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The Brazilian Bragg curve detector built for AMS studies

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Abstract

A Bragg curve detector (BCD) has been designed and built to be used for AMS purposes. Its design is described and its performance, obtained in tests at the Australian National University (ANU), is reported. At a ^{36}Cl energy of 154 MeV, the energy resolution was found to be 0.38%, and the charge resolution 1.3%. The ^{36}Cl and ^{36}S are completely discriminated. Good separation was also achieved at 64 MeV, and a measurement at this energy of the ^{36}Cl/Cl ratio of a sample measured previously at 154 MeV with the standard ANU ionization detector agreed well with the earlier value. This very simple detector has been shown to be suitable for use in AMS programs.

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Keywords: Detector; Energy loss; Mass spectrometry

1. Introduction

The Bragg curve detector (BCD) has been designed and built to be used in the Brazilian AMS program. It was based on the Munich group's Bragg curve spectroscopy (BCS) detector [1]. The detector has been designed and built at Universidade Federal Fluminense (UFF) and Universidade de São Paulo (USP) [2,3]. This type of detector has proved to be an interesting alternative to conventional ionization chambers [4,5], for heavy ion detection in AMS studies.

In this paper, the design and characteristics of the detector are described, as well as results from tests of its performance for ^{36}Cl carried out at the Australian National University (ANU).

2. Bragg detector characteristics and design

A Bragg detector has an applied electric field parallel to the incident particle direction and

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sufficient gas pressure to stop the particle [1]. These properties allow the determination of the total energy of the particle, and also of its range in the detection medium. The latter is possible because the detector effectively converts the spatial distribution of electrons produced along the path of the particles in the gas (the so-called Bragg curve) into a time distribution. The duration of the signal is therefore a measure of the range of the particle, which is a function of its A/Z^2 ratio. In addition, projectiles with different nuclear charges have different specific ionization at the maximum of the Bragg curve. A measure of the nuclear charge of the particle may therefore be obtained by integration of the specific ionization around the Bragg peak (E_B), while the total energy (E) is obtained, as usual, from the total ionization.

Fig. 1 is a schematic representation of the Brazilian Bragg curve detector (BBCD), and Fig. 2 is an exploded view of it. This was originally a spare section of accelerator tube for São Paulo's 8UD NEC Pelletron accelerator. It has a cylindrical geometry and contains 12 titanium electrodes (which function as equipotential guard rings for the detector) separated by ceramic rings. The entrance window (aluminized Mylar foil) serves as the cathode.

The electrons produced by the ionizing passage of the particle in the gas drift towards the anode and start inducing a signal when they cross the Frisch grid. The grid consists of parallel 20 μm gold-coated tungsten wires separated by 1 mm. The tube electrodes are 12 mm apart and the Frisch grid is located 10 mm from the anode and 155 mm from the cathode. A constant drift velocity is obtained by applying a uniform electric field between the cathode and Frisch grid. This is accomplished by connecting the electrodes via a chain of 11 resistors, each of 100 kΩ. The anode consists of a circular copper plate with a diameter of 65 mm. The detector connects directly to the end of a beam line.

Bragg curves for 154 MeV ^{36}Cl and ^{36}S ions are shown in Fig. 3. The specific ionizations for the two species were taken from the tables of Northcliffe and Schilling [6]. The Bragg peak is the maximum of the specific ionization, and is larger for ^{36}Cl than for ^{36}S. A signal proportional to the height of the Bragg peak (E_B) is conventionally obtained by using an amplifier with a short time constant, typically 0.25 μs, to produce a pulse which preserves the shape of this Bragg distribution. An alternative means of determining the atomic number, Z, of the incoming ion is to integrate the distribution from the end of the range

