Zeitschrift: Helvetica Physica Acta

Band: 34 (1961)

Heft: [6]: Supplementum 6. Proceedings of the International Symposium on polarization phenomena of nucleons

Artikel: The polarized proton source for the Minnesota Linear Accelerator

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DOI: https://doi.org/10.5169/seals-513257

The Polarized Proton Source for the Minnesota Linear Accelerator

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Summary. The complete vacuum system with all essential parts is assembled in the final location and is working satisfactorily. The ion current extracted from the ionizer was measured with a collector, because the source is not yet connected to the accelerating column of the 500 kV injector. The result so far is a corrected (for residual pressure change) current increase of about 100% when the beam shutter is opened.

General Remarks

A source of polarized protons for injection into the Minnesota Linear Accelerator is being constructed. It is based on a principle mentioned in the work of CLAUSNITZER, FLEISCHMANN, SCHOPPER [1][2]). A neutral hydrogen atomic beam is passed through an inhomogeneous magnetic field in which the different magnetic states are separated. Because of intensity problems, no effort will be made to separate the four hyperfine structure components in a weak field. Instead a strong field deflection is used, where the decoupled spin states $m_j = 1/2, m_i = \pm 1/2$ are separated from the $m_j = -1/2$ states. Then the beam passes into a weak magnetic field, where it is ionized. The atoms follow the field adiabatically [2], forming coupled states $f = 1$, $m_f = 1{,}0$ resulting in a nuclear spin orientation of 0,5. With this method it is possible to shorten the field considerably, allowing therefore a greater aperture of the beam. By ionizing these atoms in a weak field, polarized protons can presumably be extracted.

Since the injector of the Linear Accelerator is on a positive 500 kV potential, the whole ion source has to be on this potential. This seems to involve great difficulties because of weight, space and power needs of this special source. The finally accepted design is shown in figure 1.

The neutral hydrogen atoms are polarized on ground potential, leaving the whole high speed vacuum system there. The hydrogen beam is allowed to travel a distance of 2 meters in an insulating column and is ionized at the high potential by electron bombardment.

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[1]) On leave of absence from Universität Erlangen, Germany.

[2]) Numbers in brackets refer to References, page 47.

The necessary pit underneath the injector for the atomic beam apparatus was finished in January 1960, the equipment moved in, connected and aligned afterwards. The ionizer chamber with two Vacion pumps was fitted into the very limited space of the injector. The connection of the two systems is made by a Pyrex glass column. The whole system was completely assembled in June 1960 and test runs were made.

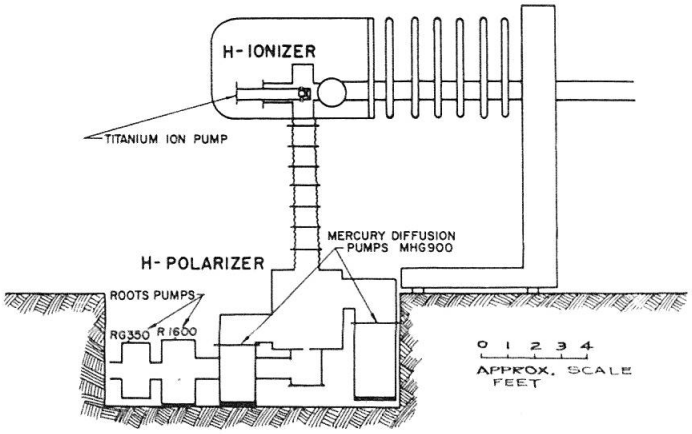

Figure 1
General design schematic of the polarized proton source

The cross section of the source is shown in figure 2; the details will be discussed in the following sections.

The Dissociation Chamber

In order to produce an intensive hydrogen atomic beam, we followed the work of BECKER and BIER [3] and KISTIAKOWSKY and SLICHTER [4], who showed that high intensity beams can be produced by using a supersonic mass flow through specially shaped nozzles. The dissociation is made by a low voltage arc discharge, which the molecules have to traverse.

This chamber was first built up according to the design described in the Progress Report of 1958 [5]. Extensive tests with different filament geometries and materials, nozzle geometries, electrode distances and gas mixtures (Helium admixtures) gave a hydrogen beam with a maximum dissociation degree of about 5%. From gas consumption measurements one could derive a flux of about 10^{21} particles/s through the first nozzle. Besides other troubles (Teflon insulators start burning when the pressure drops below 10 mm and discharge occupies the whole chamber) this scheme seemed rather unsatisfactory, because with the chosen pump units one could not obtain the necessary atomic beam intensity.

