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Reply to "Comment on 'Comparison of potential models with the pp scattering data below 350 MeV' "

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Abstract

Replying to the above Comment by G.Q. Li and R. Machleidt, we point out that the supposed "flaws" in our comparison of *NN* potential models with the *pp* scattering data [Phys. Rev. C **47**, 761 (1993)] are in reality not flaws at all.

13.75.Cs, 12.40.Qq, 21.30.+y

In a recent paper [1], we compared a number of *NN* potential models with the *pp* scattering data. The purpose of that paper was to show that of the numerous potential models that have appeared in the literature, only a few give a reasonably good description of the *pp* data. It turns out that only models which have explicitly included the *pp* data in their fit give a good description of the *pp* data. In general, potential models which have only been fitted to the *np* data give a very poor description of the *pp* data.

In a Comment on our paper, Li and Machleidt [2] claim to have found two flaws in our Comparison of potential models with the *pp* scattering data. The first flaw seems to be that, according to Li and Machleidt, *we are not allowed to compare the $I = 1$ part of an NN potential to the pp scattering data, when the ${}^1S_0$ partial wave of that potential was fitted to the np scattering length*. However, without this first "flaw," we would never have been able to come to one of the conclusions of our paper, i.e., that "only those potentials that were explicitly fitted to the *pp* scattering data give a reasonable description of these data" [1].

As a next "flaw" in our paper, Li and Machleidt claim [2] that our *"Comparison of NN potential models with the pp scattering data" has as flaw that it "compares to the pp data only".* To call this a flaw is twisting the logic. In this connection we would like to point out that our comparison of *NN* potential models with the *pp* data was written three years after completion of our partial-wave analysis of the *pp* data [3]. At that moment we had not yet finished our study [4] of the *np* data. This means that it was at that moment too early to expect from the Nijmegen group a comparison of *NN* potentials with the *np* data.

We will use the remainder of this Reply to elaborate on these points and in turn address a few flaws in the Comment.

The Comment states as the most important rule, that "a *pp* potential must only be confronted with the *pp* data, while an *np* potential must only be confronted with the *np* data" [2], where their main criterion for the denomination *pp* or *np* is whether the ${}^1S_0$ partial wave of the potential has been fitted to the *pp* or *np* scattering length, respectively. This rule sounds reasonable and noble, but is actually so often violated that it is presumptious to call it a rule. In most practical situations (e.g., in three-body, nuclear matter, and *pp* bremsstrahlung calculations), one usually starts with some nuclear potential model to represent the *NN* interaction (for *pp*, *np*, and *nn*), disregarding the details whether its parameters were fitted to the *pp* and/or *np* data. In our paper [1], we explicitly demonstrated that this is incorrect.

Moreover, we feel that with this first flaw we are in good company, because we have it in common with Machleidt *et al.* in Ref. [5]. In this paper on the Bonn *NN* potential, it is stated that "one measures *NN* observables (and not phase shifts)," and that therefore "the real test of the quality of an *NN* interaction is the comparison with these data. For their model this is done in their Fig. 16". Whereas we do a *quantitative* comparison [1] to the data, they merely do a *qualitative* comparison in their Fig. 16, from which they then claim that it can be "seen" that an "excellent description of the data is achieved" [5]. In this Fig. 16, these authors compare 10 times with the *np* data and 6 times with the *pp* data. A curious double standard: When Machleidt *et al.* [5] compare with the *pp* data, it is allowed, whereas when we compare with the *pp* data, it is called a flaw.

With respect to this Ref. [5], we would also like to point out that they write about the "*NN* potential, *NN* interaction, *NN* observables," and *not* about the "*np* potential, *np* interaction, *np* observables."

