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Lawrence Berkeley National Laboratory

Publication Date

1949-06-07

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UCRL-372

Physics-General

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Radiation Laboratory

Contract No. W-7405-eng-48

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PHYSICS DIVISION QUARTERLY REPORT

February, March and April, 1949

June 7, 1949

Berkeley, California

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General Electric Company, Richland	31-34
Hanford Operations Office	35
Iowa State College	36
Knolls Atomic Power Laboratory	37-40
Los Alamos	41-43
Mound Laboratory	44-45
National Bureau of Standards	46-47
Naval Radiological Defense Laboratory	48
NEPA Project	49
New York Operations Office	50-51
North American Aviation, Inc.	52
Oak Ridge National Laboratory	53-60
Patent Branch, Washington	61
Sandia Base	62-63
Technical Information Division, OROO	64-78
UCLA Medical Research Laboratory (Warren)	79
University of Rochester	80-81
University of California Radiation Laboratory	
Information Division	82-84
Patent Department	85
Chemistry Department	86
E. O. Lawrence	87
J. G. Hamilton	88
E. Segre	89
J. H. Lawrence	90

TOTAL

90

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TABLE OF CONTENTS

	Page
I. GENERAL PHYSICS RESEARCH	
Cloud Chamber Program	4
Film Program	5
Measurement of Total Cross Sections of Nuclei for 40 Mev Neutrons	7
Total and Inelastic Cross Sections of Nuclei for 270 Mev Neutrons	8
Mass Spectrograph	10
90 Mev Neutron Differential Scattering Cross Sections	12
Magnetic Energy Discrimination Method	13
High Energy Photons Produced by Bombarding Nuclei with High Energy Particles	14
II. ACCELERATOR OPERATION AND DEVELOPMENT	
* 184-inch Cyclotron	15
60-inch Cyclotron	18
Synchrotron	19
Linear Accelerator and Van de Graaff Machines	22
Bevatron Development	26

I GENERAL PHYSICS RESEARCH

1. Cloud Chamber Program

Evans Hayward

Several runs have been made with the cloud chamber in the neutron beam produced when protons were accelerated by the 184-inch cyclotron. The object of these runs was to determine the best way to study mesons in the neutron beam. The cloud chamber has a 22-inch diameter and is operated in a magnetic field of 22,000 gauss. Various arrangements of targets and absorbers have been used.

In an earlier report it was stated that about 200 particles obtained in one run in the neutron beam were mesons. Later work has shown that many of these probably were very energetic electrons produced by the high energy gamma rays observed by B. Moyer and H. York.

In a subsequent experiment where curvatures were measured on either side of an absorber, it was shown that many of the particles of the type that had been identified as mesons were really fast electrons (up to 100 Mev).

Of the 200 particles originally identified as mesons, 30 are surely mesons of energy less than 10 Mev. At and below this energy, the very dense ionization and large curvature leave no possibility of ambiguity. Seven of these stopped in the gas. All were negatively charged, four made stars, and in the remaining three cases, nothing was observed at the end of the track though a decay electron or recoil nucleus could easily have been obscured by the background. All but one were heavy mesons and the light meson was one of those that did not produce a star.

2. Film Program

Stanley B. Jones, R. S. White

Excitation Function

The observations on yield of 2-5 Mev mesons, reported in the last quarter, have been repeated using a proton beam on a carbon target. The relative numbers of negative π mesons created by protons of various energies is being studied. The energies were obtained by placing the targets at different radii in the 184-inch Berkeley cyclotron. The study is limited to star-producing mesons with energies of approximately 2-6 Mev emitted within $\pm 45^\circ$ of the forward direction from a $1/32$ in. carbon target. Eastman type NTB Plates were used to record the mesons.

Preliminary data is given in Table I. Column 1 gives the energy of the bombarding protons; column 2, the numbers of mesons actually counted; and column 3, the numbers of mesons relative to the number at 340 Mev, corrected for beam current, plate thickness, and area scanned.

TABLE I

<u>Beam Energy (Mev)</u>	<u>No. of Mesons</u>	<u>Corrected Relative Yield</u>
340	22	100 per cent
306	41	43 " "
272	22	27 " "
238	5	5 " "
204	2	1 " "
170	0	0 " "

Cross Section

A differential cross section measurement has been made of the production of 2-5 Mev π^- -mesons, emitted within 45° of the forward direction, by 380 Mev alpha particles. A standard plate holder was used with a $1/4$ inch carbon target, and the intensity of the beam was monitored by means of a thin polystyrene foil laid in front of the target. One-quarter inch thickness of target was chosen in order that the ion beam would scatter enough in a single passage through the target to hit the clipper and thus prevent it from making a second pass through the target. The total beam current was calculated by measuring the 20-minute positron activity induced in the carbon, whose cross section was measured by using the deflected alpha beam. Correction was made for differences in solid angle subtended by the plate for the various trajectories. Correction was made also for the decay in flight, using 0.88×10^{-8} for the half life of the meson. No correction was made for target thickness. The differential cross section for mesons produced by the alpha beam was based on the measurement of 77 mesons which were followed back to within 50 microns of the

edge of the plate and whose entrance angle was in each case checked against the range. Under these conditions, the cross section for production of π^- mesons by 380 Mev alpha particles was 3.8×10^{-32} cm² Mev⁻¹ steradian⁻¹.

A similar experiment was made in order to determine a differential cross section for π^- -mesons produced by a beam of 340 Mev protons on carbon. The differential cross section for production of mesons of 11-13 Mev emitted within $\pm 30^\circ$ of the forward direction from a 1/16" carbon target was found to be 1.0×10^{-32} cm² Mev⁻¹ steradian⁻¹ per carbon nucleus. The results are not directly comparable with the above cross section measurements on alpha produced mesons, except via the energy distribution data of Jones and White contained in the last quarterly report, which would give a cross section in the 11-13 Mev region of approximately 1.2×10^{-31} cm² Mev⁻¹ steradian⁻¹ for alpha particles on carbon nuclei.

An experiment is now being carried out by C. Richman and V. Z. Peterson to determine the total cross section for production of mesons by protons on carbon.

3. Measurement of Total Cross Sections of Nuclei for 40 Mev Neutrons

R. H. Hildebrand and C. E. Leith

Measurements of the total cross sections of nuclei have been made using the 40 Mev neutron beam produced by the 184-inch cyclotron by the stripping¹ of 90 Mev deuterons in a 1/2 inch thick Be target. The method of detection is that used by Cook, McMillan, Peterson, and Sewell² in making similar measurements for 90 Mev neutrons. The neutron intensity is determined by counting the 20 min C^{11} positron activity resulting from the $C(n,2n)$ reaction in carbon discs. The threshold for this reaction is about 20 Mev. The average energy detected is 40 ± 2 Mev.

