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STATUS OF THE BERKELEY SMALL CYCLOTRON AMS PROJECT

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Abstract

A small, low-energy cyclotron has been designed and built at Berkeley for direct detection dating of ^{14}C. The system combines the use of a negative ion source to reject ^{14}N with the high resolution of a cyclotron to reject other background ions. In order to allow the dating of old and small samples, the present system incorporates a high-current external ion source and injection beamline. The system is expected to be operational by mid-1987.

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1. Introduction

In response to the heavy demand and relatively high cost of existing accelerator mass spectrometry (AMS) techniques, the small cyclotron AMS project was born at Berkeley in 1981 [1]. The basic idea was to combine the excellent properties of a cyclotron used as a mass spectrometer [2] with the capabilites of negative ion sources to reject unwanted backgrounds such as ^{14}N [3]. A device was envisioned which would be:

1) low cost--low enough to be affordable by an individual research group (under $100,000)

2) small in size--so that it could be installed in a standard laboratory room

3) easy to operate--so that a full time accelerator operator would not be needed

4) low energy (less than 50 keV)--to avoid the dangers and inconveniences of induced radioactivity

5) designed for operation with ^{14}C, ^{10}Be, and other light radioisotopes.

Our initial work has emphasized ^{14}C, partially because of the many users interested in this isotope, and partially because the required resolution and beam currents are relatively easy to obtain.

2. Design Considerations

Design of a small, low-energy accelerator for ^{14}C dating presents numerous challenges [1,4-7]. The requirement of low energy operation precludes use of dE/dx techniques to distinguish between ^{14}C and other isotopes. Thus, it was decided to operate with negative ions and to use a cyclotron [1]. Use of negative ions avoids contamination with ^{14}N, which, although very close in mass (1 part in 83,000), does not form negative ions. A cyclotron offers the possibility of high mass resolution and tail rejection due to many gap crossings and operation at a high harmonic [1]. The low energy output (less than 50 keV) also results in interesting beam detection challenges. To meet these, a custom microchannel plate detector was designed and built which offers high sensitivity, low background count rate, and sufficient energy resolution to distinguish 30 keV ions from lower energy background ions [8,9].

Mass resolution and tail rejection requirements for ^{14}C operation place stringent limitations on a cyclotron [4-6]. The cyclotron must resolve ^{14}C from ^{13}CH, which differs in mass by 1 part in 1800 yet may be present in the beam with an intensity 10^8 to 10^{10} times greater. Attaining this resolution without sacrificing transmission efficiency necessitates isochronous orbits, precluding the use of a radial magnetic field gradient for focusing purposes. It was decided to focus the beam by electrostatic focusing alone, and to operate the cyclotron at a high harmonic to achieve the required resolution.

Based on these ideas, a small cyclotron was designed and constructed at Berkeley [5,6]. A 12-inch NMR-type laboratory magnet was used, capable of a 10 kG field. A 3 keV negatively-charged carbon beam was generated in the central region by cesium sputtering and injected into the dees on an orbit with a 3 cm radius. The beam was accelerated to about 40 keV until extracted by an electrostatic channel at a 10 cm radius. The extracted beam was then detected by the microchannel plate detector. The design, operation, and performance of this system is explained in detail in refs. [5-7].

3. Performance

System performance is illustrated by the mass resolution curve shown in fig. 1, operating at mass 12 on the 11th harmonic. The horizontal axis is calibrated in frequency, which is inversely related to mass. The count rate dropped 10.7 orders of magnitude from the peak to the background with less than 1 part in 1800 frequency (mass) offset. This resolution is adequate for ^{14}C dating.

Unfortunately, ^{14}C was not detectable because its count rate was below the background of 3 counts per hour. This low count rate was due to the performance of a compact ion source located in the central region of the cyclotron. This simple internal ion source eased development and testing of the system, but it could only produce a maximum of about 1 nA of C^-, which was not enough to see ^{14}C even in modern carbon. The system efficiency (fraction of $^{14}C^-$ reaching the detector) was about 0.5 to 1 percent [5,6], which is acceptable.