In spite of their own rule, Li and Machleidt themselves write that it is valid to confront an *np* potential with the *pp* data. The only changes one has to make are "to include the Coulomb force and to readjust the $^1S_0$ scattering length to its *pp* value" [2]. They suggest this can be achieved by a relatively small change in one of the model parameters. As an example, they state that "a change of the σ coupling constant by as little as 1% changes the $\chi^2/N_{\rm data}$ from 641 to 2" [2]. They have in mind here the full Bonn potential [5]. For the reader not familiar with the field, we would like to show how misleading these arguments of Li and Machleidt are.

First of all, the authors of the Comment fail to mention that we already showed the above example to be inaccurate in the general case. In our paper [1] we show that when we replace the $^1S_0$ phase shift of the Argonne potential [6] (fitted to the *np* scattering length) by the $^1S_0$ phase shift of the Nijmegen multi-energy analysis [3] (which roughly corresponds to having a model with "perfect" $^1S_0$ phase shifts), then the quality of the model improves considerably. However, "the resulting $\chi^2/N_{\rm data} \approx 4$ is still rather large," demonstrating that "the other phase shifts are not too good either" [1]. As is shown in Table I, the situation for the various coordinate-space Bonn potentials is worse. In this Table we show the effect of replacing the $^1S_0$ phase shifts of the potential models by the $^1S_0$ phase shift of the latest Nijmegen partial-wave analysis [4]. Clearly, the quality of these coordinate-space Bonn potentials is rather poor.

Secondly, in our potential comparison [1] we did not include the full Bonn *np* potential, but only the coordinate-space version OBEPR. The $\chi^2/N_{\rm data}$ of this Bonn potential starts at 492 (and not at 641) and after improving the $^1S_0$ phase shift by refitting, the $\chi^2/N_{\rm data}$ drops to 7.1 (and not 2). The $\chi^2/N_{\rm data}$ of this Bonn coordinate-space *np* potential OBEPR of 1987 is worse than that of the 25 years older Hamada-Johnston potential [7] of 1962. This in spite of the fact that the parameters of OBEPR were fitted [5] to arrive at a "realistic" description of the *NN* scattering data.

At this point we like to mention that we disagree with Li and Machleidt that the χ^2 of the coordinate-space Bonn potentials is of no interest. In a footnote they write that these potentials were merely constructed "to point out the deficiencies of such simple models" [2]. But when that is true, why at all bother to present a coordinate-space version of the one-boson-exchange version of the Bonn potential and then two years later again present [8] coordinate-space versions of both the Bonn A and Bonn B potentials? Moreover, as can be seen in Table II of our comparison [1], there exist other similar coordinate-space potential models which do give a reasonable description of the scattering data. We think that the users of the coordinate-space Bonn potentials should be warned, that these potentials do *not* give a reasonable fit to the *pp* scattering data and, therefore, these potentials should not be used to calculate, e.g., *pp* bremsstrahlung or the binding energy of the triton.

In their footnote 10, Li and Machleidt [2] find even fault with the energy range used by us. When these authors [9] fit the Bonn potentials to the *pp* data they use the Nijmegen partial-wave analysis. Then in their Comment these authors proceed to point out, as if we did not already know, "that the *pp* data carry a very small error at low energies" [2] and, when included, add disproportionally to the total χ^2. Of course, we are well aware of these facts. This was precisely the reason why in our comparison [1] we *also* explicitly presented the results for the case where we removed these low-energy data. Their lack of knowledge about the *NN* data is shown when, without any supporting evidence, they state that "the real potential concept is strictly speaking wrong above 280–290 MeV. It may be o.k. to stretch the limit by a few MeV up to 300 MeV, but not beyond that" [2]. This is absolutely incorrect. Because of bremsstrahlung, the real potential concept is strictly speaking wrong at any energy $E > 0$. When we include in our partial-wave analysis of the 0–350 MeV *pp* data the inelasticities as determined in a 0–500 MeV *pp* partial-wave analysis [10], then we see a drop in $\chi^2/N_{\rm data}$ of about 0.0006, which is truly negligible. This shows that the real potential concept is valid to *at least* 350 MeV and definitely a fair distance beyond that energy as well. Another way to see this is to look at Table II of Ref. [1]. There it can be seen that most potentials fit the *pp* data in the interval 290–350 MeV *better* than over the whole energy range 2–300 MeV. A notable exception, however, is the full Bonn *pp* potential [11], which in this 290–350 MeV region has a $\chi^2/N_{\rm data}$ which is *worse* than average. When a potential does not fit well the data in this energy interval, then it is the potential which is at fault, and not the potential concept.