For the new design (see figure 3) the two filament supports were replaced by one water cooled support for the negative arc electrode, which was adjustable to change the electrode distance. A Pyrex plate was used for insulation and rubber O-rings for gasketing. The inner part of the nozzle was changed, so that the closest distance of the electrodes was very near to the hole of about .6 mm diameter. The size of the nozzle is not critical, because the pressure in chamber No. 1 can always be

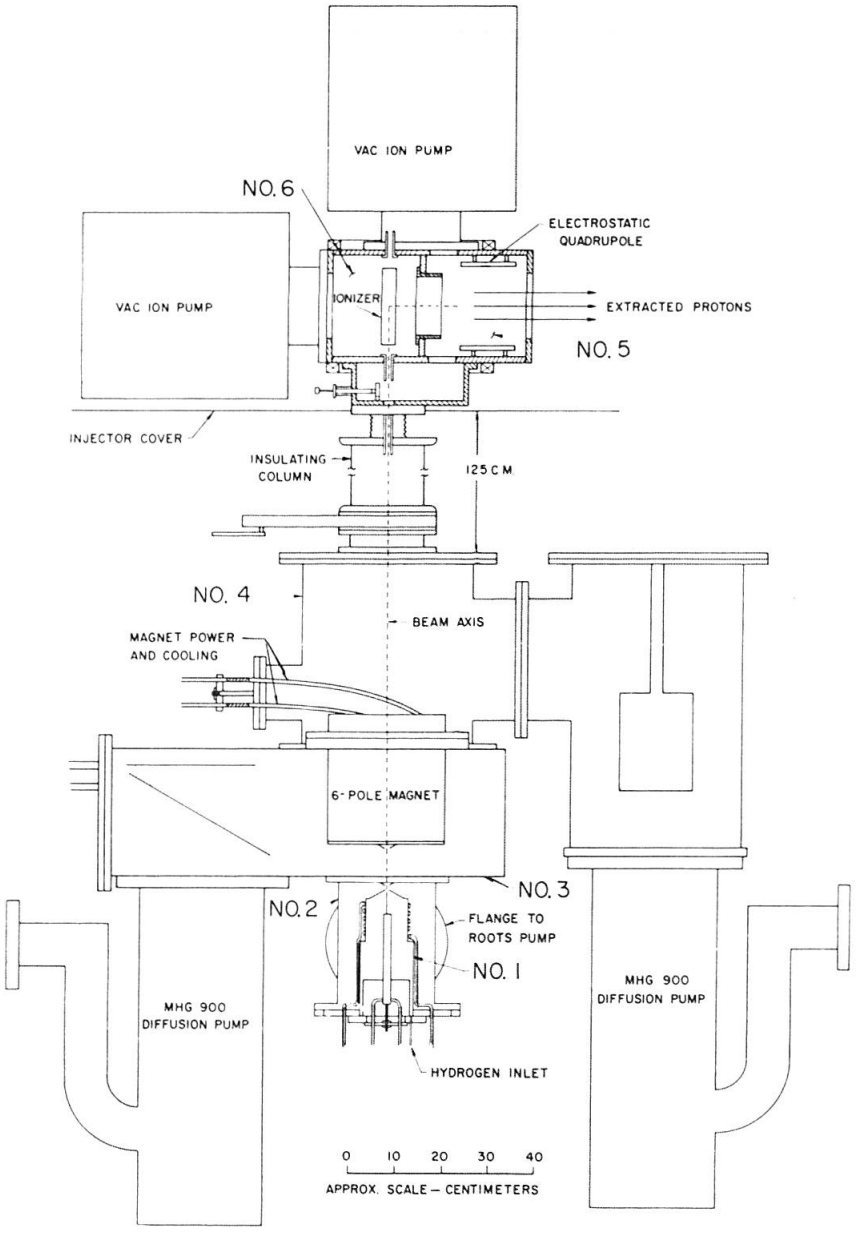

Figure 2

Detailed cross section of the polarized proton source. (Numbers are to identify the differential pumping system as explained in the text).

adjusted to give a suitable working condition. The power supply for the arc discharge can give — 500 volts, 5 amps, which is necessary for starting a glow discharge at low pressure (about 10 mm Hg). A pressure increase to 300 mm (100 to 600 mm, depending on nozzle diameter) change the discharge to an arc with typical working conditions of 100 volts and 3 amps. A voltage of 300 to 400 volts is dropped across a series resistor wich stabilizes the arc.

