Electrically-Driven Magnetically-Supported Vacuum-Type Ultracentrifuge

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Electrically-Driven Magnetically-Supported Vacuum-Type Ultracentrifuge

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A large rotor or centrifuge, an armature, and a small iron rod are anchored coaxially one above the other, in the order named, on a small flexible shaft. The shaft passes through a vacuum-tight oil gland which seals a vacuum-tight chamber surrounding the large rotor. A direct current which energizes an electromagnet situated vertically above and coaxial with the iron rod is adjusted so that the pull on the iron rod is slightly greater than necessary to support all of the rotors. The extra lift is balanced by a slight thrust against the upper end of the shaft by an oiled bronze stop in the pole piece of the electromagnet. The adjustments are made to maintain a small air gap between the rotating iron rod and the stationary pole piece. The rotors are driven by a piezoelectrically-controlled a.c. through the field of a single-phase induction motor which surrounds the armature. Six-inch centrifuges have been spun to over 1000 r.p.s. at very constant speed.

IN the self-balancing vacuum-type ultracentrifuge[1] the rotating parts are supported and driven by compressed air. This type of centrifuge possesses many properties which have made it a useful tool in several types of research.[2–4] Some of its desirable characteristics are as follows: First, the maximum rotational speed, and hence the centrifugal force, is limited only by the strength of the rotor and, therefore, is as large as it is possible to attain. Second, the temperature of the rotor is very uniform, because it spins in a vacuum and all heating effects due to air friction are eliminated. Furthermore, the temperature of the rotor can be maintained at any desired temperature over wide ranges. Third, the oil glands and shaft to the rotor are maintained at the same temperature as the centrifuge, so that material to be centrifuged can enter and leave the rotor through hollow shafts without having its temperature changed. This makes possible a process of continuous centrifuging. Fourth, the centrifuge is self-balancing, which eliminates the necessity of dynamically balancing the rotor with great accuracy after each sample of material is placed in the rotor. Fifth, the centrifuge spins about a vertical axis, which not only allows heavy rotors to be spun on flexible shafts but makes it possible to bring most types of centrifuge bowls (the angular centrifuge, for example) to rest without remixing, since the heavier materials are on the bottom of the sedimentating column.

On the other hand, the air-driven vacuum-type ultracentrifuge has been criticized by some workers as not being sufficiently "fool-proof." In most problems where the above type of centrifuge is used, it must run at a constant speed not far below the region where rotor explosion should occur. This not only requires that the air pressure be maintained constant but that a careful check be kept on the rotational speed by the operator. Furthermore, many laboratories do not have compressed air available in sufficient amounts to operate the air turbines. In previous reports[5, 6] descriptions have been given of an electrically-driven air-supported ultracentrifuge which had an inherently automatic maximum speed control. However, it was still necessary to have available compressed air for the air-bearing support.

In the present paper a description will be given of a vacuum-type self-balancing ultracentrifuge which is electrically driven and magnetically supported. It is operated from the 110-volt a.c. lines through a suitable frequency converter and is capable of precise speed control.

Figure 1 is a diagram and Figs. 2 and 3 are pictures of the apparatus. The rotating parts consist of the large rotor or "centrifuge" C, an armature D of an electrical motor, a small iron rod S, and a flexible shaft A which connects them together. The shaft A passes through the

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[1] J. W. Beams and E. G. Pickels, Rev. Sci. Inst. **6**, 299 (1935).

[2] J. H. Bauer and E. G. Pickels, J. Exp. Med. **64**, 503 (1936); **65**, 565 (1937).

[3] R. W. G. Wyckoff, Science **84**, 291 (1936); **85**, 390 (1937); **86**, 92 (1937).

[4] J. W. Beams, J. App. Phys. **8**, 795 (1937). See this paper for other references.

[5] J. W. Beams and L. B. Snoddy, Science **85**, 185 (1937).

