

On the gas desorption problem in the nn -experiment at the YAGUAR reactor

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Abstract

To address long-standing uncertainty in the charge-symmetry breaking of the nuclear force, a neutron-neutron scattering experiment designed to measure the nn scattering length, a_{nn} , is underway at the pulsed reactor YAGUAR (Snezhinsk, Russia). In recent measurements an unexpectedly large thermal neutron background, which mimics the nn scattering signal, has been seen. To examine a hypothesis that this background is produced by the neutron scattering on gases which can be desorbed from the nn cavity walls during the intense radiation of the reactor pulse, we compared the (nn) scattering runs, where the background was dominating, with (n^4He) scattering runs, where the background was relatively negligible. The shapes of the neutron time-of-flight spectra in these runs suggest neutron scattering from desorbed molecules H_2 and/or H_2O .

Introduction

Current theory gives us two ways to interpret charge-symmetry breaking within the nuclear force. QCD focuses on the mass difference between up and down quarks and the subsequent electromagnetic interactions between these quarks. Another approach is via meson-exchange, where charge-symmetry breaking can be described primarily from the neutron-proton mass difference and $\rho - \omega$ mixing. The theoretically predicted size of the symmetry-breaking effect specific to scattering lengths (Δ_{CSB}) depends on specific assumptions and at present is predicted to vary between -0.5 and +2.5 fm [1]. The difference $\Delta_{CSB} = a_{pp} - a_{nn}$ can be found experimentally from measurements of both the proton-proton scattering length as well as the neutron-neutron scattering length.

Many rigorous and careful indirect measurements of a_{nn} have been made over an impressive energy range [2,3] with a recent analysis from π^-d capture suggesting the size of the symmetry-breaking effect to be $\Delta_{CSB} = +1.1$ to $+2.1$ fm [4]. However, discrepancies in experimental results for a_{nn} persist, especially in neutron-deuteron breakup. DI a_{nn} A (Direct Investigation of a_{nn} Association) is working towards a direct measurement of a_{nn} by using a thermal neutron gas within the pulsed, high-intensity YAGUAR reactor. The progression of the experiment has been well-documented [5 - 8] with specifics of the experiment often presented at ISINN conferences [9 - 15].

The nn -scattered thermal neutrons created during the reactor pulse are counted via time-of-flight (TOF) by a well-shielded neutron detector on an underground 12m flight

path. The detector count per pulse, N_{nn} , integrated over the thermal part of the TOF spectrum, is given by [14]:

$$N_{nn} = 2 c(\tau, shape) \frac{F^2}{\tau v_{th}} \sigma_{nn} V \Omega_{\text{eff}} \quad (\text{counts/pulse}), \quad (1)$$

where $\sigma_{nn} = \pi a_{nn}^2$ is the nn scattering cross section, τ is the FWHM duration of the reactor pulse, v_{th} is the average velocity of the Maxwellian spectrum, $F = \int \Phi(t) dt$ is the neutron fluence of the total pulse, V is the nn cavity volume, and Ω_{eff} is the dimensionless value of the detector solid angle. A weakly-varying function $c(\tau, shape)$ takes account of the space-temporal variations of the neutron flux for a pulse of a given $shape$ and τ . The value $c(\tau, shape) = 0.48$ was numerically calculated in [14] for a realistic shape of the YAGUAR $1000\mu s$ pulse at a maximal power. With the parameter values for our experiment we expect approximately $N_{nn} \simeq 170$ nn counts per one burst. However, preliminary neutron-neutron scattering measurements [8] show a count rate per pulse that is 30 times higher, as evidenced in Figure 1. Moreover this large thermal background signal has an approximately quadratic dependence on the reactor pulse energy as expected for the nn -scattering signal. This is shown in Figure 2.

