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Experiments with Heavy Ions

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Several things which I shall report here have to do with accelerator procedures and I shall report the results of two experiments which have been carried out with some of these procedures. Most of the accelerator techniques were worked out by G. F. Wells, the accelerator operators and myself. I shall list the names involved with the experiments later.

Before discussing very heavy ions I wish to report on two items of general interest to users of Tandem accelerators. Wells has found a way to produce reasonably large currents of nitrogen ions, using the conventional Duo-Plasmatron ion-source system. Unlike oxygen and several other elements which form negative ions readily, nitrogen seems similar to helium in that it is difficult to get a suitable nitrogen beam for use in the Tandem accelerator. At Chalk River, nitrogen ions have been obtained from their r.f. ion sources. As in many cases where heavy negative ions are sought, it is not always clear whether N^-, NH^- or NH_2^- or some other molecule is being accelerated nor does it matter very much. The Chalk River technique involved the use of NH_3 in their r.f. source. Starting with the Chalk River experience, Wells found that the following feed gas formula seems to work well with the standard tandem source.

1. Duo-Plasmatron, oxide cathode, He + 1% NH_3

2. Donor canal NH_3

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With this recipe, target currents of 0.5 μa have been reached and performance is stable for long periods. The ions come from the source, not the donor canal.

The second matter which I shall discuss is a difficulty which may be encountered when heavy ions are accelerated in the tandem accelerator. This difficulty, if not properly appreciated, can lead to the destruction of the accelerator tube on the low-energy end of the machine. Multiple beams are produced in the negative ion source in certain instances. An example is the O^-, OH^- pair of beams often encountered in work with oxygen. These two beams are often nearly equal in intensity. After passage through the 20° magnetic analyzer these two beams are not completely separated. The result is that one component passes through the accelerator while the other component bombards the metal electrodes of the accelerator tube. Sputtered metal can reach the glass insulator walls and rapidly lead to breakdown of the accelerator tube. The Oak Ridge Tandem accelerator now has a set of slits at the entrance and these are usually kept below a total gap of 0.05". No more trouble has been encountered since the installation of these slits. This precaution is highly recommended wherever heavy ions are being used.

Now I wish to discuss two experiments which have been performed at Oak Ridge with ions of Br and I. The first was performed by Walter, Neiler, Schmitt, Gibson, Thomas and myself[1] and the second is being performed by M. D. Brown and myself.[2] The original intention was to accelerate Br and I ions to an energy not more than 35 to 45 MeV in order to get some information about the response of some Si solid state detectors being used in fission studies. The procedure was to be the usual one of accelerating Br^- and I^-

ions to ~ 7.5 MeV, stripping to Br^{5+} and I^{5+} and accelerating again to perhaps

45.0 MeV. This procedure had been used at Chalk River and the plan was to

scatter the beam from a foil into the solid state detectors. Although not

high enough in energy to simulate fission fragments it was thought that these

ions could be used to get some information about detector responses. Before

the experiment began, the process of energy compounding was discovered and

identified and this process has been used in work with artificial fission

fragments since that time. The new procedure involves additional gas stripping

of the positive ions as they traverse the second half of the accelerator.

As the beam leaves the stripper tube and enters the accelerator some of the

particles encounter gas atoms and strip to higher charge states. The process

of up-stripping is quite complicated but it seems that as the particles reach

higher energies further stripping becomes more likely. As the charge is in-

creased, the particle energy increases more rapidly, further stripping becomes

more probable, and further increases in the rate of acceleration take place;

thus for some of the particles a kind of energy compounding seems to occur.

The fraction of the beam which behaves in this way is not vanishingly small;

considerable numbers of particles reach energies as high as 120 MeV and charge

states as high as 20. For best results the accelerator potential must be kept

high, preferably above 7 MV and the gas pressure in the high energy accelerator

tube must be kept high, preferably above 2×10^{-5} mm Hg.

The experimental arrangement is as shown in the first slide.

The original procedure was to admix HBr or I_2 gas into the H_2 fed to

the Duo Plasmatron. Wells has discovered that the Heidelberg technique of

putting HBr or I_2 in the exchange canal gives 100 times more beam.

