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Research Article

A Simple Calculation of the Inter-nucleon Up-to-down Quark Bond and its Implications for Nuclear Binding

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Abstract

This paper describes an interesting and potentially significant phenomenon regarding the properties of up and down quarks within the nucleus, and how the possible inter-nucleon bonding of these quarks may affect the bonding energy of the nuclear force. A very simple calculation is used, which involves a bond between two inter-nucleon up and down quarks. This simple calculation does not depend on the type or mechanism for the bond. Furthermore, this simple calculation does not specify the shape or structure for the nucleus. This calculation only examines the energy of all possible up-to-down inter-nucleon bonds that may be formed within a quantum nucleus. A comparison of this total energy is made to the experimental binding energy with excellent results. The potential significance of this finding is discussed.
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Keywords: Inter-nucleon bond, Nuclear binding energy, Up and down Quarks

1. Introduction

The nuclear force is defined as the force which binds the protons and neutrons together within a nucleus. One of the currently accepted models of the nuclear force is the liquid-drop model [1]. This model of the nuclear force uses the Weizsäcker formula [2] to predict the binding energies of nuclides. The Weizsäcker formula is a curve-fitting formula that uses five parameters, plus one conditional logic statement, in order to achieve its results. These parameters are selected to empirically curve-fit the equation to the experimental data. The liquid drop model is considered to be a "semi-classical" model of the nuclear force [3], rather than a quantum model.

Another currently accepted model of the nuclear force is the shell model, which uses magic numbers to explain certain nuclear behavior. The nuclear shell model is similar to the electronic shell model, which describes the electrons orbiting around an atom. The nuclear shell model, however, cannot predict the. nuclear binding energy, and it makes no attempt to do so in any description of this theory.

A third currently accepted model of the nuclear force is the residual chromo-dynamic force model (abbreviated as the RCDF model in this paper). Before describing this residual chromo-dynamic force, it is useful to mention a few

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specifics about quantum chromo-dynamics (QCD). Quantum chromo-dynamics hypothesizes that the three valance quarks of protons and neutrons possess an attribute called color charge–either red, green, or blue. Historically, a contradiction of the quantum mechanical basis of nucleon properties with the Pauli exclusion principle led to the concept of the color charge for quarks [4]. (It should be noted that the words red, green, and blue are simply the names of the color charges, and do not imply any type of physically visual hue for the quarks. Also, the term "charge", when referring specifically to the color charge, is not related to electrical charge.) Quantum chromo-dynamics states that a strong bond is formed among the three color charges of the quarks *inside* the nucleon [5].

The residual chromo-dynamic force model assumes that the chromo-dynamic force also has a weaker residual force *outside* of the nucleon. The RCDF model states that this residual force forms an inter-nucleon bond, bonding the two different nucleons together. The inter-nucleon bond is formed by the residual color charges of the quarks.

While the RCDF model is considered to be the *mechanism* for nuclear bonding, the model is unable to duplicate the experimental bonding energy curve. This inability of the RCDF model to reproduce any salient nuclear behaviors currently is attributed to the extreme difficulty of modeling the multi-body interactions of the three color charges [6,7].

The problem with the derivation of nuclear forces from the residual QCD force is two-fold. First, each nucleon consists of three quarks, which means that a system of two nucleons is already a six-body problem. Second, because the chromodynamics force between quarks has the feature of being very strong compared to the lower energy scale of the residual chromo-dynamic force, this extraordinary strength makes it difficult to find converging mathematical solutions. The six-quark problem can be solved with brute computing power, by putting the six-quark system on a four dimensional lattice of discrete points: three dimensions of space and one of time. This method has become known as lattice quantum chromo-dynamics, or lattice QCD. However, such calculations are computationally very expensive and are not normally used as a standard nuclear physics tool [7]. Only the liquid drop model, with the five empirical-fit parameters, can duplicate the experimental binding curve.

The brute-force method for the computer calculations in lattice QCD puts each quark in a lattice by assigning to it an *x, y, z*, and *t* position, and then attempts to determine the binding energy. This is done through extremely complex mathematical models and often using Monte-Carlo simulations [8]. Because of the computational difficulties, binding energies of only the smallest nuclides, A <14, have been attempted. Thus, the RCDF model remains largely unverified when testing its binding energy predictions against experimental data.

