Measuring 17MeV Beam Stripping Probability

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1 Set-up

At the end of Peter's beam line, there will be a target ladder with 5 slots. In this we will place 2 'normal' Carbon stripping foils, one thicker (2× thickness) foil and a (collimated?) alpha source for magnet calibration.

We will place two silicon counters, one after the 'split-pole' magnet to measure the current of the various stripped states (we'll call this the 'primary counter'), the other placed at some angle with respect to the beam incident on the stripping foil to monitor the incoming beam intensity (we'll call this the 'Rutherford counter'). See Figure 1.

The split-pole magnet has a bending power $bp = \frac{ME}{Q^2} = 66$(the bending power is proportional to rigidity square). For 17MeV V^{51}, the magnet can bend charge +4(with $bp = 54$) and up.

Our best guidance is that the stripping probability for Vanadium at 17 MeV varies from about 0.2 for charge state +11 to about 10^{-4} for charge +5 (roughly another ×10 down for each charge state below that. See Figure 2, The Gaussian curve parameters were calculated using Kunihiro's method [1]). The basic plan is then to adjust the split-pole magnet to steer each charge state in succession to the primary silicon counter and measure the count rate while monitoring the beam rate in the Rutherford counter. A first guess as to put the Rutherford counter a scattering angle $\Theta = 10°$ would give us a count rate 3.5×10^{-5} per beam particle. This might be a problem because of the low rates. When measuring charge +5, both Rutherford counter and primary counter have suitable counting rates. However, when measuring charge +11, or +10, we can't make both suitable.

Using the alpha source, we will check the calibration of the magnet.

2 Tuning the Beam

Start with Vanadium (Z=23,A=51) and start with the 'empty' slot in the target ladder. Assume a current of 1μA beam rate out of the source (i.e. 6.25×10^{12} particles/second), then if transmission through the machine is 1% (Jeff's estimate) at low terminal voltage and we strip to charge +5 (0.24 probability with terminal voltage=2.8MV), we have a beam of energy 17MeV, intensity $\sim 1.5 \times 10^{10}$ Vanadium stripped to charge +5. This would be 13 nanoamps (of charge) and should be visible on a Faraday cup.

We should then look at the beam size using the aperture with the Faraday cup (how exactly this is done is still somewhat unclear as the exact placement of the various elements is not known). When we are satisfied that the beam is sufficiently small, we'll proceed.

Now we would like to lower the beam intensity so that we can have a suitable counting rate in our

[1]Kunihiro, S. et al, Systematics of equilibrium charge distributions of ions passing through a carbon foil over the ranges Z=4-92 and E=0.02-6 MeV/u. Physial Review A, 1989. **40**: p. 3557.

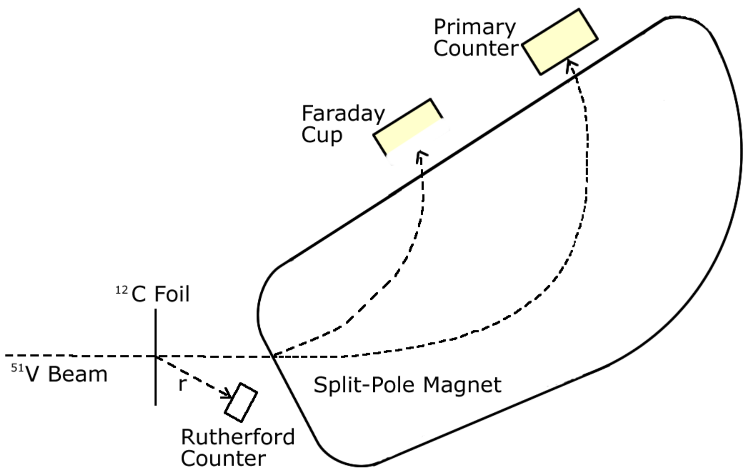

Figure 1: Schematic Setup

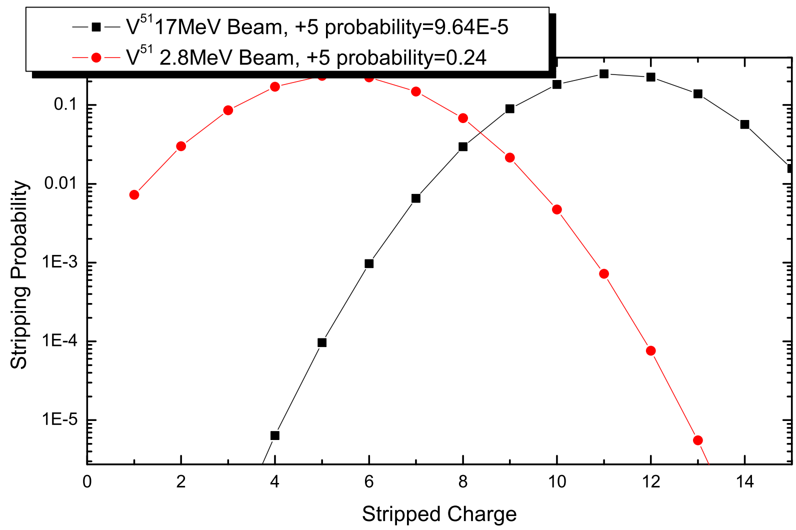

Figure 2: Stripping probability for Vanadium at 2.8MeV and 17MeV.

counters. We assume that the counters can handle something like a rate of 3000Hz of 17MeV heavy ions (?). We can accomplish this presumably by closing down the various slits.