The beam which comes from the accelerator is not monoenergetic. It consists of a large monoenergetic component and a small continuous distribution reaching out to well over 120 MeV. It should be remembered that the particles having higher energy also have higher charge. The magnetic analyzer passes all particles which have a certain value of ME/q^2. It just turns out that the charges and energies are distributed in such a way that the magnet can pass many narrow slices of the continuous distribution at the same time. A detector placed in the beams passed by the magnet shows a pulse height spectrum as shown in slide 2. There are a few extraneous peaks at low pulse heights due to oxygen ions; otherwise the spectrum shows the various components of the beam. All peaks are seen in the same run. Run times were approximately 10 minutes. The energies of the slices are quite accurately known since the magnet constant is known from nuclear thresholds; these slices are much narrower than the detector spectra indicate. The energies of the components do not depend upon accelerator terminal voltage at all, so it is not necessary to regulate the potential. To avoid several very intense oxygen peaks detectable by the slit amplifiers, the slits are connected in reverse to keep any intense component off the detector. The energies are well known and it is a simple matter to study the pulse height response of various detectors to artificial fission fragments covering the entire energy range encountered in fission experiments. The spectrum in slide 3 shows the result from Br ions. In this case Br has two isotopes rather than one and the peaks clearly show this fact; by tuning the ion source analyzer magnet one or the other of the two masses can be suppressed.