2. Properties of Up and Down Quarks

From QCD theory, we know there are six different flavors of quarks: up, down, strange, charm, top, and bottom. Of these six different flavors, only two flavors are found in the stable matter of neutrons and protons: the up and down quarks [9]. (The terms of up and down do not imply any specific orientation with regard to spatial direction, and are simply the names of these types of quarks.)

An up quark has an electric charge that is +2/3 the charge of a proton, and it also contains a positive magnetic moment, which is parallel to of the spin of the nuclide. The up quark has a spin of 1/2 and a mass of about 0.3% of the proton. The color charge of an up quark can be either red, green, or blue.

A down quark has an electric charge that is –1/3 the charge of a proton, and it contains a negative magnetic moment, which is anti-parallel to of the spin of the nuclide. The down quark has a spin of 1/2, and a mass of about 0.6% of the proton. The color charge of a down quark can be either red, green, or blue.

The magnetic moments of the up and down quarks are estimated to be +1.85 and –0.97, respectively, in units of nuclear magnetons. The electrical charges of the proton and neutron are completely contained within the quarks. The proton is comprised of two up quarks and one down quark, giving it a net charge of +1. The neutron is comprised of one up quark and two down quarks, giving it a net charge of 0.

The quarks inside of a proton and neutron have both attributes of flavor and color. Each quark inside of a proton

or neutron is one of six types: up and red, up and green, up and blue, down and red, down and green, or down and blue [5]. Both the neutron and the proton contain one each of the three different color charges: red, green, and blue. Thus in terms of the color charges, there is no difference between the proton and the neutron; the only difference in the quark characteristics between a proton or neutron resides in the number of up and down quarks. Any bond between the different color charges is also a bond between some combination of the up and down quarks. Thus, the quantum assumptions that are made in the RCDF model about the possibility of an inter-nucleon bond between the residual color charges of the quarks are also applicable to the formation of an inter-nucleon bond between up and down quarks.

3. A Simple Calculation Involving Inter-nucleon Up-to-down Quarks

Using the concept of the inter-nucleon quark-to-quark bond, and applying this concept to the up and down quarks, an interesting and potentially significant set of data emerges.

Table 1 shows a spread sheet, with a representative sample of stable nuclides. The following information is listed in this spread sheet for every nuclide:

- The nuclide name.
- The number of nucleons, A, which is the sum of neutrons plus protons.
- The number of protons, Z.
- The number of neutrons, N.
- The experimental binding energy in units of MeV, as obtained from the nuclear tables [10].
- The experimental binding energy per nucleon.
- Other columns, which are described below.

A plot of the Experimental Binding Energy per nucleon is shown in Fig. 1; this plot is similar to the usual diagrams for the nuclear binding found in textbooks.

4. An Additional Constraint for Inter-nucleon Quark-to-quark Binding

Given the consideration that the color charges contained within a nucleon does not inherently distinguish between a neutron or proton, an examination of an inter-nucleon bond being formed only between an up and a down quark is an appropriate possibility to explore. Specifically, this additional constraint is that the inter-nucleon quark-to-quark bond must between an up and a down quark; it cannot be between two up quarks or two down quarks. If this additional constraint is made to the RCDF model, then an interesting pattern emerges with regard to the binding energy.

For any given nuclide, the number of inter-nucleon up-to-down quark pairs can be determined, based on how many up and down quarks each nuclide has. For each nuclide in the table, this calculation is made, as shown in Eq. (1).

$$\begin{gathered}\text{Number of up quarks} = (Z \times 2) + (N \times 1),\\ \text{Number of down quarks} = (Z \times 1) + (N \times 2),\\ \text{Number of possible pairs} = \text{the smaller of these two numbers.}\end{gathered} \tag{1}$$

This information has been incorporated into three additional columns in Table 1, showing the number of up quarks, the number of down quarks, and the number of possible up-to-down quark pairs, for each of the nuclides.

For simplicity of this very quick and easy calculation, it is assumed that every bonded pair of up-to-down quarks has the same bonding energy. Thus, *just for this simple calculation*, the equation for the binding energy of a nuclide is the number of inter-nucleon up-to-down quark pairs times the binding energy per pair, as shown in Eq. (2).