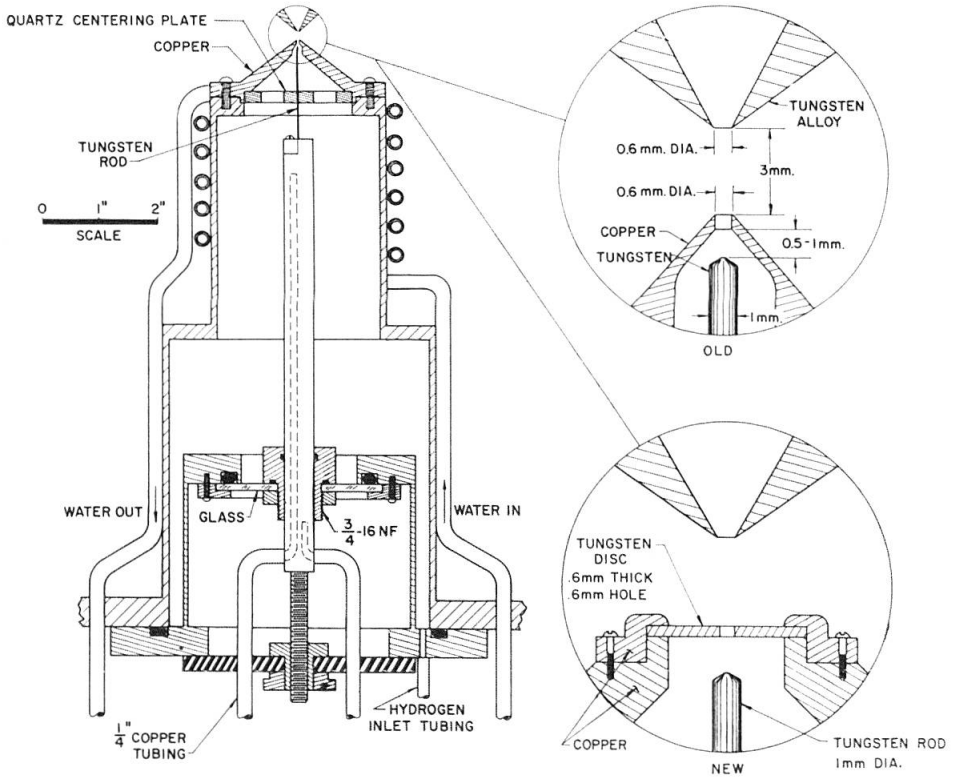

Figure 3
The dissociation chamber with old and new arc electrodes

The presently used cathode is a tungsten rod of 1 mm diameter which is set to a distance of .5 to 1 mm from the anode (nozzle). To maintain stable working conditions, it is necessary to reset the cathode every day; the tungsten consumption is about 1 mm^3/10 hours of discharge.

The arc discharge can be obtained in two different modes depending on the electrode distance. If the distance is 1 mm, the arc will burn between the electrodes and the dissociated molecules have a high chance to recombine at the walls. This results in a beam with about 5% dissociation degree and small velocity (wall temperature). If the distance is .5 mm or smaller, the plasma will be blown through the nozzle into the low pressure chamber No. 2 (.2 mm Hg) which is pumped by the Roots-

pump unit. In this mode the beam is highly dissociated (more than 50%), but the velocity of the atoms is about 12×10^5 cm/s (corresponding to a temperature of about 5000° K). This increased velocity is a disadvantage because the deflection in the magnet and the ionization probability are decreased. We tried to decrease the recombination rate in the first working condition in order to get a high intensity beam with a small velocity, by covering the nozzle inside with Pyrex glass. This melted out in the first second and only a Vicor insert could stand the discharge for about 10 minutes. A stable working condition was obtained by modifying the anode of the arc discharge as shown in figure 3 (new). The arc burns against a tungsten sheet and heats the center part to a white glow. Because of the hot aperture the recombination rate is decreased, resulting in a beam of about 8×10^5 cm/s velocity (corresponding to a temperature of about 3000° K). A beam picture with this arc condition is shown in figure 5. The arc discharge worked erratically sometimes but well enough for the test runs. The tungsten disc anode had to be exchanged after about 50 hours of running time. The system will presumably be modified to meet the requirements of stability necessary for this ion source.