When measuring charge +5, if we close the source slits down so that we can just see a 0.1nA current in Faraday Cup, our rate at the target ladder will be down to 1.5×10^6Hz(if we really have no transmission losses down the beam line), we could insert the stripping foil and count safely in the Rutherford counter(50Hz). The expected counting rate in our primary counter will be 150Hz. Both counter will work beautifully.

However, when measuring charge state +11, if we restrict counting rate in primary counter to 3000Hz, counting rate in Rutherford counter will be 0.4Hz. This is not ideal for us. If we could put a Faraday Cup after the split-pole magnet(besides our primary counter), we could solve this problem. The counting rates in Faraday cup can be as high as possible, rate in Rutherford counter can be lower by increasing the scattering angle Θ.

APPENDIX

A Stripping Probability Theoretical Calculation Results

Equilibrium charge fraction is (Gaussian):

$$F(q) = \frac{1}{\sqrt{2\pi}d} e^{-\frac{(q-\bar{q})^2}{2d^2}} \tag{1}$$

Where mean charge $\bar{q}$ and charge distribution width d are fitted from experimental data. For V^{51}, 17MeV, the parameters are:

$$\left\{ \begin{array}{l} \bar{q} = 11.2710 \\ d = 1.5806 \end{array} \right. \tag{2}$$

For V^{51}, 2.8MeV, the parameters are:

$$\left\{ \begin{array}{l} \bar{q} = 5.3718 \\ d = 1.6506 \end{array} \right. \tag{3}$$

Detailed stripping probability for different charge states are:

Charge	Prob.(17MeV)	Prob.(2.8MeV)		Charge	Prob.(17MeV)	Prob.(2.8MeV)
1	1.71E-10	0.00724		12	0.22693	7.62E-05
2	8.54E-09	0.03		13	0.13876	5.56E-06
3	2.86E-07	0.08608		14	0.05686	2.82E-07
4	6.41E-06	0.17111		15	0.01561	9.88E-09
5	9.64E-05	0.23564		16	0.00287	2.40E-10
6	9.71E-04	0.22481		17	3.54E-04	4.04E-12
7	0.00656	0.14858		18	2.93E-05	4.71E-14
8	0.02966	0.06803		19	1.62E-06	3.80E-16
9	0.08991	0.02158		20	6.02E-08	2.13E-18
10	0.18267	0.00474		21	1.50E-09	8.26E-21
11	0.24872	7.22E-04		22	2.49E-11	2.22E-23

B Stripping Probability for charge +4 to +11,, Bending Power, Rigidity of 17MeV Vanadium beam

Charge	Stripping Prob.	Bending Power	Rigidity (MeV/c)
4	6.41E-06	54.19	10.41033
5	9.64E-05	34.68	8.328265
6	9.71E-04	24.08	6.940221
7	0.00656	17.69	5.948761
8	0.02966	13.55	5.205166
9	0.08991	10.70	4.626814
10	0.18267	8.67	4.164133
11	0.24872	7.17	3.785575

C Spectrograph Design Specifications

Property	**Value**
Orbital radius r	51.1 to 92.0 cm
Resolving Power p/Dp	
(r=92 cm, 1 mm beam spot)	
1st order (x/Q)	4290 ($Q = \pm 80 mrad$)
2nd order (x/ϕ^2)	4100 ($\phi = \pm 40 mrad$)
3rd, 4th orders	negligible if ray tracing is used
Acceptance DQ	160 mrad
DF	80 mrad
DW	12.8 msr
Dispersion $\Delta x/\Delta r$	1.96
Magnification M_x	0.39
M_y	2.9
Maximum B	16.3 kG
Maximum EA/q^2	108.4

D Rutherford Scattering Calculation

The scattering of incident particles(M, Z_1) can be modeled from the Coulomb force and treated as an orbit. The scattering process can be treated statistically in terms of the cross-section for interaction with a nucleus which is considered to be a point charge $Z_2 e$. For a detector at a specific angle Θ with respect to the incident beam, the number of particles N per unit area striking the detector is given by the Rutherford formula:

$$N(\Theta) = \frac{1}{(4\pi\epsilon_0)^2}\left(\frac{Z_1 Z_2 e^2}{2KE}\right)^2 \frac{N_i \rho t}{4r^2 \sin^4(\frac{\Theta}{2})} \tag{4}$$

where
N_i=number of incident particles;

$\rho = 1.137 \times 10^{29}/m^3$ is atoms per unit volume in target;
$t = 15\mu g/cm^2 = 66nm$ is thickness of target;
$\epsilon_0 = 8.8542 \times 10^{-12} Fm^{-1}$ is the permittivity of free space;
r=target to detector distance;
$KE = 17MeV$ is kinetic energy of incident particles.

Assuming $r = 10cm$, radius of the Rutherford Counter $a = 1cm$, and angle $\Theta = 30°$ we have a counting rate $4.5 \times 10^{-7} \times N_i$ Hz. Or a $\Theta = 10°$ gives $3.5 \times 10^{-5} \times N_i$ Hz. This might be a problem because of the low rates. When measuring charge +5, both Rutherford counter and primary counter have suitable counting rates. However, when measuring charge +11, or +10, we can't make both suitable.