Tentative results follow:

Element	σ_t in 10^{-24} cm ²
H	0.202 \pm 0.010
D	0.282 \pm 0.020
C	1.092 \pm 0.015
O	1.353 \pm 0.015
Mg	1.70 \pm 0.07
Al	1.75 \pm 0.07
Fe	2.44 \pm 0.04
Cu	2.54 \pm 0.04
Zn	2.54 \pm 0.05
Mo	3.17 \pm 0.10
Ag	3.18 \pm 0.06
Sn	3.22 \pm 0.04
Ta	4.15 \pm 0.06
Pb	4.45 \pm 0.10
Bi	4.58 \pm 0.10
U	5.24 \pm 0.18

The H cross section was derived from pentane ($CH_{2,4}$) and C measurements and from H_2O and O measurements.

The D cross section was derived from D_2O and O measurements.

The O cross section was determined using liquid oxygen. In all others solid attenuators of the pure element were used.

Cross sections of other elements are being measured using where necessary simple chemical compounds.

¹R. Serber, Phys. Rev. 72, 1008 (1947)

²L. J. Cook, et al, Phys. Rev. 75, 7 (1949)

4. Total and Inelastic Cross Sections of Nuclei for 270 Mev Neutrons

J. DeJuren, B. J. Moyer

Neutrons with an average energy of 270 Mev are produced by bombarding a 2 inch Be target with 350 Mev protons in the 184-inch cyclotron. Measurements of total cross sections were made by placing the attenuators in front of the igloo, and the detector on the neutron bench outside the concrete shielding. Neutrons scattered through small angles had to pass through collimators in both the igloo and concrete shielding (which restricted the maximum angle accepted to about 0.8°) to enter the detector. As the solid angle subtended from the scatterer by the detector was only 2×10^{-5} steradians, the error introduced by diffraction scattering is negligible.

Bismuth fission counters were employed for monitors and detectors in these measurements. The monitor was placed in the broad beam slightly in front and to the side of the attenuator holder.

For three elements measurements were made of the ratio of inelastic to total cross section by placing broad absorber slabs in front of a shallow fission chamber, which was in line with the probe source and collimator, so that both inelastic and total cross sections could be measured simultaneously. Attenuation was exponential over 5 total mean free paths and 3.5 inelastic mean free paths, within the statistical error.

More accurate measurements were made using between one and two mean free paths of attenuator for 10 different elements. The results are tabulated in Table I and comparison is made of the ratio of cross sections at 270 and 95 Mev for bismuth fission detection.

TABLE I

<u>Element</u>	<u>$\sigma_t \times 10^{24} \text{cm}^2$</u>	<u>$\frac{\sigma_t(270 \text{ Mev})}{\sigma_t(95 \text{ Mev})}$</u>
Hydrogen	.037 \pm .002 .039 \pm .002	.52 \pm .03
Deuterium	.059 \pm .003	.57 \pm .03
Beryllium	.229 \pm .003	.58 \pm .01
Carbon	.287 \pm .007 .294 \pm .005 .279 \pm .009	.58 \pm .01
Oxygen	.376 \pm .007	.57 \pm .02
Aluminum	.555 \pm .010 .553 \pm .019	.56 \pm .02
Copper	1.15 \pm .02	.575 \pm .01
Tin	1.86 \pm .03	.585 \pm .01
Lead	2.82 \pm .04 2.80 \pm .06	.63 \pm .01
Uranium	3.04 \pm .09	.62 \pm .03
Deuterium-Hydrogen	.021 \pm .002	.68 \pm .07

The cross sections for elements measured from deuterium to tin at 270 Mev are all practically .575 times their values at 95 Mev.

The ratios of inelastic to total cross sections for copper and lead at 270 Mev are:

Element

$$\frac{\sigma_i}{\sigma_t}$$

Cu	$.50 \pm .02$
Pb	$.49 \pm .02$

As inelastically scattered neutrons of energy greater than 50 Mev could be counted by the poor geometry detector, these ratios represent a lower limit to the true value, but the ratios are nevertheless higher than the 95 Mev values of $.39 \pm .005$ and $.40 \pm .01$ respectively.

5. Mass Spectrograph

L. Tolman

Germanium Fluxmeter

The magnetic field measuring device which was described in previous reports has been further modified. A definite temperature effect was corrected by mounting the germanium crystal in a water-cooled copper block and filling the center with silicon oil.

A divider and bucking circuit has been added so that the recorder reads in steps of 1000 gauss, thus: 0-1000, 1000-2000, 2-3, 3-4, 4-5, etc.

Magnet Current Regulator

In order to save time in repeating scans and also to enable us to scan the complete field range a reversing switch has been added to the motor drive for the magnet current as shown in Figure 1.

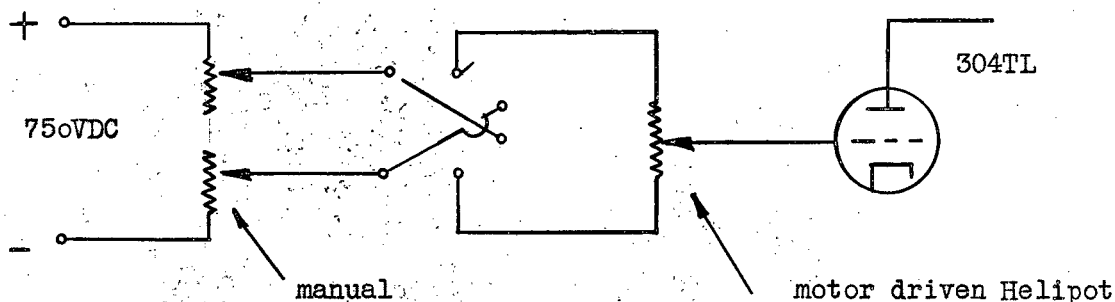


Figure 1

Magnet Current and H.V. Verniers

Vernier circuits for the magnet current and the high voltage have been designed with sensitivities of 5 mv/ma and 1 mv/volt.

Emission Regulator

An emission voltage meter and a separate meter for the trap current have been added.

Recorder Input Switches

Switching circuits have been built for each recorder with nine (9) different outputs for greater flexibility.

Sample System

A new sample system has been designed using a 10 liter reservoir and a leak which is \sim .001 inch diameter. With about 20 microns sample pressure there should be molecular flow only.

SUMMARY OF ANALYSIS

CO₂

Samples of CO₂ taken from air, water, and algae were run for William Siri. The results were as expected, showing a slight enhancement of C₁₂ in the algae phase.

Ethylene (CH₂:CH₂)

Samples of ethylene were analyzed for Dr. G. Patton and Dr. Claypool of U.C. at Davis.

Ni

Ni₅₈ and Ni₆₁ enhanced by the calutron were run but the results were not very accurate as there were large amounts of copper and zinc present.

	<u>Percent</u>	<u>Percent</u>
58	97.6	8.13
60	1.85	10.73
61	.18	77.43
62	.375	3.75
64	--	--

N-Butane

In order to prepare for analysis of organic samples, N-Butane was run. The results were fairly close to the published spectral data and with the improved sample system will probably be satisfactory.

Deuterium

A sample of deuterium was run. The results showed the presence of about 5 percent atomic H. This will be repeated with greater accuracy when the new sample system is operating.

6. 90 Mev Neutron Differential Scattering Cross Sections

A. Bratenahl, R. Hildebrand, C. Leith, B. J. Moyer

During this period it was felt desirable to bring this program to a reasonable conclusion as soon as possible at its present status with the completion of a report of the experimental results. What might be considered the final experiment in this program was completed in April, and consisted in a redetermination of total cross sections by means of the recoil proton proportional counters, and a full report is in progress.

For the purpose of calculating the correction for self-attenuation in the scatterer it is necessary to know the total cross section of the scattering material in the energy spectrum accepted by the detector. Previously, total cross sections determined by this detector appeared to be unreasonably low, corresponding to a mean detection energy of about 110 Mev. In this experiment particular care was exercised in alignment of the coincidence gates, in an effort to resolve this discrepancy, making use of greatly improved coincidence facilities. The results were in better agreement with what might be expected in view of the calculated mean acceptance energy of 90 Mev.

7. Magnetic Energy Discrimination Method

W. Crandall, J. Hadley

Work has been started on extending the magnetic method of particle energy discrimination to use with scattering experiments in the new high energy neutron beam from the 184-inch cyclotron.

The advantages of this method lie mainly in the elimination of absorbing material in the path of the particles, as is otherwise used to measure their energies. At high energies the amount of absorber that would be necessary is so large as to bring about very extensive loss from nuclear collisions between the particles being measured and the absorbing material. In addition, when more than one type of particle is being measured, the magnet, used in conjunction with some other method of energy discrimination, such as absorber and a desensitized proportional counter, provides a method of sorting out the various types of particle as well as measuring the energy distribution of each one. Disadvantages lie mainly in the very low counting rate that one must put up with in order to attain reasonable energy resolution. For heavy particles of high energy, the lowest radius of curvature that can be used is so large as to require very narrow path defining slits, and the number of particles which pass through is accordingly very small.

Due to non-uniformity in the magnet field and to the possible lack of reliability in determining the path of the particles purely by geometrical methods, it is necessary to calibrate the magnet by passing through it particles of a known energy, the energy being determined by range measurements. Once this has been done to give H_r of the particles for a given field strength, H_r at other values of the field are given by the assumption that H_r is proportional to H .

To gain experience in the method, and at the same time to fulfill a definite need, it is being used to measure the energy distribution of the neutron beam; this is actually accomplished by measuring the energy distribution of protons produced in elastic collisions of the neutrons with hydrogen nuclei. The results show a neutron energy distribution consisting of a peak at about 260 Mev, with width at half maximum of about 100 Mev, and dropping off to zero at about 125 and 360 Mev.

We plan, after completing more exact measurements of this distribution, to proceed with determinations of the angular and energy distributions of secondary particles produced in nuclei of various materials bombarded in the high energy neutron beam.

8. High Energy Photons Produced by Bombarding Nuclei

with High Energy (>100 Mev) Particles

R. Bjorklund, B. J. Moyer, H. F. York

Investigations of the high energy quanta emitted by the cyclotron target have been continued using 180° and 90° pair counters with a resolution of .2, that is the width of each energy interval is about .2 of the mean energy. The energy range of the quanta investigated extends from 30 Mev to 200 Mev.

The energy distribution of the quanta emitted in the backward direction when any nucleus is bombarded by 350 Mev protons shows a maximum at about 70 Mev, and drops to one-half of this value at about 20 to 35 Mev and 100-110 Mev. In the forward direction the distribution shows a maximum at about 125 Mev and has a proportionately larger half width. The position of these two maxima correspond to the Doppler shift to be expected if the photons are emitted spherically symmetrically in a system moving with $v = .3c$ in the direction of the impinging proton.

The absolute cross section per Be atom for producing these quanta is about 1.5×10^{-3} barns. This is about .015 of the inelastic cross section. The cross sections for other elements increase more slowly with Z than the inelastic cross sections, as shown in the following table:

	Be	Cu	Ta
Rel. cross section for producing 70 Mev γ when bombarded by 350 Mev p.	1.0	2.8	4.0
Rel. inelastic cross sections for 290 Mev neutrons	1.0	4.0	11.0

The quanta produced by bombardment with 190 Mev deuterons differ in two important ways from those produced by 350 Mev protons, namely, the distribution shows no maximum in the region investigated, but falls monotonically with increasing photon energy, and the yield is more than 100 times smaller. Both the yield and distribution of these quanta agree with the supposition that they are heavy particle bremsstrahlung.

The most that can be said about the origin of quanta produced by 350 Mev protons is as follows: They are not heavy particle bremsstrahlung, and they are not due to nuclear excitation. The results are consistent with the existence of some intermediate particle formed in a high energy nucleon-nucleon collision, which then decays with the emission of at least one quantum. The intermediate particle could be for example either a neutral meson of mass 300-400 electron masses, or an excited nucleon.

Some preliminary investigations of the relative yield of these quanta as a function of proton energy give results as follows:

Ep (Mev)	Rel. Yield
340	1.0
290	.35
230	.07

II ACCELERATOR OPERATION AND DEVELOPMENT

1. 184-inch Cyclotron

James Vale

Proton Unit Improvements

Improvements in operation of the proton unit were made during this period by removal of some of the temporary construction that had been necessary during the unit's installation. These changes have resulted in improved efficiency and ease of operation of the unit.

One of the temporary structures replaced was the box around the insulating seran tubing used to get water cooling to the dee. The new structure is superior in two main points: The danger of arcing to the seran tubing has been greatly reduced by means of improved corona shield design, and the time of replacement of the seran tubing in case of failure, has been reduced through greater accessibility to the tubing.

The rotor and the dee stem are supported on zircon insulators. Since high voltages can exist at these insulators during abnormal conditions, corona shields were designed and installed to reduce the danger of breakage to these insulators. The only way of installing whole rings on these insulators would necessitate the dismantling of the support system. Therefore the corona shields were made in sections and a clamping system was devised to hold the sections in their proper location.

In addition to the corona shields, the terminating loops and capacitors were inclosed in a box offering better high frequency shielding than the screen previously used. See Figure 1.

The change of operations from deuterons to protons necessitates certain changes in the unit to make it oscillate over the proper frequency range.

Some of these changes involve shorting the terminating loops on the dee tie rods to decrease their inductance for operation on protons, and charging the cover on the plate line box to decrease the volume of the box for the proton range.

Switches were installed to short the tie rod loops. These switches have the advantage over the flexible copper straps used previously of duplication of conditions from one change-over to another. Some irregularity of operation had been encountered previously and it was desirable to eliminate this difficulty. In addition, the switches save time in the changeover.

Another time and labor saving development involved the cover for the plate line box. This box houses the zircon insulator through which oscillator power is fed to the dee system. The volume of this box critically affects the oscillator and thus two different covers had been necessary in the past for the two ranges, protons and deuterons. Preliminary experiments when the unit was put into operation failed to find one cover which would work for both ranges but indicated that a more detailed experiment should solve the problem. The volume of the box was satisfactorily adjusted so that it now is unnecessary to make any changes on it for the two ranges.

