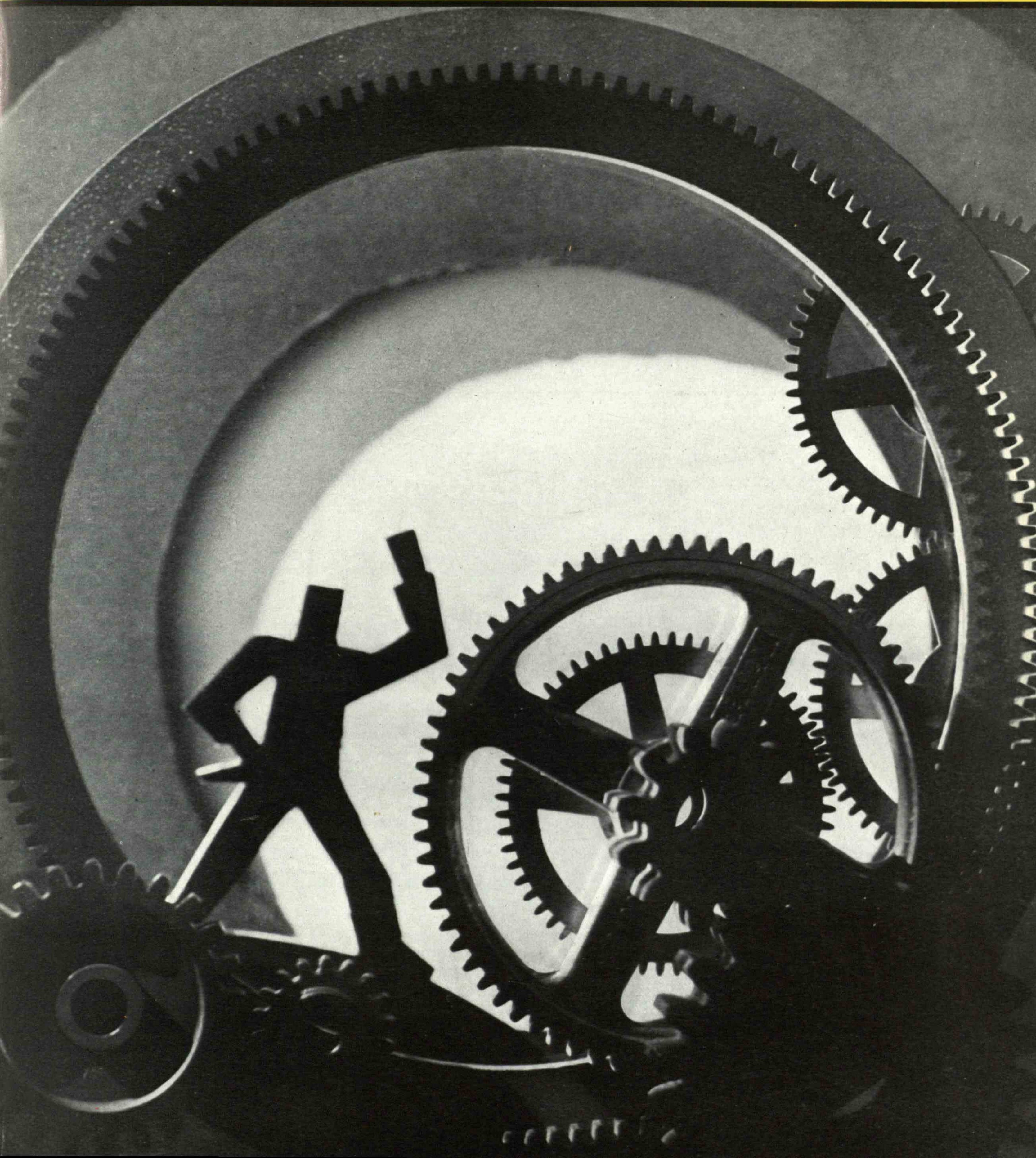
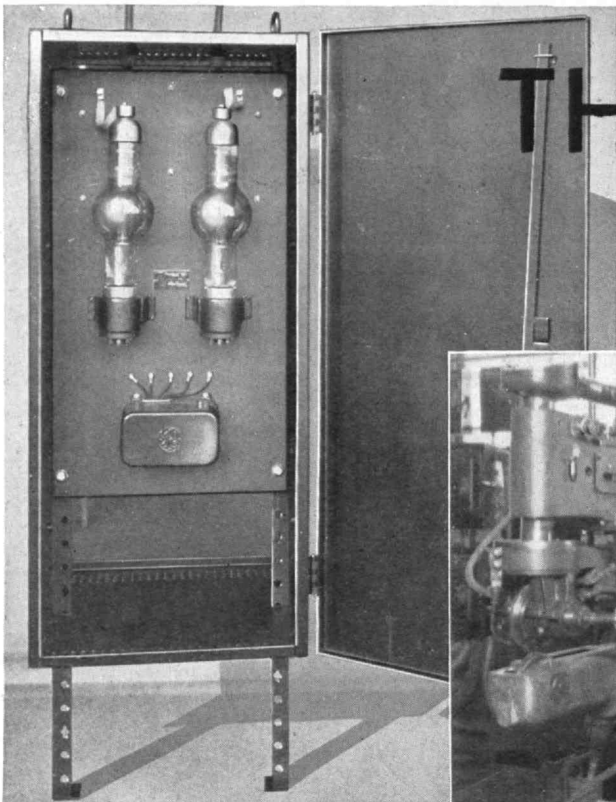
January 1932