The performance of the small cyclotron was quite promising. The resolution and tail rejection were adequate for ^{14}C dating, and efficiency was acceptable. This indicated that a useful device could be built if a higher current ion source were incorporated. A factor of 50 higher current was needed to barely see ^{14}C in modern carbon, another factor of 50 for 30,000 year old samples, and another factor of 2 or so for a reasonable signal-to-noise ratio. Thus, an ion source with about 5000 times higher current was needed.

4. Current System Design

It was obvious that an external high-current ion source was necessary to provide the necessary beam current. What was not so obvious, however, was how to inject this beam into the cyclotron.

In large cyclotrons the beam is typically injected axially into the central region of the cyclotron. The beam is then deflected 90° into the orbit plane. This approach was considered, but was deemed unacceptable for the small cyclotron. Axial injection would have required boring a hole through the center of the magnet pole piece, disturbing magnetic field uniformity (and thus orbit isochronicity). Further, beam transport through the center of a nearly saturated magnet pole is unpredictable and magnetic-field dependent. Thus, axial injection was rejected.

A radial injection scheme was proposed for this device by Morris [10]. The geometry shown in fig. 2 was finally decided upon. The beam is injected into the magnetic field region radially and then deflected in an electrostatic channel. It curves through a 180° arc, whereupon it strikes an electrostatic mirror at normal incidence. After reflection the beam travels along a circle which is nearly centered on the cyclotron axis. A final electrostatic deflection channel shifts the beam orbit slightly to center it and to provide clearance between the electrostatic mirror and the beam's first orbit.

Beam enters the dee gap at a radius of 3.8 cm and an energy of 5 keV. It is subsequently accelerated to about 35 keV after 50 to 100 turns and extracted through an electrostatic deflector at a radius of 9.8 cm. After leaving the magnetic field region, the beam enters a magnetically-shielded enclosure containing the microchannel plate detector [8,9]. There it impinges upon an aluminum dynode, ejecting secondary electrons which are collected and multiplied in the microchannel plate. The edge focusing when the beam leaves the cyclotron magnet is sufficient to nearly focus the beam in one dimension (axially) when it reaches the aluminum dynode of the detector, matching the detector's acceptance quite well.

Much control is needed of beam characteristics (beam position, beam width, and focal plane locations) on injection into the cyclotron. A combination of four electrostatic quadrupole lenses provides the needed flexibility. By independent adjustment of the powers of the four lenses, control is gained over the four degrees of freedom associated with beam focal properties. Beam steering may be accomplished by driving the quadrupoles asymmetrically; this allows adequate control of the four additional degrees of freedom associated with beam position.

Prior to the quadrupoles, a Wien filter is used to separate mass twelve and thirteen components from mass fourteen. This performs the dual purpose of reducing the ion load entering the cyclotron (including elimination of the high energy tails from ^{12}C and ^{13}C) and allowing ion source output to be monitored. Ions emanating from a slit are re-focused to a slit by the Wien filter's focal properties, where the ^{12}C and ^{13}C currents are collected (fig. 3).

The beam must be focused from the ion source into the first slit. The beam produced by the source is strongly divergent. High current ion sources are typically operated with high energy beams (20 keV or so); beam divergence is much greater with the small cyclotron's injection energy of 5 keV. To capture and slightly focus this beam an einzel lens is used. An electrostatic quadrupole lens focuses and steers the beam into the entrance slit of the Wien filter.

These design considerations result in the system geometry shown schematically in fig. 3. The cyclotron is dwarfed by the injection beamline. By careful design of the lenses and by fixing some degrees of freedom of the system, this injection system could shrink by a factor of two or so. The present size is useful for system development, however, since it allows additional flexibility in the positioning of beam optics.

A beam buncher has been suggested for the small cyclotron, since RF phase acceptance is small [5,6]. The present design allows insertion of a short buncher in the beam line. Alternatively, one could use one or two of the quadrupole lenses for beam bunching by coupling an RF signal to the lens electrodes.

4. Current Status

The mechanical hardware for this system has been constructed and about 90% has been assembled. Some electrical hardware remains to be built and internal wiring for lenses and current monitors has not yet been completed. The system has not yet been aligned or tested.

A commercially-available cesium sputter source has been purchased from General Ionex, capable of producing at least 10 µA of carbon current. This has been integrated into the system and cooling lines have been installed for its operation. An asymmetric einzel lens, similar to that described by Drummond [11], has been built and installed.

