

Brief History of Nuclear Physics

- 1896: discovery of radioactivity by Becquerel (α , β 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 ($\text{He} + \text{N} \rightarrow \text{p} + \text{O}$); discovers the proton
- 1921: discovery of nuclear isomerism by Hahn ($^{234\text{m}}\text{Pa}$)
- 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 ($n+^{238}\text{U} \rightarrow ^{239}\text{U} \rightarrow ^{239}\text{Np} \rightarrow ^{239}\text{Pu}$)

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 θ_{13}

2015: pentaquarks discovered at LHCb

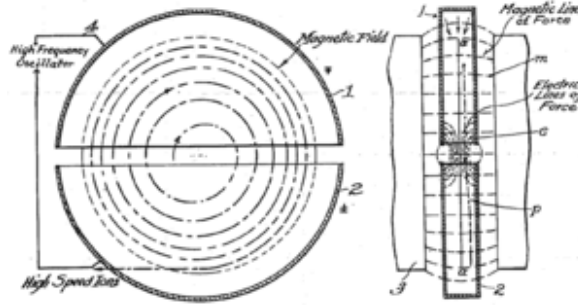
2016: element Og ($Z=118$) added to the Periodic Table

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

IUPAC Periodic Table of the Elements																	
1 1 H hydrogen [1.007, 1.009]																	18 2 He helium 4.003
3 Li lithium [6.938, 6.997]	4 Be beryllium 9.012	Key: atomic number Symbol name standard atomic weight										5 B boron [10.80, 10.83]	6 C carbon [12.00, 12.02]	7 N nitrogen [14.00, 14.01]	8 O oxygen [15.99, 16.00]	9 F fluorine 19.00	10 Ne neon 20.18
11 Na sodium 22.99	12 Mg magnesium [24.30, 24.31]	3	4	5	6	7	8	9	10	11	12	13 Al aluminium 26.98	14 Si silicon [28.08, 28.09]	15 P phosphorus 30.97	16 S sulfur [32.05, 32.08]	17 Cl chlorine [35.44, 35.46]	18 Ar argon 39.95
19 K potassium 39.10	20 Ca calcium 40.08	21 Sc scandium 44.96	22 Ti titanium 47.87	23 V vanadium 50.94	24 Cr chromium 52.00	25 Mn manganese 54.94	26 Fe iron 55.85	27 Co cobalt 58.93	28 Ni nickel 58.69	29 Cu copper 63.55	30 Zn zinc 65.38(2)	31 Ga gallium 69.72	32 Ge germanium 72.63	33 As arsenic 74.92	34 Se selenium 78.96(3)	35 Br bromine [79.90, 79.91]	36 Kr krypton 83.80
37 Rb rubidium 85.47	38 Sr strontium 87.62	39 Y yttrium 88.91	40 Zr zirconium 91.22	41 Nb niobium 92.91	42 Mo molybdenum 95.96(2)	43 Tc technetium	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57-71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium [204.3, 204.4]	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89-103 actinoids	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganeson
57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0			
89 Ac actinium	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium	103 Lr lawrencium			