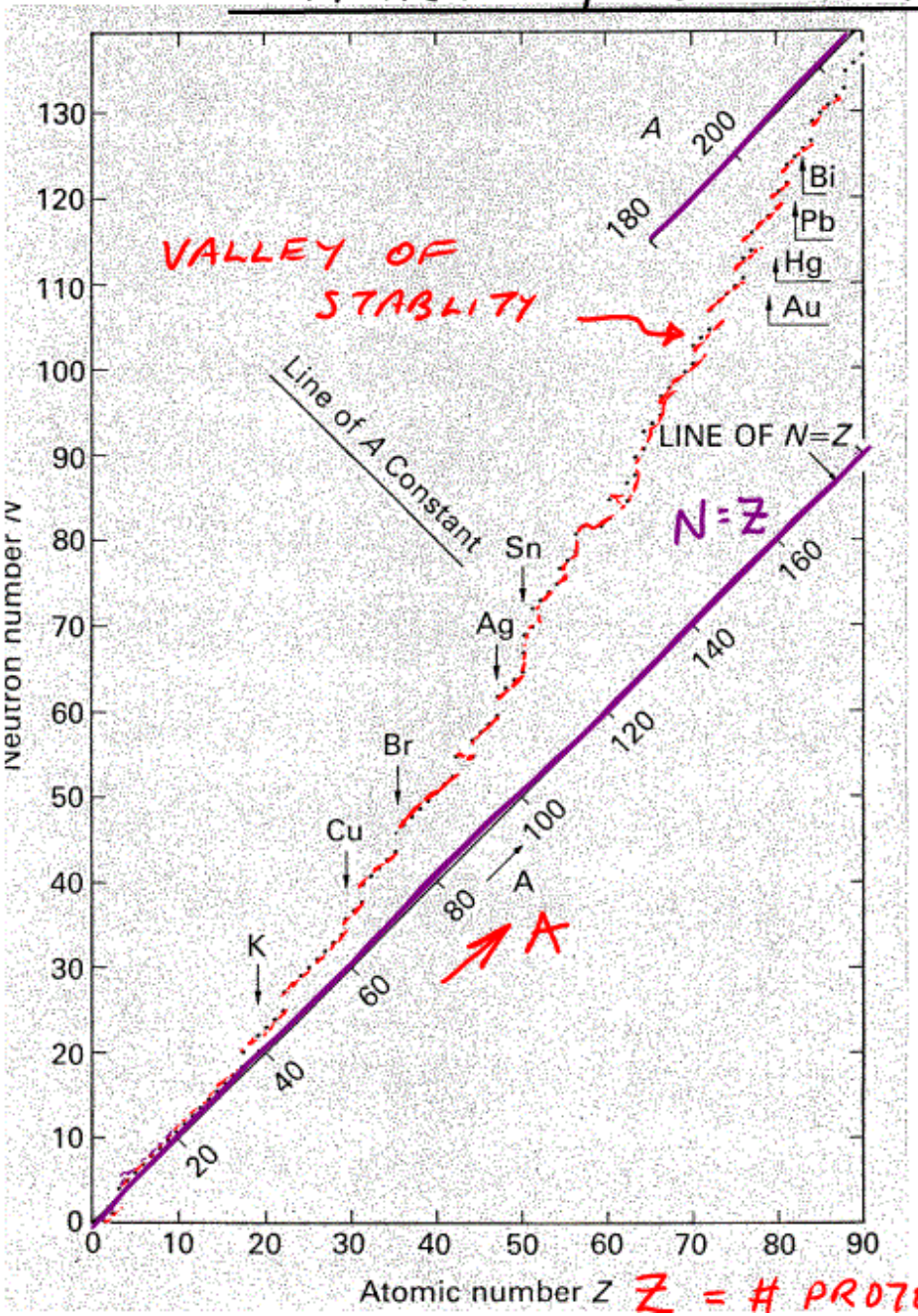
SYSTEMATICS OF NUCLEAR PROPERTIES

NUCLEAR PHYSICS — VAST SUBJECT

THIS COURSE — SOME "MUST KNOW" FACTS

- PATTERN OF STABLE NUCLEI
- INTRA NUCLEAR FORCE
- HOW NUCLEI DECAY
- NUCLEAR MODEL

NATURALLY OCCURRING STABLE NUCLEI



NUMBER OF NEUTRONS

$A = N + Z$

NEUTRONS — PROTONS

- $N = Z, Z+1, Z+2$ UP TO $A = 35$
- THEN N INCREASES FASTER THAN Z
- WHY DO NUCLEI CLUSTER AROUND VALLEY OF STABILITY
- WHY NO STABLE NUCLEI FOR $A > 209$
- WHY ONLY ONE STABLE ISOBAR IF A IS ODD