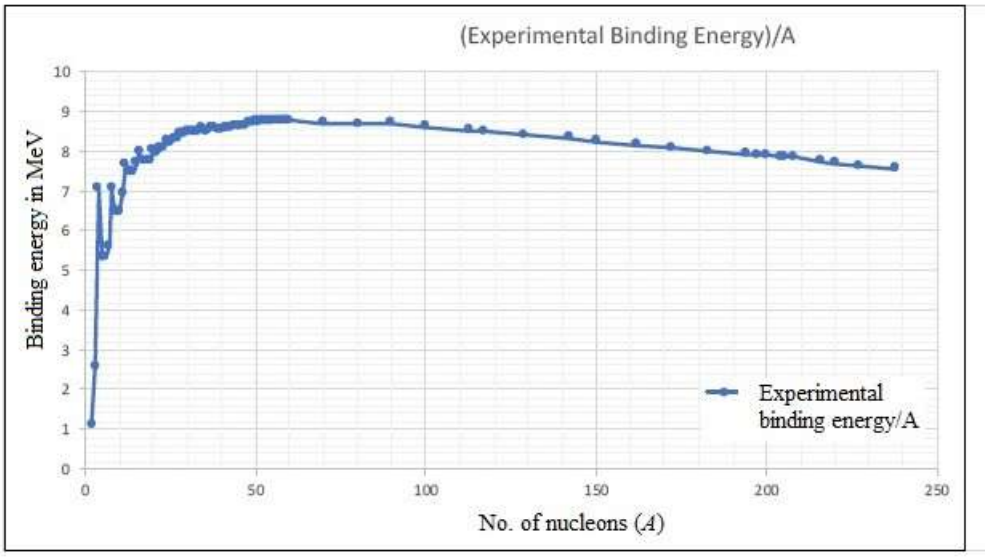

Figure 1. Plots of the experimental nuclear binding energy per nucleon (blue) and the simple calculated binding energy (orange), taking into consideration the quantum rules of hard-core repulsion and zero electric dipole moment. This is based on the number of possible quantum-allowed up-to-down quark pairs and a fixed binding energy per bonded pair.

$$\text{Calculated binding energy} = (\text{number of pairs}) \times (\text{binding energy per bonded pair})\,. \tag{2}$$

The binding energy per bonded pair is the same value for all of the nuclides, and this parameter is selected to match the empirical data. Shown is Fig. 2 is a plot of this binding energy per nucleon for a classical (non-quantum) object. Note that for Fig. 2, neither the *type* of bond nor the *structure* of these bonds comes into consideration; this is simply the number of possible pairs times a fixed binding energy per bonded pair.

5. Quantum Considerations

A nucleus is a quantum object, and being so, certain quantum rules must apply. A known phenomenological feature of the nuclear force is the QCD hard-core repulsion. The hard-core repulsion states that nucleons, such as a proton or neutron, cannot overlap in their spatial location [11,12]. The application of this phenomenon to this simple calculation reduces the number of bonds for only the two smallest nuclides. To prevent this overlap, hydrogen ^{2}H can have only one bond instead of three, and helium ^{3}He can have only three bonds instead of four. Three other stable nuclides are affected by this, the ones in which Z is odd and $N = Z$. These are ^{6}Li, ^{10}B, and ^{14}N. Other nuclides are not affected by the application of this rule, for this simple calculation.

Table 1. A representative sample of nuclides, with the nuclide name, A, Z, N, experimental binding energy of the nuclide, and the experimental binding energy per nucleon. Also shown is the number of up quarks, down quarks, and the number of possible inter-nucleon up-to-down quark bonded pairs.