The Differential Pumping System

In figure 2 the vacuum chambers are numbered according to the steps to lower pressures. Chamber No. 1, the arc chamber, is connected to a hydrogen supply (cylinder) and the flow rate can be adjusted with a needle valve to give the pressure of 300–400 mm Hg in working condition. Chamber No. 2 is pumped by two Roots pumps (in series) and a Kinney pump (KD 30).

The choice of the heavier Roots pump RG 350 for backing the high speed pump R 1600 was found necessary. Even in this arrangement the water cooling of the R 1600 is not sufficient, when the pump compresses large amounts of hydrogen. Additional cooled flanges are necessary to maintain safe operation.

The next chamber (No. 3) is rectangular with 1/2″ stainless steel walls so that no additional flanges are needed. The connected chambers are bolted to the walls of chamber No. 3. This design gives the shortest possible connection, which is necessary to obtain maximum pumping speed. The chosen mercury diffusion pump MHG 900 did not give satisfactory working pressures because of incomplete baffling. Improved baffles would have cut down the pumping speed to an untolerable value, so that a change to an oil diffusion pump was necessary for this chamber.

The equilibrium pressure in working condition is 10^{-4} mm Hg, which is satisfactory to step down to the low pressure region of the magnet

chamber. With this pump unit it is possible to produce a pressure difference from 300 mm Hg to 10^{-4} mm Hg within a distance of a few millimeters.

The chamber No. 3 has adjustable steel legs so that it can be exactly connected to the Roots pump unit. All the other parts are mounted onto this rectangular chamber. The magnet drops in from the top and the diffusion pump is bolted on from underneath. The distance between the entrance aperture (beam defining aperture) to the magnet chamber and the source (nozzle) will be 5 to 10 cm (variable for best beam geometry). The following detection measurements have been made in this chamber at the pressure of 10^{-4} mm Hg.

The results of the different detectors indicate a flux of 10^{18} atoms/sec-cm^2 about 8 cm behind the source. The beam was first detected with molybdenum oxide (MO) which gave an indication of the above mentioned flux and dissociation degree (this was roughly found from gas consumption measurements and blackening time of the detector, using a calibration from Erlangen with the nearly 100% dissociated beam of a Woods discharge).

The high flux was also detectable with an electron bombarder and following mass analysis. The signal obtained from the beam (10 cm distance from the source) was the same as that from a pressure change of 10^{-5} mm Hg in this chamber (produced by pressure increase in chamber No. 1). This gives a rough means to calculate the flux. With an assumed velocity of 5×10^5 cm/s, one also gets the above mentioned value.

The measurement of recombination heat of the hydrogen atoms was not convincing because one cannot easily eliminate effects of radiation, heat, conduction change of the residual gas, tungsten condensation and ion recombination. It would need some work, to make it dependable.

The flux was measured again with a microbalance, an open microampmeter in a vacuum with a 1 cm^2 aluminium foil glued to the needle, rectangular to the beam. Calibrated with a milligram weight it can measure directly the momentum of the beam particles, or for a known momentum, the flux. For the molecular beam the result was 2×10^{18} particles/sec-cm^2 at 8 cm distance from the source (the deflection of the needle was about 1 cm). For the measurement of the atomic beam one needs two informations, the velocity of the atoms and the dissociation degree. The deflection of the scale for a typical atomic beam condition was 2 cm. This would give the order of magnitude of the above mentioned flux.

The entrance aperture of the magnet chamber has a diameter of 3/64″ with an inner stopper with a diameter of 1/64″, thus giving a ring-shaped area of about 1 mm^2. Therefore about 10^{16} atoms/sec will enter the magnet chamber.

The 6-Pole Magnet

The magnet design was changed from the one on page 47 of the 1958 Progress Report in two major points. The whole pole-pieces with the coils are in the vacuum, resulting in much better vacuum conditions for pumping away the unwanted defocused component of the beam. The pole pieces were fabricated with a taper along the beam axis with the distance between opposite pole pieces being 1/8″ at the entrance and 1/2″ at the exit of the magnet (see figure 4a, b). Each pole piece carries 12 turns of 3/16″ water-cooled copper tubing and the insulation is made by Teflon carries and spacers. The coils are connected in series pairs inside the vacuum and the six leads of the three pairs are fed through the chamber with Teflon insulators and gaskets. For water cooling, the pairs are connected in parallel to the city water, which produces a flow rate high enough to dissipate 10 KW with a tolerable temperature increase of 25° C.

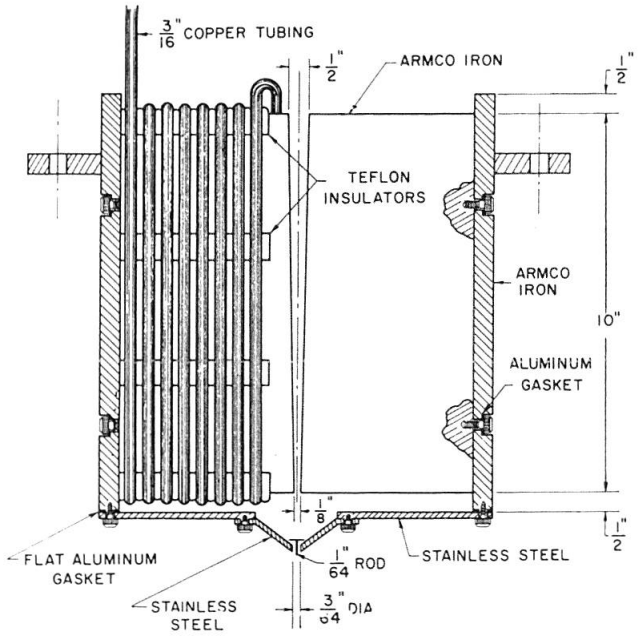

Figure 4a
The 6-pole magnet, side view

The coils are electrically connected in series to give a resistance of .1 ohms, so that a motor generator for 30 volts can produce currents up to 300 amps. At this current a magnetizing force of only 180 oersteds is produced because of the shape of the coils. For the pole pieces Armco iron (Permendur would have been better) and for the yoke a normal soft (low carbon) steel was used. The pole tips on the entrance side are already saturated at about 100 amps, nevertheless the maximum 300 amps were used to get the largest possible deflection.

Measurements of the magnetic field strength were made with a little calibrated Hall probe (figure 4c). This measurement shows that the typical 6-pole field properties ($|H|$ prop. r^2) are only obtained in a region $-1/2\,a < r < 1/2\,a$, where $2\,a$ is the distance between opposite pole pieces. For $|1/2\,a| < r < |a|$ the field is linearly proportional to the distance r from the symmetry axis, so that the gradient is constant. Because of intensity reasons, the whole region between the pole pieces is used for the beam. The middle part of the beam is stopped with the 1/64″ insert in the beam defining aperture because the field gradient drops to zero on the symmetry axis and no separation takes place. This insert also prohibits molecules and atoms of the unwanted component from entering the ionizer region. Only atoms which have been deflected toward the axis can enter the ionizer chamber.

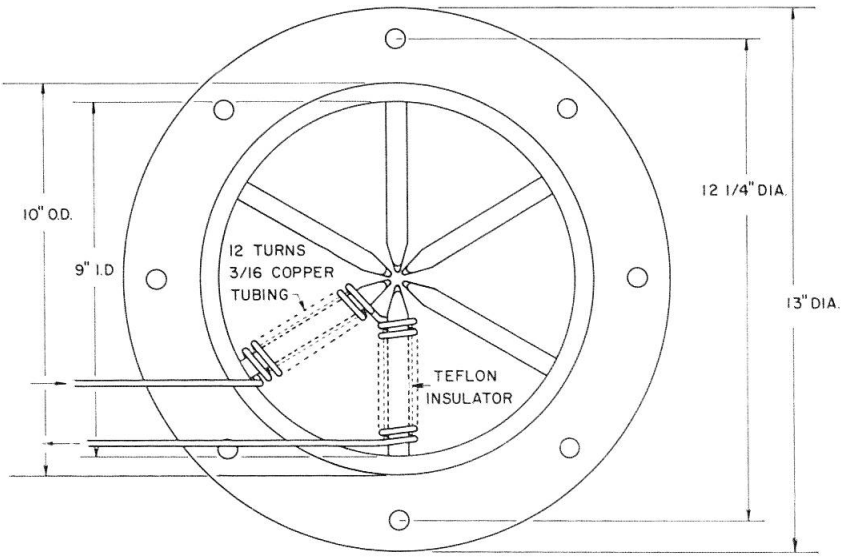

Figure 4b
The 6-pole magnet, top view

The measured field gradient on the entrance side was 85,000 gauss/cm (in the region where $|H|$ prop. r) and on the exit side 12,000 gauss/cm for 300 amps current through the coils (see figure 4c).

The magnet was built with a fixed welded-on flange for support, so that one can use appropriate distance rings between the rectangular chamber (No. 3) and the magnet, to change the beam geometry.

To increase the field gradient, the pole pieces of the 6-pole magnet were shimmed with tapered steel sheets, which decreased the distance between opposite pole pieces by 0,6 mm at the entrance side and by 3,5 mm at the exit. (New dimensions 2,5 mm at entrance, 9 mm at exit). This increased the available deflecting force by approximately 50%.

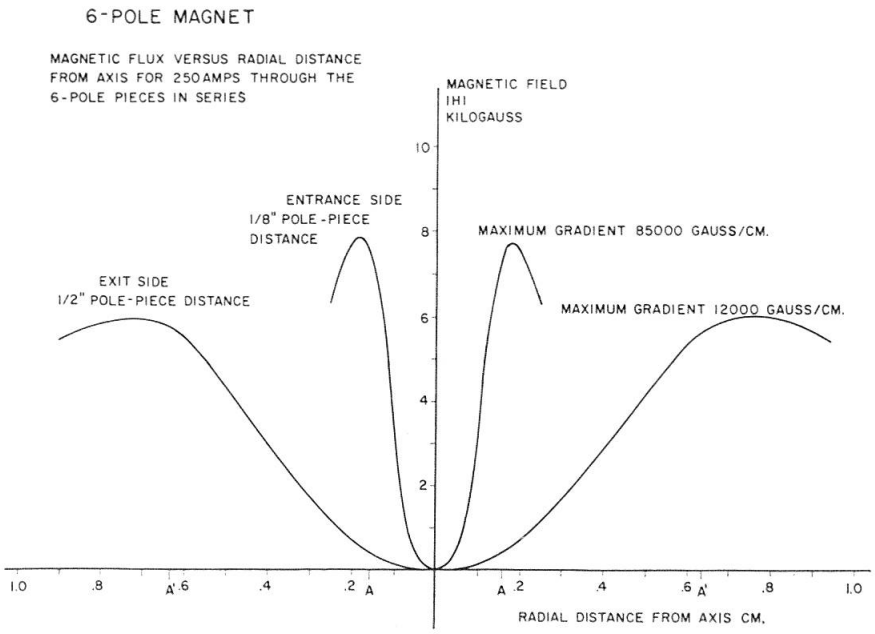

Figure 4c

The 6-pole magnet, field measurements. (2A is the distance between opposite pole-pieces on the entrance side, 2A′ on the exit side.)

The Detector

The vacuum chamber for the magnet (No. 4) was made out of stainless steel, welded from the inside to avoid cracks. The beam deflection pictures were taken either in this chamber or at the end of a 1.2 meter glass column (ionizer position).

For detection of the hydrogen atoms we used the chemical reduction of yellow molybdenum oxide to a blue oxide with less oxygen content. Thin layers of molybdenum oxide were produced by burning a molybdenum sheet metal in a gas-oxygen flame and condensing the produced vapor on a cold glass plate. One can derive a sensitivity of this detector, from earlier measurements of 10^{16} atoms/sec entering the magnet chamber, the exposed area of 10 cm^2, and the necessary 6 seconds for the first visibility. This is assuming that no atoms are lost on a path of 0.5 meters in a vacuum of 10^{-5} mm Hg. The involved definition of the first visibility of the picture contains some error, but nevertheless allows an order of magnitude measurement of the atomic flux. For example, a flux of 10^{14} atoms/sec-cm^2 produces a visible picture after a one minute exposure.

Pictures were taken from the undeflected beam at different distances from the source (first nozzle), to measure the divergence of the beam. With the magnet switched on, the same exposures were made again.

On the pictures of the deflected beam, one can recognize a rather sharp border-line between a region of high and one of low intensity. The diameter of this borderline was measured in the pictures taken at different distances from the source and a divergence of the deflected component was derived. From the change of divergences of the undeflected and deflected beam, an approximate velocity was calculated. The velocity values given above were obtained in this way. This measured velocity is connected to the unknown velocity distribution of the beam, but since this outer borderline of the wanted component defines our entrance aperature to the ionizer very well, this is the necessary information.

Figure 5 shows a beam picture taken 1 meter behind the field end with magnet off (left) and magnet on (right). The exposure time was 1 minute, first visibility 10–15 seconds indicating a flux of about 4×10^{14} atoms/s.cm^2. With a velocity of 8×10^5 cm/s this represents a beam pressure of 2×10^{-8} mm Hg.