Z = # PROTONS

NUCLEAR BINDING ENERGIES

- SOME FORCE BINDS PROTONS & NEUTRONS INTO NUCLEI
- PATTERN OF BINDING ENERGIES → NATURE OF FORCE
- NUCLEUS → BOUND STATE OF PROTONS & NEUTRONS
  → MUST DO WORK TO PULL IT APART

$$M(A,Z) < Z \cdot m_p + (A-Z) \cdot m_n$$

MASS OF NUCLEUS — PROTON MASS — NEUTRON MASS

$$\Delta M(A,Z) = M(A,Z) - Z \cdot m_p - (A-Z) m_n$$

MASS DEFICIT

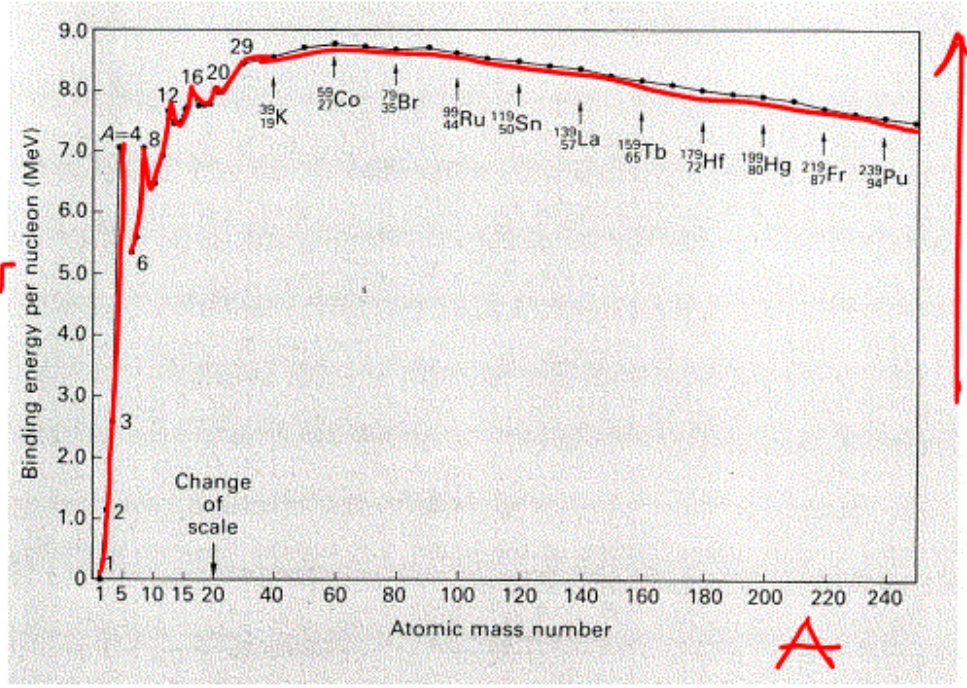
$$-\frac{BE}{A} = -\frac{\Delta M(A,Z)\, c^2}{A}$$

BINDING ENERGY PER NUCLEON

"CURVE OF BINDING ENERGY"

BINDING ENERGY PER NUCLEON

$\frac{BE}{A}$



INCREASING STABILITY

- INCREASES RAPIDLY → SPIKES → VERY STABLE
- PEAKS AT 9MeV/NUCLEON
- DROPS SLOWLY → ROUGHLY CONSTANT AT 8 MeV/NUCLEON

"SATURATION" IS AN IMPORTANT INDICATOR OF FORCE BETWEEN NUCLEONS.

NUCLEAR PHYSICS MASS UNITS

- TWO SCALES — OLD O^{16}
  NEW C^{12}

- 16 amu = MASS OF O_8^{16} ← NUCLEAR MASS = ATOMIC MASS − Zme
- 12 u = MASS OF C_6^{12} ← SI UNIT.

$m_p = 1.00728$ amu

1 amu: $\frac{938.27}{1.00728} \frac{MeV}{c^2}$

1 amu $= 1.6726 \times 10^{-27}$ kg

1u = 931.49432 $\frac{MeV}{c^2}$

$= 1.66054 \times 10^{-27}$ kg

$m_p = 938.27 \cdot \frac{1}{931.494} \cdot u$

$m_p = 1.00727$ u

m_p IS SAME PHYSICAL VALUE 938.27 $\frac{MeV}{c^2}$

NUCLEAR FORCE ≡ FORCE BETWEEN NUCLEONS

- REMNANT OF COLOUR FORCE BETWEEN QUARKS

cf VAN DER WAAL'S FORCE – INTER MOLECULAR

– REMNANT OF COULOMB

EXPERIMENTAL FACTS:

- ATOMIC STRUCTURE ACCURATELY MODELED BY COULOMB
  - NUCLEAR FORCE DOES NOT EXTEND BEYOND NUCLEUS
- BE/NUCLEON ROUGHLY CONSTANT WITH A

