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The recalculation of ωγ for the ^{21}Ne(p, γ) reaction

The ^{21}Ne(p, γ) reaction has been carried out a few times at the DRAGON facility with the intent of calculating the resonant strength of the reaction. Two known resonant center of mass energies have been used for this reaction, that of 731.5 keV and 258 keV, but only the latter energy will be discussed here. This reaction was analyzed in Sabine Engel's thesis, but a few problems were discovered that lead to the need to re-examine the data. These problems will be discussed later. This report will begin with the analysis of the most recent runs carried out with this reaction, and then will re-examine some old data that was analyzed in Sabine's thesis.

During the most recent runs (#12804-#12841), the beam charge state distribution was measured directly. The following distributions were found by normalizing the ratios between the FCM2 scalar and EM0 counts[i]:

3+	12.84 %
4+	43.61 %
5+	35.36 %
6+	7.79 %
7+	0.40 %

The 2+ distribution could not be measured directly due to the insufficient strength of the instruments, but its contribution is minimal.

The next step was to calculate a value for k, the EM0 response (beam ions/EM0 count). This was done using the equation

$$k = \frac{Q_{3+}^{FCM2}}{3|e|N_{3+}^{EM0}} + \frac{Q_{4+}^{FCM2}}{4|e|N_{4+}^{EM0}} + \frac{Q_{5+}^{FCM2}}{5|e|N_{5+}^{EM0}} + \frac{Q_{6+}^{FCM2}}{6|e|N_{6+}^{EM0}} + \frac{Q_{7+}^{FCM2}}{7|e|N_{7+}^{EM0}}$$

Where Q^{FCM2} = total charge in FCM2 (10 counts/nC)
e = charge of one electron ($1.602 * 10^{-19}$)
and N^{EM0} = number of counts on the EM0 monitor taking into account the live time factor. The value of k was calculated to be

$k = 3.52\times10^{7} \pm 0.04\times10^{7}$ beam ions/EM0 count[ii]

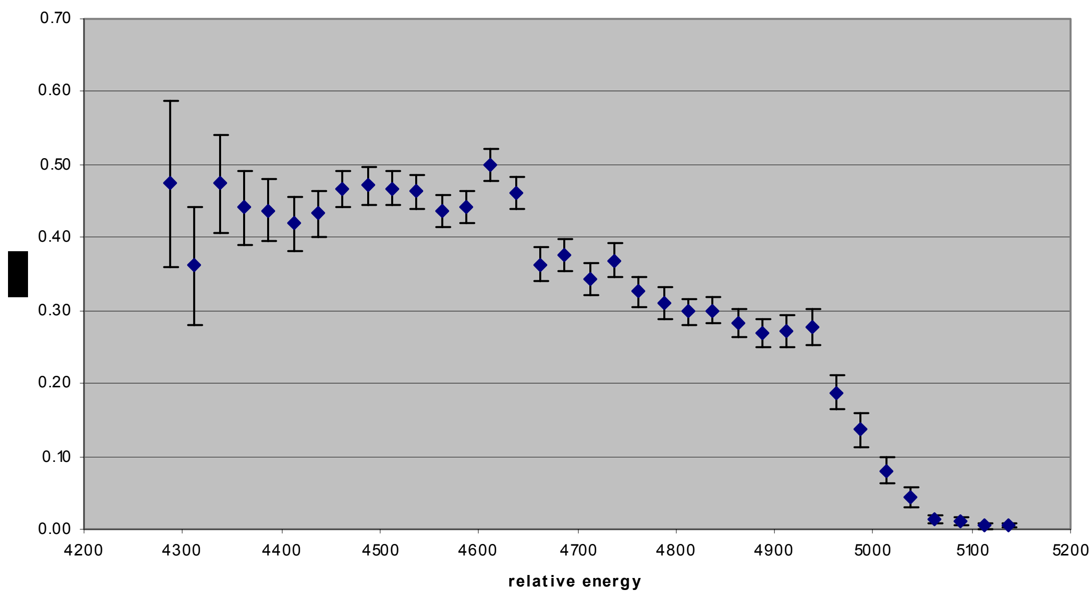
Partial yields of recoils were then calculated using the formula:

$$Y_{x+} = \frac{N_{x+}^{DSSSD}}{kN_{x+}^{EM0}}$$

Where N^{DSSSD} = total coincidence counts

Note that live time factor does not need to be taken into account here because it cancels out of the equation. The total coincidence counts was calculated using the BGO efficiency. The ratio of singles to coincidence on the DSSSD (double sided silicon strip detector) was observed and the point at which the ratio plateaued was assumed to be the BGO efficiency. An example of this is given in Figure 1[iii].