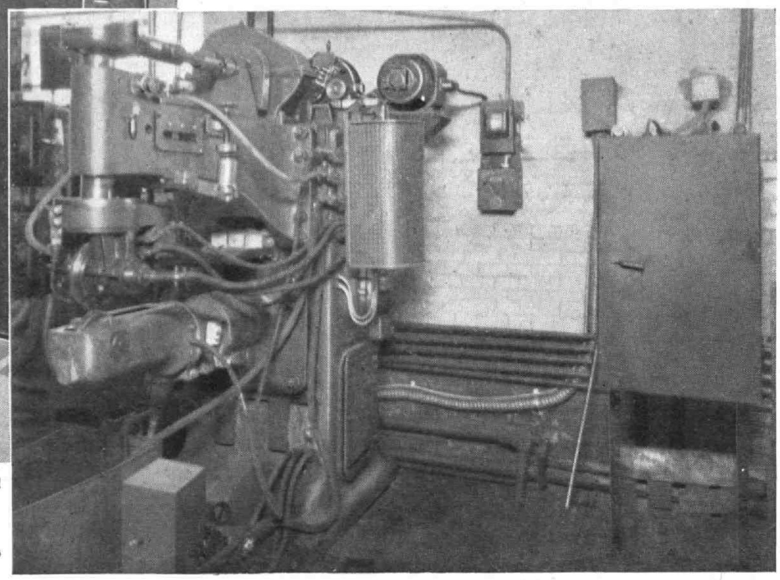
TECHNOLOGY REVIEW



THYRATRON
THE OPEN DOOR



Close-up of a Thyratron control panel for high-speed welding applications



G-E Thyratron control equipment (in case) operates this line welder through a reactor

THE new electron tube, the Thyratron, is the most versatile servant developed in recent years. Already it has a host of applications. It will open windows, count anything that will interrupt a beam of light, operate welding machines, sort beans or buttons, operate drinking fountains as you bend over them, light buildings, windows, and theaters, and measure the intense heat of furnace interiors. And it has a thousand other applications.

