# Brief History of Nuclear Physics

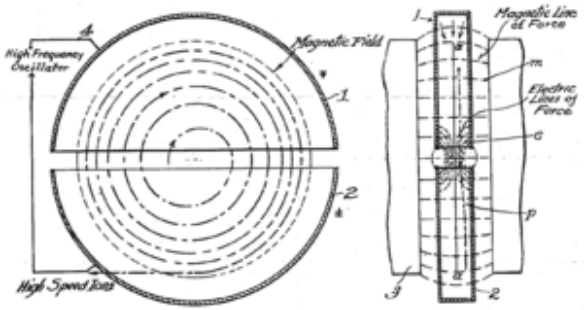
1896: discovery of radioactivity by Becquerel ($\alpha$. $\beta$ rays)
1898: separation of Radium by Maria and Pierre Curie
1900: gamma rays discovered by Villard
1902: Rutherford and Soddy identified the phenomenon of radioactive half-life
1909: alpha-particle experiment by Rutherford, Geiger and Marsden
1911: nucleus as a central part of an atom – Rutherford
beta-decay spectrum is continuous (Meitner, Hahn, Danysz, Chadwick)
1913: Soddy and Richards elucidate the concept of nuclear mass: isotopes are born
1917: Rutherford carries out first transmutation (He+N → p+O); discovers the proton
1921: discovery of nuclear isomerism by Hahn ($^{234m}$Pa)
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: neutrino; Dirac: antimatter; Chandrasekhar: limit for the white dwarf mass
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 → $^{239}$U →$^{239}$Np→$^{239}$Pu)
1942: first self-sustaining fission reaction (Fermi); Manhattan project (Oppenheimer)
1946: Carbon-14 dating was proposed by Libby
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)
V-A Lagrangian for weak interactions by Marshak and Sudarshan
1958: nuclear superconductivity (Bohr, Mottelson, Pines)
1961: first positron emission tomography (PET) scan at Brookhaven
1962: muon neutrino discovered by Lederman
1964: quarks proposed (Gell-Mann, Zweig); Higgs boson proposed (Higgs, Englert,+4)
1967: discovery of neutron stars (Hewish, Shklovsky, Bell)
1969: intrinsic structure of the proton (SLAC)
1972: color charge and quantum chromodynamics (Fritsch, Gell-Mann)
1977: The first MRI scan of a human is made

1978: discovery of the gluon by PLUTO detector at DESY; gluon has S=1.
1982: chiral symmetry on the lattice (Ginsparg, Wilson)
1983: discovery of W and Z intermediate vector bosons (CERN)
1995: top quark discovered (Fermilab)
2001: neutrino oscillations (Super-Kamiokande, SNO)
2002: element Z=118 produced in Dubna
2005: quark–gluon liquid of very low viscosity discovered at RHIC
2010: antihydrogen trapped in CERN
2012: Higgs boson discovered at CERN; Daya Bay measures neutrino mixing angle $\theta_{13}$
2015: pentaquarks discovered at LHCb
2016: element Og (Z=118) added to the Periodic Table
2017: Gravitational wave GW170817 and a kilonova detected; r-process site established

HW#1: What milestones would you add to the “Brief History of Nuclear Physics” list?
(The more the merrier)

# 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.

# Four elements earn permanent seats on the periodic table

IUPAC announces the names of the elements 113, 115, 117, and 118 (11/30/2016)

- Nihonium and symbol Nh, for the element 113
- Moscovium and symbol Mc, for the element 115
- Tennessine and symbol Ts, for the element 117
- Oganesson and symbol Og, for the element 118