Spectra have been taken for many types of Si counters. Surface barrier and diffused junction detectors were studied and some of the detectors were biased into the so-called "proportional-counter" region. One of the response curves is shown in slide 4.[1] The results show a rather small value for the so-called pulse height defect. Br response is closer to the alpha-particle line both in slope and in pulse height defect. The results have indicated some discrepancies with other results taken by fission particle time-of-flight. Presently the Tandem accelerator is being used to cross correlate a complete time-of-flight and pulse height analysis experiment in an attempt to remove these discrepancies.
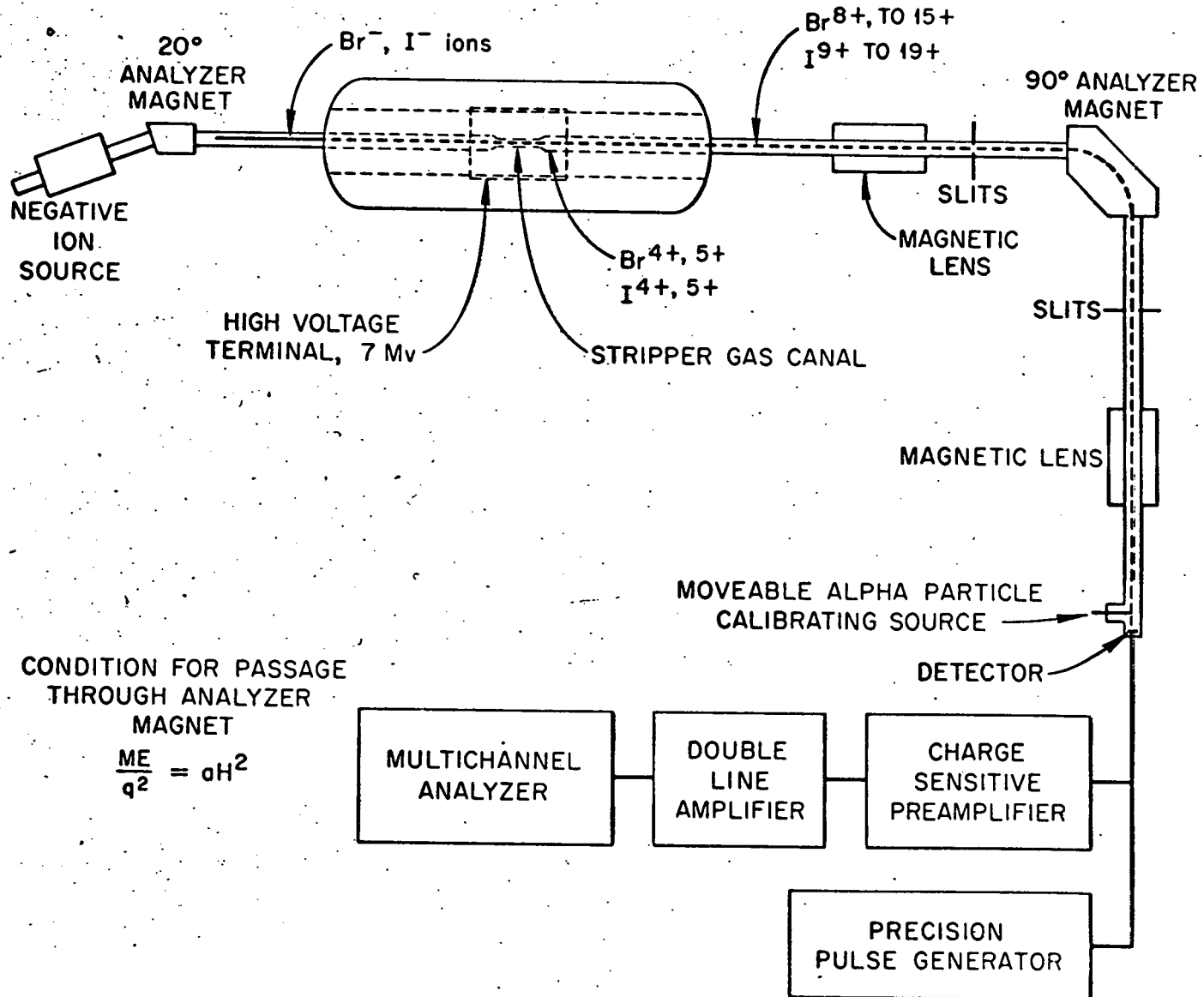
With artificial fission fragments with a spectrum such as this it appears that accurate work can be done to measure the stopping powers of various elements for very heavy ions. One merely observes a pulse height spectrum once, then inserts a suitable absorber foil and measures the shifted lines of the spectrum to get many points on a heavy ion dE/dx curve. Some spectra taken by M. D. Brown and myself, are shown in slide 5. The upper curve is the "no-foil" spectrum. The lower curve was taken with a semicircle of Au evaporated onto a carbon target. The particles going through one side were degraded by carbon alone while those going through the other side were degraded by carbon and gold. Some of the early results, expressed in the usual units of atomic stopping cross-section, are shown in slide 6. The trend with energy illustrates the fact that as the ion slows down its effective charge is reduced and this reduction of charge causes a slow reduction of the stopping power. Theoretical estimates for stopping power in this velocity range were thought not to be reliable and they are not. Derivations of range differences from