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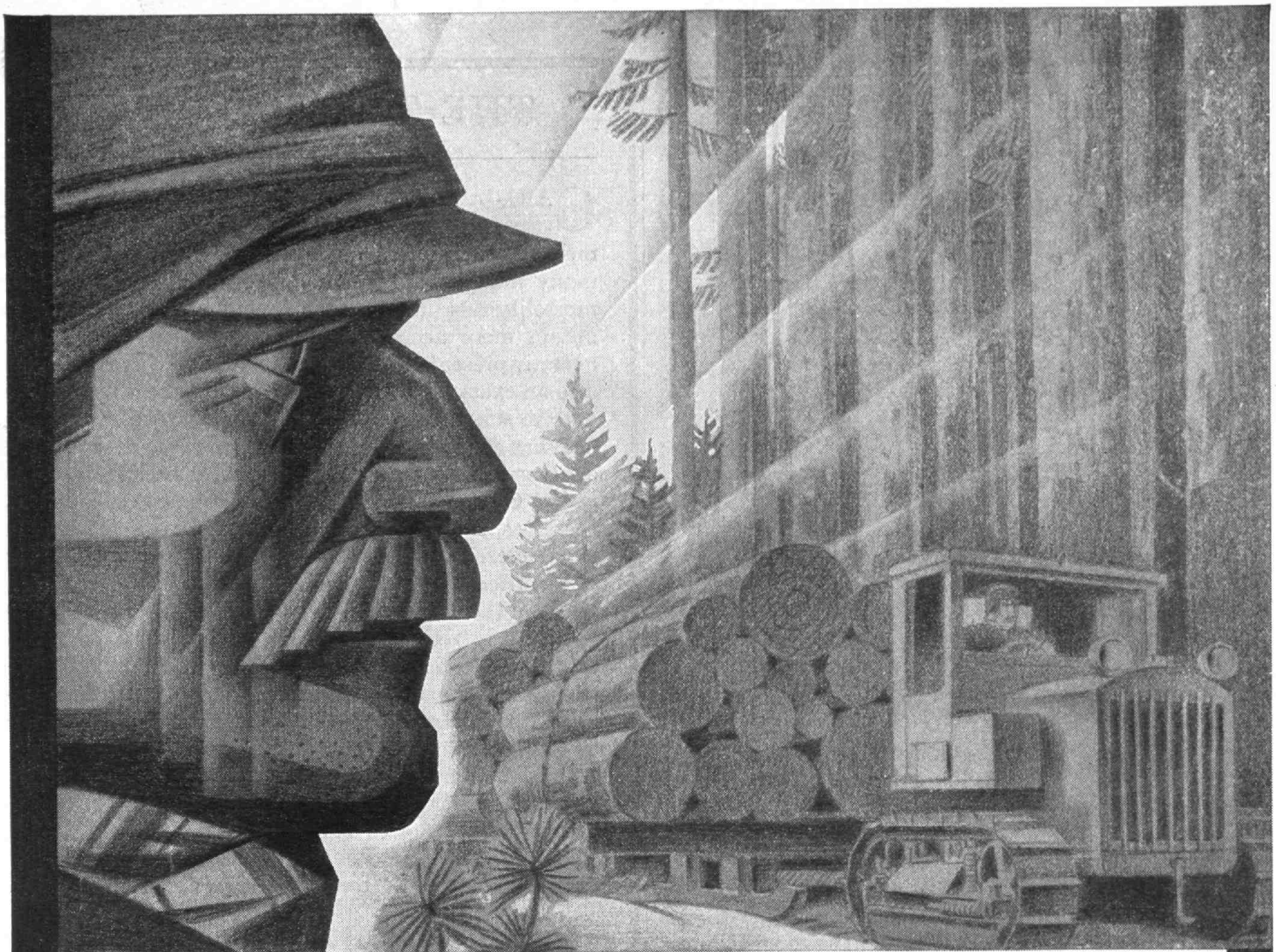

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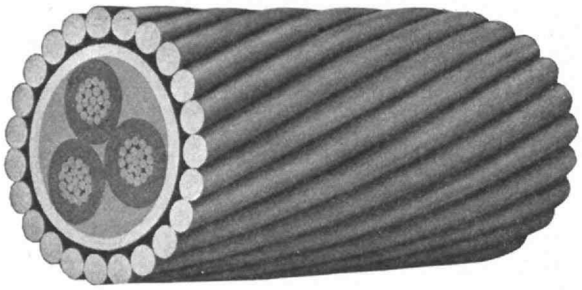

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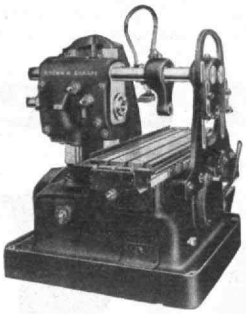
THE TABULAR VIEW