Nuclide	*A*	*Z*	*N*	Exp. binding energy (MeV)	Exp. binding energy/*A*	No. of up quarks	No. of down quarks	No. of up-down bonds,classical	No. of up-down bonds, quantum
^{2}H	2	1	1	2.225	1.11	3	3	3	1
^{3}He	3	2	1	7.718	2.57	5	4	4	3
^{4}He	4	2	2	28.296	7.07	6	6	6	6
^{5}He	5	2	3	26.626	5.33	7	8	7	4
^{6}Li	6	3	3	31.995	5.33	9	9	9	6
^{7}Li	7	3	4	39.245	5.61	10	11	10	7
^{8}Be	8	4	4	56.5	7.06	12	12	12	9
^{9}Be	9	4	5	58.165	6.46	13	14	13	10
^{10}B	10	5	5	64.751	6.48	15	15	15	12
^{11}B	11	5	6	76.205	6.93	16	17	16	13
^{12}C	12	6	6	92.162	7.68	18	18	18	15
^{13}C	13	6	7	97.108	7.47	19	20	19	16
^{14}N	14	7	7	104.659	7.48	21	21	21	18
^{15}N	15	7	8	115.492	7.7	22	23	22	19
^{16}O	16	8	8	127.619	7.98	24	24	24	21
^{17}O	17	8	9	131.762	7.75	25	26	25	22
^{18}O	18	8	10	139.808	7.77	26	28	26	23
^{19}F	19	9	10	147.801	7.78	28	29	28	25
^{20}Ne	20	10	10	160.65	8.03	30	30	30	27
^{21}Ne	21	10	11	167.406	7.97	31	32	31	28
^{22}Ne	22	10	12	177.77	8.08	32	34	32	29
^{23}Na	23	11	12	186.564	8.11	34	35	34	31
^{24}Mg	24	12	12	198.257	8.26	36	36	36	33
^{25}Mg	25	12	13	205.587	8.22	37	38	37	34
^{26}Mg	26	12	14	216.681	8.33	38	40	38	35
^{27}Al	27	13	14	224.952	8.33	40	41	40	37
^{28}Si	28	14	14	236.537	8.45	42	42	42	39
^{29}Si	29	14	15	245.01	8.45	43	44	43	40
^{30}Si	30	14	16	255.62	8.52	44	46	44	41
^{31}P	31	15	16	262.917	8.48	46	47	46	43
^{32}S	32	16	16	271.78	8.49	48	48	48	45
^{33}S	33	16	17	280.422	8.5	49	50	49	46
^{34}S	34	16	18	291.839	8.58	50	52	50	47
^{35}Cl	35	17	18	298.21	8.52	52	53	52	49
^{36}S	36	16	20	308.71	8.58	52	56	52	49
^{36}Ar	36	18	18	306.716	8.52	54	54	54	51
^{37}Cl	37	17	20	318.784	8.62	54	57	54	51
^{38}Ar	38	18	20	327.343	8.61	56	58	56	53
^{39}K	39	19	20	333.724	8.56	58	59	58	55
^{40}Ar	40	18	22	343.81	8.6	58	62	58	55

^{40}Ca	40	20	20	342.053	8.6	60	60	60	57
^{41}K	41	19	22	351.619	8.6	60	63	60	57
^{42}Ca	42	20	22	361.895	8.6	62	64	62	59
^{43}Ca	43	20	23	369.828	8.6	63	66	63	60
^{44}Ca	44	20	24	380.96	8.7	64	68	64	61
^{45}Sc	45	21	24	387.849	8.6	66	69	66	63
^{46}Ca	46	20	26	398.772	8.7	66	72	66	63
46Ti	46	22	24	398.194	8.7	68	70	68	65
^{47}Ti	47	22	25	407.072	8.7	69	72	69	66
^{48}Ca	48	20	28	415.992	8.7	68	76	68	65
^{48}Ti	48	22	26	418.699	8.7	70	74	70	67
^{49}Ti	49	22	27	426.841	8.7	71	76	71	68
^{50}Ti	50	22	28	437.78	8.8	72	78	72	69
^{50}Cr	50	24	26	435.047	8.7	74	76	74	71
^{51}V	51	23	28	445.842	8.7	74	79	74	71
^{52}Cr	52	24	28	456.345	8.8	76	80	76	73
^{53}Cr	53	24	29	464.287	8.8	77	82	77	74
^{54}Cr	54	24	30	474.009	8.8	78	84	78	75
^{54}Fe	54	26	28	471.765	8.7	80	82	80	77
^{55}Mn	55	25	30	482.075	8.8	80	85	80	77
^{56}Fe	56	26	30	492.257	8.8	82	86	82	79
^{57}Fe	57	26	31	499.905	8.8	83	88	83	80
^{58}Fe	58	26	32	509.945	8.8	84	90	84	81
^{58}Ni	58	28	30	506.456	8.7	86	88	86	83
^{59}Co	59	27	32	517.314	8.8	86	91	86	83
^{60}Ni	60	28	32	526.842	8.8	88	92	88	85
^{70}Zn	70	30	40	611.08	8.7	100	110	100	97
^{70}Ge	70	32	38	610.519	8.7	102	108	102	99
^{80}Se	80	34	46	696.867	8.7	114	126	114	111
^{80}Kr	80	36	44	695.438	8.7	116	124	116	113
^{90}Zr	90	40	50	783.895	8.7	130	140	130	127
^{100}Ru	100	44	56	861.929	8.6	144	156	144	141
^{113}Cd	113	48	65	963.557	8.5	161	178	161	158
^{113}In	113	49	64	963.091	8.5	162	177	162	159
^{117}Sn	117	50	67	995.623	8.5	167	184	167	164
^{129}Xe	129	54	75	1087.65	8.4	183	204	183	180
^{142}Ce	142	58	84	1185.28	8.4	200	226	200	197
^{142}Nd	142	60	82	1185.15	8.4	202	224	202	199
^{150}Sm	150	62	88	1239.25	8.3	212	238	212	209
^{150}Gd	150	64	86	1236.39	8.2	214	236	214	211
^{162}Dy	162	66	96	1323.88	8.2	228	258	228	225
^{172}Yb	172	70	102	1392.76	8.1	242	274	242	239
^{183}W	183	74	109	1465.53	8	257	292	257	254
^{194}Pt	194	78	116	1539.58	7.9	272	310	272	269
^{197}Au	197	79	118	1559.4	7.9	276	315	276	273

