A Simple Calculation of the Inter-Nucleon Up-to-Down Quark Bond and Its Implications for Nuclear Binding

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Brief Review of Nuclear Force Models

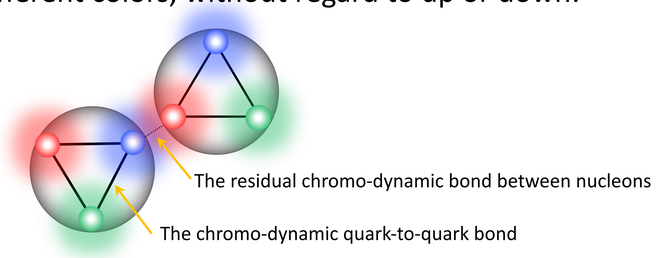
- Liquid Drop Model
  - Semi-classical
  - Curve-fitting with 5 variables
- Shell Model
  - Independent particles
  - Does not consider quarks
- Residual Chromodynamic Force Model
  - Extremely difficult math
  - Similar to Electromagnetic Van der Waals force
  - Generally accepted as the bonding mechanism
- Cluster Model
  - Recently gaining popularity

Brief Review of Quark Properties

- Quarks come in 6 flavors
  - Up, Down, Strange, Charm, Top, Bottom
- Quarks come in 3 colors
  - Red, Green, Blue
- Only Up and Down flavors in stable matter
  - Up +2/3 charge of proton
  - Down -1/3 charge of proton
- All electric charge of nucleons resides in the quarks
  - Magnetic moment in quarks

What if it's not just quark color that matters?

- Residual Chromo-Dynamic model—the bond is between different colors, without regard to up or down:



- Residual Chromodynamic bond does not fundamentally distinguish between protons or neutrons
  - Only the up and down quarks do that
- What if the Residual CD bond is also a bond between up and down quarks?

Quantum Considerations

- QCD hard-core repulsion--Nucleons cannot overlap in spatial location.
  - ^{2}H can have only 1 bond instead of 3.
  - ^{3}He can have only 3 bonds instead of 4.
  - ^{6}Li, ^{10}B, and ^{14}N (Z odd, N=Z) have one less bond.
- No net electric dipole moment for the nuclide.
  - Subtract 3 more bonds to remove electric dipole
  - One for each spatial direction of x, y, and z.
  - This subtraction applies to all nuclides except for ^{2}H & ^{3}He.
- The energy per bond is the one fitted parameter
  - For this simple calculation, it is 6.000 MeV per bond.

The Simple Calculations

For each nuclide, the table shows:

- A, Z, N
- Experimental Binding Energy per nucleon, EBE/A
- # of Up quarks
- # of Down quarks
- Number of classically-allowed bonds
- Number of Quantum-allowed bonds
- Calculated Binding Energy per nucleon, CBE/A
  - CBE=(# of bonds) x 6.000 MeV
- This table goes all the way to U-238. Shown here is a representative sample.

Nuclide	A	Z	N	(EBE) /A	# of up quarks	# of down quarks	# of possible up-down quark pairs, classical	# of up-down quark pairs, quantum	(CBE)/A
H2	2	1	1	1.113	3	3	3	1	3
He3	3	2	1	2.573	5	4	4	3	6
He4	4	2	2	7.074	6	6	6	6	9
He5	5	2	3	5.325	7	8	7	4	4.8
Li6	6	3	3	5.333	9	9	9	5	5
Li7	7	3	4	5.606	10	11	10	7	6
Be8	8	4	4	7.063	12	12	12	9	6.75
Be9	9	4	5	6.463	13	14	13	10	6.667
B10	10	5	5	6.475	15	15	15	11	6.6
B11	11	5	6	6.928	16	17	16	13	7.091
C12	12	6	6	7.68	18	18	18	15	7.5
C13	13	6	7	7.47	19	20	19	16	7.385
N14	14	7	7	7.476	21	21	21	17	7.286
N15	15	7	8	7.699	22	23	22	19	7.6
O16	16	8	8	7.976	24	24	24	21	7.875
O17	17	8	9	7.751	25	26	25	22	7.765
O18	18	8	10	7.767	26	28	26	23	7.667
F19	19	9	10	7.779	28	29	28	25	7.895
Ne20	20	10	10	8.033	30	30	30	27	8.1
Ne21	21	10	11	7.972	31	32	31	28	8
Ne22	22	10	12	8.08	32	34	32	29	7.909
Na23	23	11	12	8.111	34	35	34	31	8.087
Mg24	24	12	12	8.261	36	36	36	33	8.25
Mg25	25	12	13	8.223	37	38	37	34	8.16
Mg26	26	12	14	8.334	38	40	38	35	8.077
Al27	27	13	14	8.332	40	41	40	37	8.222
Si28	28	14	14	8.448	42	42	42	39	8.357
Si29	29	14	15	8.449	43	44	43	40	8.276
Si30	30	14	16	8.521	44	46	44	41	8.2
P31	31	15	16	8.481	46	47	46	43	8.323
S32	32	16	16	8.493	48	48	48	45	8.438
S33	33	16	17	8.498	49	50	49	46	8.364

Plot and Compare to Experiemental Values

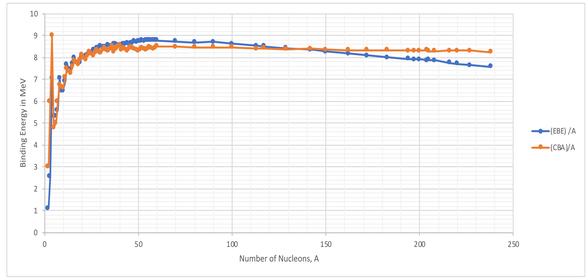


Fig. 3a. Plots of the Experimental Binding Energy (EBE) per nucleon and the Calculated Binding Energy (CBE) per nucleon, a representative sample of nucleons.

This is based on the number of possible quantum-allowed up-to-down quark pairs and a fixed binding energy per bonded pair.

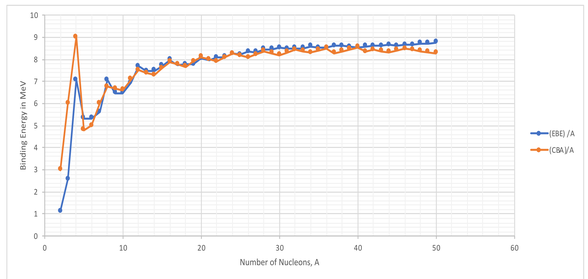


Fig. 3b. Plots of the Experimental Binding Energy per nucleon and the simple Calculated Binding Energy, showing the detail of the first 50 nuclides.

Discussion and Conclusions

- Excellent reproduction of experimental data
  - Only 1 fitted parameter instead of 5.
- The resulting errors for nuclides going up to Uranium ^{238}U are less than 10%.
- The average error from A=12 to A=50 is 1.83%.
- Possible types of bonds
  - Residual Chromodynamic force
  - Electromagnetic
  - Some combination of the two
- Due to the similarities to the residual chromo-dynamic force, the existence of an inter-nucleon up-to-down quark bonding cannot be considered implausible.
- An obvious implication is that some part of the nucleon-to-nucleon force is electromagnetic.
- This data strongly suggests the inter-nucleon up-to-down quark bonding should be seriously considered and more thoroughly examined.