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# THE ORIC HIGH-RESOLUTION SPECTROGRAPH FACILITY*

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## Abstract

The installation of a broad-range spectrograph system at ORIC has now been completed. The system consists of a beam analyzing magnet, two triplet quadrupole magnets, and the spectrograph magnet. These magnets are operated as a compound system to obtain optimum energy resolution. The quadrupole pair gives the system a unique flexibility in matching the properties of the beam preparation and the spectrograph magnets. Preliminary results of the operation of the system show the importance of this compound operation with obtained resolutions approaching 1 part in 2000.

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The last of the major pieces of equipment to be installed at the ORIC was the broad-range spectrograph. This magnet and its associated components were received and assembled, in the larger of the two experimental areas, during the last half of 1965. Calibration and preliminary runs were made during January and February of 1966. It is the purpose of this paper to discuss some of the unique features of this system and to report some preliminary results.

The layout of the spectrograph system, with respect to the ORIC cyclotron, is shown in Figure 1. This figure indicates the elements which are active in the operation of the system.

The external beam from the cyclotron is passed through quadrupole Q1. This doublet quadrupole is adjusted to provide a parallel beam in both the radial and axial directions. This parallel beam is then focussed by quadrupole Q2 onto the entrance slit of the 153 degree analyzing magnet.

The beam analyzer is an $n = 1/2$, double focussing magnet with a 72 inch radius of curvature. The entrance and exit slits are equidistant from the field boundary so that the magnet operates with unity radial magnification. If both entrance and exit slits are set to the same opening, then a slit width of 0.072" corresponds to an energy resolution of 1 part in 1000. This has been the slit setting for all of the preliminary work described here.

With the proper setting of Q1 and Q2 it is possible to get 50% of the extracted beam through the 0.072" entrance slit of the 153 degree magnet. Transmission through this slit is somewhat aided by the relative orientation of the cyclotron and the analyzer bending plane. The narrow dimension of the entrance slit corresponds to the axial co-ordinate of the cyclotron. The axial divergence of the extracted beam is significantly less than the radial divergence.

The exit slit of the 153 degree magnet serves as the object for the two triplet quadrupole magnets Q3 and Q5. This quadrupole pair transports the analyzed beam to the spectrograph target chamber at station 4.

The spectrograph magnet is a uniform field, single wedge magnet of the type described by Elbek and co-workers.[1] The magnet covers a range of radii of curvature from 30" to 63" and operates at fields up to 13.5 kGauss. The magnet sits on a cradle which rotates about the scattering chamber with an angular coverage of -10 to +160 degrees. The spectrograph gap is two inches and lies in the same plane as the gap of the 153 degree magnet. Both magnets deflect particles in the same direction. The solid angle of the spectrograph is of order $4 \times 10^{-4}$.

The importance of the pair of quadrupoles between the beam analyzing magnet and the spectrograph can be qualitatively explained using the schematic representation of the optics shown in Figure 2.

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Since the energy spread in the cyclotron beam passing through the entrance slit S2 is greater than the spread defined by the width of the exit slit S3, the particles will be distributed across the opening of S3 with a definite energy gradient. Particles with lower energies will have smaller radii of curvature in the analyzer and will be focussed closer to the lower slit than those particles having higher energy.

The purpose of the quadrupole pair is to transmit the beam to the spectrograph target while maintaining the directional sense of this energy gradient. We thus obtain an image on the target with an energy gradient as indicated in Figure 2. The effect of this gradient is most easily seen by imagining a point source of particles on the focal plane at point FP. If these particles travel backwards through the spectrograph they will be dispersed across the target with an energy gradient having the same sense as the gradient in the beam. Now, if the two gradients are matched, the particles coming from the target will tend to focus to a point image at the focal plane. (It must be remembered that there is an incoherent energy spread introduced by the finite width of S2.)

The importance of this dispersion matching has been discussed by Cohen[2, 3] for a system of two wedge magnets without quadrupoles. In that case the dispersion matching was accomplished by appropriate choice of target angle. However, it is also important to choose the target angle to minimize the spread in particle energy loss. In the system described by Cohen the target angle is chosen as a compromise between dispersion matching and energy spread.

In the ORIC system described here, the dispersion matching is accomplished by choice of appropriate magnification of the two quadrupole system. This leaves the target angle a free parameter. Since a real image is inverted, we must run the quadrupole system with an intermediate image to obtain the proper gradient. It would have been possible to partially satisfy these requirements by using only one quadrupole and installing the spectrograph magnet to deflect particles in the other direction. This would have the difficulty that the magnification is fixed and can be changed only by physically moving the quadrupole. In the ORIC system the magnification is changed simply by adjusting the two quadrupole currents and hence shifting the position of the intermediate image.

There is one additional advantage to the ORIC system. At large angles it becomes necessary to take reflection data rather than transmission data. As the situation is drawn in Figure 2, it is apparent that this would result in an energy gradient across the target in the wrong direction. The necessary "flipping" of the gradient is accomplished by making the beam parallel between the two quadrupoles. This feature is not available with the simpler systems.

The effect of this careful dispersion matching is to remove the effect of the target spot size on the final line width. Another way of stating this is that by operation of the magnets as a compound system, the final line width is determined by the width of slit S2 and not by the combination of S2 and S3.

For a beam preparation magnet with unit magnification the energy spread in the prepared beam is proportional to the sum of entrance and exit slits. This means that for cyclotron systems where we have the condition of the energy spread in the raw beam exceeding the spread defined by an analysis magnet, spectrograph magnets are intrinsically better than other types of detectors by a factor of two in energy resolution.

The relative independence of overall resolution on target spot size for the compound system is illustrated in Figure 3. This shows the line width for 31 MeV protons elastically scattered from a 0.5 mg/cm$^2$ target of $^{60}$Ni. A slit placed in front of the target was respectively opened to allow the natural image width on the target (about 0.060"), closed to 0.040", and finally closed to 0.020". The observed line width varies only slightly with the reducing target spot size. With an incident beam having an energy resolution of 0.1%, the observed line width is about 0.06%.

One of the first spectra taken with the magnet during its initial operation is shown in Figure 4. These are deuterons resulting from the reaction of 31 MeV protons with $^{89}$Y. The incident protons have an energy spread of about 31 keV. The deuterons have an energy of about 21 MeV with an observed line width of 17 keV.

It is expected that after some experience has been gained in the operation of this system, decreases in the energy spread of the prepared beam and in target thicknesses will allow improvements over the present resolution of the spectrograph system.

## References

1. J. Borggreen, B. Elbek, and L. Perch Nielson, Nucl. Instr. and Methods, 24, 1 (1963).
2. B. L. Cohen, Rev. Sci. Inst. 30, 415, 1959.
3. B. L. Cohen, Rev. Sci. Inst. 33, 85, 1962.

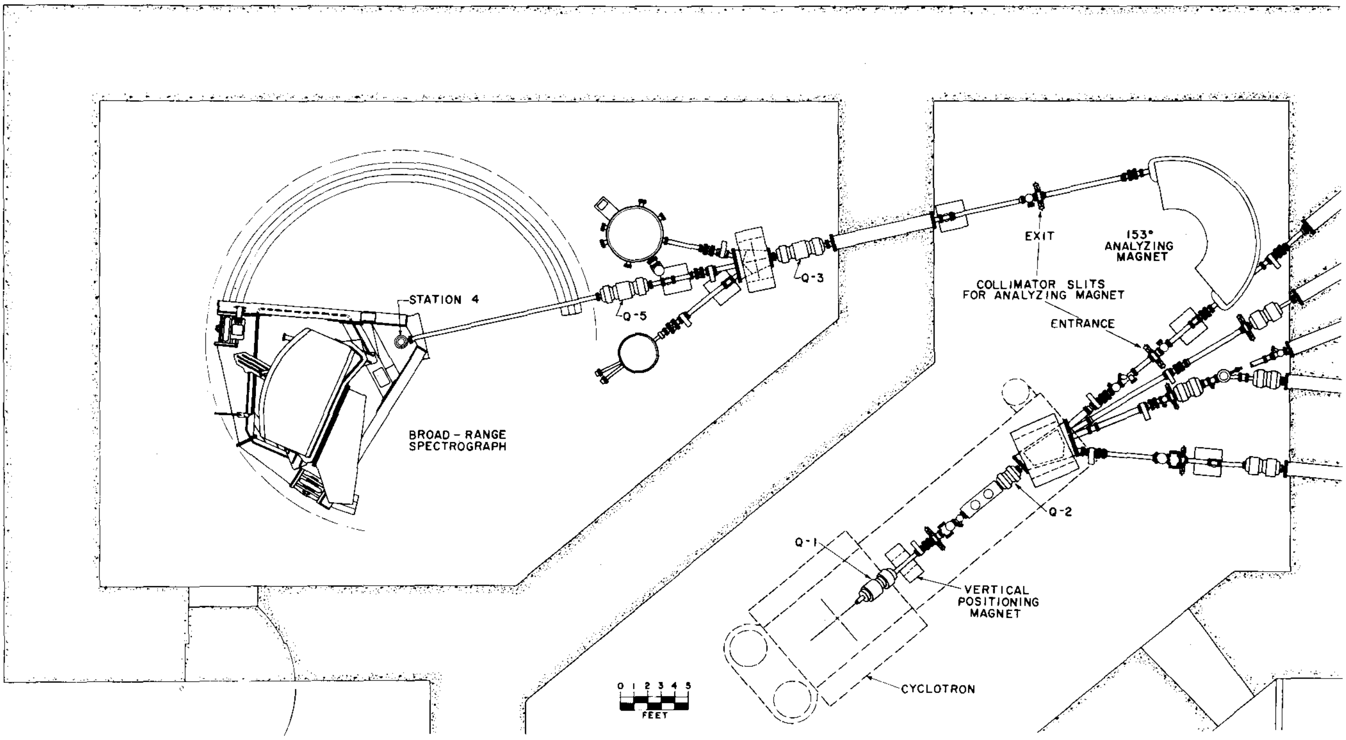

Fig. 1. Beam optics layout at ORIC showing components used in the spectrograph system.

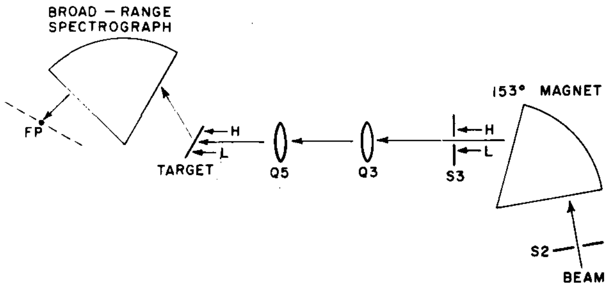

Fig. 2. Schematic representation of spectrograph system to illustrate dispersion matching.

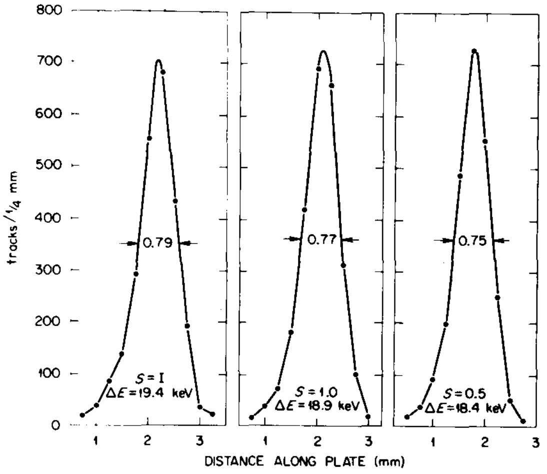

Fig. 3. Observed line width as a function of target spot size.

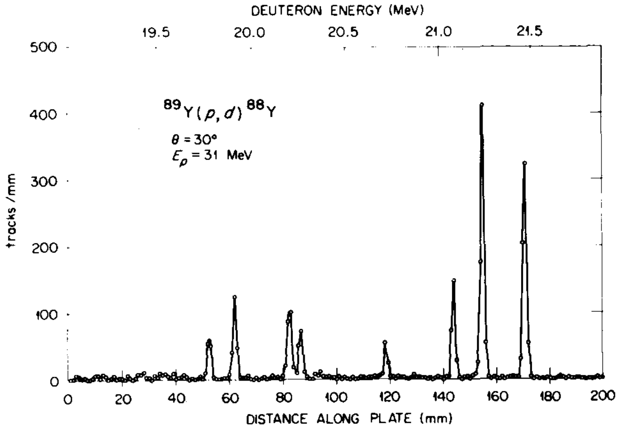

Fig. 4. Spectrum of deuterons from the $^{89}$Y(p, d)$^{88}$Y reaction.

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DISCUSSION

THIRION: We are using somewhat the same trick with a quadrupole at Saclay.