Quadrupole lenses have been made with a bore of 4.4 cm and a length of 10 cm. Less than 500 volts on the electrodes is sufficient for focusing. Power supplies have been designed to allow easy control of lens powers and beam deflections, but have not yet been constructed.

A Wien filter has been designed and machined, incorporating a small samarium cobalt permanent magnet structure. The entire assembly is housed in vacuum. It produces a 4 kG magnetic field in a 2.2 cm gap over a length of about 12 cm. Field uniformity is designed to be better than 1% in a 1 cm x 1 cm central region. The electric field is produced by applying about 3 kV between two parallel plates; the edges of the plates are electrically connected by a high-resistivity conducting sheet (about 300 MΩ per square) to eliminate electric field distortion due to edge effects.

The electrostatic deflectors and electrostatic mirror have been designed and constructed. Copper dees have been built with an 8 mm inside height, as in the previous version of the small cyclotron [5,6]. These components are shown in fig. 4. The dee probe, electrostatic extractor, and ion detector from the previous version are still used. A magnetically-shielded steel enclosure has been built to hold the ion detector.

The entire system, at present, is shown in fig. 5. The vacuum chamber and optical elements have been built and assembled. Wiring, alignment, and some supporting electronics assembly must still be done. It is expected that the system will be operational by mid-1987.

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References

[1] R.A. Muller, T.S. Mast, P.P. Tans, and J.J. Welch, Proc. Symp. on Accelerator Mass Spectrometry, Argonne Nat. Lab Report ANL/PHY-81-1 (1981) 342; Lawrence Berkeley Laboratory Report LBL-12797 (1981)

[2] R. A. Muller, Lawrence Berkeley Laboratory Report LBL-5399 (1976); Science **196**, (1977) 489.

[3] D. E. Nelson, R. G. Korteling, W. R. Stott, Science **198**, (1977) 507; C. L. Bennett, R. P. Beukens, M. R. Clover, H. E. Gove, R. B. Liebert, A. E. Litherland, K. H. Purser, W. E. Sondheim, Science **198**, (1977) 508.

[4] J.J. Welch, K.J. Bertsche, P.G. Friedman, D.E. Morris, R.A. Muller, and P.P. Tans, Proc. AMS '84, Nucl. Instr. and Meth. B5 (1984) 230.

[5] J.J. Welch, PhD Thesis, Lawrence Berkeley Laboratory Report LBL-21255 (1984).

[6] J.J. Welch, K.J. Bertsche, P.G. Friedman, D.E. Morris, R.A. Muller, Nucl. Instr. and Meth. **B18** (1987) 202.

[7] J.J. Welch, K.J. Bertsche, P.G. Friedman, D.E. Morris, R.A. Muller, Proceedings of the U.C.-Cal Tech AMS Workshop, Feb. 15, 1986, to be published (1987).

[8] P.G. Friedman, PhD Thesis, Lawrence Berkeley Laboratory Report LBL-17804 (1986).

[9] P.G. Friedman, K.J. Bertsche, M.C. Michel, D.E. Morris, R.A. Muller, P.P. Tans, J.J. Welch, to be published, Rev. Sci. Instr. (1987).

[10] D.E. Morris, Nucl. Instr. and Meth. A248 (1986) 297.

[11] I.W. Drummond, Vacuum **34** (1984) 51.

Figure Captions

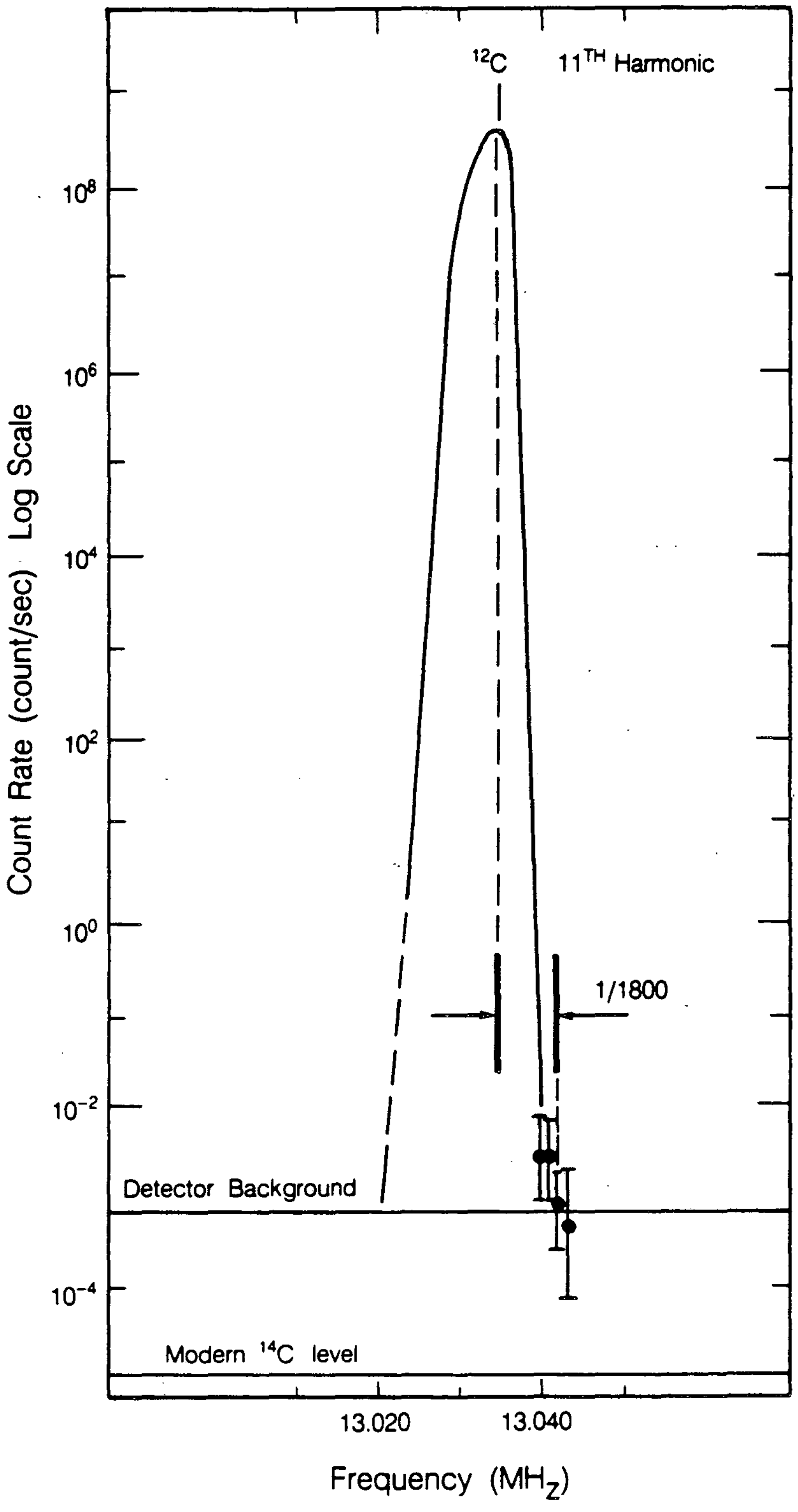
Fig. 1. Tuning curve of the small cyclotron at mass 12, obtained by accelerating a beam of $^{12}C^-$ on the 11th harmonic of the cyclotron frequency. This is effectively a plot of mass resolution, as mass is inversely proportional to frequency. From ref. [5,6]

Fig. 2. Radial injection geometry for the small cyclotron. Arrows show the path of a typical ion as it is injected from the left and is made to orbit the cyclotron axis by passage through electrostatic deflectors and a mirror. After 50 to 100 turns, it exits through another electrostatic deflector and is sent to an ion detector.

Fig. 3. Beam injection scheme for the small cyclotron. The magnet is 30 cm in diameter and the beamline is about 1.2 m long.

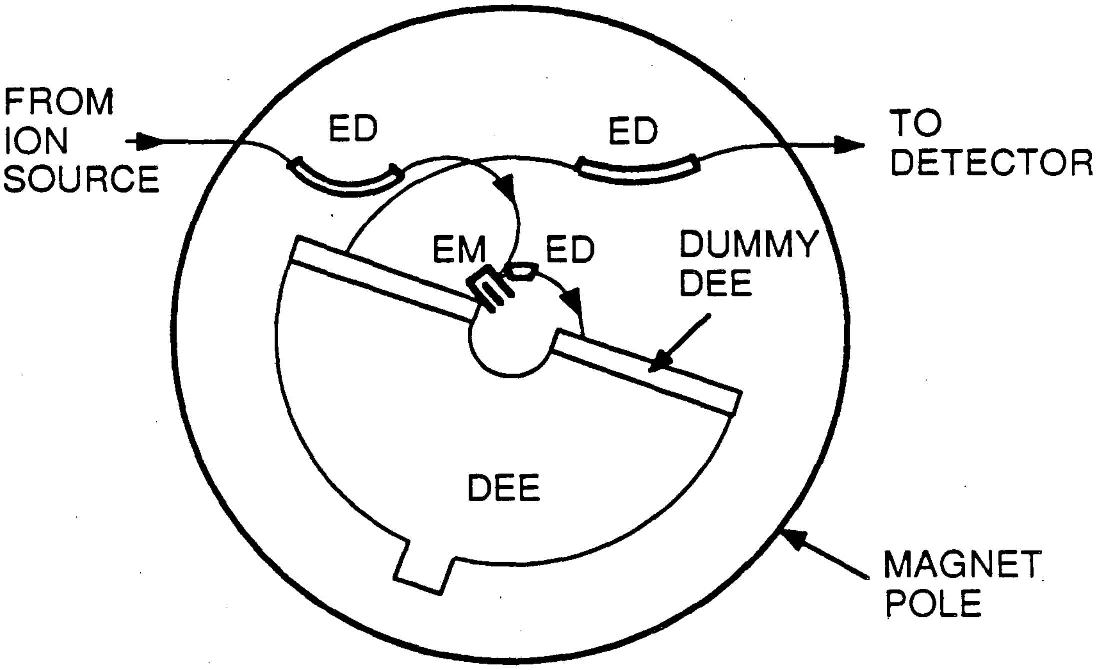
Fig. 4. Central portion of the small cyclotron, designed for radial injection. Compare with fig. 2.

Fig. 5. Overall view of the small cyclotron system. The ion source is in the foreground at the left. The large tank in the center contains the beamline. A current probe is shown being inserted into the dee region.