[6] S. A. Black, J. W. Beams and L. B. Snoddy, Phys. Rev. **53**, 924A (1938).

vacuum-tight oil glands G_1, which seals the vacuum chamber, and G_2, which serves to center D in the field F. The oil glands G_1 and G_2 are mounted in oil-resistant, flexible, round Neoprene rings, as in the case of the air-driven vacuum-type machine.[4] The rotating members are supported by an electromagnet consisting of an iron core M and windings L. The current through L is so adjusted that the magnetic attraction between M and the small iron rod S, rigidly attached to and coaxial with A, is just greater than necessary to lift S, A, D, and C. The end of the shaft S fits into a bronze bushing and lightly presses against a bronze plug or stop, both anchored in M. The rotor D is a squirrel-cage type of armature, and F the field of an induction motor, so that an alternating current in the field coils of F causes D to spin. Shading coils, each consisting of a single turn of strip copper, are wound on F so that the single-phase induction motor will start from rest. The variable frequency power supply which furnishes the a.c. to the field F is shown in Figs. 4 and 5. A variable frequency oscillator (controlled by a variable frequency piezoelectric crystal) and a fixed frequency oscillator of about 3500 kilocycles (controlled by a fixed frequency piezoelectric crystal) produce a beat frequency which, after detection and amplification, is supplied to the field coils F of the motor. The entire circuit is made of standard commercial parts.

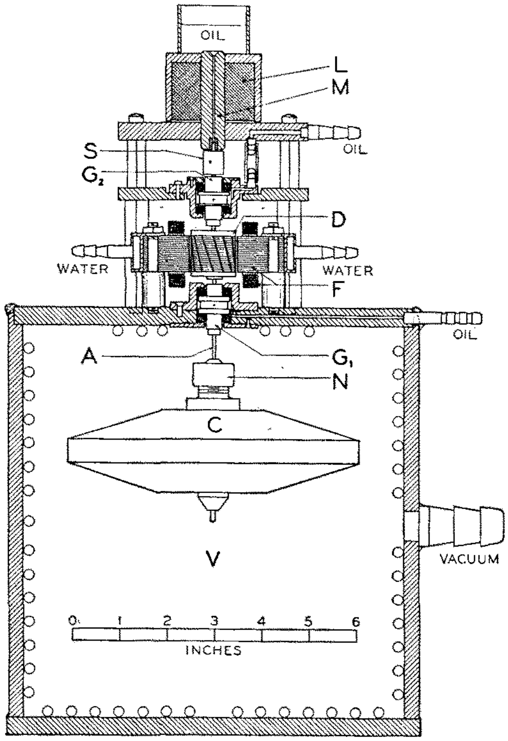


FIG. 1.

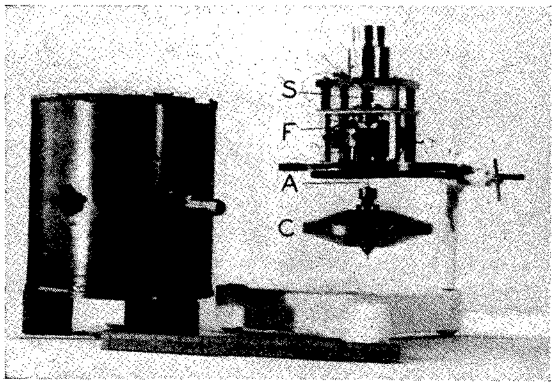


FIG. 2. Photograph of the ultracentrifuge with vacuum chamber removed.

To operate the centrifuge the glands G_1 and G_2 and the field F are adjusted until D and F are coaxial. C is then attached to A by the clutch N about $\frac{1}{2}$ inch below G_1. The direct current, which is just large enough to lift the rotating members and pull the end of the shaft A lightly against the bronze stop in M, is passed through L. The air space between M and S is usually about 0.2 or 0.3 mm. It will be observed that the magnetic field is symmetrical over the top face of S so that the drag due to eddy currents is negligible. The machine is then set and waxed on the vacuum chamber, as shown in Fig. 1, and vacuum pump oil under a few lb./in.^{2} is forced into G_1 and G_2, which serves the dual purpose of lubricating the glands and making G_1 vacuum-tight. Tap water or some other cooling liquid is next circulated, first through the copper coils in good thermal contact with the inside of the vacuum chamber, and then through a jacket surrounding the field F. The vacuum chamber is next evacuated to less than a micron and the axis of rotation made vertical by leveling. The frequency of the power supply is first set at something under a hundred cycles per second. As the rotor speeds up, the frequency of the power supply is increased at the proper rate (found by approximate theory and by trial) to give the maximum torque. The frequency is varied by a rough micrometer screw