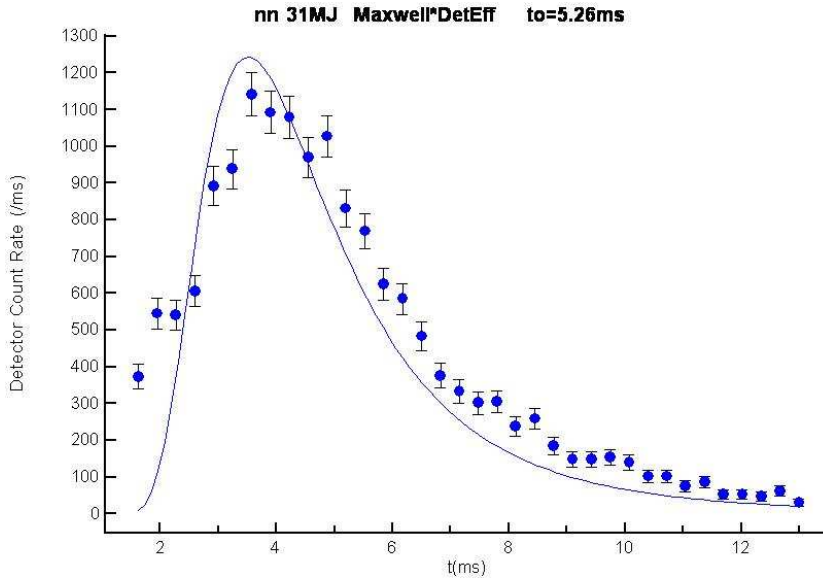


Figure 1: The data points represent time-of-flight data for neutron-neutron scattering at a reactor pulse energy of 31 MJ and a 12 meter flight path. The overall count rate is approximately 30 times higher than predicted. The relatively poor fit (solid line) demonstrates the inability to fit the data with only a Maxwellian (with a most probable neutron speed of 2200 m/s) and the appropriate detector efficiency.

We propose the source of thermal background is due to radiation-induced desorption. The aluminum wall of the nn cavity is subject to 6×10^5 Rad during the YAGUAR pulse [16]. Molecular gas created by the radiation-induced desorption remains in the cavity during the pulse and serves as a target for thermal neutrons from the same pulse. The density of such a target depends on the reactor power and may depend on characteristics

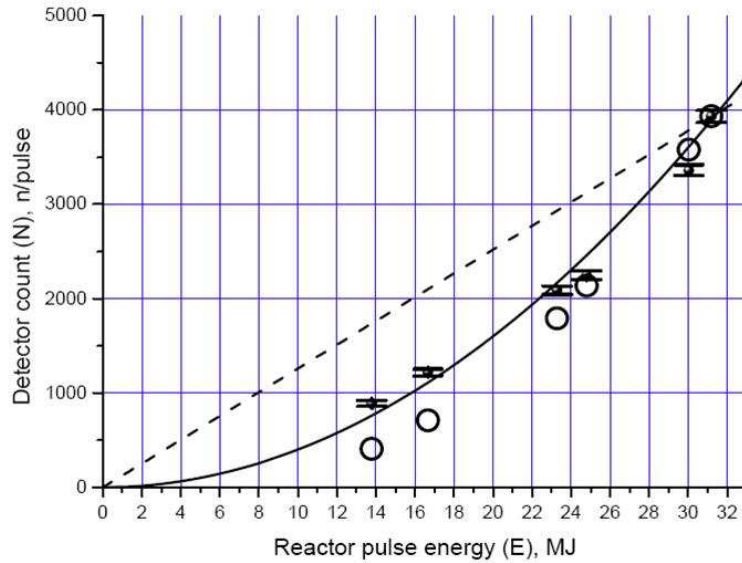


Figure 2: Detector counts N versus the reactor pulse energy E . The dashed line is the $N \sim E$ dependence; the solid curve represents the $N \sim E^2$. The solid points are measured data, the open circles are the calculated N_{nn} values, which have been normalized to experimental data for the 31 MJ pulse.

of the vacuum system. Therefore, if desorption is the mechanism responsible for a large background, then the effect should depend on some power of the pulse energy. Other candidates for thermal background (due to thermal neutrons scattering from collimators or beamline, for example) will have a linear dependence on pulse energy. To determine candidates for the gas being desorbed, we compared data from the (nn) runs with (n^4He) runs.