Figure 1 - coincidence/singles for run 12836 (4+ charge)



As can be seen in Figure 1, there is an apparent plateau for the first fifteen data points, so the weighted mean was calculated for these points. The reason for the sudden drop off in the graph can be explained by the appearance of the leaky beam, please refer to Figures 2 and 3[iv]. As the recoils have a relatively lower energy than the leaky beam, it is realized that the first peak in Figure 2 represents the recoils, whereas the slightly smaller second peak represents the leaky beam that managed to get through the separator. This is confirmed by looking at Figure 3, which only shows the hits on the end detector that are in coincidence with the BGO. In this Figure, no similar second peak exists. The plateau of coincidence/singles occurs in the area with the best statistics, which is around the first peak. The sudden drop off then occurs when there is no more coincidence counts remaining.

A value of 0.458 +/- 0.008 was found for the BGO efficiency of run 12836. The same procedure was done for runs 12839 (3+) and 12840 (5+), finding values of 0.44 +/- 0.02 and 0.39 +/- 0.01 respectively. This procedure was attempted for run 12841 (6+) but the statistics were inadequate. The weighted mean of the three runs was 0.435 +/- 0.02[v].

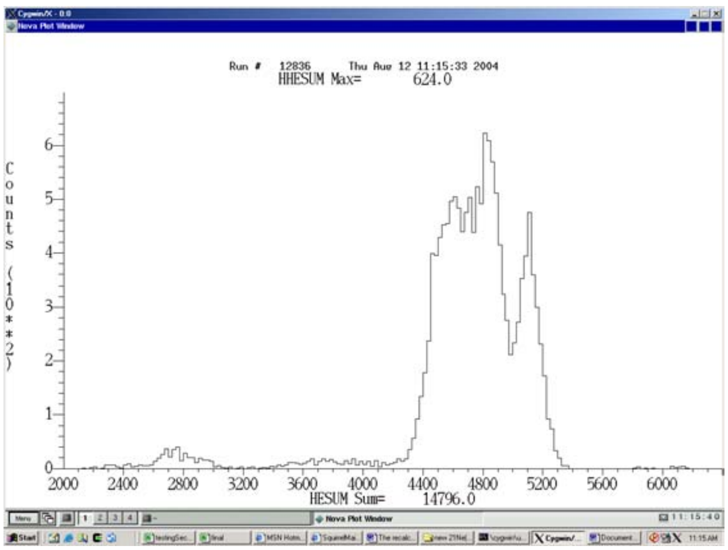


Figure 2 – Total counts at the DSSSD, including both leaky beam and recoils, vs the relative energy. The first peak is the recoils, whereas the second smaller peak on the right is the leaky beam.

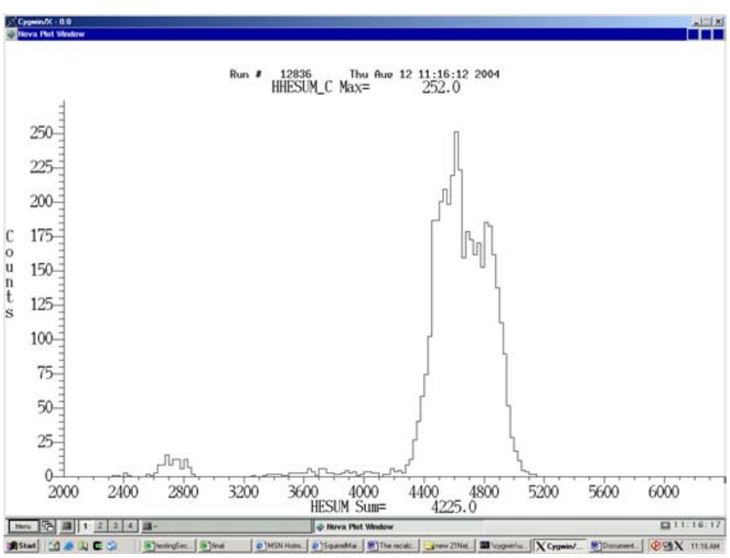


Figure 3 – The number of counts vs relative energy for hits located at the DSSSD that are considered to be in coincidence with a hit on the BGO, the gamma array detector.

After finding the efficiency, the value for N^{DSSSD} was calculated by dividing the number of coincidence counts recorded on the DSSSD for each run by the average efficiency.