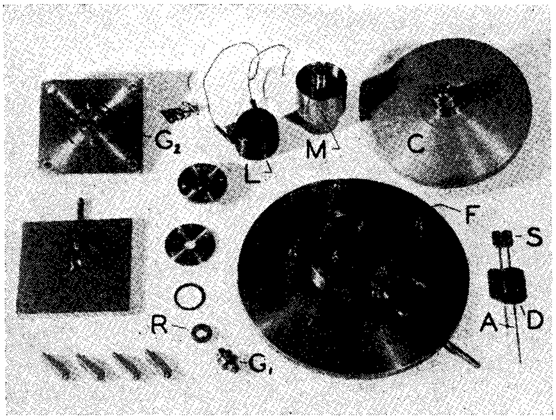
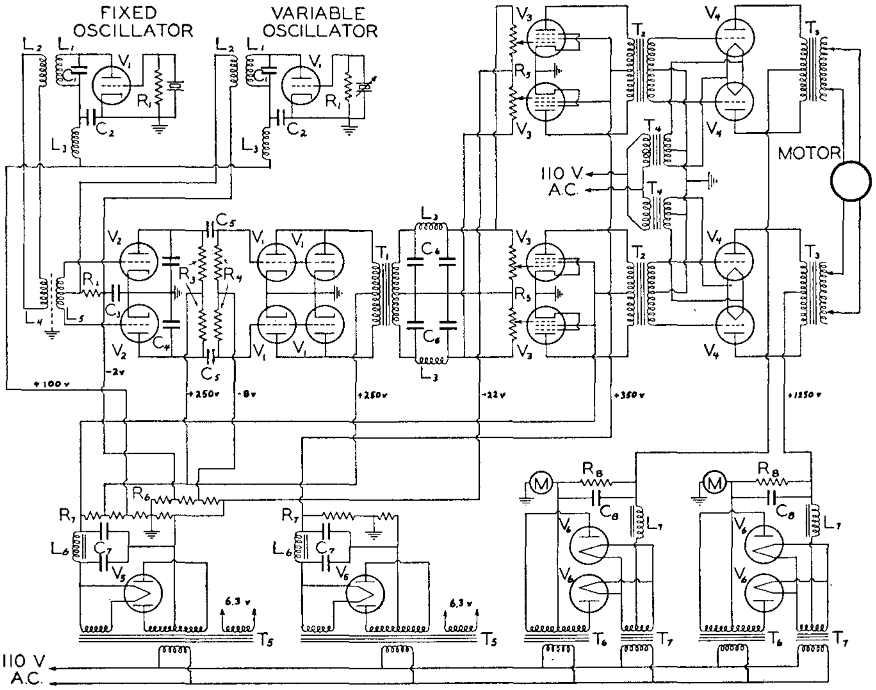


FIG. 3. Photograph of the different parts of the ultracentrifuge. The lettering is the same as in Fig. 1.

arrangement attached to the mounting of the variable frequency piezoelectric crystal. The micrometer screw is turned by hand or by a clock-work arrangement. The frequency of the circuit shown in Fig. 4 can be varied from zero to 5000 cycles, although in the apparatus of Fig. 1 danger of explosion occurs above 1200 r.p.s., so that frequencies above this were not utilized. As the rotors speed up they, of course, pass through the same kind of natural vibration periods as observed in the air-driven centrifuges,[4] and in the same way these are damped sufficiently by G_1 and G_2 to prevent trouble. The centrifuge is always operated at a speed well removed from the vibration speeds. The maximum rotational speed



Circuit Elements

V_1	6C5
V_2	6F5
V_3	6F6
V_4	805
V_5	80
V_6	866
R_1	50,000 ohms, 1 watt
R_2	50,000 ohms, 1 watt
R_3	150,000 ohms, 1 watt
R_4	500,000 ohms, 1 watt
R_5	dual 50,000-ohm volume control
R_6	5000 ohms, 10 watt
R_7	25,000 ohms, 50 watt
R_8	50,000 ohms, 80 watt

