Journal of Modern Physics, 2021, 12, 161-166
https://www.scirp.org/journal/jmp
ISSN Online: 2153-120X
ISSN Print: 2153-1196

On Dineutron and Deuteron Binding Energies

F. C. Hoh

Retired, Dragarbrunnsg, Uppsala, Sweden
Email: hoh@telia.com

How to cite this paper: Hoh, F.C. (2021) On Dineutron and Deuteron Binding Energies. *Journal of Modern Physics*, **12**, 161-166.
https://doi.org/10.4236/jmp.2021.123014

Received: January 8, 2021
Accepted: February 6, 2021
Published: February 9, 2021

Abstract

The binding energy of the deuteron is estimated from the scalar strong interaction hadron theory SSI. The predicted value is 7.7% lower than the measured value. Existence of a spin 1 dineutron with a binding energy 4/5 that of the deuteron or 1.78 MeV is predicted. This is verified by the dineutron, first observed in 2012, in ^{16}Be decay. No free dineutrons are expected to exist in nature as they can decay into deuterons. These binding energies are limited by short range strong interaction internucleon forces but consist of long range electrostatic energies from quark charges.

Keywords

Scalar Strong Interaction Hadron Theory SSI, Deuteron Structure, Dineutron Structure, Electromagnetic Energy, Deuteron Binding Energy, Dineutron Binding Energy, Dineutron Decay

1. Introduction

The current mainstream particle theory, the standard model SM [1], can say nothing about binding energies of two nucleon nuclei. In its place, the scalar strong interaction hadron theory SSI has been proposed [2] [3]. The purpose of this paper is to provide estimates of the binding energies in the two nucleon system based upon SSI.

In Section 2, the triplet deuteron binding energy is estimated and compared to data. Section 3 shows that the singlet deuteron is not a bound state. The same conclusion is reached for the singlet dineutron in Section 4. In Section 5, the triplet dineutron binding energy is estimated and its decay mode is shown. This dineutron is assigned to the observed one in ^{16}Be decay. Some related considerations are given in Section 6.

2. Triplet Deuteron Binding Energy

In SSI [3] (Ch 9), the ground state of a proton consists of a diquark *uu* and a quark *d*.

Consider such a free proton and change its *u* quarks into *d* quarks and vice versa. The result is a neutron with the same spin configuration. Put these two nucleons next to each other to form a deuteron, as is depicted in **Figure 1**.

The configuration in **Figure 1** is fixed by the: following two conditions: 1) the total spin in a two nucleon system can only be 1 with the nucleon spins parallel or 0 with the spins antiparallel and 2) both nucleons are on equal footing and the configuration remains symmetric with respect to them after an interchange or a space inversion.

In SSI, R_a is in the "hidden" relative space x between the diquark and the quark [4] (A1) and is determined by strong interquark forces. It is hence not observable. On the other hand, the internucleon distance R_{nn} in the laboratory space is observable.

When the two nucleons in **Figure 1** are far apart or R_{nn} is large, they do not interact with each other. When they are sufficiently close to each other, they form a triplet deuteron ${}^2H_1$. Let q denote quark charge, then

$$q_u = 2e/3,\ q_{uu} = 4e/3,\ q_d = -e/3,\ q_{dd} = -2e/3 \tag{1}$$

Consider the total electrostatic energy E_{em2H1} of the triplet deuteron in **Figure 1**. There are four contributions, between *uu* and *dd*, *uu* and *u*, *d* and *dd*, and *d* and *u* so that

$$E_{em2H1} = \frac{q_{uu}q_{dd} + q_d q_u}{R_{nn}} + \frac{q_{uu}q_u + q_d q_{dd}}{\sqrt{R_{nn}^2 + R_a^2}} = \frac{10e^2}{9}\frac{1}{R_{nn}}\left[-1 + \frac{1}{\sqrt{1 + R_a^2/R_{nn}^2}}\right] \le 0 \tag{2}$$

For large neutron-proton separation R_{nn}, $E_{em2H1} \approx 0$ but < 0. Let now the neutron move closer to the proton, R_{nn} decreases and E_{em2H1} becomes more negative. However, R_{nn} cannot be too small because the neutron will then experience the short range strong interaction force from the proton which prevents the merger of these two nucleons.