Experimental work has been going on to find a more satisfactory type of brushes for the rotary condenser. These brushes are used to by-pass the r-f around the ball bearings, which support the rotating condenser, to prevent rapid failure due to arcing in the bearings. The present brushes consist of molybdenum fingers pressing against a rotating disc faced with stellite. A design using a carbon ring was tried which ended in failure. Further experiments with carbon rings are contemplated, however, before the idea is discarded, because a ring type brush should provide practically ideal protection for the bearings.

Deflector

To get an external beam of 350 Mev protons requires a higher voltage on the electrostatic deflector than the 200 Mev deuterons. Consequently, a new pulser unit was constructed which produced almost twice as much voltage as the old pulser unit. The rest of the deflecting system did not need to be altered in any way. In addition, to providing a higher voltage, the new unit has a faster rise time, reaching 250 kilovolts in about one-sixth of a microsecond.

Other refinements include a voltage regulated power supply which increases the stability of the pulser, and air cooling of the coupling capacitors. The capacitors in the old pulser were water cooled, but this led to electrolysis of the cases and eventual failure whenever a pin hole had been eroded in the case. This problem might have been solved by proper plating or painting of the cases, but air cooling was certain to work and has been entirely satisfactory so far.

The stray capacity and inductance of the leads from the pulser unit through the tank wall to the electric deflector was also lowered by redesigning the feed-through bushings. These changes helped to utilize more efficiently the faster rise time and higher voltage of the new unit.

Probe Developments

The jiffy probe head was modified to permit its quick removal from the probe tube. This is accomplished by the use of a bayonet type locking device which is actuated by means of a worm gear. The plate upon which the thin foil is supported, has a hook so that it can be safely handled at a distance by the use of a long pole. The worm gear is operated by a long rod so that exposure to radioactive foil heads is minimized. Thus two important factors are utilized for reducing radiation exposure: Handling at a safe distance plus the short handling time. See Figure 2.

Improved handling equipment has also been constructed for the removal and insertion of targets and other equipment on the auxiliary probe which is located on the west side of the tank. The handling can all be accomplished by the use of long poles and this radiation exposure is minimized by means of safe distances.

Oscillator Pulsing Equipment

The oscillator has to be pulsed in order to operate smoothly and efficiently and therefore pulsing equipment was installed with the proton unit. Since it has not been mentioned in previous reports it is perhaps proper to give a brief description of the magnetic pickups at this time. These pickups provide signals for the control of the oscillator during the frequency-modulation cycle. These signals are induced in a coil wound on a magnet by a strip of magnetic material moving past the poles of the magnet. These strips of magnetic material are embedded in a disc of brass which

rotates with the rotary condenser. There is one of these magnetic strips for each blade of the condenser, making a total of six. See Figure 3 and figure 4.

The pickups consisting of the coils and magnets can be moved through fixed positions enabling the signal to occur at any point of the frequency modulation cycle. One of these pickups is moved by an electric motor which is operated from the control room and thus can be moved during operation. This pickup provides the signal which determines the turn-on point of the oscillator. The other two pickups are moved manually and provide emergency signals for the turn-off point. Normally the turn-off signals are provided by tuned circuits.