The total yield can then be calculated using:

$$Y = \sum_{x=3}^{6} Y_x$$

This is assuming that the partial yields for x<3 and x>6 are negligible. Table 5 shows the values for Y_x for every calculated charge state.

Table 5[vi] – Values for all calculated charge states for Y_x (in recoils/particle)

3+	4+	5+	6+
$7.87\times10^{-11} \pm 1.18\times10^{-11}$	$2.76\times10^{-10} \pm 0.21\times10^{-10}$	$1.15\times10^{-10} \pm 0.09\times10^{-10}$	$1.45\times10^{-11} \pm 0.17\times10^{-11}$

The value calculated for total yield was
$Y = 4.8\times10^{-10} \pm 0.4\times10^{-10}$ recoils/particle[vii]

The last value needed for the calculation of ωγ is ε, which represents the stopping cross section

$$\varepsilon = \frac{\Delta E}{\mathrm{N}^+ g^+}$$

$$\text{and} \quad \mathrm{N}^+ g^+ = \frac{2N_A}{22400 cm^3} \times \frac{P}{760} \times \frac{273}{T} \times L_{eff}$$

Where ΔE = energy lost through the target (15 keV/u = 315 keV)
N_A = Avogadro's number (6.02×10^{23} molecules/mole)
22400cm^3 = the volume of a mole of gas at normal temperature and pressure
P = pressure in target (4.5 Torr)
T = temperature in target (299.5 K)
L_{eff} = 12.5 cm

The final result gives

$$\varepsilon = 8.86\times10^{-14} \pm 0.09\times10^{-14}$$

The calculation of ωγ can then be carried out

$$\omega\gamma = \frac{2Y\varepsilon}{\lambda^2}\frac{M}{m+M} = 118 \pm 11\,\text{meV}$$

Where $\lambda^2 = 33\times10^{-24}\,\text{cm}^2$
M=1.007 amu
and m=20.994 amu

The calculation of λ^2 was redone using the equation

$$\lambda^2 = \frac{h^2}{2\mu E_{CM}}$$

where $h = 6.6262\times10^{-27}\,ergs\cdot s$

$\mu = \dfrac{m_p m_t}{m_p + m_t}$ with m_p = 20.994 amu, m_t = 1.007 amu
and E_{CM} = 258.6 keV

Now, the problem of BGO asymmetry comes into focus. A problem occurred throughout the runs based on a very obvious asymmetry between the left and right BGO detectors. It appears as though counts went missing on the detectors located on the left side of the target. Figure 4 shows a graph of counts vs. BGO position, where all the detectors on the left assume one identity, along with the middle and the right. This figure, whose data was retrieved from run 4955, shows what the graph should look like, a balance between the left side and the right side (although it can be seen that there are still slightly more counts on the left than the right).

Figure 3 shows the results of run 12836, where there is an obvious lack of symmetry between the left and the right. The reason for the loss of counts on the left is unknown, but is being looked into. All that can be done at this point is assume that the counts were lost and therefore the calculation of $\omega\gamma$ must be adjusted. To account for this, the difference between the left and the right was calculated to be 20%, and this amount was added to the upper error of our result.