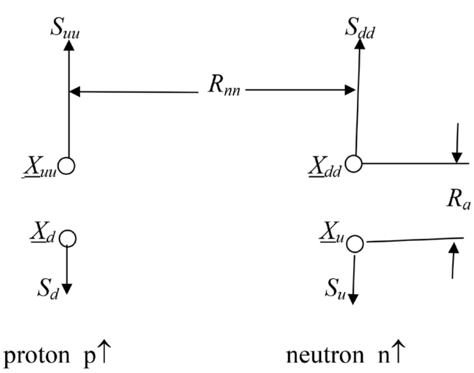

Figure 1. Schematic configuration of the spin ↑↑ component of a triplet deuteron ${}^2H_1$. $\underline{X}$ denotes the coordinate and S the spin of the diquarks and quarks. The subscripts refer to the quark content. $S_{uu} = S_{dd} = 1$ and $S_u = S_d = -1/2$ with signs given by the arrow ↑ for + and ↓ for −. $\underline{X}_{uu} = \underline{x}_I$ and $\underline{X}_d = \underline{x}_{II}$ in [3] (10.1.1) or [4] (A2). $R_a \approx 3.23$ fm [5] (2.5) is the mean value of the diquark-quark distance. The neutron configuration is obtained from the proton configuration via the interchange $u \leftrightarrow d$. R_{nn} is distance between the both nucleons.

Let the diquark *uu* be fixed at $\underline{X}_{uu}$ in **Figure 1**. Then the *d* quark can lie anywhere on the surface of a sphere with radius R_a centered at $\underline{X}_{uu}$ to form the same proton. This scenario can be taken over by the neutron in **Figure 1** via the interchange $u \leftrightarrow d$. The same neutron is obtained when the *u* quark is R_a away from $\underline{X}_{dd}$. Since the proton and the neutron cannot occupy the same space,

$$R_{nn} \ge 2R_a, \frac{R_a}{R_{nn}} \le 0.5 \tag{3}$$

With $R_a \approx 3.23$ fm from the caption of **Figure 1**, $e^2 = 4\pi/137$, (2) and (3) yield the estimate

$$E_{em2H1} \ge -2.0653 \text{ MeV} \tag{4}$$

The lower limit of $R_{nn} = 2R_a$ in (3) leads to the triplet deuteron binding energy $E_{B2H1} = -E_{em2H1} = 2.0653$ MeV which is 7.7% smaller than the measured 2.2245 MeV.

The present treatment is phenomenological and $R_{nn} = 2R_a$ used above is not an exact criterion. If $R_{nn} = 1.846R_a$ were used instead, the predicted binding energy E_{B2H1} will agree with the measured one. Similarly, the diquark-quark distance is a continuous variable represented by an average value R_a here. If $R_a \approx 3.23$ fm $\to$ 3 fm, then prediction and data will likewise agree.

The above R_a/R_{nn} ratios are also in qualitative agreement with the ratio

$$\frac{\text{proton charge radius}}{\text{deuteron charge radius}} = \frac{0.843\,\text{fm}}{2.128\,\text{fm}} = 0.395 < 0.5 \tag{5}$$

Note here that the charge radius arises from long range electromagnetic interactions and is an observable in the laboratory space. It is not to be confused with the unobservable short range strong interaction interquark radius $R_a \approx 3.23$ fm in the "hidden" relative space *x* between quarks.

3. Singlet Deuteron Binding Energy

The neutron spin in Figure 1 has been chosen to be parallel to that of the proton spin. But it can also be chosen to be antiparallel to the proton spin. This can be achieved by inverting the neutron configuration in **Figure 1** upside down or, equivalently, by rotating this configuration 180˚. This is carried out in **Figure 2**.

Analogous to (2), there are also four contributions, now between *uu* and *u*, *d* and *dd*, *uu* and *dd*, and *d* and *u* so that the total electrostatic energy E_{em2H1} in (2) is changed to E_{em2H0},

$$\begin{aligned} E_{em2H0} &= \frac{q_{uu}q_u + q_d q_{dd}}{R_{nn}} + \frac{q_{uu}q_{dd} + q_d q_u}{\sqrt{R_{nn}^2 + R_a^2}} = \frac{10e^2}{9}\frac{1}{R_{nn}}\left[1 - \frac{1}{\sqrt{1 + R_a^2/R_{nn}^2}}\right] \\ &= -E_{em2H1} \ge 0 \end{aligned} \tag{6}$$

For large neutron-proton separation R_{pn}, $E_{em2H0} \approx 0$ but now > 0. Let now the neutron move closer to the proton, R_{nn} decreases and E_{em2H0} becomes more positive. Using the lower limit in (3), the singlet deuteron binding energy $E_{B2H0} = -E_{em2H0} = -2.0653$ MeV is negative so that there is no stable spin 0 deuteron, in agreement with observation.