Let us conclude with some additional remarks on why we only made a comparison with the *pp* data. It is not surprising that the more recent potentials (e.g., the Argonne [6] and Bonn [5] potentials) were fitted only to the *np* data. It is much easier to fit a potential model to the *np* scattering data than it is to the *pp* data, because in that case it is not necessary to go through all the difficulties of making all kinds of electromagnetic corrections. And as already stressed before, it is often assumed that with only a minor adjustment in one of the parameters of the model, that model will also give a good description of the *pp* data. By explicitly confronting some of these *np* potentials with the *pp* data, we showed [1] that this assumption is not always valid. Even readjusting the $^1S_0$ phase shift is often not good enough. So it is definitely *not true* to state that "a potential that fits the *np* phase shifts well, will automatically fit the *pp* phase shifts well", and that "there is no need to bring the *pp* data into play" [8].

Moreover, one has to bear in mind that the older potential models were fitted using old databases. For example, the Nijm78 and Paris80 potentials [12,13] were fitted to the 1969 Livermore database [14]. At that time the *pp* data were already accurate enough to pin down the $I = 1$ partial waves. So well even that at the present time these Nijm78 and Paris80 potentials still give a good description of the *pp* data, including the more accurate recent data. On the other hand, the quality of the *np* data was very poor at that time. In the last two decades the quality of the *np* data has improved enormously, especially in providing more accurate bounds on the $I = 0$ partial waves. Hence, it is not so surprising that the old Nijm78 and Paris80 potentials give a rather poor description of the present *np* data, whereas the full Bonn87 potential is claimed to fit these recent *np* data much better. It should be noted, however, that by simply refitting the parameters, the Nijm78 and Paris80 potentials are likely to describe the *np* data equally well as the *pp* data. As a matter of fact, an updated [15] version, Nijm92, of the Nijmegen potential describes all *NN* scattering data (*pp* and *np*) with $\chi^2/N_{\rm data} = 1.9$.

Therefore, it is incorrect to compare the $I = 0$ partial waves of the Nijm78, Paris80, and Bonn87 potentials, and then (because of the large differences) come to the conclusion that [9] "The more seriously and consistently meson theory is pursued, the better the results." The χ^2 is the product of the number and kind of free parameters in the model and the effort one wants to invest in fitting the data. The increase in computing power over the last decade, together with the ease of access to scattering data, to partial wave analyses, and their improved accuracy, has made it possible to construct easily much better potentials [15] than the Nijm78, Paris80, and Bonn87 potentials. This makes a farce of the incorrect claim by Machleidt et al. that “their better results indicate, that they apply meson theory more seriously and consistently” [9].

In summary, our earlier paper [1] gives a fair comparison of the quality of a number of *NN* potential models with respect to the *pp* scattering data. It clearly demonstrates the fact that potentials which have only been fitted to the *np* data do not automatically give a good description of the *pp* data, even after adjusting the $^1S_0$ partial wave. In fact, most potential models do not. Therefore, our paper [1] perfectly serves its purpose: namely, to point out this misconception, and to warn other physicists to administer some care in using these models in practical calculations.

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TABLES

TABLE I. $\chi^2/N_{\rm data}$ results in the 2–350 MeV range for the coordinate-space OBEPR [5], Bonn A and Bonn B [8] potentials. In the second line the $^1S_0$ of the potential is replaced by the $^1S_0$ of the Nijmegen analysis [4].

$^1S_0$	OBEPR	Bonn A	Bonn B
potential	13.4	10.4	9.2
analysis	8.1	6.8	5.5