accelerated function of the time. This is shown graphically in Fig. 2. The two irregularities occurring at 40 and 80 ohms, respectively, are not indicated in the curve.

Summary. 1. Stimulation of nerve by electrical fields associated with the charging and discharging of condensers has been obtained, although the efficacy of increasing and decreasing fields is not identical; 2. a strength-duration curve of excitation with diminishing electrical fields associated with the discharge of condensers has been determined wherein E is at first a decreasing and then an increasing negatively accelerated function of the time. The region of inversion is between .0001 and .00038 mscs; 3. the curve is in marked contrast with those obtained by discharging condensers through nerve tissue, in that these (a) are not characterized by an inversion, (b) show E as a *diminishing* negatively accelerated function of the time;[2] 4. there are great differences in the stimulability of preparations.

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An Automatic Electron Tube Stimulator and Recorder.*

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As a result of the development of radio apparatus and of new types of vacuum tubes, it became possible to devise stimulators having desirable features impossible to inductorium or neon tube stimulators, *i. e.*, greater range of frequency of stimulation, greater range of intensity of each shock, and methods for recording the frequency of the stimulation. Many instruments, incorporating some or all of these features, have been devised, outstanding examples being those of Scheminzky,[1] Schmitt,[2] Nicolai,[3] and Bouman.[4] Although these instruments can be considered as great improvements

2 Katz, B., *Electrical Excitation of Nerve*, Oxford Press, 1939, p. 5.

* The authors are indebted to Dr. Reginald A. Cutting, director of the Department of Physiology, for the use of his personal electrical apparatus and for stimulating the investigation in many ways.

1 Scheminzky, F., *Arch. f. d. ges. Physiol.*, 1930, **225**, 303.

2 Schmitt, H. A., and F. O., *Science*, 1932, **76**, 328.

3 Nicolai, L., *Pflügers Archiv.*, 1930, **225**, 131.

4 Bouman, H. D., *Arch. Neérl. Physiol.*, 1935, **20**, 155.

over earlier types, they all have one or more of the following undesirable features: (1) large, complicated and expensive, (2) operate on batteries, (3) unwanted and irregular leakage currents, and (4) the wave form of the stimulating current is not independent of frequency.

A recent instrument which is especially noteworthy for its portability is that devised by Cullen.[5] The attached signal magnet, however, always vibrates at a frequency of 60 times per second and so provides no means of indicating the frequency of stimulation. Furthermore, after having used this particular instrument the authors have found that the high amperage delivered to the signal magnet considerably shortens its life when the ordinary classroom type is used. Another undesirable feature is the presence of "stray charges in the instrument" which renders it unfit for precision work.

The authors have designed a portable (operating on 110 volts, A.C.) and inexpensive stimulator which does not have the disadvantages discussed and enumerated above. This is mainly accomplished by (1) the introduction into the oscillator circuit of a current limiting tube (type 6SK7) which takes the place of the variable resistor in the relaxation oscillator circuit of other stimulators; the resistance of this tube is a function of the control grid and screen grid voltages—the less the screen voltage and the more negative the control grid, the higher the resistance; it gives a much better control of frequency both as to range of coverage and at very low frequencies, and (2) isolating the oscillator from the output circuits by interposing a beam power tube amplifier which prevents interaction of the output circuits on the oscillator, resulting in more stable output—a result which is further assured by using inverse feedback in the amplifier circuit. Another new feature is the use of a "tuning indicator tube" (type 6E5) which blinks synchronously with each stimulus and so provides a means of visually indicating the frequency of stimulation which can be set to the chosen rate before applying the stimulating current to the tissue and signal magnet. Other features of the instrument are: (1) it is automatic; (2) it generates an ideal type of stimulating current; (3) the frequency of stimulation can be varied at will from a single shock every six seconds to a maximum rate of 2500 per second; slower or faster rates can be effected by changing the capacity of condenser C_1 or C_2; (4) the intensity can be varied without affecting the frequency, each being adjusted independently by their respective control knobs; (5) provision is made for the operation of a signal

[5] Cullen, A. B., *Science*, 1941, **94**, 219.

magnet which records each shock synchronously; (6) the intensity of the stimulating shocks may be adjusted to any value from zero to a maximum of ca 20 volts.

Details of the circuit are shown in Fig. 1. The wave form of the stimulating current is shown in Fig. 2; each stimulating shock is seen to consist of a single momentary unidirectional current.