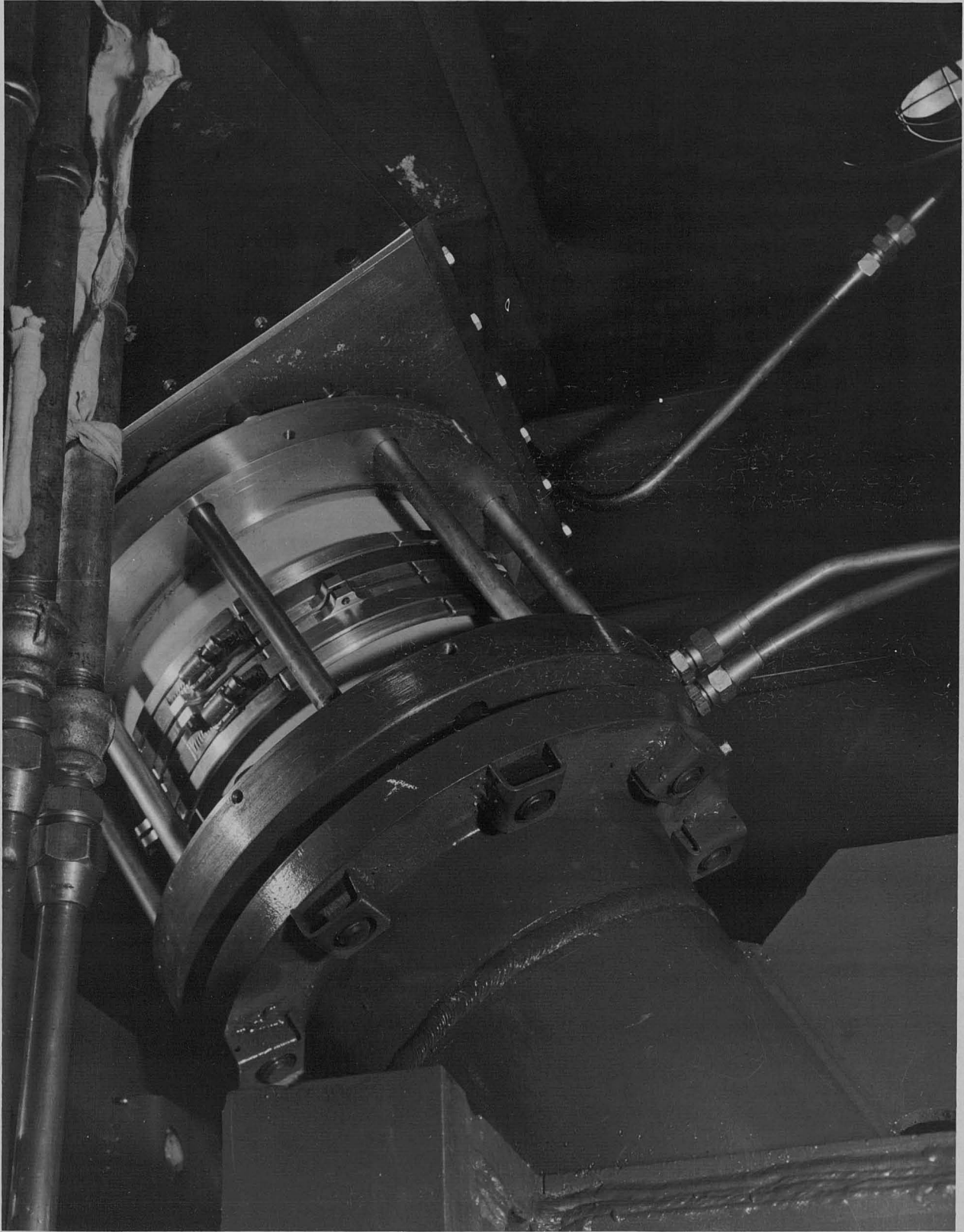


FIG. 1

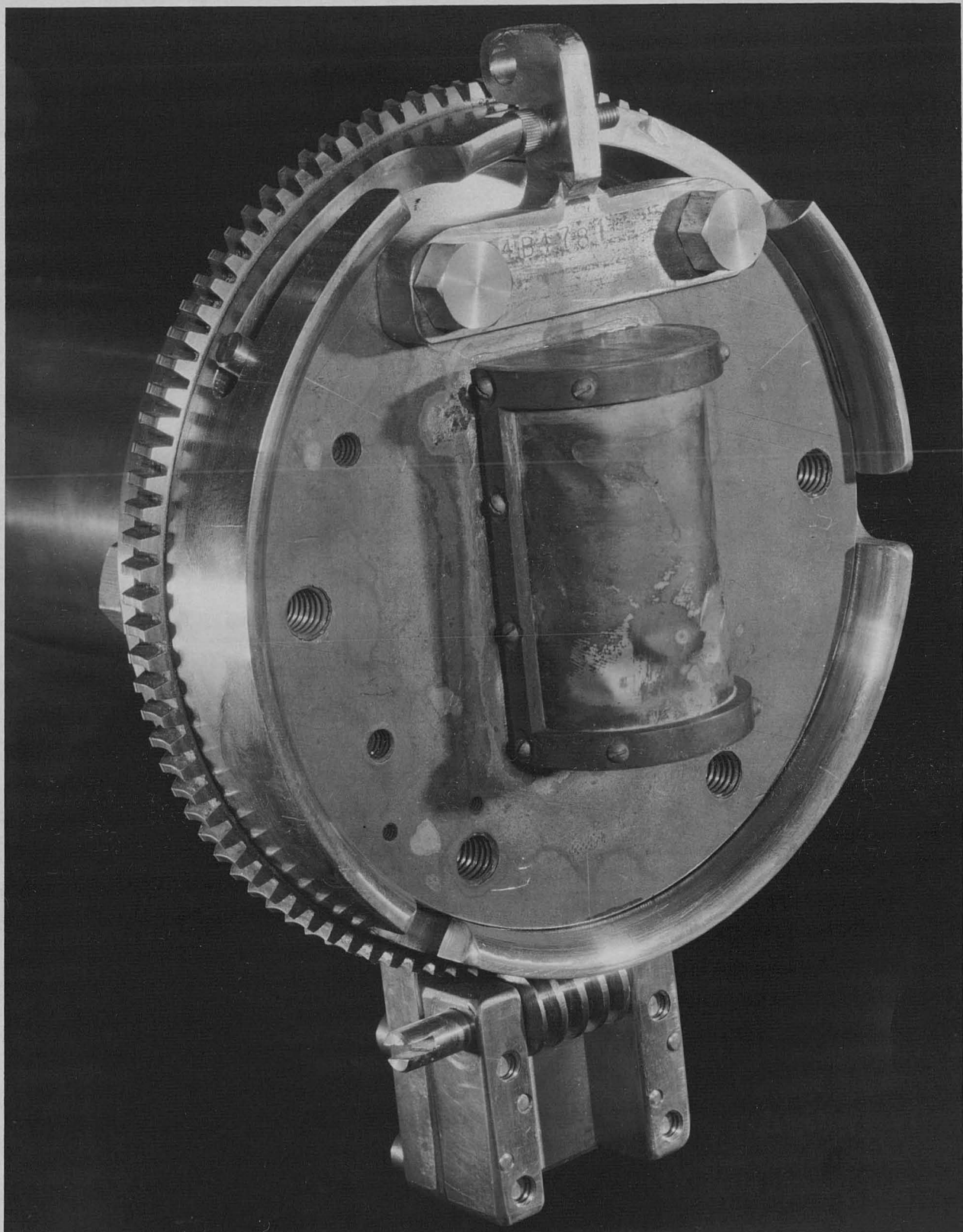


FIG. 2

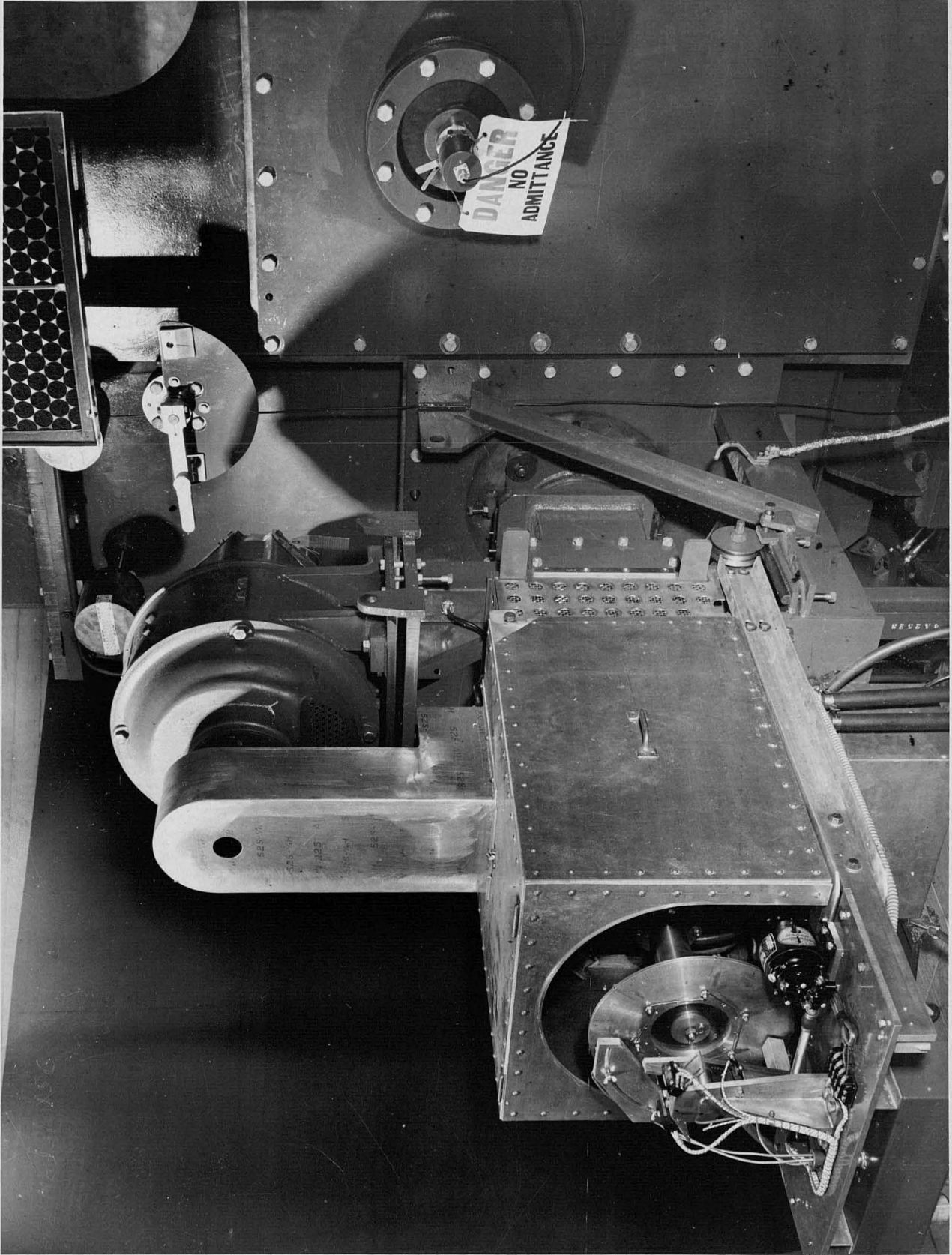


FIG. 3

184" 995

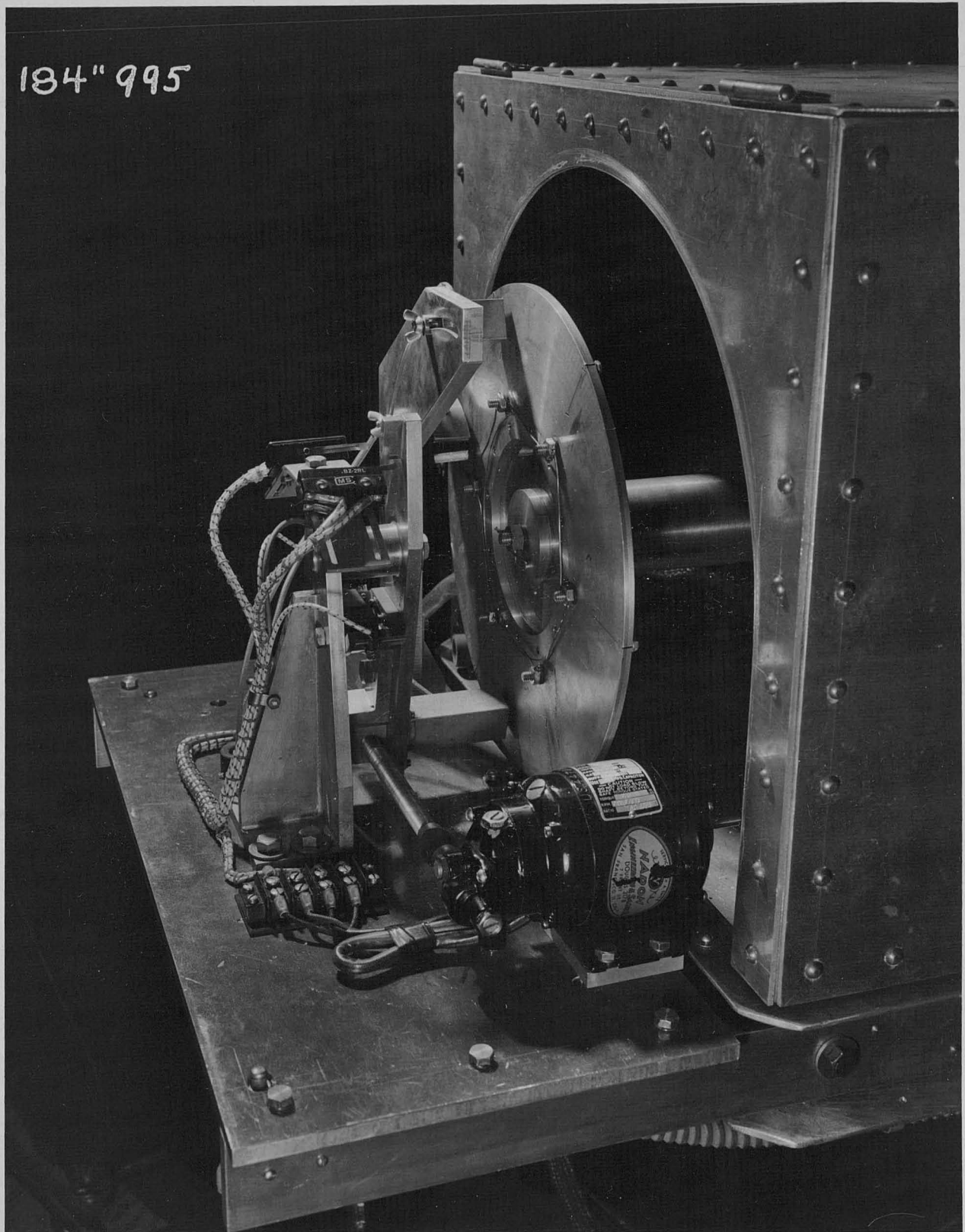


FIG. 4

OZ 479

2. 60-inch Cyclotron

J. G. Hamilton

The 60-inch cyclotron has been out of operation for repairs and alterations. A detailed summary of the changes involved and succeeding operation will be given in the Quarterly Report to follow.

3. Synchrotron

Marvin Martin

The effort of the synchrotron group during the past quarter has been devoted to a redesign of components which did not stand up well in service, and to experimental work aimed at increasing the output of the machine.

A number of measurements of operating characteristics have been made in an attempt to determine the tolerances which should be placed on the operation of various component parts. Some of these results are listed below:

Injector timing has been investigated and it was found that in order to maintain the peak output of which the machine is capable, the overall tolerance on triggering the injector must be held to within plus or minus .05 μ secs. Most of the jitter in the electronic components has been removed and the largest remaining error in timing seems to be due to jitter in the peaking strip signal. Attempts are being made to make this signal sharper in order that the triggering circuits may be initiated at a more constant time. Associated with this trouble are variations in the magnitude of the injector high voltage. A Sorenson regulator has been placed in the primary of this circuit to reduce the effects of fluctuations in line voltage. The above tolerance on injector timing implies a voltage tolerance of plus or minus 500 volts. Additional design work will be required to bring the injector performance to these tolerances.

The above tolerances are apparently required because of attempts which have been made to shape the injector pulse. It is believed that by allowing the injector voltage to rise in time at a rate which corresponds to the rising magnetic field, injection can be accomplished over a longer period of time, thereby increasing the total charge which can be injected into a stable betatron orbit. If injection occurs too early in the cycle, electrons will be injected into a stable orbit during a very short interval of time while the voltage is rising through the acceptance period and a short time later while it is again falling through the acceptance period. A relatively small beam is obtained under these circumstances, but the operation of the machine is not critical to timing when this type of injection is used. As injection is delayed, however, the peak of the curve of injector voltage versus time becomes tangent to a curve representing the rising magnetic field. Under these conditions, the performance is very sensitive to injector timing as indicated by the measurements given in the preceding paragraph. However, the output of the machine is improved by a factor of four or five over that which can be obtained by using early injection.