the data shown here show that the range of I ions varies almost perfectly linearly with particle velocity. Other measurements will be made for Br ions in the near future.
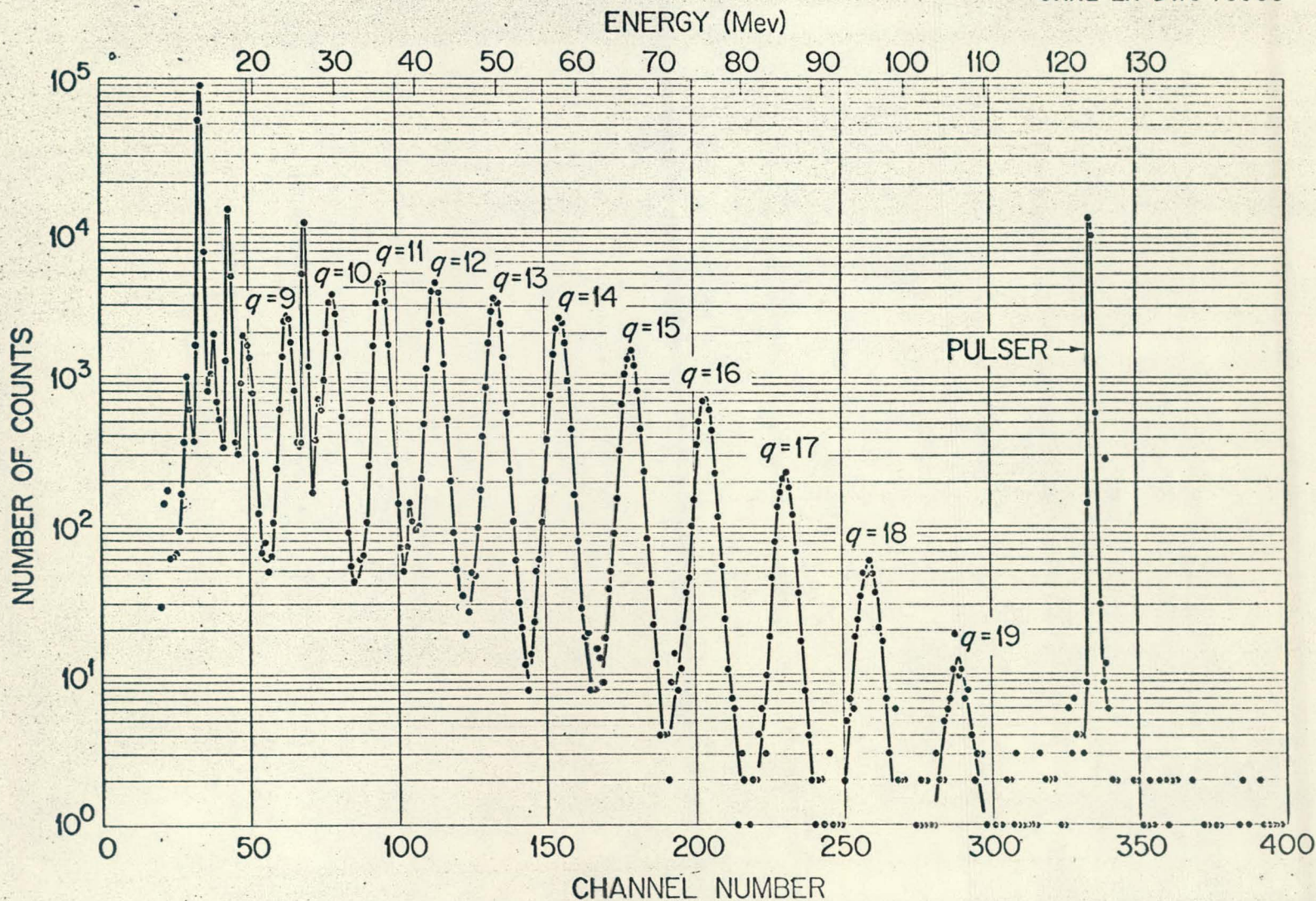
Additional experiments which seem feasible involve simultaneous charge state and energy loss measurements, rates of charge equilibration studies, solid state studies, radiation damage and many others. Although the beams are small ($\sim$ 1 pa.) they seem to be enough to perform many useful experiments.

