PHYS 3446 – Lecture #8

Wednesday, Sept 28, 2016

Dr. Jae Yu

- Nuclear Models
  - Liquid Drop Model
  - Fermi Gas Model

Announcement

- First term exam
  - Date and time: 2:30 – 3:50pm, Monday, Oct. 10
  - Location: SH125
  - Covers: Ch 1 – Ch 3 or what we finish Wednesday, Oct. 5, + Appendix A
  - Can bring your calculator but no phone or computer can be used as a replacement
- Colloquium
  - Dr. Amir Farbin on Deep Learning

Physics Department
The University of Texas at Arlington
Colloquium

Deep Learning in High Energy Physics

Dr. Amir Farbin

University of Texas at Arlington

Wednesday September 28, 2016
4:00 p.m. Room 100 Science Hall

The recent Deep Learning (DL) renaissance has yielded impressive feats in industry and science, replacing laborious feature engineering with automatic feature learning, providing better algorithms, and enabling analysis of unlabeled data. DL is applicable to a large number of High Energy Physics (HEP) problems such as tracking, calorimetry, particle identification, simulation, monitoring, anomaly detection, noise reduction, data compression, workflow optimization, and data analysis. I will discuss how DL can be applied to many of these areas and overview the first attempts of DL in HEP. I will also present several public datasets that we have been compiling to enable collaborations with the Machine Learning community and contributions from the public.

Refreshments will be served at 3:30 p.m. in the Physics Library

Reminder: Homework Assignment #4

1. Compute the mass density of a nucleus (10points)
   - Pick two nuclei for this. I would like you guys to do different ones.
2. Compute the de Broglie wavelengths for (15 points)
   - Protons in Fermilab's Tevatron Collider
   - Protons in CERN's Large Hadron Collider (LHC)
   - 500 GeV electrons in the International Linear Collider
3. Compute the actual value of the nuclear magneton (5 points)

- Due for the above is next Monday, Oct. 3

Nuclear Models

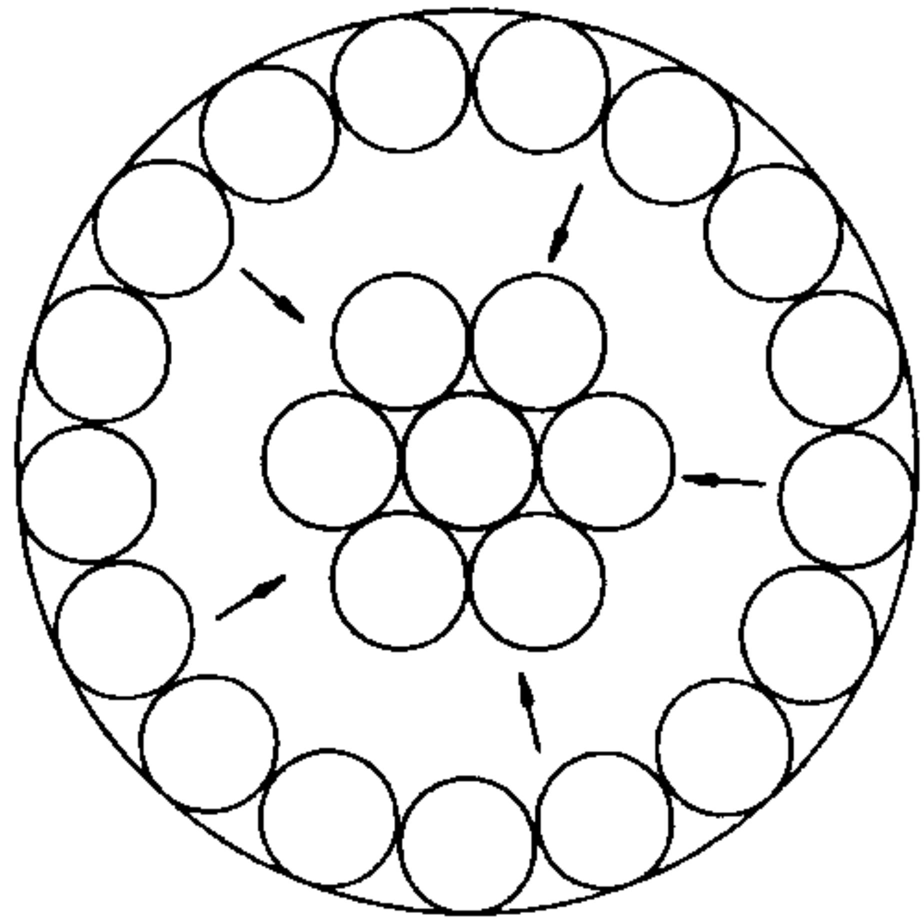
- Experiments showed very different characteristics of nuclear forces than other forces
- Quantification of nuclear forces and the structure of nucleus were not straightforward
  - Fundamentals of nuclear force were not well understood
- Several phenomenological models (not theories) that describe only limited cases of experimental findings
- Most the models assume central potential, just like the Coulomb potential

Nuclear Models: Liquid Droplet Model

- An earliest phenomenological success in describing binding energy of a nucleus (George Gamow)
- Nucleus is essentially spherical with radius proportional to $A^{1/3}$.
  - Densities are independent of the number of nucleons
- Led to a model that envisions the nucleus as an incompressible liquid droplet
  - In this model, nucleons are equivalent to molecules
- Quantum properties of individual nucleons are ignored