Similar experiments to those described above have been performed on the turning on of the oscillator. Fortunately, this timing is not nearly as critical as that of the injector. A tolerance of about ± 5 μ secs is permissible and the rate of rise of oscillator voltage with time makes no measurable difference in total output. It was at first thought that a rise in oscillator voltage which just corresponded to the deficiency in betatron flux might improve the catching efficiency of electrons into a synchronous orbit. Any improvement which was obtained with this pulse shape over a sharper rising envelope was so small that it could not be measured. Subsequent measurements of the amount of beam indicated by a scintillation counter located inside the orbit when the oscillator is operated for about 50 μ sec after picking up the betatron beam indicate that about 70 percent of the betatron beam is being accepted into a synchronous orbit. It, therefore, appears that very little improvement can be obtained by improving the catching efficiency.

Early experiments on the use of a contractor coil which surrounded the flux bars indicated that no substantial improvement could be made in the output after the peak magnetic field had been increased to one quarter of its rated value. Recent experiments, however, have indicated that some improvement is possible by using a contractor composed of one of the octant coils. In practice, it has been possible to double the output by discharging a capacitor into the circuit at a time very close to that of injection.

Recently a mechanism has been installed for rotating the injector about a horizontal axis which forms a radius of the orbit and about a vertical axis passing through the filament. Using these adjustments, it has been possible to reduce some of the variations in performance which previously had been noted on changing injectors. It is believed that this improvement results from the fact that the electron optics are not identical in all injectors and that the injected beam can be aimed so that its maximum intensity lobe is utilized.

Considerable effort has been devoted to improving the extent to which the betatron flux condition is met during the interval of betatron acceleration. It is apparent that only a barely sufficient cross section of iron is available in the flux bars to accelerate electrons to such an energy that they can be caught in a synchronous orbit. During this period, which lasts about 100 μ sec, the central flux varies from minus 1 percent to plus 2 percent from its theoretical value. Attempts are being made to pass currents through auxiliary coils around the flux bars, which will add to or subtract from this flux at the proper instant in order to reduce the radial motion of the equilibrium betatron orbit, in the hope that fewer electrons will be lost on the walls. So far, it has been possible to match the betatron condition more closely, but no marked increase in output has been noticed due to these changes. Additional experiments are planned to determine if any appreciable losses exist which may be attributed to this condition.

A number of experimental injectors have been tried. Many tests have been made recently on injectors using a large amount of barium aluminate packed around a tungsten heater and enclosed by a perforated zirconium foil. In tests made to date, this injector appears to have about ten times the emission which can be obtained from the standard tungsten filament. No satisfactory tests of this injector in the synchrotron have yet been obtained.

Another injector modification which appears to be very promising consists of cutting a slot in the ground shield on the opposite side from that on which the electrons leave the gun. It is believed that this slot permits the electric field to penetrate a short distance from the injector and results in decelerating electrons which would otherwise have hit the injector during their first few revolutions. If this deceleration is so slight that they will not be forced into the inner wall of the doughnut, a considerable increase in injection efficiency may be obtained. The best shape and location of slot to date has increased the output of the machine by a factor of four, resulting in an intensity, measured on the ionization chamber described in the last Quarterly Report, of 4.6 r/hour.

The circuits for compensating errors in the magnetic field have been completely redesigned since it was found that optimum performance was obtained with currents which were somewhat too high for the circuits as originally designed. The redesign has sufficient capacity for rms currents of 50 amperes in each octant.

It has been found that the coils located above and below the orbit, usually referred to as "n" coils, are quite important in obtaining maximum performance. It

is necessary to bring the resistors which control the currents in these coils to the control desk in order that the operator may easily adjust the value of n to correspond to the radial position of the injector which is found to be most desirable at the moment.

Another operating variable which was inadvertently incorporated in the original design is the phase with respect to line voltage at which the magnet cycle is started. It is not certain why this variable is important. Two possible explanations have been advanced. The first, which seems improbable, is that some magnetic fields are produced by various wires in the building carrying 60 cycle currents and that these fields interact with the synchrotron field at injection in some manner. The other possible explanation is that the magnetic field generated by the injector filament which is heated by 60 cycle alternating current interacts with the main synchrotron field and that an optimum condition is achieved by controlling the phase of either of these fields. Additional investigation of this phenomenon is planned.

One of the principal difficulties in operating the synchrotron is the large number of controls which must be adjusted to obtain optimum performance. So far, it has not been possible to fix any of these variables. It is hoped, however, that additional investigation may determine the interrelationship of many of the operating parameters so that they can be permanently adjusted, thus making it unnecessary for the operator to adjust so many controls in combination with each other.

4. Linear Accelerator and Van de Graaff Machines

L. Alvarez

Performance and Development of the Accelerator

The linear accelerator and Van de Graaff machines were in regular scheduled operation until March 28. Up to that time extensive bombardments were made on proton-proton scattering, inelastic scattering, range energy relations, chemistry and health physics.

Operation until the March 28 shutdown was very reliable both as far as the Van de Graaff and linear accelerator were concerned. Operating time was approximately 90 percent of available time.

A scheduled shutdown of both machines was made on March 28 to accomplish the following:

1. To increase the current output of the Van de Graaff generator (and hence the linear accelerator) by installing the Phillips Ion Gauge (PIG) type ion source recently developed.
2. To increase the pulse length of the linear accelerator plate pulses from 300 μ seconds to 540 μ seconds, thus more than doubling the useful pulse time (build-up time = 100 μ seconds), and to extend the possible pulse repetition rate to 30 c.p.s.
3. To increase the x-ray shielding of the linear accelerator by placing 1/2 inch lead shields inside the bottom section of the vacuum tank under the liner and by improving the shielding at the various orifices.
4. To reduce the basic cause of x-ray production in the linear accelerator, namely field emission from the round drift tube edges by polishing the drift tubes using a procedure which had been established as effective by short section model tests.
5. To increase the utility, safety and accessibility of the target area by suitable building alterations. Extra space has been provided by removal of the men's toilet and locker facilities and by relocation of the rectifier and pulse-forming line equipment. The utilization of the target space has been increased by providing additional ports on the output analyzing equipment and by suitable additional electric and mechanical facilities.
6. To reduce the neutron background near the bombardment area, the new area has been surrounded by a wall of 14 inch thickness by 9 ft. height of ferrite-concrete. This wall was found advisable in view of past neutron surveys and the beam current increase.

These modifications are now completed, with very satisfactory results and the machines are in regular operation. The performance is now as follows:

1. Van de Graaff beam current: 900 μ A during 540 second pulse; 50 μ A average current at 4.0 Mev. For reasons not well understood, the Van de Graaff generator column will sustain a larger average beam under pulsed operation than under steady ion currents. The x-ray level produced by the Van de Graaff generator is now

negligible at the operating position.

2. The ion current of the linear accelerator is 4×10^{-8} ampere average (6 μ A during the pulse) at a repetition rate of 15 c.p.s. Measurements at higher repetition rate have not been made and further increases are expected. At the above current level, the neutron level in the bombardment area produces an equivalent dosage of .5 r/hour which makes the shielding installation described above mandatory. The level immediately outside the shielding is of the order of 3 mr/hour.

3. The x-ray level due to electron field emission within the linear accelerator has been reduced by a factor of about 10.