CARDIAC diseases cause more deaths in the United States than any other affliction. The forces of medical science are converging upon the problem from many angles with the hope of lowering this terrific mortality rate and one example of what is being done to obtain more accurate information about the human heart is presented as the first article in this issue. It is also an example of the bonds which connect apparently diverse scientific subjects. In this instance, the physician has called in the electrical engineer to devise a new cardiograph for studying electrically the action of the heart. ¶ Physician and electrical engineer collaborate, therefore, in the preparation of this announcement of a new electrocardiograph. VANNEVAR BUSH is Professor of Electrical Power Transmission at M. I. T. In 1928 he received the Louis Edward Levy medal of the Franklin Institute in recognition of his distinguished contributions to physics and electrical engineering. He has supervised the design and construction of the various integraphs and analyzers which have been developed at the Institute, and one of these is described on page 171. W. D. REID is an Associate Member in Cardiology a at the Evans Memorial Hospital, of which ~~that~~ well-known contributor to The Review, Dr. Allen W. Rowe, '01, is Director. Dr. Reid is also Assistant Professor of Cardiology at the Boston University School of Medicine.

PRESIDENT COMPTON of M. I. T. by word and action exalts the position of the engineer in society. His article in this issue is a fitting sequel to the stirring article by Stuart Chase entitled "Prometheus Enchained," which appeared in The Review for November, 1930. ¶ HAROLD E. LOBDELL is, of course, the publisher of The Review and Dean of Undergraduate Students at the Institute. His collaborator, H. H. W. KEITH, is Professor of Naval Architecture at M. I. T. In addition, he is an advisor on launching problems for the Fore River shipyard of the Bethlehem Shipbuilding Company. He is also consulting architect for that firm and takes an active part in the design and construction of warships built there. Professor Keith is a reserve officer in the Navy, and at the present time is taking an active part in the design of a proposed experimental naval tank to be built at Technology.

RALPH E. FREEMAN is Associate ~~Assistant~~ Professor of Economics at M. I. T. After graduating from McMaster University in Canada, he went to Oxford as a Rhodes Scholar, studying in Balliol College. Subsequently, he held a fellowship in the Department of Economics at the University of Chicago, and he was for six years Head of the Department of Economics and Political Science at the University of Western Ontario. He is the author of "Economics for Canadians," published in 1928. In addition to his teaching, he has had valuable experience in business. ¶ Professors Tenney L. Davis, '13, and Norbert Wiener are two of The Review's star *feuilletonists*. Professor Davis is now back in the States.



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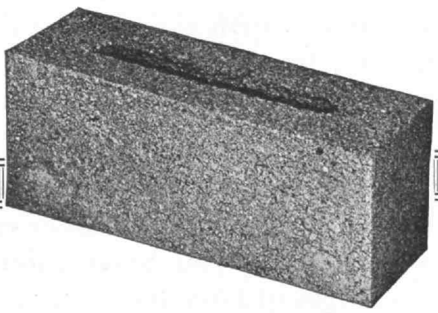

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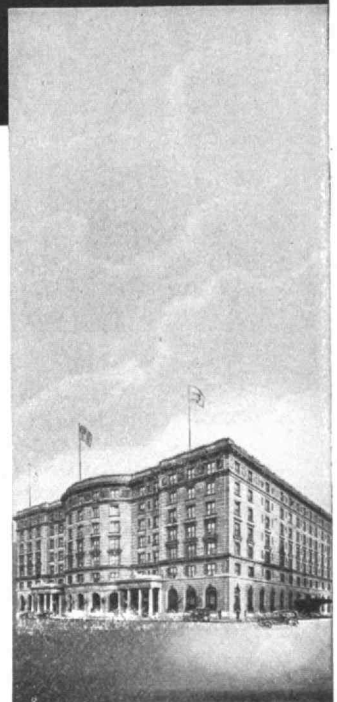

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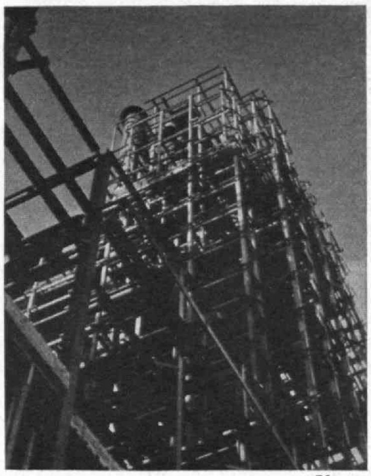