^{200}Hg	200	80	120	1581.2	7.9	280	320	280	277
^{204}Hg	204	80	124	1608.7	7.9	284	328	284	281
^{204}Pb	204	82	122	1605.3	7.9	286	326	286	283

Quantum mechanics also states there can be no net electric dipole moment for the nuclide [13,14]. For this second quantum rule, three more bonds must be subtracted from the number of bonds available, in order to remove the electric dipole moment. Without stating any specific configuration for the nuclide in this very simplified calculation, this reduction of bonds can be best understood from the fact that the electric charge distribution of the nuclide must not have a net difference in electrical charge for any of the three spatial dimensions, x, y, or z. To prevent an electric dipole moment, a bond is broken in each of these three dimensions, so that the net charge is symmetric about the x, y, and z axes. This quantum requirement removes three of the classically allowed bonds. This rule applies to all nuclides, except for the very smallest nuclides, ^{2}H, ^{3}He, and ^{4}He. The inclusion of these two quantum rules is shown in Table 2. As before for this simple calculation, the calculated binding energy is the number of bonds times a fixed energy per bond. The energy per bond is the one selected parameter; for this simple calculation, it is 6.000 MeV per bond. These data are plotted in Figs. 3 and 4. In Fig. 3 all of the stable nuclides are shown, out to lead ^{204}Pb. In Fig. 4, only the first 50 nuclides are shown, to show the detail there. When there is more than one stable nuclide for a given A, these are shown as well in Figs. 3 and 4. To re-iterate, this is a very quick and easy calculation, involving only the counting of bonded inter-nucleon up-to-down quark pairs. This calculation does not specify the arrangement of the nucleons or the mechanism of the bond. It is just a simple counting of the quantum-allowed bonds.

6. Discussion

The excellent reproduction of the experimental data for these simple calculated results is impressive, especially considering that there is only one variable that must be selected, instead of five variables as in the Weizsäcker formula. The excellent reproduction of the experimental data is especially impressive considering that other currently accepted nuclear theories cannot easily duplicate this curve.

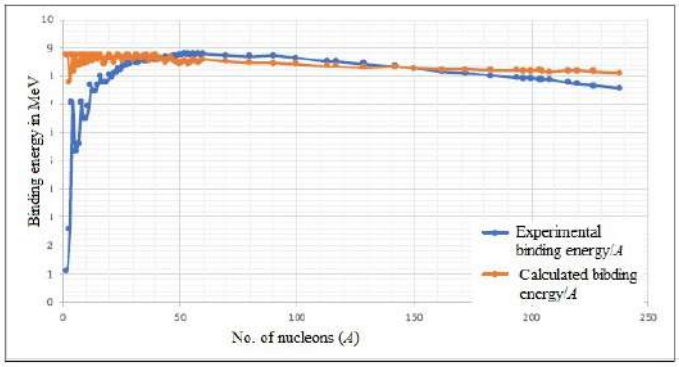

Figure 2. Plots of the experimental nuclear binding energy per nucleon (*blue*) and the simple calculated binding energy (*orange*), taking into consideration the quantum rules of hard-core repulsion and zero electric dipole moment. This is based on the number of possible quantum-allowed up-to-down quark pairs and a fixed binding energy per bonded pair.