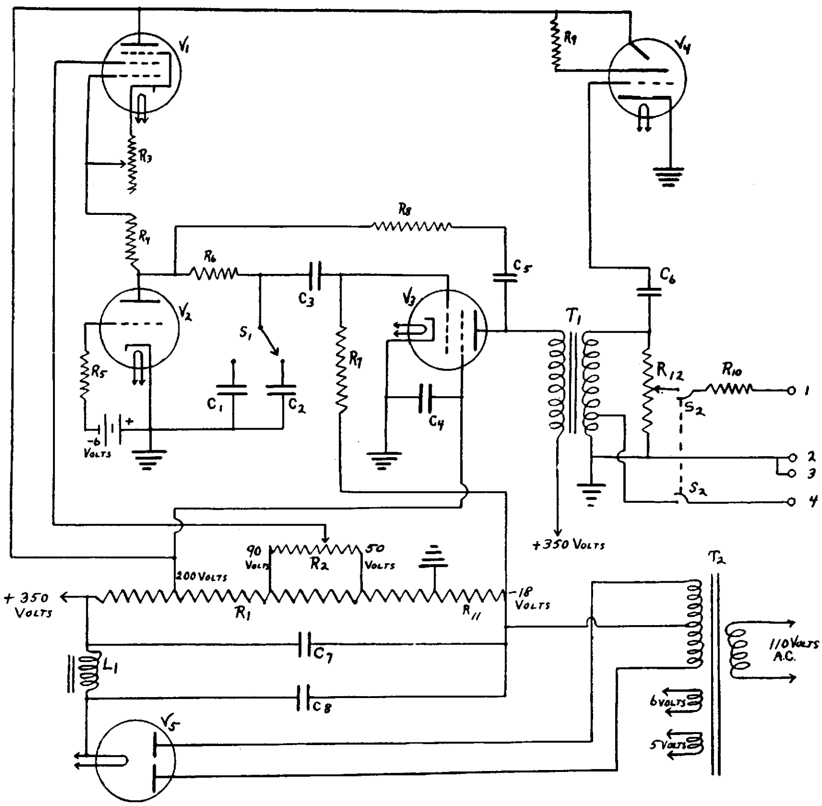


FIG. 1.

Circuit of Automatic Electron Tube Stimulator and Recorder.

V_1	Type 6SK7 tube.	R_{11}	200 ohms, 25 watt, variable.
V_2	" 884 "	R_{12}	5,000 " potentiometer.
V_3	" 6L6 "	C_1	0.5 Microfarad
V_4	" 6E5 "	C_2	0.01 "
V_5	" 83 "	C_3	0.5 "
R_1	20,000 ohms, 75 watts.	C_4	1.0 "
R_2	10,000 ohms potentiometer.	C_5	0.015 "
R_3	3 megohms "	C_6	0.00001 "
R_4	50,000 ohms, 1 watt.	C_7	10.0 "
R_5	75,000 " 1 "	C_8	10.0 "
R_6	500 " 1 "	T_1	Output transformer.
R_7	1 megohm 1 "	T_2	Power "
R_8	1 " 1 "	L_1	10 to 20 Henry choke.
R_9	1.5 " 1 "	S_1	S.P.D.T. switch.
R_{10}	1000 ohms, 1 "	S_2	D.P.S.T. "

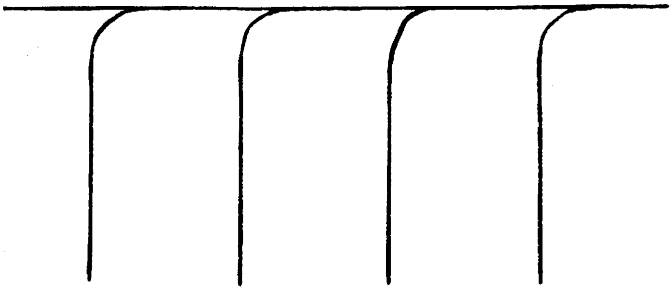
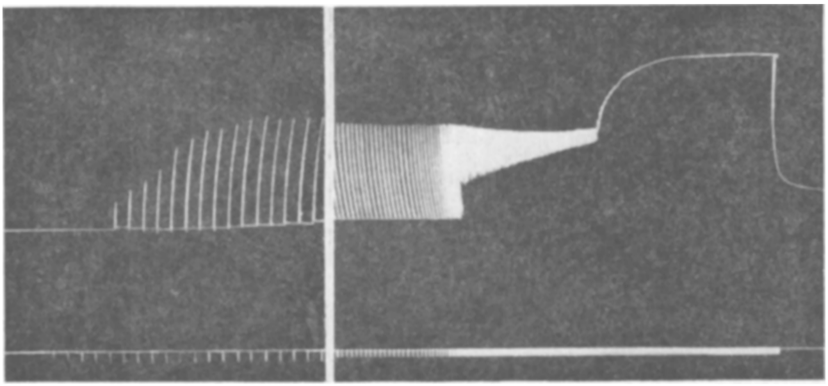


FIG. 2.
Tracing of the form of the stimulating current as visualized on the screen of an oscilloscope.



A B

FIG. 3.
Responses of a frog's gastrocnemius muscle to different (A) intensities and (B) frequencies of stimulation.

Actual responses of a frog's gastrocnemius muscle to different intensities and frequencies are shown in Fig. 3. Note that the signal magnet works in complete unison with the stimulating current.