Experimental evidence of desorption

To understand the performed comparison it is important to keep in mind that the (nn) runs and the (n^4He) runs were taken with different configurations of the neutron detector. The reasons for this are as follows. The thermal neutron gas pressure during a neutron-neutron scattering experiment is small, about 0.1 mbar, which requires the use of a neutron detector with a high efficiency. For the (n^4He) calibration runs, however, instead of using an equivalently small pressure of 4He , the nn cavity was filled to 100 mbar of 4He gas for a better statistics and a good control of the target pressure. To successfully deal with scattering from a target it was necessary to reduce the neutron detector efficiency for (n^4He) runs.

A unique neutron detector was developed at the Frank Laboratory of Neutron Physics [8]. Figure 3 shows the detector schematic. To provide the required 10% pulse height resolution while using the ~ 100 ns signal duration, the detector is sectioned and all 10 sections are filled with a gas mixture of 3He (0.5 bar) + CF_4 (0.7 bar). Signals from each

of the sections are amplified by fast preamplifiers and treated separately – digitized and stored for a subsequent offline analysis. The detector efficiency for this gas mixture is 86% for 25-meV neutrons. The reduction of the detector efficiency for (n^4He) runs was

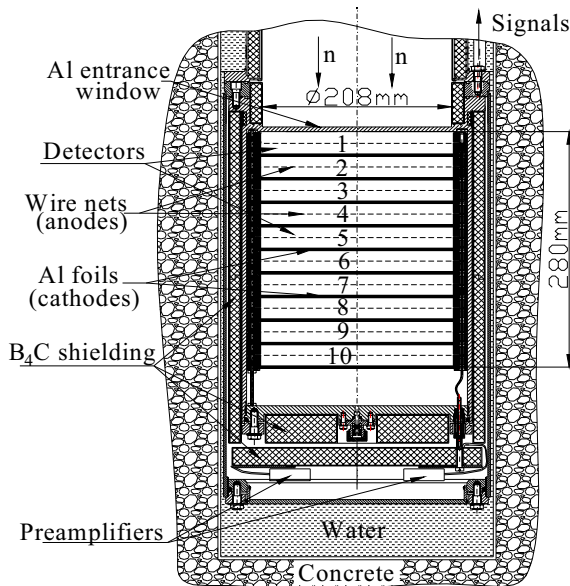


Figure 3: Cross-sectional view of DIa_{nn}A's unique ^3He detector. The detector consists of ten independent disc-shaped sections separated by Al foil with a net of parallel wires as anodes.

done by refilling the detector with a gas mixture of ^3He (0.5 mbar) + ^4He (0.5 bar) + CF_4 (0.7 bar). This reduction in ^3He and the addition of ^4He reduces the thermal neutron efficiency by a factor about 10^3 but produces very little change in the efficiency for fast neutrons and γ -rays when compared to the detector configuration for neutron-neutron scattering. All other technical characteristics of the detector for (n^4He) runs were identical to the (nn) scattering case.

With the detector configuration set up for the (n^4He) experiment, the detector efficiency for thermal neutrons is no longer velocity-independent as it is in the (nn) scattering case: the detector efficiency has a $1/v$ dependence. Therefore, for the energy independent (n^4He) scattering cross section a graph of the detector count rate as a function of neutron energy (in time-of-flight) should be the product of a Maxwellian neutron flux distribution with the $1/v$ detector efficiency. In Figure 4 the (n^4He) data from a typical reactor pulse is shown fit to the product of a Maxwellian neutron flux distribution and a detector efficiency that depends on $1/v$.

