Charge-independence-breaking in the triton

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Physics Division, Argonne National Laboratory, Argonne, IL 60439**ABSTRACT**

We find the effect of the observed charge-independence-breaking in 1S_0 nucleon-nucleon scattering on the binding energy of the triton to be of order 80 keV. When corrections for this effect are made in an 18-channel momentum-space Faddeev calculation, we find the Paris and Argonne v_{14} potentials give triton binding energies that differ by only 20 keV.

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In this short note we report a calculation of the charge-independence-breaking (CIB) effect in the triton. We assume no charge-symmetry-breaking (CSB) so $V_{nn} = V_{pp} \neq V_{np}$. We start with the observation that the Paris potential¹ and the Argonne v_{14} potential² give very similar high-quality fits to low-energy nucleon-nucleon (NN) scattering data and deuteron properties. The main difference between the two models is that the Paris potential is fit to pp data in $T=1$ states, while the Argonne v_{14} potential is fit to np data. This difference is most noticeable in the 1S_0 channel, and is illustrated in Table I where we compare the singlet scattering lengths of the two models with experiment.³ We exploit this difference to calculate the CIB effect in the triton.

Previous results for CIB in the triton with realistic interactions give differences of order 300 keV. Brandenburg, Sauer, and Machleidt⁴ made 5-channel momentum-space Faddeev calculations for various combinations of the one-boson exchange potentials HM1 (fit to np data) and EHM (fit to pp data), and the Reid soft-core potential (also fit to pp data). Friar, Gibson, and Payne⁵ made 5-channel configuration-space Faddeev calculations for the Reid potential and a variant in which the repulsion of the 1S_0 channel was altered to fit the np scattering length. These calculations give 300 keV and 310 keV, respectively, as the difference between models where the 1S_0 channel is fit to either pp or np data.

The present calculations have been made using the momentum-space Faddeev method developed at Böchum.⁶ Our results for the Paris and Argonne v_{14} potentials without CIB effects are shown in Table II for 5- and 18-channel calculations. (The 18-channel binding energy we report here is 70 keV greater than that reported in Ref. 6.) The energies are in good agreement with those of other groups as shown.⁷ The Argonne v_{14} potential gives 170 keV more binding than the Paris potential in the 5-channel calculation, and 240 keV more in the 18-channel calculation. The greater attraction of the Argonne v_{14} model is due primarily to its more attractive 1S_0 potential, as expected from the scattering length comparison. This is partially offset by the smaller deuteron D-state percentage in the Paris model.

A correct calculation of the three-nucleon ground state including CIB, but neglecting CSB, should use a potential fit to pp scattering data for the one pp or nn pair and a different potential fit

to np data for the two np pairs. This can be done in the momentum-space Faddeev formalism by setting (for the triton)

$$t^{T=1} = \frac{2}{3} t_{nn}^{T=1} + \frac{1}{3} t_{np}^{T=1}, \quad (1)$$

where $t_{NN}^{T=1}$ is the fully-off-shell NN t-matrix calculated with the appropriate potential for the isospin triplet state. This form was suggested by Brandenburg, et al.⁸ It is a good approximation since the $T=3/2$ three-nucleon component which can be admixed with the $T=1/2$ component due to the presence of CIB forces is negligible. Friar, Gibson, and Payne used the same weighting to define the input potential for their configuration-space calculations of CIB. However, mixing the potentials would only yield our relation approximately.

In the present calculation we use Paris potential for $t_{nn}^{T=1}$ and Argonne v_{14} for $t_{np}^{T=1}$ to define our 1S_0 interaction. The interactions in other partial waves are generated either from the Paris potential or from Argonne v_{14} . These results are shown in Table III. It is seen that the CIB effect makes the Paris result more attractive, and the Argonne result more repulsive, as expected. The difference between these two potentials becomes only 40 keV in the 5-channel calculation, and only 20 keV in the 18-channel calculation.

The shift in energy from adding CIB is about 100 keV in the 5-channel calculation, and about 80 keV in the 18-channel calculation. Our 5-channel results are in substantial agreement with those of Refs. 4 and 5. The size of the effect seems to be fairly constant in the more precise 18-channel calculation.

In summary, we have calculated the charge-independence-breaking effect due to $V_{nn} = V_{pp} \neq V_{np}$ by using Eq. (1) to define a mixed 1S_0 interaction from the Paris and Argonne v_{14} potentials. The calculated CIB effect is about 80 keV in an 18-channel calculation. The triton binding energies calculated from these two potentials are then very close to each other.

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TABLE I. Singlet NN scattering lengths in fm.

	l_{ann}	l_{app}	l_{anp}
experiment	-18.45 ± 0.46	-17.9 ± 0.2	-23.748 ± 0.010
Paris		-17.60	
Argonne v14			-23.67

TABLE II. Triton binding energies compared with other calculations.

	Paris		Argonne v ₁₄	
	5-channel	18-channel	5-channel	18-channel
present work	7.27	7.40	7.44	7.57
Hannover	7.30	7.38	—	—
Los Alamos-Iowa	7.31	7.39	7.44	7.57
Sendai	7.48	7.56	7.45	7.58

TABLE III. Triton binding energies with charge-independence-breaking effect in 1S_0 channel: t_{nn} is derived from Paris and t_{np} is derived from Argonne v_{14} .

Potential	5-channel	18-channel
Paris	7.27	7.40
$^1S_0 \left(\frac{2}{3} t_{nn} + \frac{1}{3} t_{np} \right) + \text{Rest (Paris)}$	7.38	7.48
$(\Delta E)_{\text{CIB}}$	0.11	0.08
Argonne v_{14}	7.44	7.57
$^1S_0 \left(\frac{2}{3} t_{nn} + \frac{1}{3} t_{np} \right) + \text{Rest (Argonne } v_{14})$	7.34	7.50
$(\Delta E)_{\text{CIB}}$	-0.10	-0.07

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