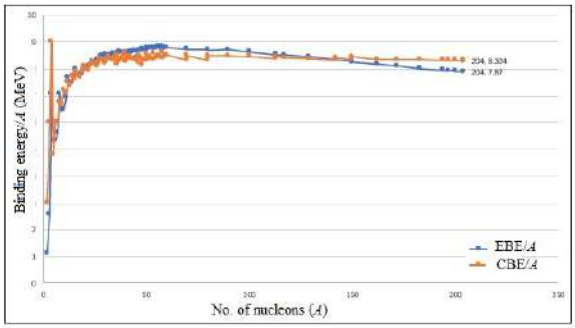

Figure 3. Plots of the experimental nuclear binding energy per nucleon (*blue*) and the simplistic calculated binding energy (*orange*), taking into consideration the quantum rules of hard-core repulsion and zero electric dipole moment, showing only the first 50 nuclides.

The residual chromo-dynamic force for quark-to-quark bonding is one possibility for the mechanism of this bond. Another possibility for this bond becomes apparent when it is recalled that the up quark has a charge +2/3 charge of a proton, the down quark has a –1/3 charge of a proton, and they both carry a magnetic moment. These electromagnetic properties of the up and down quarks create an attractive electromagnetic force between the up and the down quarks. The strength of this electromagnetic force is dependent only on the minimum proximity between the up and down quarks engaged in a bond. (Historically, it was believed that the strength of the electromagnetic force had an upper limit. However, this misconceived notion is now known to be invalid.)

The inter-nuclear bond is most likely some type of combination of both the electric charge and the color charge of the quarks, but the relative percentages of these two contributions is not postulated here. However, regardless of the relative percentages, the electromagnetic component of this bond must be taken into consideration. A more detailed analysis of the electromagnetic part of this inter-nuclear up-to-down quark bonding can easily be made.

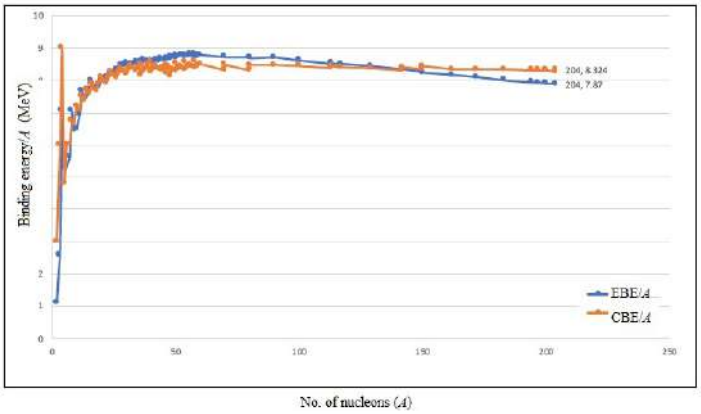

Figure 4. A plot of the experimental nuclear binding energy per nucleon, for a representative sample of nuclides.