C_1	10–70 mmf trimmer
C_2	0.004 mf
C_3	0.1 mf
C_4	0.002 mf
C_5	0.01 mf
C_6	0.002 mf
C_7	5–15 mf, 475 volt
C_8	4 mf, 1500 volt
L_1	18 turns No. 22 d.c.c. on 1½″ form
L_2	5–7 turns No. 22 d.c.c., ¼″ from L_1 on same form
L_3	16 mh choke
L_4	5–10 turns No. 22 d.c.c. wound on copper sheet around L_5
L_5	30 turns No. 22 d.c.c. on 1½″ form
L_6	30 h, 90 ma
L_7	8.2–17 h, 500 ma

T_1	3 : 1
T_2	3.2 : 1
T_3	300-watt U. T. C. Varimatch
T_4	10 v, 6.5 a
T_5	745 v c.t., 145 ma 6.3 v c.t., 4.5 a. 5 v, 3 a
T_6	2670 v c.t., 500 ma
T_7	2.5 v, 10 a
M	0–500-ma milliammeter

FIG. 4. Diagram of the variable frequency power supply.

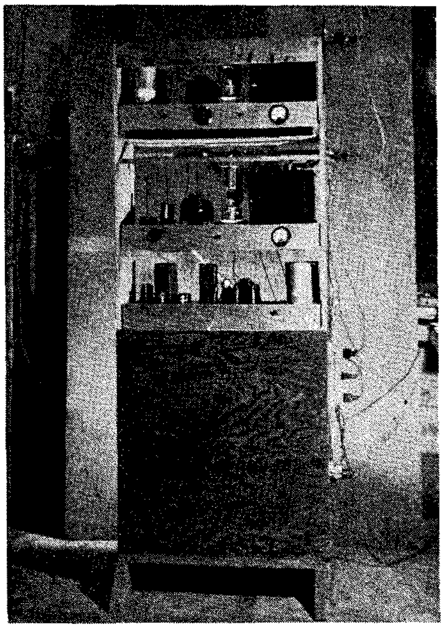


FIG. 5. Photograph of the variable frequency power supply. The power pack is not shown.

attainable is set by the bursting strengths of *C* and *D*. For essentially all practical cases *D* can be made enough smaller than *C* to stand a higher rotational speed. It was found that the rotational speed remained almost as constant as the frequency of the piezoelectrically-controlled power supply, i.e., the slip was remarkably constant.

Several different single-phase induction motors have been used, two of which were specially constructed. For the latter, seven and one-half ml silicon steel laminations were used for the cores of *D* and *F*, while circular bronze plates were anchored to the top and bottom of *D*. The two armatures were $1\frac{5}{32}''$ and $1\frac{1}{8}''$ in diameter and $\frac{13}{16}''$ and $1\frac{1}{8}''$ long, respectively. They each contained 25 No. 14 copper bars anchored to the steel in the usual way around the periphery. The fields were made in the usual way and were wound with No. 18 copper wire. The clearance between the field and armature was $\frac{1}{32}''$. However, it was found, after making a few simple alterations, that certain commercial electric fan motors were well suited for the purpose.

The field *F* and armature *D*, shown in cross section in Fig. 1, were taken from an ordinary General Electric "Junior 10"" fan. The original large shaft was removed from *D* and a clutch substituted to grip *A*. Next, a bronze disk $\frac{1}{16}''$ thick was silver-soldered on each end of *D* to increase its conductivity. *D* was then turned in a lathe to give it a smooth surface. When finished, the diameter of *D* was approximately $\frac{31}{32}''$ and the clearance between *D* and *F* was $\frac{1}{32}''$.

The field coils of *F*, which were originally wound for 110 volts, were rewound each with 50 turns of No. 18 enameled copper wire. Each coil was then carefully shellacked to give the required insulation. The original shading coils were replaced by a single turn of $\frac{1}{4}''\times\frac{1}{16}''$ copper strap. Since the impedance of the motor varies as the frequency is increased, it was matched to the final amplifier stage by means of the variable ratio audiofrequency transformer (Fig. 4). A water jacket was then placed around the field, as shown in Figs. 1, 2, and 3, to keep it cool. The lifting electromagnet was constructed of a core of soft iron, around which were wound 400 turns of No. 18 enameled copper wire. The end of *A* was oiled from above with a 2" gravity head.