References

1. Walter, Moak, Neiler, Schmitt, Gibson and Thomas, Bull. Am. Phys. Soc. II, 8 January 1963, JA8.

2. C. D. Moak and M. D. Brown, Phys. Rev. Letters 11, 284 (1963).

20° ANALYZER MAGNET

Br⁻, I⁻ ions

Br^{8+}, TO 15+
I^{9+} TO 19+

90° ANALYZER MAGNET

NEGATIVE ION SOURCE

SLITS

MAGNETIC LENS

$Br^{4+, 5+}$
$I^{4+, 5+}$

SLITS

HIGH VOLTAGE TERMINAL, 7 Mv

STRIPPER GAS CANAL

MAGNETIC LENS

MOVEABLE ALPHA PARTICLE CALIBRATING SOURCE

DETECTOR

CONDITION FOR PASSAGE THROUGH ANALYZER MAGNET

$$\frac{ME}{q^2} = aH^2$$

| MULTICHANNEL ANALYZER | DOUBLE LINE AMPLIFIER | CHARGE SENSITIVE PREAMPLIFIER |

PRECISION PULSE GENERATOR

Arrangement for Measuring Heavy Ion Energies in Semiconductor Detectors

1ˢᵗ Slide

Pulse Height Spectrum of Iodine Ions from the Oak Ridge Tandem Van de Graaff Accelerator. The Ions are Deflected Through a 90° Analyzing Magnet onto a Silicon Surface Barrier Detector.
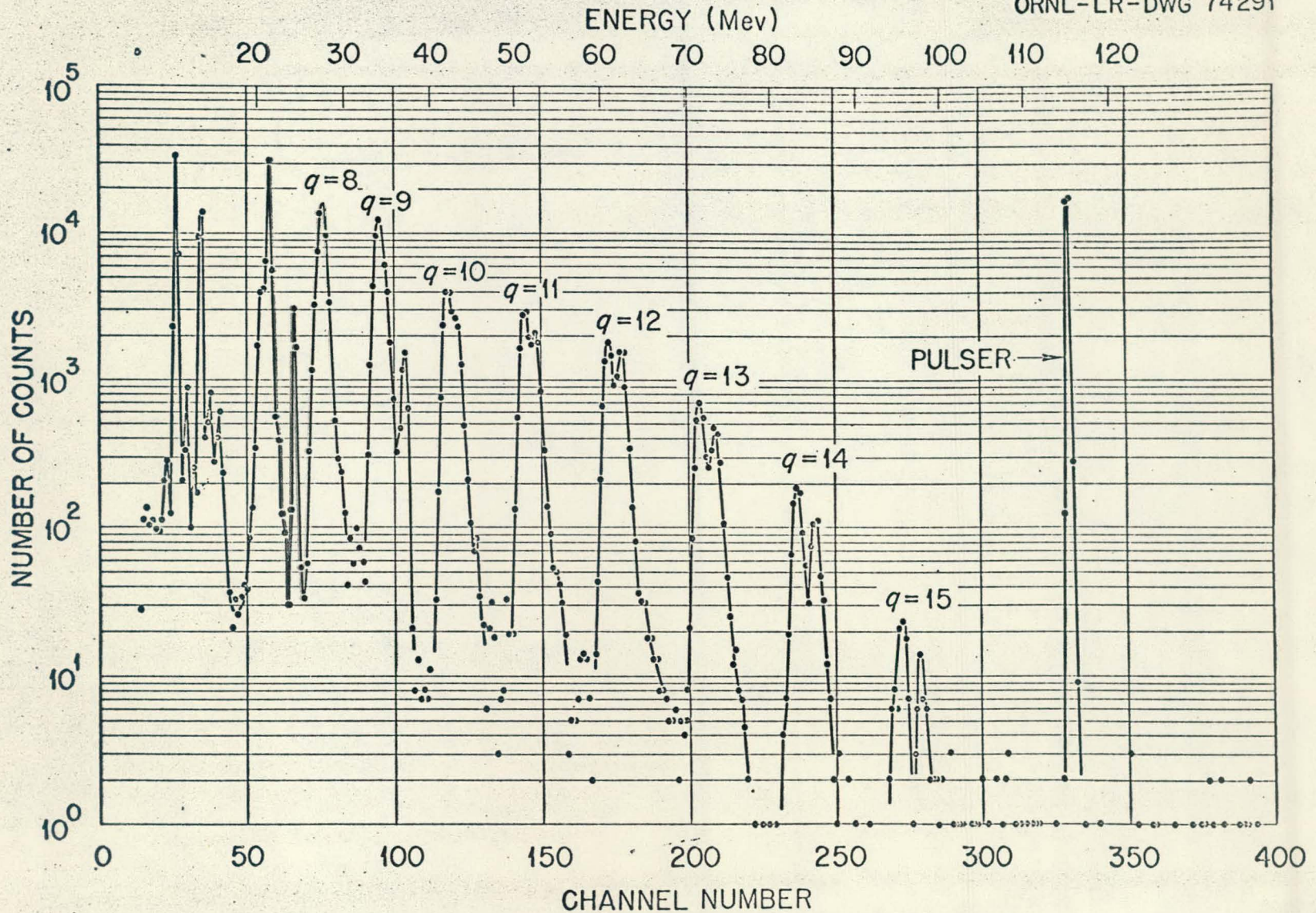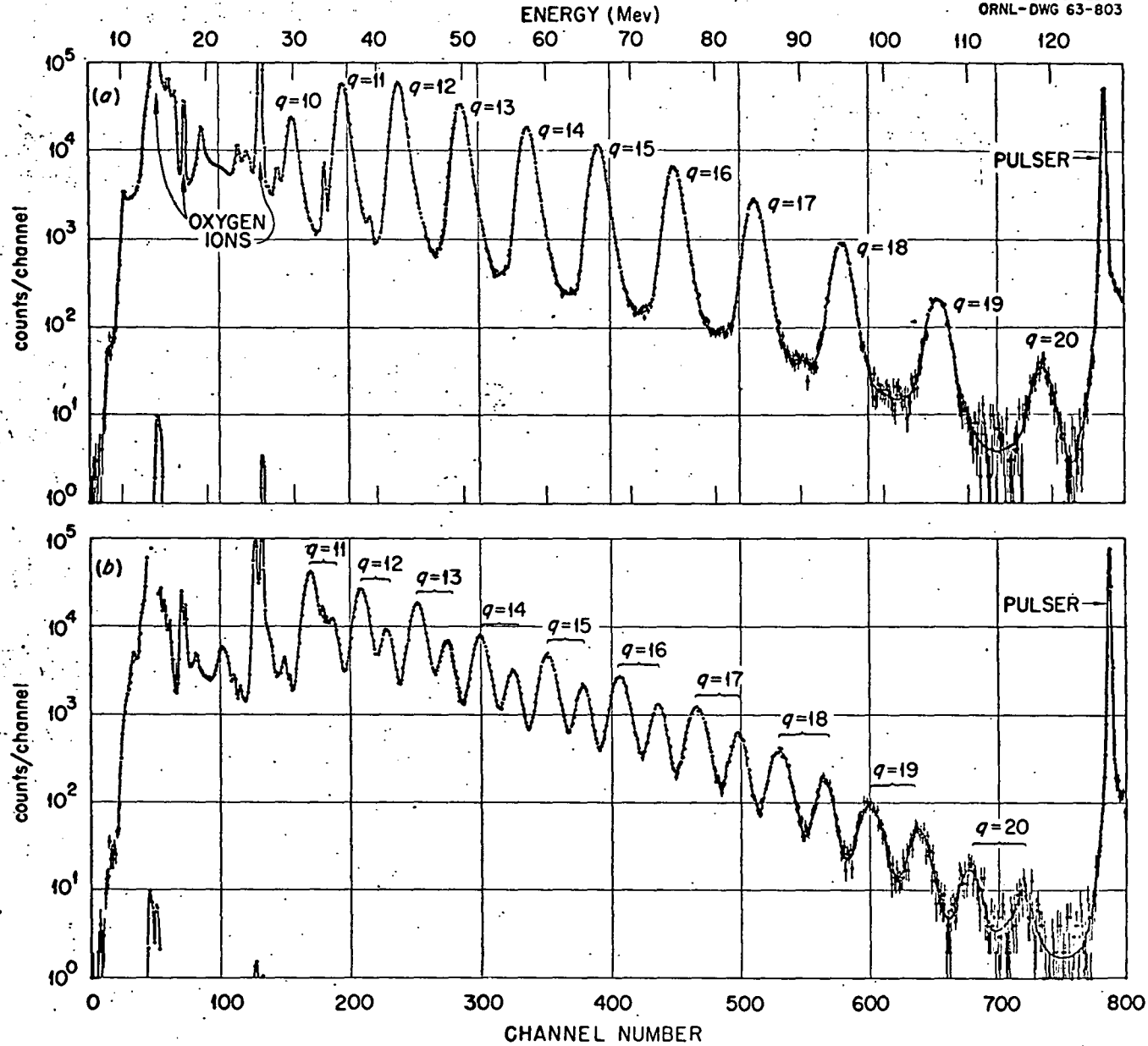
Pulse Height Spectrum of Bromine Ions from the Oak Ridge Tandem Van de Graaff Accelerator. The Ions are Deflected Through a 90° Analyzing Magnet onto a Silicon Surface Barrier Detector.
