistic heavy ions, which examines the state of melted nuclei and with that knowledge seeks to shed light on the nature of those quarks and gluons that are the constituent particles of nuclei
- cold QCD, or hadron structure, which explores the characteristics of the strong force and the various mechanisms by which the quarks and gluons interact and result in the properties of the protons and neutrons that make up nuclei.
- fundamental symmetries, those areas on the edge of nuclear physics where the understandings and tools of nuclear physicists are being used to unravel limitations of the Standard Model and to provide some of the understandings upon which a new, more comprehensive Standard Model will be built.