Nuclide	A	Z	N	Experimental binding energy (MeV)	Experimental binding energy/A	No. of up quarks	No. of down quarks	No. of up-down bonds, classical	No. of up-down bonds, quantum	Calculated binding energy	Calculated binding energy/A	%Error
^{1}H	2	1	1	2.225	1.11	3	3	3	1	6	3	
^{3}He	3	2	1	7.718	2.57	5	4	4	3	18	6	-133.2
^{4}He	4	2	2	28.296	7.07	6	6	6	6	36	9	-27.23
^{5}He	5	2	3	26.626	5.33	7	8	7	4	24	4.8	9.86
^{6}Li	6	3	3	31.995	5.33	9	9	9	6	36	6	-12.52
^{7}Li	7	3	4	39.245	5.61	10	11	10	7	42	6	-7.02
^{8}Be	8	4	4	56.5	7.06	12	12	12	9	54	6.75	4.42
^{9}Be	9	4	5	58.165	6.46	13	14	13	10	60	6.667	-3.15
^{10}B	10	5	5	64.751	6.48	15	15	15	12	72	7.2	-11.2
^{11}B	11	5	6	76.205	6.93	16	17	16	13	78	7.091	-2.36
^{12}C	12	6	6	92.162	7.68	18	18	18	15	90	7.5	2.35
^{13}C	13	6	7	97.108	7.47	19	20	19	16	96	7.385	1.14
^{14}N	14	7	7	104.659	7.48	21	21	21	18	108	7.714	-3.19
^{15}N	15	7	8	115.492	7.7	22	23	22	19	114	7.6	1.29
^{16}O	16	8	8	127.619	7.98	24	24	24	21	126	7.875	1.27
^{17}O	17	8	9	131.762	7.75	25	26	25	22	132	7.765	-0.18
^{18}O	18	8	10	139.808	7.77	26	28	26	23	138	7.667	1.29
^{19}F	19	9	10	147.801	7.78	28	29	28	25	150	7.895	-1.49
^{20}Ne	20	10	10	160.65	8.03	30	30	30	27	162	8.1	-0.84
^{21}Ne	21	10	11	167.406	7.97	31	32	31	28	168	8	-0.35
^{22}Ne	22	10	12	177.77	8.08	32	34	32	29	174	7.909	2.12
^{23}Na	23	11	12	186.564	8.11	34	35	34	31	186	8.087	0.3
^{24}Mg	24	12	12	198.257	8.26	36	36	36	33	198	8.25	0.13
^{25}Mg	25	12	13	205.587	8.22	37	38	37	34	204	8.16	0.77
^{26}Mg	26	12	14	216.681	8.33	38	40	38	35	210	8.077	3.08
^{27}Al	27	13	14	224.952	8.33	40	41	40	37	222	8.222	1.31
^{28}Si	28	14	14	236.537	8.45	42	42	42	39	234	8.357	1.07
^{29}Si	29	14	15	245.01	8.45	43	44	43	40	240	8.276	2.04
^{30}Si	30	14	16	255.62	8.52	44	46	44	41	246	8.2	3.76
^{31}P	31	15	16	262.917	8.48	46	47	46	43	258	8.323	1.87
^{32}S	32	16	16	271.78	8.49	48	48	48	45	270	8.438	0.65
^{33}S	33	16	17	280.422	8.5	49	50	49	46	276	8.364	1.58
^{34}S	34	16	18	291.839	8.58	50	52	50	47	282	8.294	3.37
^{35}Cl	35	17	18	298.21	8.52	52	53	52	49	294	8.4	1.41
^{36}S	36	16	20	308.71	8.58	52	56	52	49	294	8.167	4.76
^{36}Ar	36	18	18	306.716	8.52	54	54	54	51	306	8.5	0.23
^{37}Cl	37	17	20	318.784	8.62	54	57	54	51	306	8.27	4.01
^{38}Ar	38	18	20	327.343	8.61	56	58	56	53	318	8.368	2.85
^{39}K	39	19	20	333.724	8.56	58	59	58	55	330	8.462	1.12
^{40}Ar	40	18	22	343.81	8.6	58	62	58	55	330	8.25	4.02
^{40}Ca	40	20	20	342.053	8.55	60	60	60	57	342	8.55	0.02
^{41}K	41	19	22	351.619	8.58	60	63	60	57	342	8.341	2.74
^{42}Ca	42	20	22	361.895	8.62	62	64	62	59	354	8.429	2.18
^{43}Ca	43	20	23	369.828	8.6	63	66	63	60	360	8.372	2.66
^{44}Ca	44	20	24	380.96	8.66	64	68	64	61	366	8.318	3.93
^{45}Sc	45	21	24	387.849	8.62	66	69	66	63	378	8.4	2.54
^{46}Ca	46	20	26	398.772	8.67	66	72	66	63	378	8.217	5.21
^{46}Ti	46	22	24	398.194	8.66	68	70	68	65	390	8.478	2.06
^{47}Ti	47	22	25	407.072	8.66	69	72	69	66	396	8.426	2.72
^{48}Ca	48	20	28	415.992	8.67	68	76	68	65	390	8.125	6.25
^{48}Ti	48	22	26	418.699	8.72	70	74	70	67	402	8.375	3.99
^{49}Ti	49	22	27	426.841	8.71	71	76	71	68	408	8.327	4.41
^{50}Ti	50	22	28	437.78	8.76	72	78	72	69	414	8.28	5.43
^{50}Cr	50	24	26	435.047	8.7	74	76	74	71	426	8.52	2.08
^{51}V	51	23	28	445.842	8.74	74	79	74	71	426	8.353	4.45
^{52}Cr	52	24	28	456.345	8.78	76	80	76	73	438	8.423	4.02
^{53}Cr	53	24	29	464.287	8.76	77	82	77	74	444	8.377	4.37