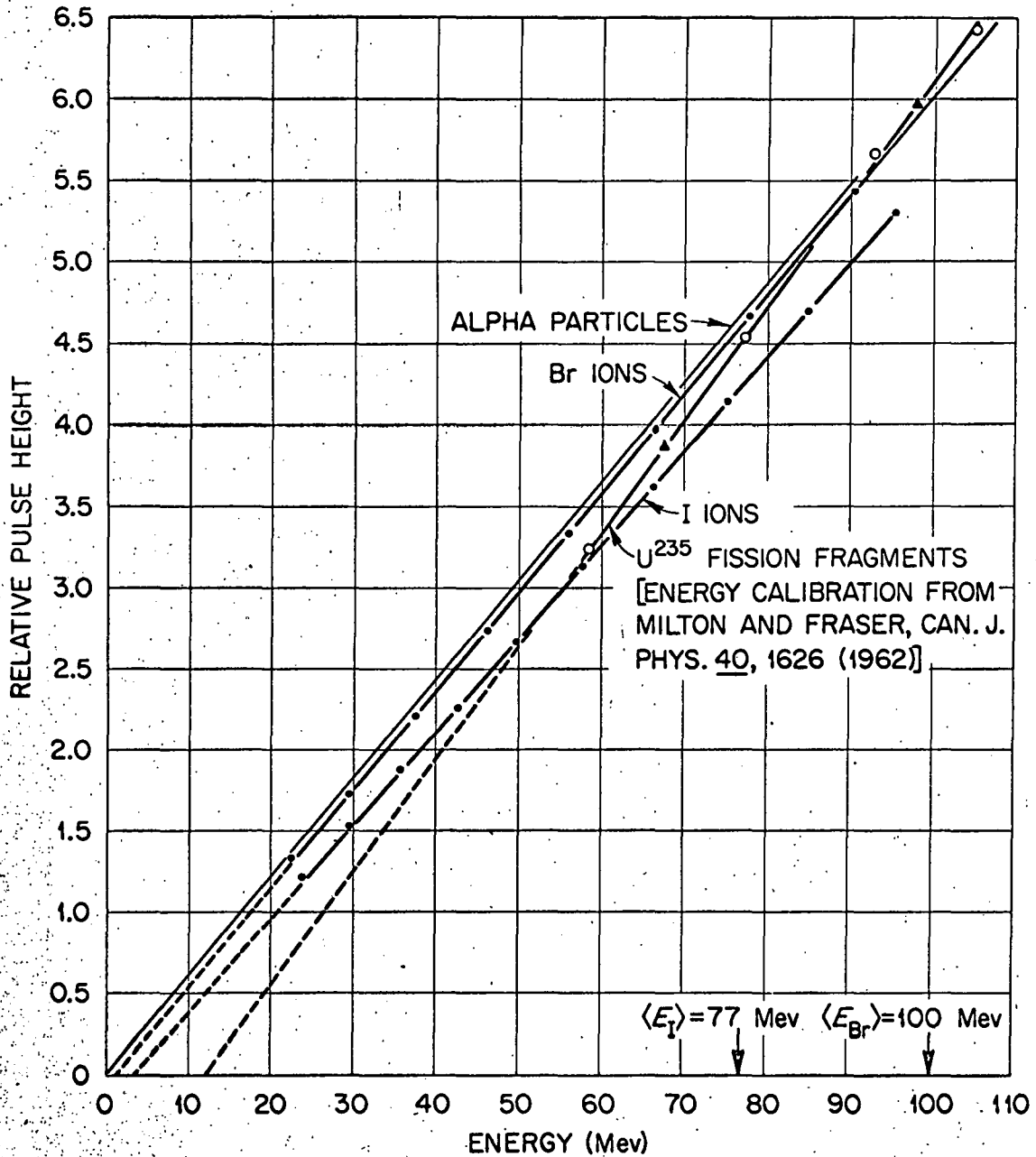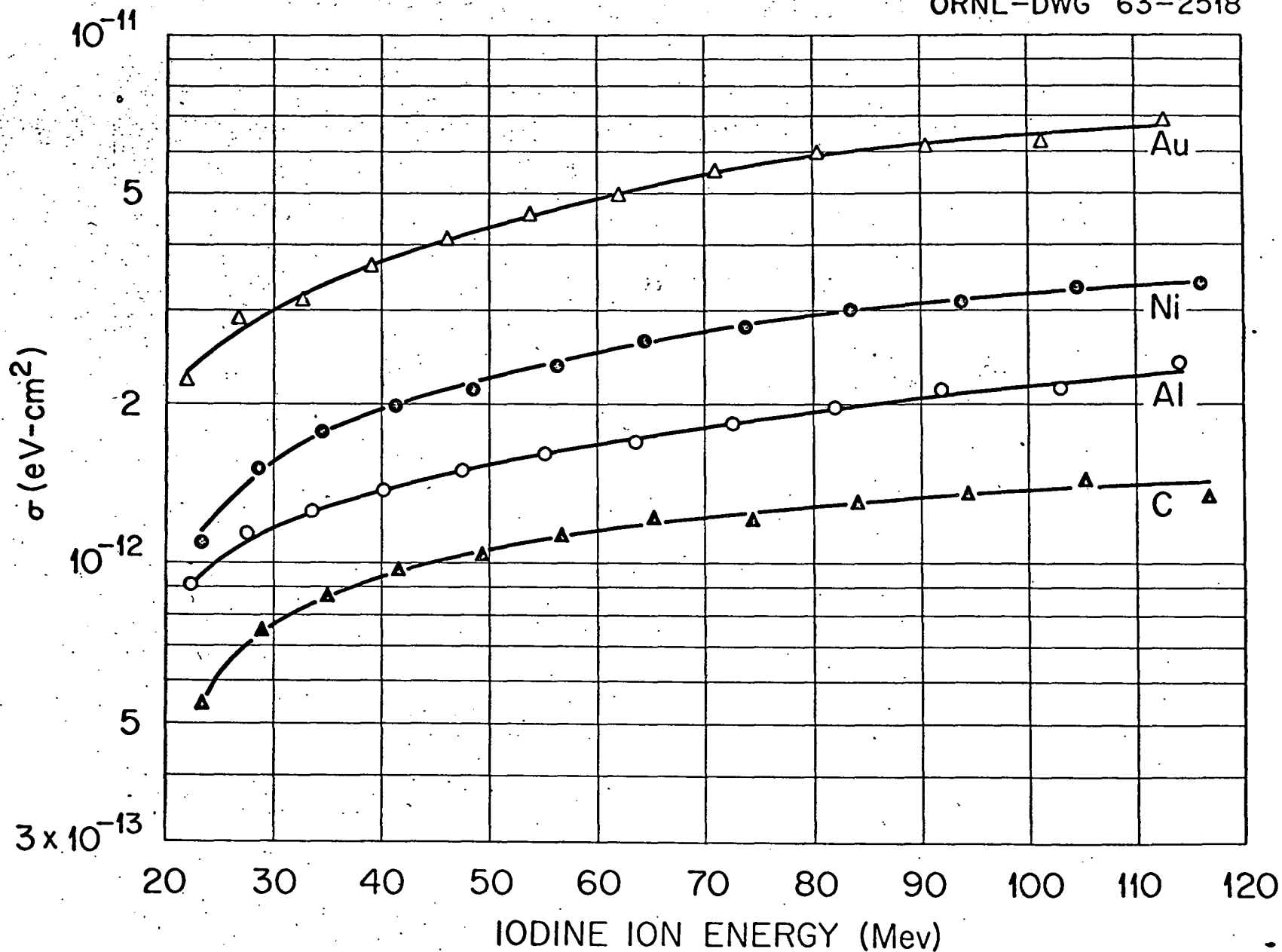
SILICON SURFACE BARRIER DETECTOR, $\rho = 500$ Ω-cm.

Pulse Height vs Energy Relation.

Slide 4

I^{127} Pulse Height Spectra Obtained with (a) no Absorber and (b) 283 μg/cm^2 Au Semicircle on a 37 μg/cm^2 C Foil.

Slide 5

Stopping Cross Section for Iodine Ions in Au, Ni, Al and C.