4. Singlet Dineutron Binding Energy

Perform the interchange $u \leftrightarrow d$ for the proton $p\uparrow$ in Figure 1. This turns $p\uparrow$ into $n\uparrow$ which is the same as the $n\uparrow$ on the right half of Figure 1. By Pauli's principle, these two neutrons $n\uparrow$ and $n\uparrow$ cannot coexist. However, if the spin of this left neutron is switched to ↓, then the aggregate $n\downarrow$ and $n\uparrow$, assigned to the singlet dineutron ${}^2n_0$, can exist. The configuration is depicted in Figure 3.

Analogous to (6), the total electrostatic energy E_{em2n0} for ${}^2n_0$ reads

$$E_{em2n0} = \frac{q_u q_u + q_{dd} q_{dd}}{R_{nn}} + \frac{q_u q_{dd} + q_{dd} q_u}{\sqrt{R_{nn}^2 + R_a^2}} = \frac{8e^2}{9}\frac{1}{R_{nn}}\left[1 - \frac{1}{\sqrt{1 + R_a^2 / R_{nn}^2}}\right] \geq 0 \qquad (7)$$

which is simply 0.8 × E_{em2H0} = −1.652 MeV for the lower limit of (3). Analogous to the singlet deuteron ${}^2H_0$ case in Section 3, the singlet dineutron ${}^2n_0$ binding energy $E_{B2n0} = -E_{em2n0}$ = −1.652 MeV is similarly negative so there is no stable spin 0 dineutron.

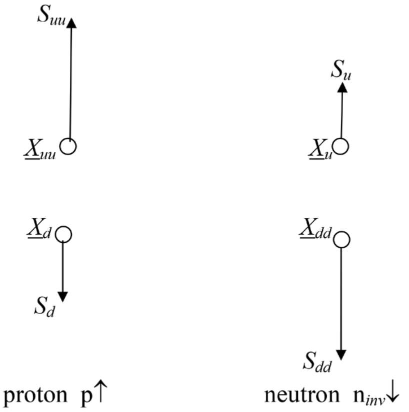

Figure 2. Schematic configuration of a singlet deuteron ${}^2H_0$ with spin 0. The proton configuration is the same as that in Figure 1. The neutron configuration has been inverted upside down relative to that in Figure 1, indicated by the subscript *inv*.

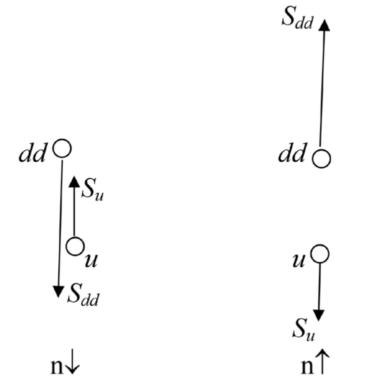

Figure 3. Schematic configuration of a singlet dineutron ${}^2n_0$. The right neutron configuration is the same as that in Figure 1. Switching the spin directions in $n\uparrow$ on the right leads to the $n\downarrow$ configuration on the left.

5. Triplet Dineutron Binding Energy and Decay

In Section 3, the right neutron configuration in **Figure 1** has been inverted to become the right configuration in **Figure 2**. Perform the same inversion to the right neutron in **Figure 3** yields **Figure 4**.