Nuclear Models: Liquid Droplet Model

- Nucleus is imagined to consist of
  - A stable central core of nucleons where nuclear force is completely saturated
  - A surface layer of nucleons that are not bound tightly
    - This weaker binding at the surface decreases the effective BE per nucleon (B/A)
    - Provides an attraction of the surface nucleons towards the core just as the surface tension to the liquid would

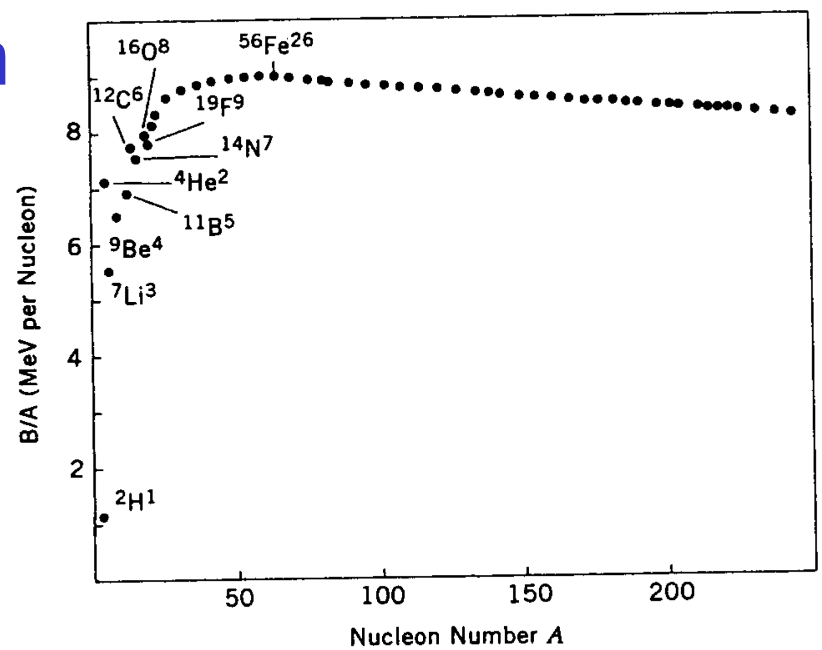


Liquid Droplet Model: Binding Energy

- If a constant BE per nucleon is due to the saturation of the nuclear force, the nuclear BE can be written as:

$$BE = -a_1 A + a_2 A^{2/3}$$

- What do you think each term does?
  - First term: volume energy for uniform saturated binding
  - Second term corrects for weaker surface tension
- This can explain the low BE/nucleon behavior of low A nuclei
  - For low A nuclei, the proportion of the second term is larger.
  - Reflects relatively large number of surface nucleons than the core.



Liquid Droplet Model: Binding Energy

- Small decrease of BE for heavy nuclei can be understood as due to the Coulomb repulsion
  - The electrostatic energies of protons have a destabilizing effect
- Reflecting this effect, the empirical formula for BE takes a new correction term

$$BE = -a_1 A + a_2 A^{2/3} + a_3 Z^2 A^{-1/3}$$

- Each term of this formula has a classical origin.
- This formula does not explain
  - Lighter nuclei with the equal number of protons and neutrons are stable or have a stronger binding (larger –BE)
  - Natural abundance of stable even-even nuclei or paucity of odd-odd nuclei
- These could mainly arise from quantum effect of spins.

Liquid Droplet Model: Binding Energy

- Additional corrections to compensate the deficiency, give corrections to the empirical formula (again…)

$$BE = -a_1 A + a_2 A^{2/3} + a_3 Z^2 A^{-1/3} + a_4 \frac{(N-Z)^2}{A} \pm a_5 A^{-3/4}$$

  – All parameters are assumed to be positive
  – The forth term reflects N=Z stability
  – The last term
    - Positive sign is chosen for odd-odd nuclei, reflecting instability
    - Negative sign is chosen for even-even nuclei
    - For odd-A nuclei, a_5 is chosen to be 0 since BE can be described well for these nuclei without this term

Liquid Droplet Model: Binding Energy

- The parameters are determined by fitting experimentally observed BE for a wide range of nuclei:

$$a_1 \approx 15.6 MeV \quad a_2 \approx 16.8 MeV \quad a_3 \approx 0.72 MeV$$
$$a_4 \approx 23.3 MeV \quad a_5 \approx 34 MeV;$$

- Now we can write an empirical formula for masses of nuclei

$$M(A,Z) = (A-Z)m_n + Zm_p + \frac{BE}{c^2} = (A-Z)m_n + Zm_p$$
$$-\frac{a_1}{c^2}A + \frac{a_2}{c^2}A^{2/3} + \frac{a_3}{c^2}Z^2A^{-1/3} + \frac{a_4}{c^2}\frac{(N-Z)^2}{A} \pm \frac{a_5}{c^2}A^{-3/4}$$

- This is Bethe-Weizsacker semi-empirical mass formula (1935)
  – Used to predict stability and masses of unknown nuclei of arbitrary A and Z

THE PERIODIC TABLE OF THE ELEMENTS

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.972	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

Lanthanide Series	57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide