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CHARRISSA INTERNAL REPORT.

Multiple Alpha Breakup.

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Abstract

This report details the analysis of data collected during an experiment carried out in February 1993 at the Daresbury NSF. The original aim of the experiment was to investigate the breakup of Mg via the $^{12}C(^{24}Mg,^{12}C(0_2^+)^{12}C_{gs})^{12}C_{gs}$ reaction. Unfortunately, however, the detected yield to this channel proved to be rather small. Further analysis has revealed larger yields to a number of other exit channels. Where possible double-differential cross sections and energy levels of excited states are quoted for these channels.

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1 Introduction.

An experiment was performed at the Nuclear Structure Facility at Daresbury in February 1993 to investigate the breakup of ^{24}Mg to ^{12}C+^{12}C with one of the carbon's in a hyper-deformed state, the other in the ground state. The excited state of interest was the 7.65 MeV 0_2^+, which may be considered to be a linear chain of 3α particles. The experiment was performed using a 170 MeV ^{24}Mg beam on a 450 μgcm^{-2} natural Carbon target, the final state α- particles were detected using a strip detector, and a hybrid detector was used to detect the heavy ions. Specific exit channels were examined by gating on a particular heavy ion in the hybrid, in coincidence with multiple hits in the strip detector. The detectors used were 50mm x 50mm 16 strip position sensitive silicon detectors.

1.1 Experimental Details.

The setup for this experiment is shown in figure 1. The strip detector was placed 120 mm from the target, while the silicon detector in the hybrid was further back at a distance of 240 mm. The central angles were -19.7^0 and 14.6^0 respectively.

The front face of the hybrid detector had a aluminised mylar window to constrain the gas within. This was thought to be either 5 or 6 μm thick, (because of this uncertainty of the thickness a value of 5.5 μm was used in the analysis. This approximation is not affect the energies of the heavy ions significantly). The detector was filled with isobutane gas to a pressure of 100 torr. A pressure of approximately 120 torr would have been prefered, however, due to a gas leak, this pressure could not be maintained.

In front of the strip detector a 125 μm thick mylar sheet was placed to reduce damage from the high intensity ionisation of heavy nuclei. This thickness was chosen such that it would allow alpha particles to pass through whereas heavy ions would be stopped.

For the position and energy calibrations, mask slits were placed in front of the detectors during the whole of the calibration runs. The masks had a specific pattern so that when looking at spectra it was possible to tell which slits were observerd. For position calibrations the detectors were scanned through the beam axis while looking along the beam line with an optical telescope and the arm angle for which the slit was aligned with

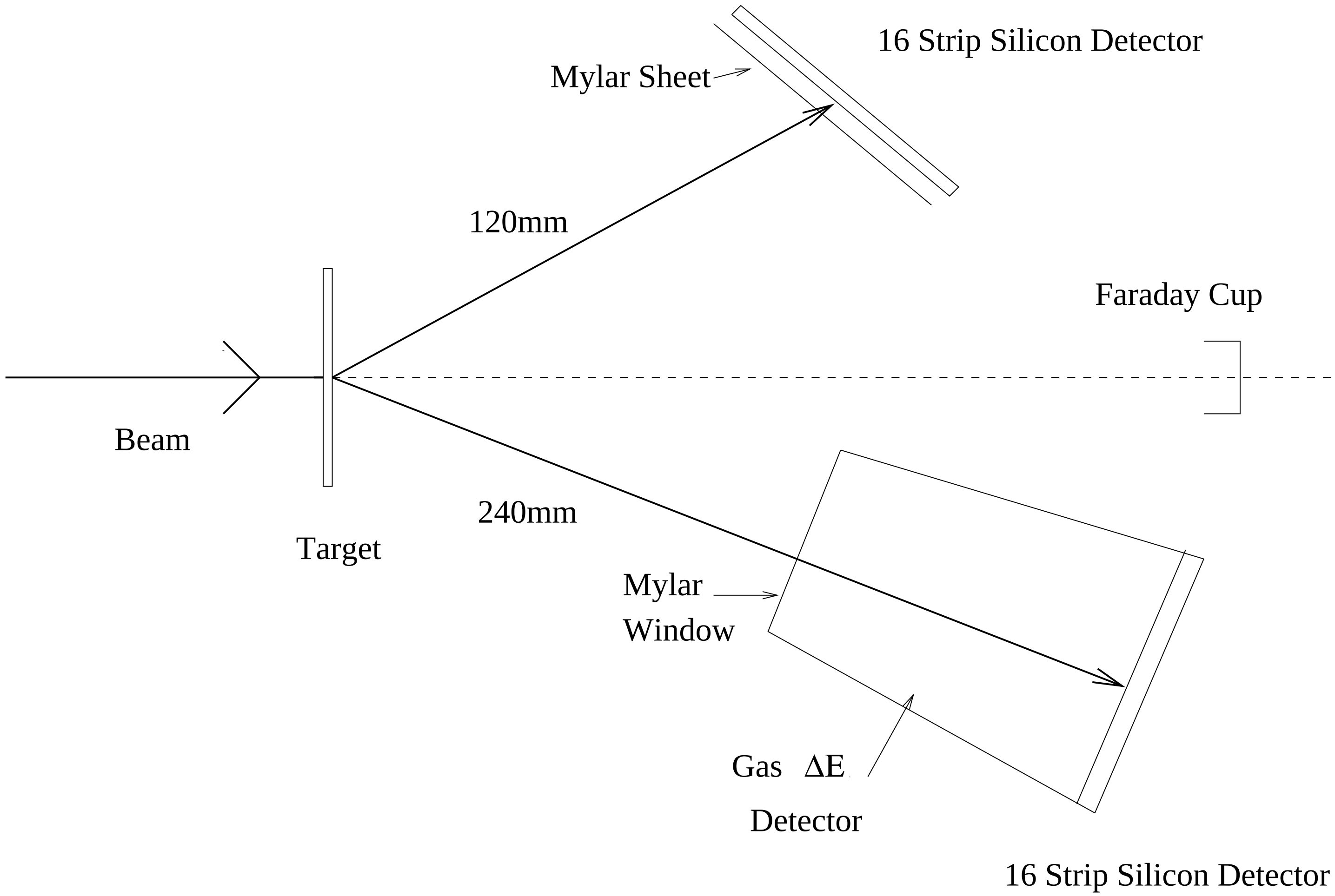

Figure 1: Schematic diagram of the chamber set-up.

the telescope's cross hairs was recorded. From this information, the in plane angle for each slit could be calculated. The distance of the strip above or below the reaction plane could be used to deduce the angle of each slit on each strip. A number of calibration runs were performed: a ^{12}C beam on a ^{12}C target, which was used to determine the offsets of the detectors, also a ^{12}C beam on a ^{197}Au target to provide elastic scattering data to determine the detector gains. Both 40 MeV and 85 MeV energies were used to ensure that these parameters were independent of energy.

Runs were carried out both with and without the gas in the hybrid detector, however the thin mylar window was always present. The energy loss through the mylar window was calculated from the code DEDX and thus the energy of the particle hitting the detector could be determined from kinematics. The detector response was then deduced by fitting a Gaussian to the elastic peak from the data taken. It was found that the response along the length of individual strips was not linear, and therefore this procedure needed to be performed for the data at each mask position. If a two dimensional spectrum of position against energy for each strip is then plotted, a correctly gain matched strip with no position dependence should have a horizontal line of elastic scattered data. The dispersion was then deduced from the elastic scattering data. The same was done with the strip detector, with and without the mylar sheet placed in front of it.

The analogue signals from the detectors were passed through pre-amplifiers, amplifiers and on to ADC's and then the logic signals were passsed through octal shapers, logic delays and coincidence units. For this experiment the coincidence requirement to register and record an event was set at 2 or more hits in the strip detector, with a hit in both the gas Δ E detector and the silicon strip detector in the hybrid. TDC's were attached to all the detector elements to ensure that true coincidences could be identified.

2 Results

When the gold-elastics data was plotted on a graph of position against energy, rather than the expected horizontal band of data, a curiously curved locus was observed. The 85 MeV ^{197}Au elastics data, with the mylar absorber in place, suggested that the mylar was actually thicker than 125 μm. The actual thickness of the mylar was then determined by calulating the expected energy of the particle without the mylar (found using RELKIN) and comparing this with the energy that the particle hit the detector with when the mylar sheet was placed in front of the detector. The code DEDX was then used to calculate the mylar thickness. This was done for every slit on each strip so that a two-dimensional map of the mylar thickness was constructed. It was discovered that the mylar thickness varied between 138 μm and 145 μm. To correct for this a 4th order polynomial was fitted across each strip.