Analogous to (2), the total electrostatic energy E_{em2n1} for $^2n_1$ reads

$$\begin{aligned} E_{em2n1} &= \frac{q_u q_{dd} + q_{dd} q_u}{R_{nn}} + \frac{q_u q_u + q_{dd} q_{dd}}{\sqrt{R_{nn}^2 + R_a^2}} \\ &= \frac{8e^2}{9} \frac{1}{R_{nn}} \left[-1 + \frac{1}{\sqrt{1 + R_a^2 / R_{nn}^2}} \right] = -E_{em2n1} \le 0 \end{aligned} \tag{8}$$

Comparison with (2) together with the lower limit of (4) yields the triplet dineutron $^2n_1$ binding energy $E_{B2n1} = -E_{em2n1} = 0.8 \times E_{B2H1} = 1.652$ MeV. This value is expected to be 7.7 % smaller than its actual value by analogy to the triplet deuteron case mentioned beneath (4). Correcting for this discrepancy, the binding energy E_{B2n1} becomes $1.077 \times E_{B2n1} = 1.78$ MeV.

$^2n_1$ is thus a stable nucleus, like $^2H_1$, but its binding energy 1.78 MeV is weaker than 2.2245 MeV for $^2H_1$. Energetically, it can decay into deuteron via neutron beta decay,

$$^2n_1 \to {}^2H_1 + e^- + \bar{\nu}_e \tag{9}$$

where ν_e denotes the electron neutrino. Since each of the neutrons in $^2n_1$ can decay separately, the decay time is expected to be half of the neutron decay time or 440 sec.

While the deuteron can be the nucleus of an atom, the deuterium, the neutral dineutron cannot form an atom. The decay (9) implies that there are no free dineutrons in nature, just like neutrons.

Dineutron has been first observed some years ago in ^{16}Be decay [6]. It is assigned to $^2n_1$ here but needs not decay according to (9). Instead, it can decay into two neutrons when excess energy is available. The predicted $^2n_1$ binding energy 1.78 MeV has not been measured.

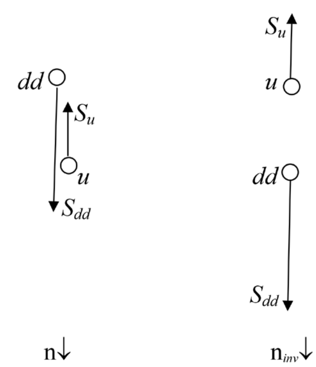

Figure 4. Schematic configuration of the spin ↓↓ component of a triplet dineutron $^2n_1$. The right neutron configuration is the same as that in **Figure 2**. The left neutron configuration is the same as that in **Figure 3**.

6. Related Considerations

The third member in the two nucleon system, the diproton pp, can be treated in an entirely analogous fashion. The results are that the binding energies of a singlet diproton E_{B2p0} as well as that for a triplet diproton E_{B2p1} are the classical value $-e^2/R_{nn}$ for large R_{nn}. For the lower limit in (3), $R_{nn} = 2R_a$, $E_{B2p1} = -19.26$ MeV and $E_{B2p0} = -14.1$ MeV. Thus, pp is not bound, as expected.

Thus, in the two nucleon system, only the triplet deuteron $^2H_1$ and the triplet dineutron $^2n_1$ are bound electromagnetically. The former is 20% stronger than the latter. The remaining four combinations, $^2H_0$, $^2n_0$ and the triplet and singlet diprotons are not electromagnetically bound states. This is reflected in the composition of nuclei which consist mostly of *pn* pairs, to an less degree *nn* pairs but no pp pair.

The above results show that the binding energies of the deuteron and dineutron are of long range, electromagnetic nature arising from the quark charges. Short range, strong interaction forces between the nucleons set the limits of these binding energies but do not contribute to them.

For heavier nuclei, the above electrostatic confinement is insufficient and strong interaction forces, akin to those that led to the confinement characterized by Ra in Section 2, need be included. To accommodate the additional quarks, the two dimensional **Figures 1-4** here have to be extended to three dimensions.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Burgess, C. and Moore, G. (2007) The Standard Model, A Primer. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511819698

[2] Hoh, F.C. (1994) *International Journal of Theoretical Physics*, **33**, 2325-2349. https://doi.org/10.1007/BF00673960

[3] Hoh, F.C. (2019) Scalar Strong Interaction Hadron Theory II. Nova Science Publishers, New York.

[4] Hoh, F.C. (2021) *Journal of Modern Physics*, **12**, 139-160.

[5] Hoh, F.C. (2020) *Journal of Modern Physics*, **11**, 967-975. https://doi.org/10.4236/jmp.2020.117060

[6] Spyrou, A., Kohley, Z., Baumann, T., Bazin, D., *et al.* (2012) *Physical Review Letters*, **108**, Article ID: 102501.