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Edited at the Massachusetts Institute of Technology

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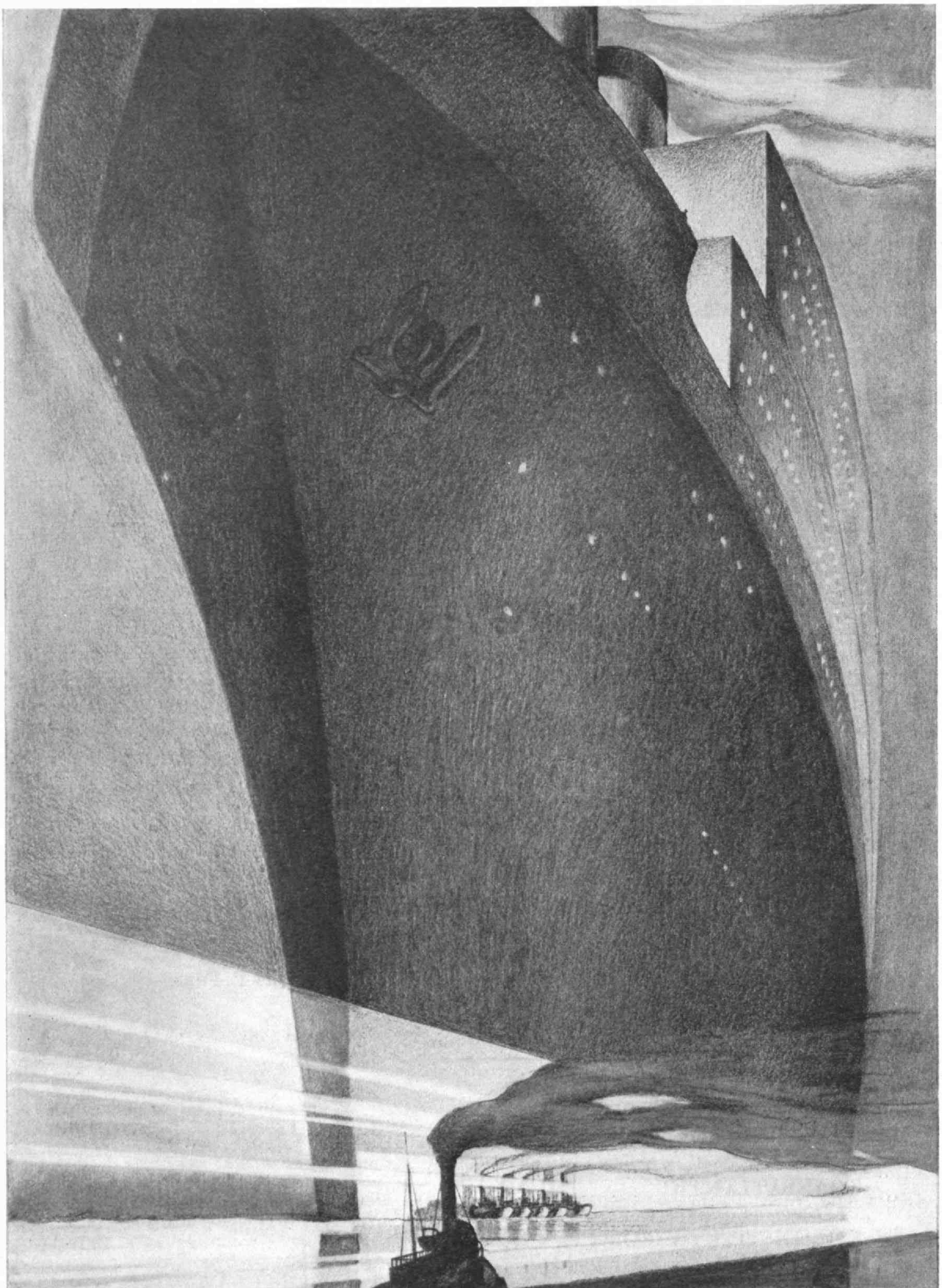

From a pencil and crayon drawing by Leopold de Postels of the de Postels Studio

Leopold de Postels

AT THE behest of a traveling public insatiable for speed, spectacular size, and voluptuous luxury, the shipbuilding industry is strenuously planning ships that are a little longer, a bit swifter, and more elaborately comfortable. In the article on page 165, this course of events is analyzed, and in the tables on pages 166 and 167 an inventory of the world's great passenger vessels, built or planned, is presented

THE

TECHNOLOGY

REVIEW

Vol. 34, No. 4 January, 1932

THE HUMAN POWER PLANT

Peak Capacity of American Hearts over Half a Million H. P.