A similar calculation was carried out to determine the thickness of the gas. Polynomial fits were also made to correct for this.

The TDC signals were required to ensure that the alpha-particles really did come from an excited ^{12}C and that these 3 hits in the strip detector are actually in coincidence with a hit in the hybrid detector.

Particle identification was possible with the hybrid detector. Figure 2 shows that the individual loci of the different elements can clearly be seen when the energy in the silicon is plotted against the energy signal from the gas.

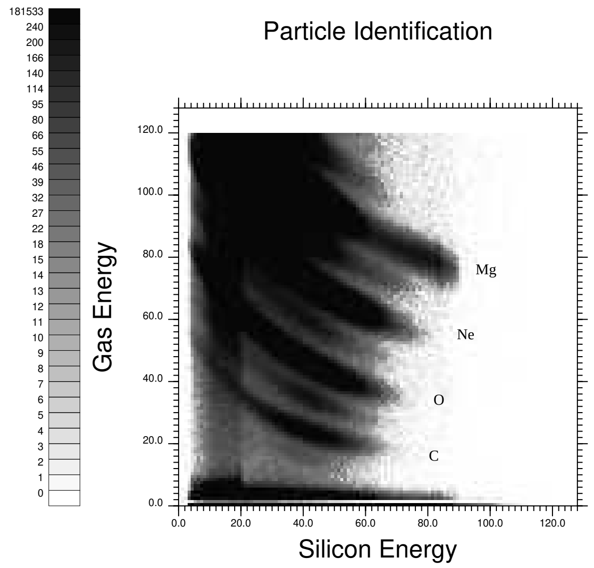

Figure 2: A typical E-Δ E plot for the hybrid.

The 3 perpendiclular components of momentum for each individual particle were calculated using the angle and energy of each hit. The vertical angle (ϕ) between the centre of the detector and the centre of the strip that fired was calculated from trigonometry using the strip height (assuming strips 8 and 9 lay either side of reaction plane) and the distance that the detector was from the target. The in-plane (horizontal) angle (ω) could be determined using the angle that the particle hit the detector (θ) and ϕ . The momentum components could then be resolved into P_x, P_y and P_z.

$$P_x = \sqrt{(2mE)} \cos\phi \sin\omega;\ P_y = \sqrt{(2mE)} \sin\phi;\ P_z = \sqrt{(2mE)} \cos\theta; \tag{1}$$

From the components of the individual α particle momenta, the momentum of the ^{12}C nucleus could also be calculated and hence its energy.

$$P^2 = (\sum P_{xi})^2 + (\sum P_{yi})^2 + (\sum P_{zi})^2 \tag{2}$$

The momentum and energy for the unobserved recoil particle can be determined through conservation of momentum requirements. The energy loss of the beam through the target was also included.

The Q-value for the reaction can be determined from summing the energies of the final state particles.

$$E_{total} = \sum E_{\alpha i} + E_{heavyion} + E_{recoil} = E_{beam} - Q_3 \tag{3}$$

Where Q_3 is the Qvalue for the 3 body break-up.

Excitation energy spectra of the resonant particle whose decay produced the $^{12}C^*$ and the heavy ion could then be deduced. This is done by calculating the relative energy between the two particles and subtracting on the Q-value for the 2-body breakup.

$$E_{rel} = \frac{1}{m_1 + m_2}[m_1 E_2 + m_2 E_1 - 2\sqrt{m_1 m_2 E_1 E_2} \cos\theta_{12}] \tag{4}$$

m_1, m_2, E_1 and E_2 are the masses and energies of the 2 particles respectively.

Cos θ_{12} is the angle between the $^{12}C^*$ before it decays into 3 alpha particles and the heavy ion,and may be determmined by the cosine rule.

$$P_1.P_2 = \mid P_1 \mid\mid P_2 \mid (\cos\theta_{12}) \tag{5}$$

2.1 $^{12}C^{*}$ Exit Channels.