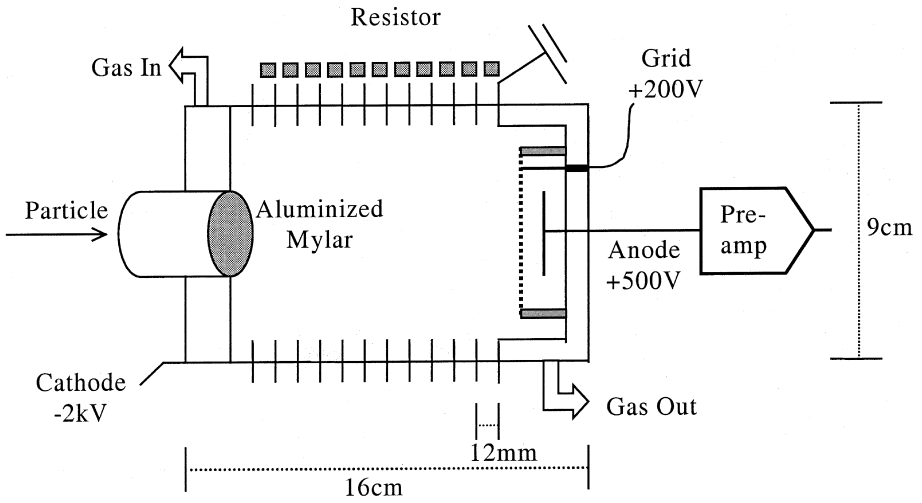

Fig. 1. Schematic layout of the Bragg detector. The entrance window is the cathode, and the indicated voltages correspond to the optimum values for detection of 154 MeV ^{36}Cl.

Fig. 2. An exploded view of the BBCD. The anode is in the front of the figure, with the gas inlet and electrical feedthroughs to the anode and Frisch grid. The entrance window and gas exit are in the flange near the screw. The last two parts are the insulator and adapter flanges for mounting at the end of a beam line.

back to the Bragg peak by using the bipolar output of the amplifier and an appropriate time constant. Both approaches have been employed here.

Separate signals representing the total ionization and the specific ionization at the Bragg peak are obtained by feeding the output of the preamplifier to two shaping amplifiers. One, with a long time constant $\geqslant 6$ μs, integrates the electrons from the full length of the track and provides a total energy signal (E). This permits discrimination against other ions such as ^{12}C, ^{18}O and ^{37}Cl which must have different energies from ^{36}Cl and ^{36}S. The other, with a shorter time constant (<1 μs), provides a signal (E_B) which is sensitive to the Z of the ion. One of the aims of the present study was to determine the value of this time constant which produces optimal separation between ^{36}Cl and ^{36}S.

Table 1 summarises the BBCD's main parameters.

Preliminary tests were performed at the laboratory of the USP [2,3], with ^{35}Cl, ^{37}Cl and ^{36}S beams, with the detector at zero degree and energies of 64.0, 60.5 and 62.4 MeV, respectively. The beams were defocused in order to obtain suitably low counting rates. The Z information was derived conventionally using the unipolar output from the short time-constant amplifier. In these tests the cathode, grid and anode voltages, and the amplifier shaping time were varied. The gas used was P 10, at a pressure of 165 Torr. For the optimum values of the various parameters (cathode, Frisch grid and anode voltages of −1000, +100 and +200 V, respectively, time constants of 6 and 0.2 μs), the energy resolution was found to be $\Delta E(\mathrm{FWHM})/E = 1.7\%$ and the Bragg peak resolution $\Delta E_B(\mathrm{FWHM})/E_B = 1.5\%$.

3. Tests at the ANU 14UD tandem accelerator

In order to test the performance of the BBCD for ^{36}Cl under realistic conditions, the detector was taken to Canberra. Measurements were performed at 154 MeV ($^{36}Cl^{10+}$ at 14 MV), which is the standard energy employed for ^{36}Cl measurements at ANU, and at 64 MeV ($^{36}Cl^{7+}$ at 8 MV), which is the energy available at São Paulo. The standard ANU ^{36}Cl set-up procedure was used during the

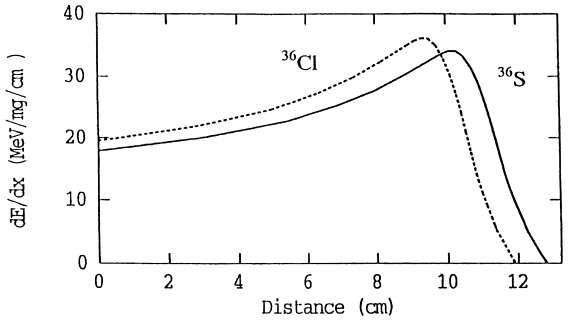

Fig. 3. Specific ionization [6] as a function of the distance into the Bragg detector for 154 MeV ^{36}Cl and ^{36}S ions, for a Mylar window thickness of 2 μm and a propane gas pressure of 164 Torr.

tests. The Z information was obtained from the bipolar output of the short time-constant amplifier (see Section 2). Subsequent tests with a similar detector at a ^{36}Cl energy of 154 MeV have shown that equivalent results are obtained using the bipolar pulse and a time constant of 1 μs or a unipolar pulse and a time constant of 0.25 μs.