XBL 8410-8777

Fig. 1



ED = ELECTROSTATIC DEFLECTOR
EM = ELECTROSTATIC MIRROR

XBL 874-1818

Fig. 2

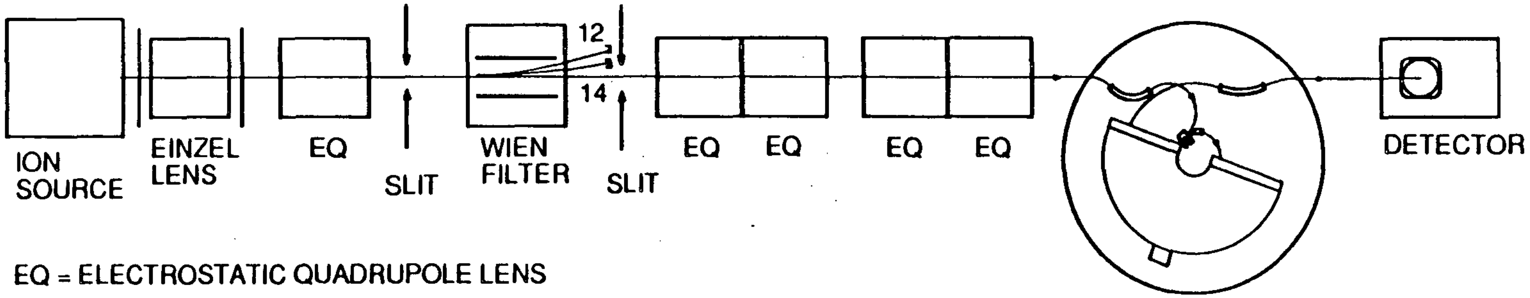


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Fig. 3

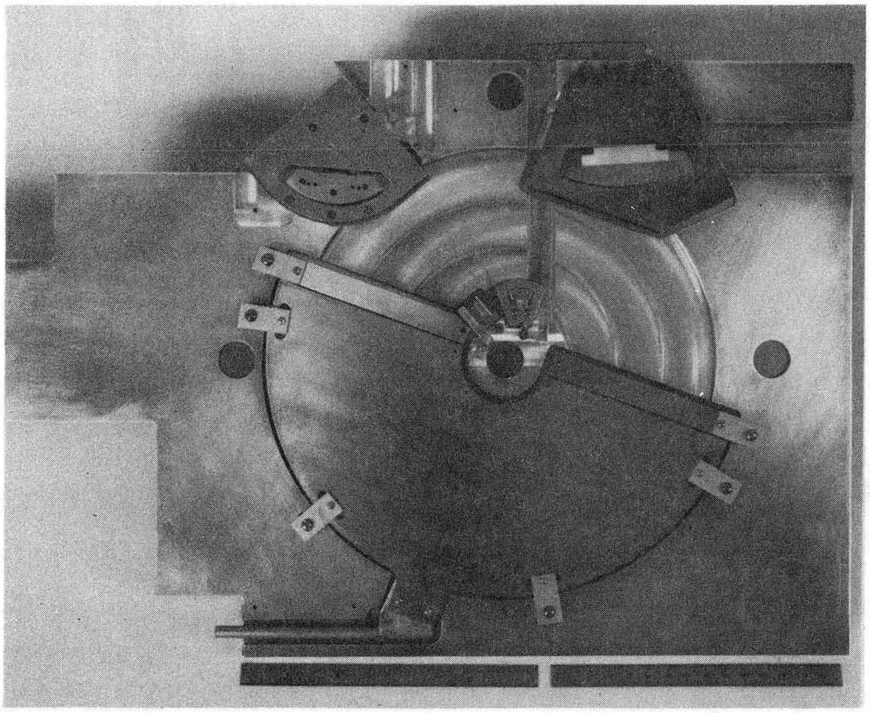

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Fig. 4

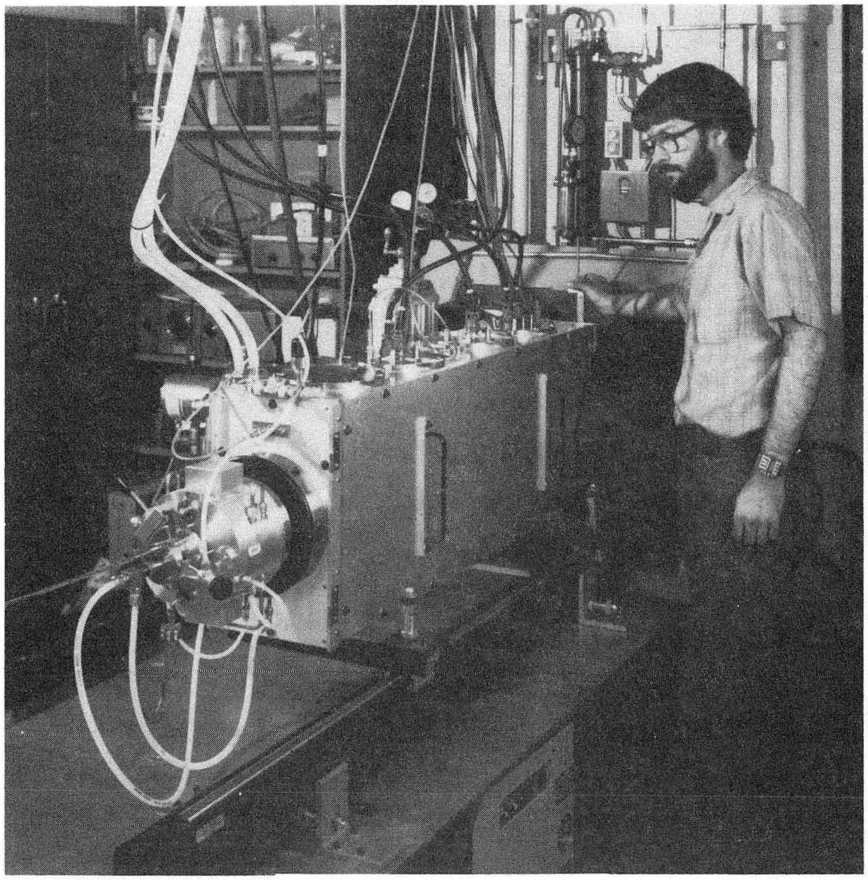

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Fig. 5

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