2.1.1 $^{12}C(^{24}Mg,^{12}C(0_2^+)^{12}C)^{12}C$

This was the main exit channel that was hoped to be observed from the experiment. Unfortunately this was the channel that had the lowest overall yield making analysis very difficult. Figure 3 shows the relative energy spectrum for the ^{12}C. This is formed by summing the energies of the 3 α's and subtracting away from this the reconstructed energy of the $^{12}C^{*}$ nucleus.

$$E_{rel} = \sum_{i=1}^{3} E_i - \frac{((\sum P_{xi})^2 + (\sum P_{yi})^2 + (\sum P_{zi})^2)^{0.5}}{2m} \tag{6}$$

There are 2 distinctive peaks corresponding to the 0_2^+ and 3^- states. The 0_2^+ peak lies at 390 keV (which should be 380 keV), the 3^- state lies approximately 2 MeV up from this.

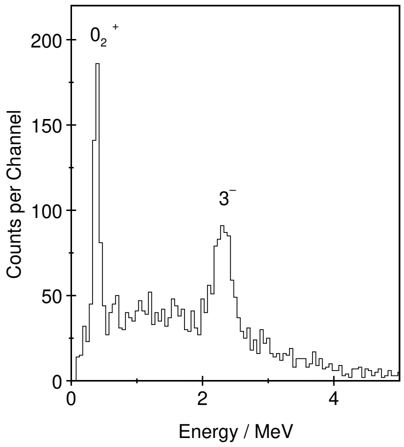

Figure 3: Relative Energy of the 3 alpha particles.

It was found that the background could be reduced by requiring that two of the alpha-particles are from a ^8Be nucleus. The events that fall in the 0_2^+ peak were then filtered so that a Q-value spectrum could be reconstructed to determine the Q-value of the reaction breakup. This can be seen in figure 4.

The Q_{gg} peak for ^{12}C(^{24}Mg,^{12}C(0_2^+),^{12}C)^{12}C lies -21.55 MeV, the calculated Q-value is -21.58 MeV. Due to the lack of counts in this peak no further analysis was possible.

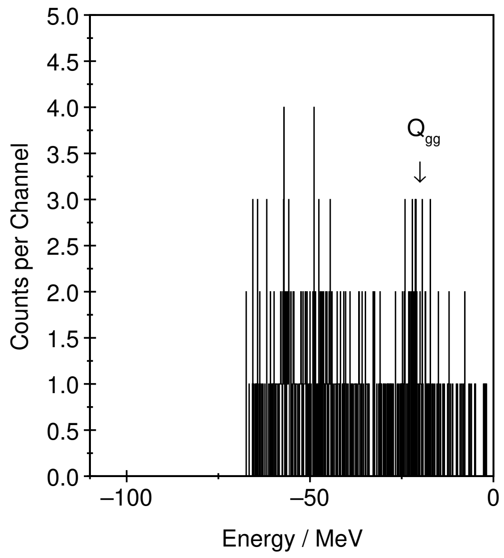

Figure 4: Q-value Spectrum of $^{12}C(^{24}Mg,^{12}C(0_2^+)^{12}C))^{12}C$ reaction.

When the 3^- peak was gated on a similar spectrum was seen only this time the Qgg peak was not as clearly defined.

2.1.2 $^{12}C(^{24}Mg,^{12}C(0_2^+)^{16}O)^8Be$

The excitation spectrum of the ^{12}C was similar as figure 3 but had a higher yield. Again the (0_2^+) state in carbon was gated on so as to obtain a Q-value spectrum for the above reaction. This can be seen in figure 5.

The Q-value for the ^{12}C(^{24}Mg,^{12}C(0_2^+) ^{16}O)^{8}Be reaction is -21.78 MeV so there should be a peak at this energy. There is possibly a peak around this energy but the energy resolution is too poor to draw any further conclusions.

2.1.3 $^{12}C(^{24}Mg,^{12}C(0_2^+)^{20}Ne)^4He$

Once again an excitation spectrum of the excited carbon was formed, only in this instance the two excited states sat on a much higher background. This is probably due to the fact that the recoil in this reaction is an alpha particle, and hence could be detected in coincidence with 2 of the alphas from the break-up of the carbon. However the 0_2^+ peak remains well resolved and may be gated on to produce a Q-value spectrum for coincidences with a ^{20}Ne in the heavy ion detector. This can be seen in figure 6.