By V. Bush and W. D. Reid

Editorial Note. This article contains an announcement of a new and marvelously sensitive electrocardiograph for studying the action of the heart. The device is the result of joint research carried on by the Evans Memorial Hospital, Boston, and the Electrical Engineering Department of M. I. T.

HUMAN hearts of the United States develop normally a combined output of about 70,000 horse power, an amount approximately equivalent to that necessary on the average for light and power in a city the size of Boston. They have, moreover, a very large overload capacity, and can produce in a pinch about eight times normal output for a short interval. The installed peak internal pumping capacity of the population is hence over a half-million horse power. This pump delivers some 130 billion gallons of blood a day which is about 40 times the total flow of water used for all domestic purposes throughout the country, nearly equivalent to the flow of the Niagara River, or enough to fill the largest reservoir of the world behind the Hoover Dam in two months' time. The aggregate size of this pumping plant is therefore considerable, but its size is completely overshadowed by its reliability.

Most hearts proceed throughout a complete lifetime without servicing, completing a total of 2,000 million fairly complex complete operations without overhaul or major failure. An automobile engine, after an extreme life of 50,000 miles of operation, completes only 200 million revolutions, or 10% of the complete operations of a heart; and it very seldom does this much without overhaul.

About one heart in six actually fails in service. This ratio would be significantly decreased if hearts were given the periodic attention habitually lavished by many on fine motors, and if the accumulated knowledge of cardiac experts were utilized freely by those whose hearts were shown by diagnosis to have need of service. It is not considered good form to operate a fine car with leaky valves. Those of the heart cannot be taken out and ground, it is true, but many an incipient leak can, nevertheless, be rectified.

The heart is not only a pump, it is also a generator of electricity. Like other muscle tissues its operation is accompanied, in a way which is still in its detail mysterious, by the production of differences of electrical potential. That the actuating mechanism of a muscle is susceptible to electrical stimulation became convincingly apparent when, about 1770, Galvani first made a frog's legs twitch by connecting crude electric cells between a nerve and muscle. It had, in fact, been illustrated much earlier by the violent contraction of the muscle of the first victim to pick up inadvertently a charged Leyden jar. Similarly, it has long been known that natural muscular contractions are accompanied by changes in electrical potentials, and as early as 1855, Kolliken and Müller demonstrated that this was true of the heart muscle of a frog.

As an electrical generator, however, the human heart is not a powerful apparatus. The electric eel, *electrophorus electricus*, can generate in some very clever way enough electrical energy to stun a large antagonist, and this in spite of the fact that he

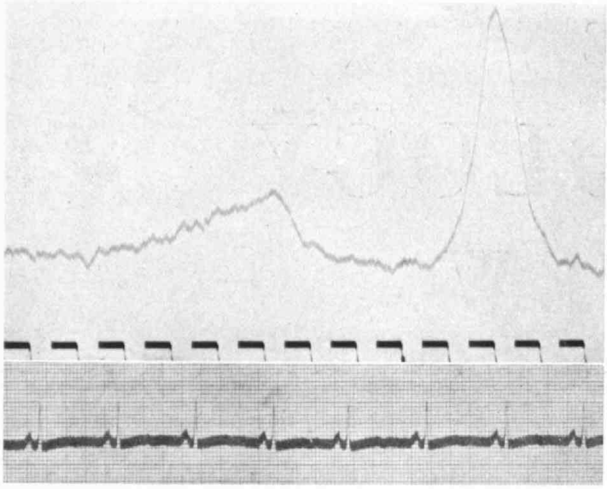

Figure 1

appears to be continuously short circuited by the medium in which he lives. Compared to this eel, man is a weak generator indeed. Accompanying heart action, there appears at electrodes placed far apart on a human body a difference of potential which has a value when averaged against the total time of about one-quarter of a millivolt. The body resistance varies widely, but a representative value is about 2,500 ohms. Hence the maximum of the mean electrical power output into an external circuit from this source of potential difference can be only about six micromicrowatts, or, in the terms previously used, about one one-hundred-million-millionth of a horse power. If applied for lighting purposes this amount of power would be capable of giving a one-second illumination of a small flash light bulb once in a thousand years. This is not a large amount, yet the accurate measurement of the time variation of this potential difference furnishes one of the accepted means of investigating the performance of the heart. This is the subject of electrocardiography.