Figure 5 shows a fit to the (nn) data which was taken, as explained above, with a nearly constant detector efficiency. And yet the neutron-neutron scattering time-of-flight spectra seems described by a product of a Maxwellian flux density and a $1/v$ dependence term, which can be understood if the scattering cross section in this case is not constant (as in the (n^4He) case) but depends on $1/v$. Both H_2 and vapor H_2O have scattering cross sections that are nearly $1/v$ dependent in the thermal energy region, as demonstrated in [17]. Figure 5 shows a fit to the neutron-neutron scattering data assuming the desorbed

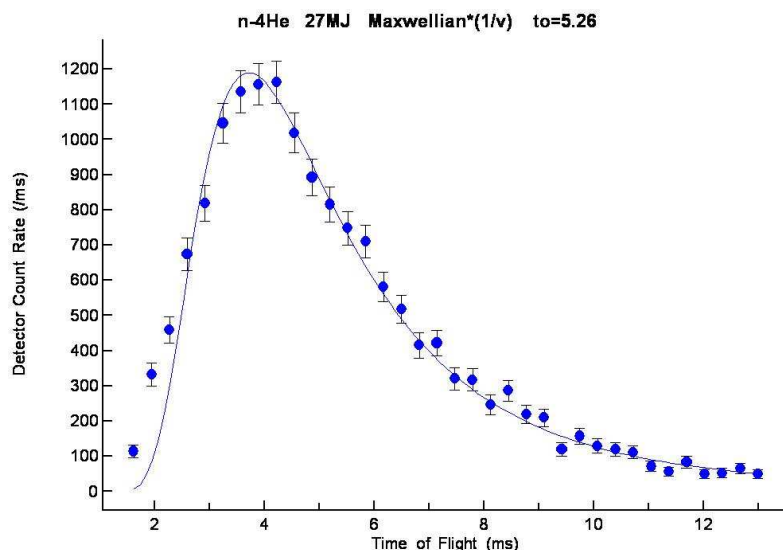


Figure 4: Time-of-flight data (12 m) for a (n^4He) run produced during a 27 MJ YAGUAR reactor pulse. The solid line represents the fit to the data, taking into consideration the $1/v$ dependence of the detector efficiency as well as a Maxwellian velocity distribution.

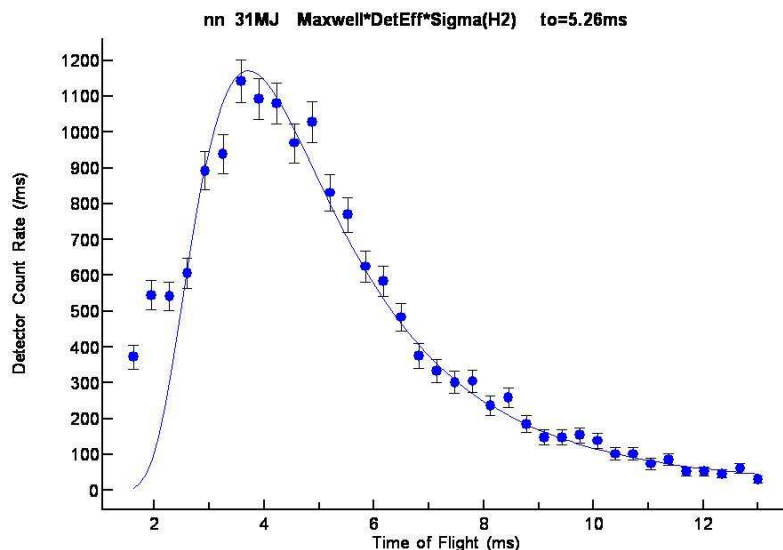


Figure 5: Neutron-neutron scattering data assuming desorption scattering from H_2 gas. The data points are identical to those in Figure 1 but the solid line fit is to a Maxwellian distribution, the appropriate detector efficiency and the scattering cross section of H_2 .

gas is H_2 . A similar fit assuming H_2O as the desorbed gas leaves the question open as to which molecular gas dominates. Other gases, like nitrogen or carbon dioxide, have nearly constant neutron scattering cross sections in the thermal energy region.

Conclusion

Although radiation-induced desorption has been studied for many years, no physical models allow calculations of the number of gas molecules released during the reactor pulse. In short, it is a source of background that must be confronted experimentally and not computationally. Various desorption reduction techniques developed by high-energy physics exist. Determining the optimal technique for reducing radiation-induced desorption at the YAGUAR reactor is in process.

Acknowledgments

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