During these tests many parameters were checked; the cathode, Frisch grid and anode voltages were varied, as well as the time constant for the Bragg peak signal. Propane was used as the detector gas throughout.

3.1. Tests at 154 MeV

These tests were carried out at a detector gas pressure of 164 Torr, which was sufficient to stop the ^{36}S ions before the Frisch grid. The cathode voltage was varied from −1000 to −2000 V, the anode-grid voltage from 100 to 300 V, and the short time-constant from 0.1 to 1.0 μs. Within this parameter space, the optimal performance was obtained at the maximum value of each of the parameters. Performance was measured in terms of a figure of merit, defined as the ratio of the separation of the ^{36}Cl and ^{36}S peaks in the Bragg signal to their FWHM, i.e.,

$$\text{Figure of merit} = \{E_{\mathrm{B}}(\mathrm{Cl}) - E_{\mathrm{B}}(\mathrm{S})\}/\Delta E_{\mathrm{B}}(\mathrm{FWHM}).$$

At optimal performance, this figure of merit was 4.6 with an estimated uncertainty of 5%. The corresponding charge resolution, $\Delta Z/Z$, is 1.3% ($\Delta Z/Z = 1/Z_{\mathrm{av}} \times 1/[\text{Figure of merit}]$, where Z_{av} was taken to be 16.5). Resolutions of 0.38% on total energy and 0.75% on the Bragg signal were obtained under these conditions. Fig. 4 shows the biparametric spectra, together with the projections on to the total energy and energy loss axes, obtained for an AgCl sample with a ^{36}Cl/Cl ratio of 5.4×10^{-12}.

Table 1
Parameters of the Brazilian Bragg curve detector

Cathode to grid distance	155 mm
Grid to anode distance	10 mm
Grid wire diameter	20 μm
Grid wire spacing	1 mm
Cathode window diameter	27 mm
Cathode window thickness	1.7 μm (230 μm/cm^2)
Grid efficiency	98.3%
Geometrical transmission	97.5%
Gas	P 10 (10% CH_4, 90% Ar) or propane (C_3H_8)

The sensitivity of the detector response to the various parameters was as follows.

1. *Cathode voltage*. The pulse heights of both the E and E_{B} signals increased almost linearly with increasing voltage, and resolutions also improved, although less dramatically. Concerns about high-voltage breakdown across the insulator between beam line and detector prevented the exploration of higher values.
2. *Anode-grid voltage*. Significant gains in pulse-height and resolution were observed up to 200 V, but only marginal changes beyond this.
3. *Time constant*. The figure of merit increased by almost a factor of three between 0.1 and 1.0 μs. Note that the maximum separation between ^{36}Cl and ^{36}S was actually observed at 0.5 μs, but the improvement in resolution at 1.0 μs more than compensated for the reduction in separation leading to a higher value for the figure of merit at 1.0 μs. Because the separation decreases rapidly at longer time constants, the value of 1.0 μs is expected to be optimal.

3.2. Comparison of Bragg detector performance with the standard ANU ionization chamber

The standard ANU ionization chamber [7] normally used for ^{36}Cl measurements is a multi-