$$\omega\gamma = 118 \; {}^{+35}_{-11}\ \text{meV}$$

Figure 4- BGO symmetry for run 4955

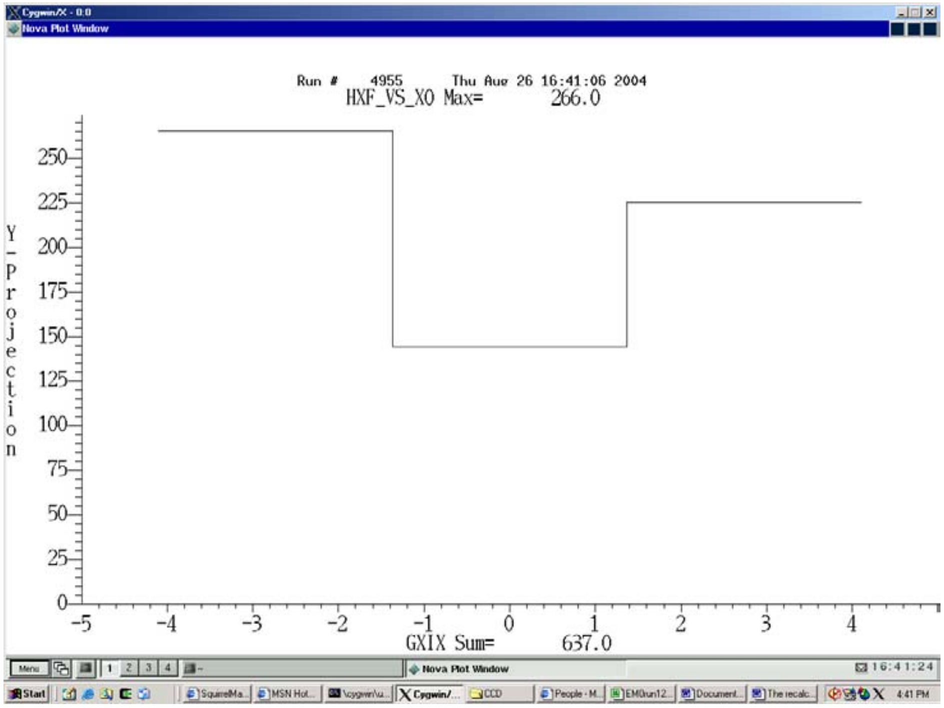
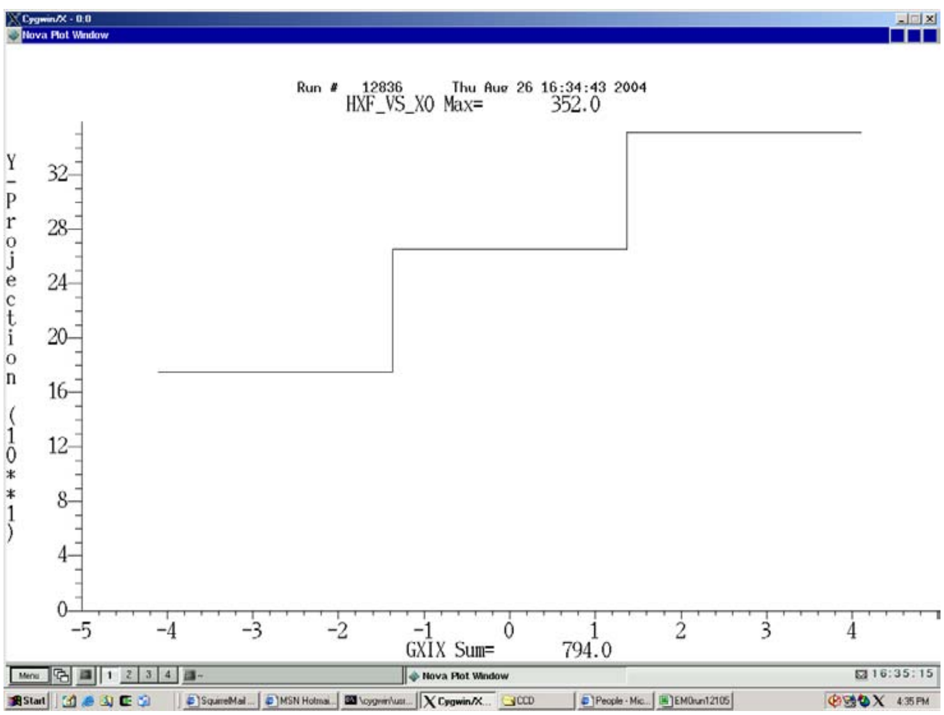