^{54}Cr	54	24	30	474.01	8.78	78	84	78	75	450	8.333	5.07
^{54}Fe	54	26	28	471.77	8.74	80	82	80	77	462	8.556	2.07
^{55}Mn	55	25	30	482.08	8.77	80	85	80	77	462	8.4	4.16
^{56}Fe	56	26	30	492.26	8.79	82	86	82	79	474	8.464	3.71
^{57}Fe	57	26	31	499.91	8.77	83	88	83	80	480	8.421	3.98
^{58}Fe	58	26	32	509.95	8.79	84	90	84	81	486	8.379	4.7
^{58}Ni	58	28	30	506.46	8.73	86	88	86	83	498	8.586	1.67
^{59}Co	59	27	32	517.31	8.77	86	91	86	83	498	8.441	3.73
^{60}Ni	60	28	32	526.84	8.78	88	92	88	85	510	8.5	3.2
^{70}Zn	70	30	40	611.08	8.73	100	110	100	97	582	8.314	4.76
^{70}Ge	70	32	38	610.52	8.72	102	108	102	99	594	8.486	2.71
^{80}Se	80	34	46	696.87	8.71	114	126	114	111	666	8.325	4.43
^{80}Kr	80	36	44	695.44	8.69	116	124	116	113	678	8.475	2.51
^{90}Zr	90	40	50	783.9	8.71	130	140	130	127	762	8.467	2.79
^{100}Ru	100	44	56	861.93	8.62	144	156	144	141	846	8.46	1.85
^{113}Cd	113	48	65	963.56	8.53	161	178	161	158	948	8.389	1.61
^{113}In	113	49	64	963.09	8.52	162	177	162	159	954	8.442	0.94
^{117}Sn	117	50	67	995.62	8.51	167	184	167	164	984	8.41	1.17
^{129}Xe	129	54	75	1087.6	8.43	183	204	183	180	1080	8.372	0.7
^{142}Ce	142	58	84	1185.3	8.35	200	226	200	197	1182	8.324	0.28
^{142}Nd	142	60	82	1185.1	8.35	202	224	202	199	1194	8.408	-0.75
^{150}Sm	150	62	88	1239.3	8.26	212	238	212	209	1254	8.36	-1.19
^{150}Gd	150	64	86	1236.4	8.24	214	236	214	211	1266	8.44	-2.39
^{162}Dy	162	66	96	1323.9	8.17	228	258	228	225	1350	8.333	-1.97
^{172}Yb	172	70	102	1392.8	8.1	242	274	242	239	1434	8.337	-2.96
^{183}W	183	74	109	1465.5	8.01	257	292	257	254	1524	8.328	-3.99
^{194}Pt	194	78	116	1539.6	7.94	272	310	272	269	1614	8.32	-4.83
^{197}Au	197	79	118	1559.4	7.92	276	315	276	273	1638	8.315	-5.04
^{200}Hg	200	80	120	1581.2	7.91	280	320	280	277	1662	8.31	-5.11
^{204}Hg	204	80	124	1608.7	7.89	284	328	284	281	1686	8.265	-4.81
^{204}Pb	204	82	122	1605.3	7.87	286	326	286	283	1698	8.324	-5.77

Table 2. A representative sample of nuclides, showing quantum-allowed bonded up-to-down quark pairs for each nuclide, taking into consideration the QCD hard-core repulsion and the elimination of a nuclear dipole moment.

A detailed analysis would include the addition of the energy due to all electric charges interacting with each other, which would be a double summation of the interaction of each electric charge with every other electric charge [15]. Similarly, this more detailed analysis would also include the variation of the electromagnetic bond due to the vector orientation of the magnetic moments. Additionally, the energy of the magnetic moments interacting with each other, should be included, which is a double summation over all magnetic moment vectors [16]. And finally, the kinetic energy of the quantum spin of the nuclide should also be included in this overall binding energy calculation [17,18]. For more detailed and accurate calculations to be done, however, the lowest energy configuration of the nuclide must be specified before the interaction energies can be accurately calculated.

7. Conclusion

An extremely simple calculation of the inter-nuclear up-to-down quark bonding has been made, giving excellent results in duplicating the nuclear bonding energy curve, using only one parameter rather than five. The resulting errors for nuclides going up to lead ^{204}Pb are on the order of a few percent. The average error from A =12 to A =50 is less than 2%. Also, due to the similarities of this concept to the residual chromo-dynamic force model, the existence of inter-nucleon up-to-down quark bonding cannot be relegated as inconceivable or implausible. An obvious implication of these results is that some significant part of the nucleon-to-nucleon force is electromagnetic. The excellent reproduction of experimental data strongly suggests that the inter-nucleon up-to-down quark bonding is a concept that should be seriously considered and more thoroughly examined by mainstream nuclear physics.

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