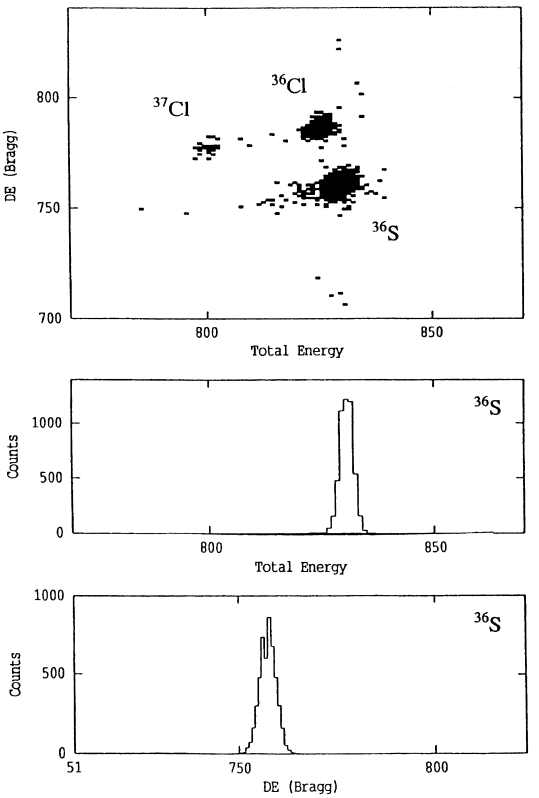

Fig. 4. Biparametric spectra of the Bragg peak versus total energy, and projections of the ^{36}S group (a simple rectangular box is sufficient to exclude any counts from chlorine ions) on to the total energy and energy loss axes, for $E_{Lab} = 154$ MeV. Detector voltages were – 2 kV for the cathode, 500 V for the anode and 200 V for the Frisch grid. The amplifier time constant for the Bragg (bipolar) signal was 1.0 μs. For these conditions, the electron drift velocity is $v_d = 3.6$ cm/μs. The horizontal axis is in channels.

anode device which collects electrons transversely to the particle track through the gas. Energy resolution for 154 MeV chlorine and sulphur ions is 0.6%. The 0.38% resolution of the Bragg curve detector is clearly somewhat better than this.

The two types of detector, however, achieve their Z discriminations in rather different ways, so that resolution alone of the energy-loss signal is not the only consideration.

1. In the ionization chamber, the electrons are collected transversely to the track over fixed lengths of track. Because the ranges of the two species are different, large differences in signal are obtained from an electrode spanning a portion of the track to the right of the crossover of the two Bragg curves (Fig. 3). The resolution of this signal is poor due to range straggling, but this may be balanced by the large separations achieved. In fact, similar figures of merit to that achieved with the Bragg detector are obtained from this "residual energy" signal. A possible advantage of the multi-anode configuration is that several signals are obtained, which provides some redundancy in ion identification, and assists in the elimination of "tail" events.
2. In the Bragg detector, on the other hand, electrons are collected from a fixed length backwards from the end of the track, wherever that is, and hence the signal is relatively immune to range straggling and the resolution is very good. On the other hand, the difference in signal height between the two ion species is substantially less than that obtained from the final electrode of the ionization chamber because the Bragg detector is not exploiting the difference in range.

3.3. Tests at 64 MeV

A similar array of tests were performed at this lower energy. The detector gas pressure of 56 Torr was chosen so that the ions travelled about the same distance into the detector as they did at 154 MeV. The cathode voltage was varied from −800 to −1400 V, the anode-grid voltage from 100 to 300 V, and the time constant from 0.5 to 1.0 μs. Within this parameter space, optimal performance was achieved at −800 V, 300 V and 0.5 μs, respectively, though the figure of merit was less sensitive to variations around these values than at the higher energy and pressure. A value of 2.1 was obtained for the figure of merit, which corresponds to $\Delta Z/Z = 2.9\%$. Resolutions of 0.8% and 2.2% were observed for E and E_B, respectively.

Note, however, that operation at higher pressure should in principle give superior performance at the lower energy. If the pressure had been retained at the value of 164 Torr used at the higher energy, the shape of the Bragg peak would not have changed – it would simply have moved much closer to the window. In the absence of any dis-

persion of the electrons as they drift through the detector, and with the same voltages and time constant, the Bragg signals should therefore be the same at the two energies. An even closer match between the performance at the two energies should be possible by making the detector shorter for the lower energy, so that the Bragg peak to grid distance is the same as at the higher energy with the present detector. It should then be possible to achieve the same figure of merit at the lower as at higher energy.

4. Measurement at 64 MeV, with the BBCD, of a ^{36}Cl sample previously measured at 154 MeV with the ANU ionization detector

Under the conditions mentioned above, ($E_{lab} = 64$ MeV, voltage: −800 V for the cathode, 380 V for the anode and 80 V for the Frisch grid and time constant 0.5 μs), we have measured a known sample. The result was: $^{36}Cl/Cl = (5447 \pm 175) \times 10^{-15}$, which is in reasonable agreement with the previously measured value of $^{36}Cl/Cl = (5155 \pm 160) \times 10^{-15}$, using an energy of 154 MeV and the ANU ionization detector. This indicates that the BBCD is suitable for use in the AMS program on the 8UD accelerator at São Paulo, where the available ^{36}Cl energy is 64 MeV.

5. Conclusions

The results obtained in these tests at the ANU have largely confirmed the conclusions from the first test at the 8UD Pelletron accelerator (USP), and indicate that the detector is suitable for quantitative ^{36}Cl measurements. Therefore, a very simple detector, such as the one described in this paper, is suitable for use in AMS programs.

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