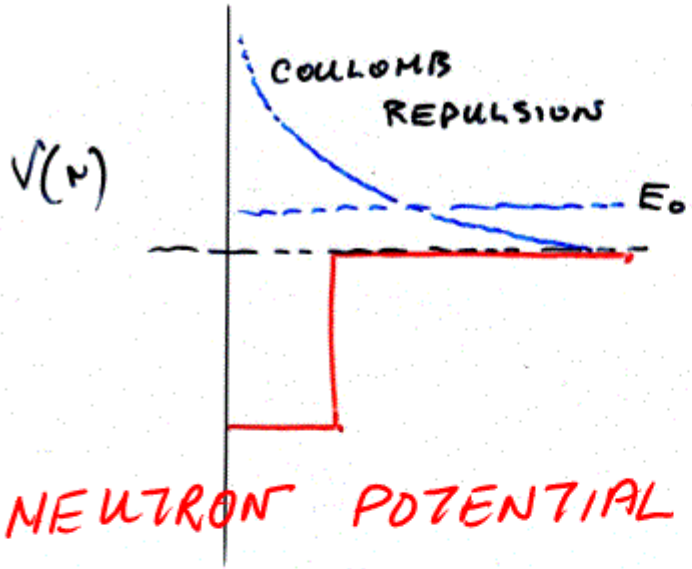
– BE DOES NOT DEPEND ON SIZE OF NUCLEUS

LONG RANGE FORCE $\frac{1}{2}(A-1)A$ PAIRS

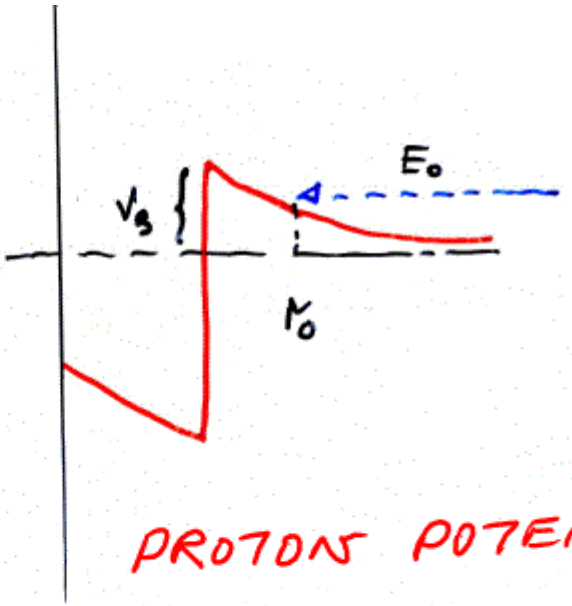
BE ~ TOTAL FOR ALL COMBINATIONS $B \propto A(A-1)$

$B \propto A(A-1) \Rightarrow$ FOR LARGE $A \rightarrow B \propto A^2 \rightarrow \frac{B}{A} \propto A$

$\frac{B}{A} \propto A \rightarrow$ LONG RANGE FORCE BUT NUCLEAR $\frac{B}{A}$ – CONST.



NEUTRON POTENTIAL



PROTON POTENTIAL

- LONG RANGE FORCE $B/A \propto A$
- EXPERIMENTALLY $B/A \sim$ CONSTANT → SATURATES
- A GIVEN NUCLEON ONLY INTEACTS WITH NEAREST NEIGHBOURS
- ADDING MORE NUCLEONS INCREASES SIZE OF NUCLEUS – BUT NOT BINDING ENERGY/NUCLEON
- ATTRACTIVE FORCE WITH REPULSIVE CORE

- INDEPENDANCE ON ELECTRIC CHARGE

  MIRROR NUCLEI X^{A}_{Z} Y^{A}_{A-Z}

  O^{15}_{8} N^{15}_{7}

- SAME NUMBER OF n-p INTERACTIONS
  - DIFFERENT NUMBER OF pp nn PAIRS

- AFTER CORRECTING FOR COULOMB FORCE

  nn FORCE = pp FORCE

- NEUTRON & PROTON TWO CHARGE STATES OF SINGLE PARTICLE NUCLEON

- TWO ORIENTATIONS IN ABSTRACT SPACE

  ISOTOPIC SPIN → cf ANGULAR MOMENTUM

NUCLEON PAIRING IN NUCLEUS

- NEUTRON & PROTON SPIN 1/2 ($\hbar/2$)

EVEN A → INTEGRAL NUCLEAR SPIN
ODD A → ½ INTEGRAL NUCLEAR SPIN

- EXPERIMENTAL FACTS

– EVEN # PROTONS, EVEN # NEUTRONS → ZERO NUCLEAR SPIN

– LARGE A NUCLEI → SMALL SPIN

– QUANTUM MECHANICAL PHENOMENON
→ LIKE NUCLEONS PAIR UP

→ ENERGETICALLY PREFERRED

CONSISTENT WITH OBSERVATION THAT NUCLEAR MAGNETIC MOMENTS SMALL $-3\mu_N \rightarrow +10\mu_N$