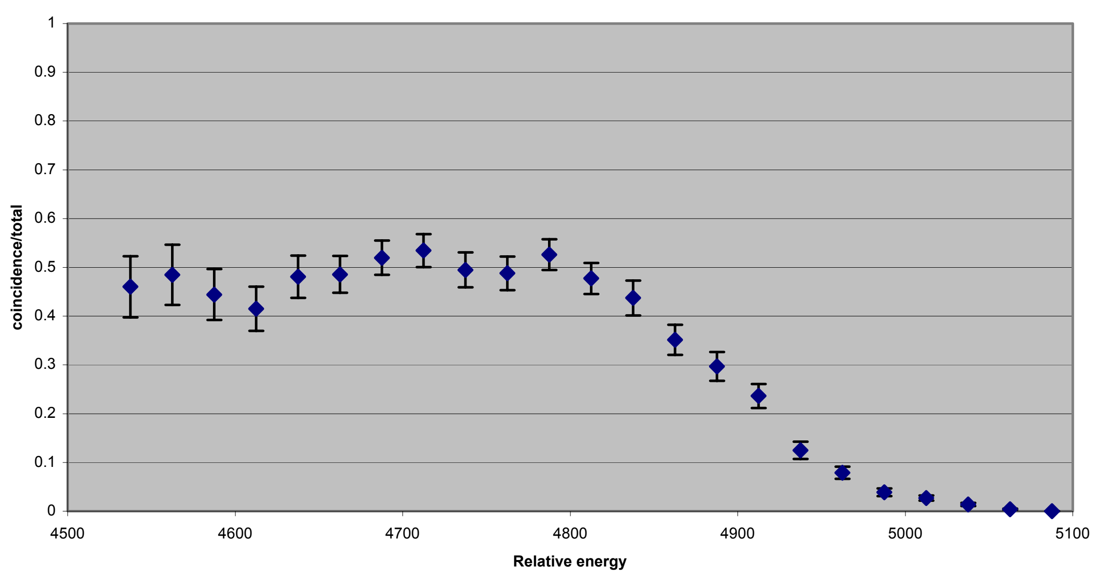
Figure 5- BGO asymmetry for run 12836



The recalculation of the resonance strength of three earlier runs was also carried out. Two of the three runs analyzed were performed in April 2000, and the data was analyzed in Sabine Engel's thesis, *Awakening of the DRAGON*. A few problems were discovered, which is why a re-analysis was done. The value for the resonance strength calculated in the thesis was 209 ± 35 meV, a value of more than twice as much as the previously published literature value. This result was calculated using a charge state distribution that was not measured directly. It was discovered that the distribution used in the thesis was for a recoil charge state of 5+, when the recoils actually had a charge of 4+. This would have dramatically offset the results. The charge state distribution used for the 5+ state was 35%, which is a considerable amount off from the 4+ distribution of 44%. It should be noted here though that the value for the 5+ state is very close to the value that was obtained when measured directly, which was also 35%.
A similar approach to the calculation of the resonance strength was used. The differences were that not every charge state was measured directly, so a charge state distribution was assumed and the total yield was calculated using only a 4+ run. The values for the charge state distribution were taken to be numbers that were measured directly in the later runs, found on page 1.

The value calculated for ε was found to be $8.27 \times 10^{-14} \dfrac{eVcm^2}{atom}$, with the slight change in value being due to a target pressure of 4.7 Torr and temperature of 22 Kelvin. The BGO efficiency was found in the same manner as well. See Figure 4[viii] for a view of the plateau of coincidence/singles for run 4955. The value calculated for this run was found to have an efficiency of 0.49 ± 0.01.

Figure 4- Finding BGO efficiency by looking at coincidence/singles for run 4955



Yield was then calculated knowing the coincidence/s, the BGO efficiency, 4+ charge state distribution and the current of the beam. Refer to Table 6[ix] for the values for each run. The 4+ distribution was taken to be 43.61%.

Table 6 - BGO efficiency and Yield as calculated from 3 different runs.

Run Number	mean (BGO efficiency)	coin/s 4+	recoils/s (total)	current (nA)	Yield
4955	0.4875	0.49	2.35	2.88	6.53E-10
5232	0.4821	0.40	1.93	2.75	5.61E-10
12199	0.5012	1.00	4.67	5	7.48E-10

The resonance strength was then calculated as before, with the final values found in Table 7. These values are then compared with the literature value.

Table 7 - Calculated resonance strength for $^{21}Ne(p,\gamma)$ reaction

Run Number	$\omega\gamma$ meV	$\frac{\text{measured}}{\text{published}}$
4955	148.9	1.80
5232	127.8	1.55
12199	170.5	2.07
12836-41	118	1.43

Appendix

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[i] Refer to DRAGON logbook #15 for calculation of result

[ii] The calculation of k can be found on pages 75-76 of my logbook

[iii] Figure 1 and the results for runs 12839-12841 can be found on isdaq04 in the koraas/new 21Ne(pg) directory

[iv] These graphs can be reproduced by opening /data2/dragon/na21pg/run12836.mid replaying the run in nova

[v] All data points collected can be found in the same folder as iii, isdaq04/koraas/new 21Ne(pg)

[vi] This table can be found in my logbook on page 87

[vii] The calculation of individual yields can be found in my logbook on page 82

[viii] The excel worksheets and graphs showing the data for the calculation of BGO efficiency for all three runs can be found on isdaq04 in the koraas/Ne21(pg) folder

[ix] This figure and the information in Figure 6 can be found on isdaq04 in the koraas/Ne21(pg) folder