In 1887 Waller made use of the capillary electrometer on man, and in 1892 Bayliss and Starling obtained the first good records which could truly be called electrocardiograms. The capillary electrometer, which has now been largely forgotten by experimenters, consists of a column of mercury in a capillary tube on top of which is sulphuric acid, and it depends for its action upon the fact that the surface tension in the interface is considerably changed when the interface is polarized. The fact that this instrument was successfully used to record the rapid variations in the weak potential difference accompanying heart action, crude though the results were bound to be in terms of present-day technique, excites intense admiration when one properly evaluates the work in terms of the experimental situation of the time.

In 1903 Einthoven of Leyden introduced his string galvanometer, and the use of this greatly simplified the problem and rendered possible rapid advance. This instrument consists essentially of a very fine wire stretched in a powerful constant magnetic field. Very minute currents through the wire cause it to deflect appreciably, and optical arrangements make possible a time record of the movements. A typical record obtained in this manner is shown at the bottom of Fig. 1. For nearly 30 years and until quite recently this has been the only working tool for both clinical and research electrocardiography. It has accomplished much, and by its use has been built up an invaluable record of experience, so that this form of the electrocardiograph has certainly made it possible for the modern physician to understand numerous cardiac conditions and often to apply effective treatment to sick human beings in a way that was quite impossible to physicians of a few decades ago. String galvanometer studies have gone far to determine what drugs are really valuable and what are ineffective or worse. The instruments are used in many of the larger hospitals and clinics throughout the world and much significant knowledge has been obtained by careful correlation of electrocardiographic findings in life with conditions disclosed at post-mortem examinations. Yet the string galvanometer has very serious limitations, and the art of measuring minute electrical magnitudes has proceeded far since Einthoven's work in 1903.

THE advent of the thermionic tube really revolutionized the technique of fine electrical measurement. Concurrently with its widespread use in radio and telephony it has had a less spectacular application in all sorts of investigatory work in the laboratory. This is primarily due to two outstanding characteristics which render it uniquely applicable to the measurement of rapidly varying or very weak phenomena. The first of these is its almost complete lack of inertia, the only time-lag present being due to the small time it takes for an electron to pass over the short distance from the filament to the plate. Thus, as an oscillator, it can readily be made to repeat a predetermined performance 100 million times per second. The second characteristic is the fact that a significant power output from its plate circuit can be accurately and completely controlled by an extremely small input to its grid. How small this can be is not always realized. A tube recently produced by the General Electric Company, and designed to have a very low grid current, can operate with an input current of 10^{-17} ampere. Several analogies have been given to aid in visualizing this magnitude, in comparison with the full ampere taken by an incandescent lamp of moderate size, but, if it is permissible to add to these, the following analogy seems to have been overlooked. If the single ampere in the lamp be represented by all the women of this country talking in unison at the rate of 150 words per minute, then the grid

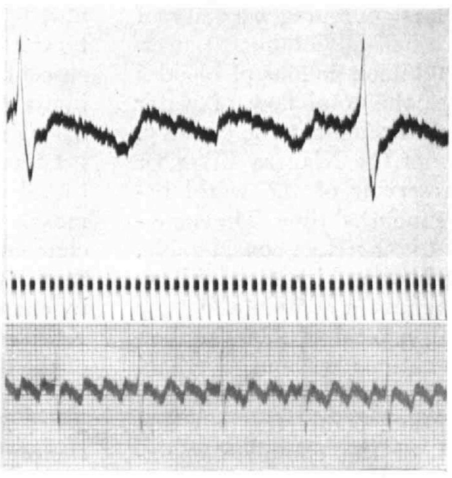

Figure 2