A model of a new oscillator employing two Eimac XM-15 tubes has been placed in operation on an air cavity short section (9 ft. in length). Thus far 250 kw pulsed peak power (\sim 7 MV cavity voltage) has been obtained in the cavity excited with a single tube. Tests with the oscillator employing two tubes are in progress. This project aims at replacing the present multiple oscillator system with oscillators using only 4 Eimac XM-15 tubes.

Full scale short section model tests are being initiated to study drift tube geometry for acceleration of protons from .5 Mev to 4.0 Mev. Acceleration starting from this low voltage is of interest to other institutions and also to the planned use of the linear accelerator as a bevatron injector.

Proton-Proton Scattering

The measurements made by the proportional counter techniques have been continued. The internal consistency as to the relation between the coincidence counts possible at 45° , and 39° with 51° and the individual counting rates is excellent. Also the counting rates are sufficient that statistics at all angles can be better than 1 percent for a day's observations. A new possible source of systematic error has been uncovered: Owing to the fact that during r.f. build-up the linear accelerator produces low energy beam components, corrections up to 15 percent are introduced due to the differential effect of the aluminum absorbers on these low energy components. Background corrections are still about 20 percent. In the target area revisions referred to above, provisions have been made for improved shielding and for magnetic beam analysis; the total required corrections will thus be greatly reduced.

Three successful hydrogen runs and several background runs have been made with the photographic plate technique. At this date, 13,000 tracks have been read and the background plates have been analyzed. Tracks have been tabulated over the angular range $10^\circ < \theta < 80^\circ$; the number of tracks show symmetry about $\theta = 45^\circ$ to within the present statistics. Analysis of the background plates shows that less than 1-1/2 percent of the observed tracks on the plates exposed in hydrogen as read by the present techniques, are due to background. Analysis of the ranges of the protons in the photographic emulsion shows that the bombarding beam (magnetically analyzed) was homogeneous, but that the energy selected is only $31.0 \text{ Mev} \pm .5 \text{ Mev}$.

Both methods are now essentially in agreement within the uncertainties referred to above and within the statistics of the tracks tabulated thus far. This agreement includes the absolute cross sections. The conclusions which can be drawn unambiguously thus far from the data are:

1. The data are compatible with a pure S-wave interaction. The absolute cross sections agree with the phase shifts calculated for a Yukawa well potential which fits the low energy data. The principal question is why the D contribution which can definitely be

predicted from the potential is not observed. For any simple potential, the theory predicts an attractive D-interaction which would give a cross section rising toward small scattering angles by an amount definitely outside the observational error of either experiment.

2. There is also no evidence for an interaction in the P-state. Since also no appreciable interaction was observed in the n-p scattering experiments at 90 Mev in the 184-inch cyclotron, this observation leaves the question as to the source of repulsive forces responsible for nuclear saturation quite open. If any P-interaction at all is compatible with the data, it is weakly attractive, rather than repulsive.

Inelastic Scattering of Protons

The analysis of plates studying the inelastically scattered protons from carbon and aluminum at 90° has been completed. The principal results are as follows:

1. In carbon, only 3 levels are observed up to the highest excitation available (29 Mev). No evidence of a continuum is observed. A peak corresponding to deuterons from $C^{12}(p,d)C^{11}$ is observed.
2. In aluminum a continuum of secondary protons is obtained in qualitative agreement with a statistical nuclear model.

Equipment has been designed to do the experiment with proportional counters. Exposures have been made to study the angular distribution of secondary particles from gold; these exposures have not yet yielded any results.

Range Energy Relations

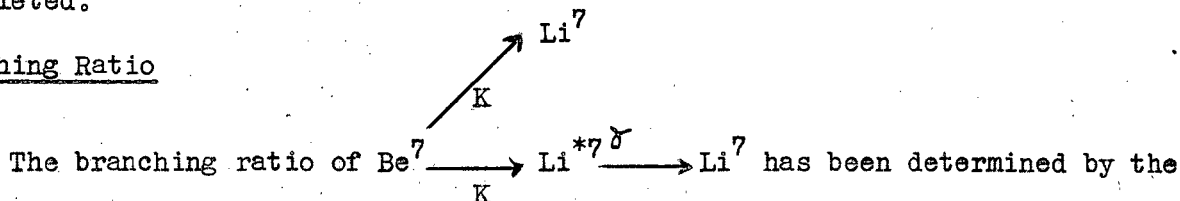
Further exposures of photographic plates have been made to give points on the range energy relations in emulsions.

A study of Bragg curves in air of the beam absorbed in aluminum has been started.

Chemistry and Health Physics

Chemistry bombardments on A and CCl_4 have been made. Exposures on mice in the proton beam have been made at various dosages. Various radiation surveys have been completed.

Be⁷ Branching Ratio



method described before. Results to date indicate that the ratio lies close to 0.1 which is in agreement with the results of a recent measurement at the University of Wisconsin.

Neutron Half Life

The neutron half life equipment is now in operating condition. Experiments have demonstrated the need for reduction of neutron pulse after-effects. An appreciable background appears between pulses and is interpreted as due to incomplete de-ionization

of the Van de Graaff column and ion source. Some interference is also being caused by light produced in the vacuum chamber in the process of applying the deflecting pulse.

Short Half Life Activities

A new half life of 0.5 second has been obtained by bombardment of boron with protons. Heavy particles are emitted during decay. The activity has as yet not been positively assigned; it is probably B^8 , but C^9 is not excluded.

Half Life of Positive π Meson

The half life of the positive π meson has been investigated by tracing the numbers of mesons produced in the 184-inch cyclotron in a helical path. Approximately 750 mesons were counted. By comparing the number of mesons which have traveled an arc of 180° , 540° and 900° , a preliminary result of $T_{1/2} = (.65 \pm .04) \times 10^{-8}$ second was observed. This result is still subject to possible correction pending a calibration of the helical geometry used with α particles from a radioactive source.

5. Bevatron Development

W. M. Brobeck

The principal development of this project during the period was the completion of construction and initial operation of the quarter scale model bevatron. This machine accelerated protons to several million volts energy for the first time on April 30. This successful operation proves the principal of acceleration with a magnet consisting of four separate quadrants as planned for the bevatron and several other machines now under construction. The model will be run during the next few months to determine the strength and characteristics of the ion beam and its dependence on adjustments and operating variables. The aperture will be reduced by obstructions to indicate the effect of aperture size in the final machine. If these results are encouraging the large aperture stage of the full size machine may be skipped and construction of the six billion volt design started immediately. Conversion of the model to provide 1 billion electron volts energy is also being considered.

Other tests have continued during the period on mechanical parts, on model magnets and on frequency control. Model magnet tests have verified the performance predicted from previous less exact tests. A new scheme to control the frequency to correspond with the magnetic field as it rises during the pulse is being worked out which appears very attractive.

Drawings of the full size magnet, magnet foundation and the bevatron building are being prepared. A sample order of steel is to be rolled by the end of May for one of the 144 sections of the magnet. The magnet cable is ordered and the order is about to be placed for machining the steel. The present schedule calls for completion of the magnet by the end of 1950.