With this apparatus the 6" rotor shown in Figs. 1, 2, and 3 was accelerated to 800 r.p.s. in about 15 min. with a power input to the motor of approximately 260 watts (total input to power supply was 1600 watts). With this same power input to the motor, the rotor was accelerated to 1050 r.p.s. in 30 min. When allowed to coast freely, it required over two hours for the rotor to come to rest from 1050 r.p.s., although it could be stopped from 1050 r.p.s. in 10 min. by driving it down by the power supply. The rotational speed was not increased beyond 1150 r.p.s. because of the danger of rotor explosion, but there is little doubt but that, with stronger rotors, this could have been exceeded with the power available. It was found that as the power applied to the motor was increased, the time required for acceleration was decreased.

The rotational speed remained remarkably constant. For example, it was maintained at 1050 r.p.s. for a running period of five hours without any variation that could be detected with the measuring apparatus, which would have recorded a variation of ±1 r.p.s. In this run no attention was required of the operator. This constant speed results from the fact that the "slip" remains remarkably constant at high rotational speeds. Furthermore, the slip was only about 30 cycles per sec. During this run the temperature of the 6″ rotor *C* did not vary from that of the cooling water.

It is indeed a pleasure to record our indebtedness to Professor L. B. Snoddy, who gave us much valuable assistance, to Messrs. F. Linke, P. Sommer, and T. Kishbaugh, instrument makers who constructed most of the apparatus, and to the National Science Division of the Rockefeller Foundation for a grant which has made the work possible.

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A Capillary Ion Source for the Cyclotron

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SINCE the inception of the cyclotron, the source of ions used by all experimenters has been a beam of electrons from a heated filament which traverses the central region between the high frequency electrodes and produces ionization in the gas which fills the cyclotron chamber. This gas pressure must be low (about 10^{-3} to 10^{-4} mm of Hg) to prevent electrical discharge. Ion beam intensities of one to ten microamperes are normally obtained with such a source. At the University of California, beam intensities of the order of 100 microamperes have been obtained by increasing the size and emission of the filament and by expanding the vertical aperture of the electrodes (colloquially known as "*D*'s"). This procedure requires a longer magnetic gap in the cyclotron and consequently a greater expenditure of power. The large physical extent of the region of ionization has resulted in a beam divergent in direction and energy at the exit port, and a large intensity of off-focus ions which do not emerge from the chamber (10 times the observed beam intensity at Berkeley).

This paper reports the present stage of development of a new type ion source for the cyclotron, giving a concentrated beam of ions of high intensity, and effectually isolated from the cyclotron chamber.[1]

The cyclotron used for these experiments[2] has 16-inch diameter cylindrical poles with flux densities up to 14,500 gauss, and produces protons of 2.0 Mev or deuterons of 1.2 Mev. Two chambers were used, one with a vertical distance of 3 inches between pole faces, and one with a 2-inch gap. With the use of the standard filament type ion source ion beams of 5 microamperes of protons and 3 microamperes of deuterons were customary in the two chambers. The capillary ion source has been successfully installed in each and has resulted in intensities of 70 microamperes of protons and 35 microamperes of deuterons. The ion beams have not been measured for energy distribution, but the directional divergence is considerably smaller than with the more extended filament type sources.

The development started with an attempt to adapt the capillary discharge source so successful in direct acceleration apparatus,[3, 4] to the geometrical limitations and high magnetic fields of the cyclotron. It was found possible to operate a discharge through a copper tube of $\frac{1}{8}$-inch inside diameter in the magnetic field of the cyclotron if the tube was mounted accurately parallel to the field, i.e., vertically. Enlarged chambers at top and bottom of the capillary housed the cathode and anode. Magnetic fields of up to 1000 gauss improved the stability and characteristics of the discharge, but with higher fields the discharge potential drop was considerably increased. A design using only a very short length of capillary with enlarged conical

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* Now at Massachusetts Institute of Technology.

[1] C. P. Baker and M. S. Livingston, Phys. Rev. **51**, 1011 (1937).

[2] M. S. Livingston, Rev. Sci. Inst. **7**, 55 (1936).

[3] M. A. Tuve, O. Dahl and L. R. Hafstad, Phys. Rev. **48**, 241 (1935).

[4] E. S. Lamar, E. W. Samson and K. T. Compton, Phys. Rev. **48**, 886 (1935).