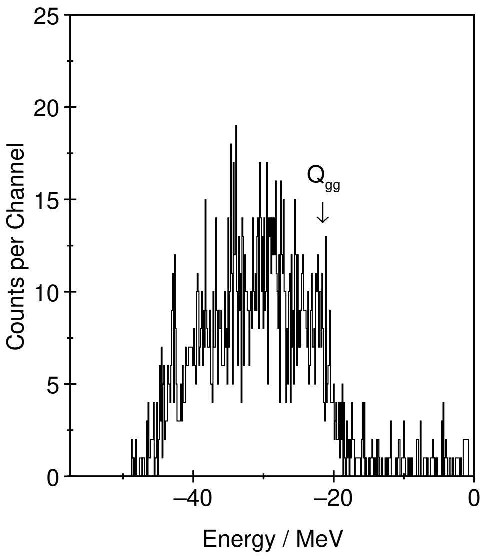

Figure 5: Q-value spectrum for $^{12}C(^{24}Mg,^{16}O^{12}C(0_2^+))^8Be$

The Qgg peak appears around -17 MeV, the actual Q-value for the break up is -16.9 MeV. There is also the possibility a Qg peak as well, this would correspond to the ^{20}Ne being in it's 2^+ excited state. This state appears at -18.6, in agreement with the known excited state in ^{20}Ne at 1.6 MeV. Once again the experimental resolution appears to be too poor to clearly resolve these states. To be sure that the Qgg peak is independent of energy, a 2-d plot of the Q-value for the break-up against the energy of the ^{20}Ne was plotted. Straight vertical lines were observed, showing that it is indeed not dependent on energy. A 2-d software gate was placed around the Qgg peak in this spectrum and the events which fell in this window filtered, so an excitation spectrum can be constructed.

Unfortuanetly, probably due to the fact that the ground and 2^+ states could not be resolved fully, no clear states in the excitation spectrum of ^{32}S could be identified.

2.2 ^8Be Exit Channels.

The exit channel observed here is with a ^{8}Be splitting into 2 α's which are in coincidence with a heavy ion being detected in the hybrid.

The relative energy between the two α's is calculated using equation 3. This produces the spectrum shown in figure 7.

Only the ground state state in Beryllium is observed (92 KeV) as there is a small

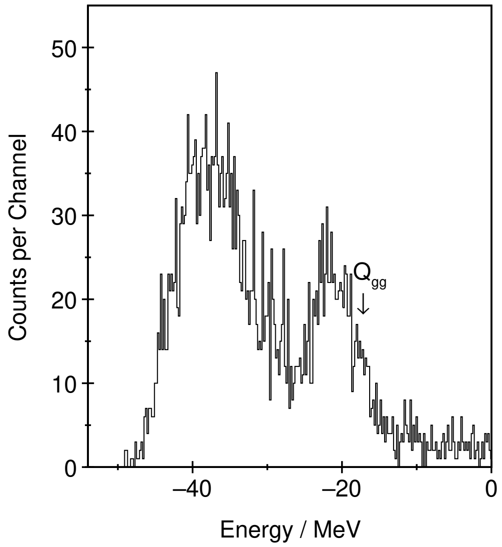

Figure 6: Q-value spectrum of $^{12}C(^{24}Mg,^{12}C(0_2^+)^{20}Ne)^4He$ showing the Q_{gg} peak.

detection efficieny for the other states which are very broad. The small peak at a lower energy occurs from spurious events, and is ignored. Only the events that fall in the peak at 92 keV are considered and a Q-value spectrum is constructed.

2.2.1 $^{12}C(^{24}Mg,^{8}Be,^{12}C)^{16}O$

This breakup involves detecting the beryllium in the strip detector and the carbon in the hybrid. There was not a particularly high yield in this exit channel and the peaks are not clearly resolved.

A small Q_{ggg} peak can be seen around -16 MeV, whereas the actual Q-value for the break-up is -14.13 MeV. There is a possiblity that there is a Q_{gg} peak which corresponds to one of the exit particles being in its first excited state. This is at an energy of -20.79 MeV with repect to the beam energy.

Due to the poor resolution and the lack of statistics there was no possibilty of obtaining a meaningful excitation energy spectrum.

2.2.2 $^{12}C(^{24}Mg,^{8}Be,^{16}O)^{12}C$

Once the data had been filtered, a total energy spectrum was constructed. The Q-value for this breakup is -14.2 MeV. Also the first excited state, in ^{12}C and ^{16}O can be seen.