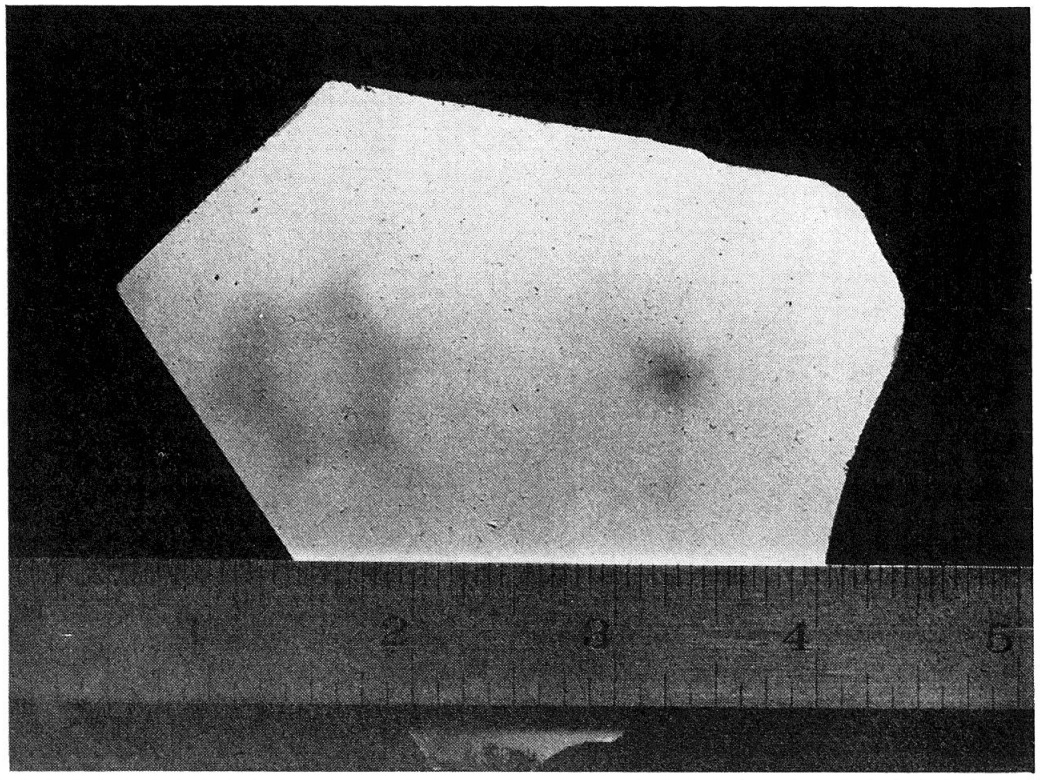

Figure 5

Beam pictures; magnet off (left), magnet on (right),

detector position: 1 meter behind field end
exposion time: 1 minute
First visibility: 10–15 seconds

The Ionizer Chamber

Because the beam pressure is expected in the order of 10^{-8} mm Hg, the residual gas pressure in the ionizer region has to be lower than this value in order to get as satisfactory polarization degree. Therefore the ionizer chamber (No. 6, figure 2) will be pumped down by an Vacion-pump of 100 liters/sec pumping speed for air. The unused (not ionized) atomic beam will leave this chamber again and will be pumped away by a second Vacion-pump of the same type, which also serves to pump the region around the ionizer chamber (No. 5). The chambers are connected with channels of low flow rate, which allow a pressure difference of a factor 10 between chamber No. 4 and No. 5 and also between chamber No. 5 and No. 6.

The Vacion pumps are working satisfactorily; we were able to pump down below 10^{-7} mm Hg within one day after the system had been open to air. After about 3 days of pumping and baking (the ionizer was used as a heat source) the pressure was below 10^{-8} mm Hg. These values were taken from current curves measured by the manufacturer.

The gasketing is done with pure aluminium wire of 0,6 mm diameter, welded together and clamped between flat polished flanges. The wire is compressed to about 0,2 mm and the bolts have to be tightened a few times because the aluminum flows during baking. The pressure readings with the beam going into the ionizer chamber were $< 10^{-7}$ mm Hg in chamber No. 5 and $< 10^{-8}$ mm Hg in chamber No. 6 after about 5 days of pumping.

The Ionizer

An electron bombarder ionizer was built following in principle the design of FRICKE [6] and BERNHARD [7].

The length was chosen to be 10 cm, the ionized volume is then about 10 cm^3. For this large volume a careful Pierce cathode design seemed rather difficult. The system is designed to stand high temperatures during operation and baking. It is assembled on four stainless steel posts insulated with a Vicor tubing. The different parts are then insulated with Vicor spacers fitting over the tubing. The geometry is shown in figure 6.

The six tungsten filaments (0.4 mm diameter) are heated in parallel by a current of 60 to 80 amps A.C. The grid consists of thin tungsten wires in order to obtain a maximum electron current through the atomic beam volume. Presumably the electrons will oscillate and therefore increase the current density and so the ionization probability.

Cathode-grid potentials up to 400 volts were used and the produced ions extracted at right angles to the atomic beam as a flat bundle. With

electron currents of 1 A we were able to extract 0,8 μ A in a residual gas pressure of 10^{-7} mm Hg. So far this was our ultimate pressure for this high emission because the chamber was heated up. With 0,1 A emission current the ultimate pressure was below 10^{-8} mm Hg. At this pressure we could detect a signal from the beam without a mass analysis of the ion current. Opening the beam shutter increased the collector current (extracted ions) by a factor 2,5. The pressure in the ionizer chamber increased by a factor 0,3 due to back streaming of hydrogen from the chamber No. 5. This leaves a signal/noise ratio (beam signal/residual gas noise) of approximately 1.

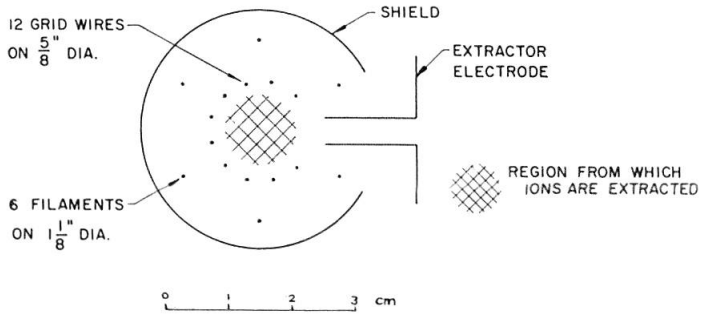

Figure 6
Cross section of the electron bombarder ionizer

Tests were so far made without the 6-pole magnet working and without the beam stopper in the beam defining aperture, so that molecules could not be distinguished from atoms. The polarization direction of the protons is defined by the direction of the magnetic field which acted on the neutral atoms before they were ionized. A field of about 30 gauss is furnished by two Helmholtz coils outside the ionizer chamber. This provides an easy means to make asymetry measurements because one does not have to use two counters. A change of the field direction provides the same information as a counter changed to the negative angle. In order to avoid troubles because of polarization fluctuations one can change the spin direction fast (every machine pulse) and switch the signal in phase into different channels for counting.

Acknowledgment

Important contributions to the success of this project have been made by DAVID NORDBY and BAILEY DONNALLY. Special thanks are due to the Physics machine shop for their careful fabrication of the leak tight stainless steel vacuum chambers. The author wishes to acknowledge the support of the U. S. ATOMIC ENERGY COMMISSION and of the LINEAR ACCELERATOR staff in making this project possible.

Note added in Proof. During the first weeks of November 1960 protons were accelerated to 10 MeV and the polarisation was detected by left-right (and spin up-down) asymmetry measurements of the 150° scattered protons from aluminium. From the first experiment together with Rosen's data on aluminum the polarisation is estimated to 0.15 ± 0.04. The useful current beam in this experiment was $2 \cdot 10^{-13}$ amps.

From signal/noise measurements (at 10 MeV) with the atomic beam on/off and sixpole-magnet on/off one can estimate a polarisation of 0.25. The discrepancy can be caused by stray fields from the filaments and Vacionpumps because the guide field of the Helmholtz coils is only 10–15 gauss.

REFERENCES

[1] G. Clausnitzer, R. Fleischmann, H. Schopper, Z. Phys. *144*, 336 (1956).
[2] G. Clausnitzer, Z. Phys. *153*, 609 (1959).
[3] E. W. Becker, K. Bier, Z. Naturf. *9a*, 975 (1954).
[4] Kistiakowsky, Slichter, Rev. Sci. Instr. *22*, 332 (1951).
[5] Annual Progress Report, University of Minnesota (1958).
[6] G. Fricke, Z. Phys. *141*, 166 (1955).
[7] F. Bernhard, Z. angewandte Phys. *9*, 68 (1957).