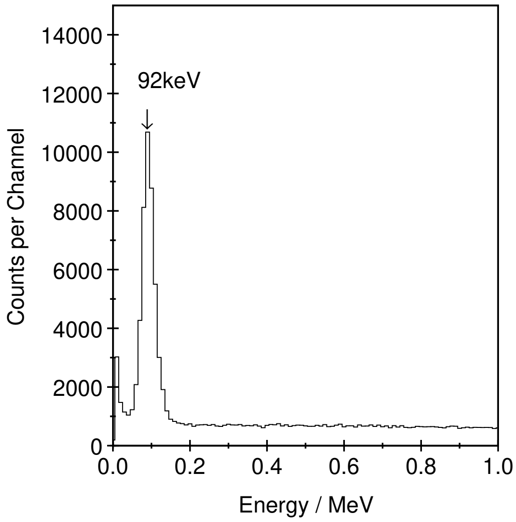

Figure 7: The relative energy between the two α's from the ^{8}Be

The Q_{ggg} peak should lie at -14.57 MeV, the peak is actually centred at -15.5 MeV. Here all 3 particles are in their ground state. The Q_{gg} peak, where the oxygen is in it's first excited state (about 6 MeV above it's ground state), is at -19.97 MeV with respect to the energy of the beam, but this may also contain the peak corresponding to the carbon being in it's first excited state. Therefore this peak would be a doublet, due to the poor resolution this could not be resolved.

The Q_{ggg} peak is gated on to produce an excitation spectrum of the Magnesium from which the Oxygen and Beryllium came from.

This excitation spectrum is similar to one already seen by Pople [1] and has a possible four states. These are at:-

1. 20.06 MeV
2. 21.48 MeV
3. 23.17 MeV
4. 24.93 MeV

But due to the small yield no further anaylsis could be undertaken.

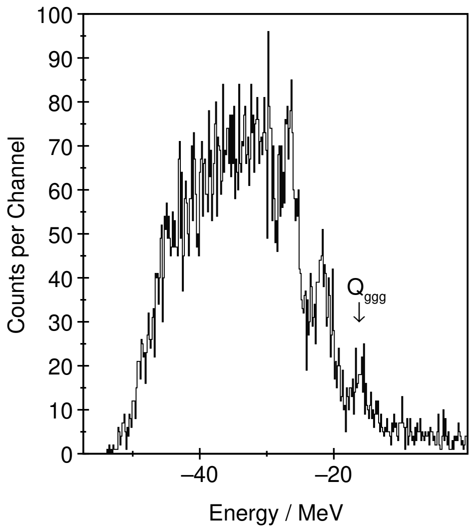

Figure 8: Total energy spectrum of $^{12}C(^{24}Mg,^{8}Be,^{12}C)^{16}O$ showing the Q_{ggg} peak.

2.3 $^{12}C(^{24}Mg,^{8}Be,^{20}Ne)^{8}Be$

Unfortunately there was no structure in this exit channel what so ever, ie nothing in the Q-value spectrum.

2.4 Double Differential Cross Sections.

Estimates of the double differential cross-sections for the reactions are shown in table 1. They were calculated using Equation 7.

$$\frac{d^2\sigma}{d\Omega_1 d\Omega_2} = \frac{counts}{3.7}\frac{Z}{Q_{eff}}\frac{m_t}{T}\frac{1}{\Delta\Omega_1\Delta\Omega_2} \tag{7}$$

where:- Z is charge state of beam fully stripped (as it has passed through the target)

Q_{eff} is integrated charge in Faraday Cup (nC s^{-1})

m_t is mass of target in a.m.u.

T is target thisckness

$\Delta\Omega_1\Delta\Omega_2$ are the solid angles subtended from the detectors in milli sr.

These are estimates because the solid angle subtended from the strip detector is smaller than that for the whole detector. This is smaller due to the fact that it is detecting multiple particles that have come from an undetected particle. To be able to reconstruct this particle all its constituents must be detected. If an event occurs near the edge of the

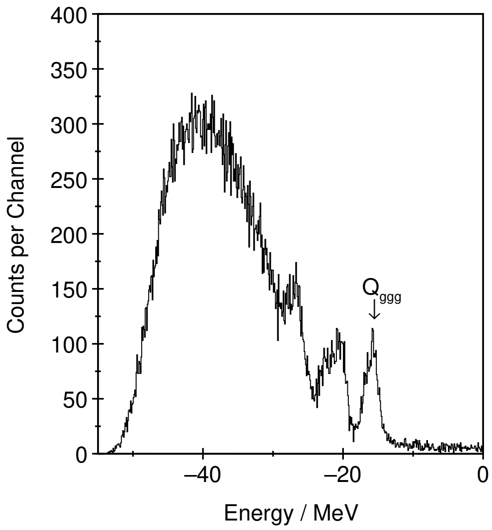

Figure 9: Q-value spectrum of $^{12}C(^{24}Mg,^{8}Be,^{16}O)^{12}C$ showing the Q$_{ggg}$ peak.

detector, then not all of the required particles may be detected, and so decreasing the solid angle of detection.

Reaction	$d^2\sigma/d\Omega_1 d\Omega_2$ [mb/sr^2]
$^{12}C(^{24}Mg,^{12}C^{12}C^{*})^{12}C$	2.2x10$^{-4}\pm$ 1.68x10^{-4}
$^{12}C(^{24}Mg,^{16}O^{12}C^{*})^{8}Be$	7.4x10$^{-4}\pm$ 3.08x10^{-4}
$^{12}C(^{24}Mg,^{20}Ne^{12}C^{*})^{4}He$	7.5x10$^{-4}\pm$ 3.10x10^{-4}
$^{12}C(^{24}Mg,^{8}Be^{12}C)^{16}O$	2.3x10$^{-3}\pm$ 5.42x10^{-4}
$^{12}C(^{24}Mg,^{8}Be^{16}O)^{12}C$	1.8x10$^{-2}\pm$ 1.53x10^{-3}

Table 1: Double Differential Cross- Sections.

To be able to get a true value for the differential cross-section then Monte-Carlo simulations need to be carried out to get a more accurate value for the solid angle that is subtended by the strip detector. This will depend on each reaction as the detected alpha-particles will have varying energies. There will also be a difference in efficiency between detecting two and three alpha's.

The cross-sections are particularly small, this may well be due to the fact that number of counts in the integrated peaks were exceptionally small, and that there was a large integrated charge in the Faraday cup.

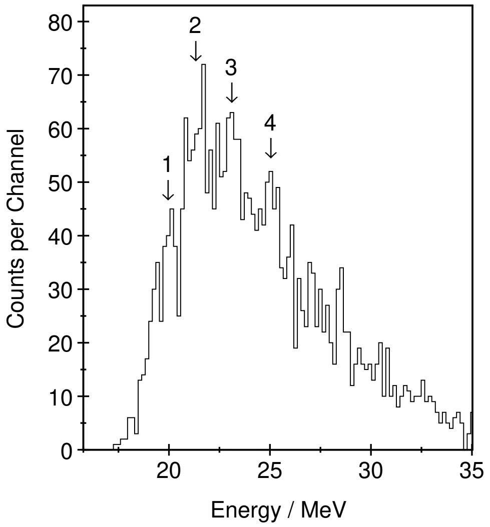

Figure 10: Excitation spectrum for ^{24}Mg.

3 Summary

An experiment has been performed to investigate the break-up of a number of reaction produced when a magnesium beam is scattered off a carbon target at 170 MeV. The detection system employed allowed exit channels consisting of one heavy ion being detected in coincidence with multiple alpha-particles to be analysed. Break-up has been observed in $^{12}C(^{24}Mg,^{12}C^{12}C^{*})^{12}C$, $^{12}C(^{24}Mg,^{16}O^{12}C^{*})^{8}Be$, $^{12}C(^{24}Mg,^{20}Ne^{12}C^{*})^{4}He$, $^{12}C(^{24}Mg,^{8}Be^{12}C)^{16}O$, $^{12}C(^{24}Mg,^{8}Be^{16}O)^{12}C$, and excited states in Mg following

$^{12}C(^{24}Mg,^{8}Be,^{16}O)^{12}C$ reaction have been seen. Double differential cross-sections for all the reactions have been measured.

References

[1] J. S. Pople Ph.D. Thesis, (University of Birmingham, 1994) unpublished.