were considerably higher and much better sustained than those observed after 200,000 units given in the same volume of the water-in-oil emulsion.

Conclusion. The previous observation that only a slight and inconstant prolongation of penicillin blood levels is obtained by the use of a water-in-oil emulsion is confirmed. The present findings suggest further that a substantial increase in the intramuscular dose of penicillin in the same volume of saline will give considerably higher and better sustained plasma levels than the smaller dose given in a water-in-oil emulsion and the disadvantages of the latter method are thus avoided.

15547

A Constant Current Square Wave Stimulator.

HENRY W. NEWMAN.

From the Department of Medicine, Stanford University School of Medicine, San Francisco, Cal.

In the study of neuromuscular excitability, both experimental and clinical, a source of stimulating electric current is required. As the tests employed have been refined, there has been simultaneous refinement and complication of the apparatus required to perform them, with the development of a multiplicity of stimulators, each designed for one specific test. It is the purpose of this paper to describe the construction of a stimulator which may be used both for the older and the more recent tests, yet which is not unduly complex, and which may be constructed from standard radio components.

This stimulator is capable of producing waves of essentially square form as seen in Fig. 1, with constant current at full output of 20 milliamperes so long as the output re-

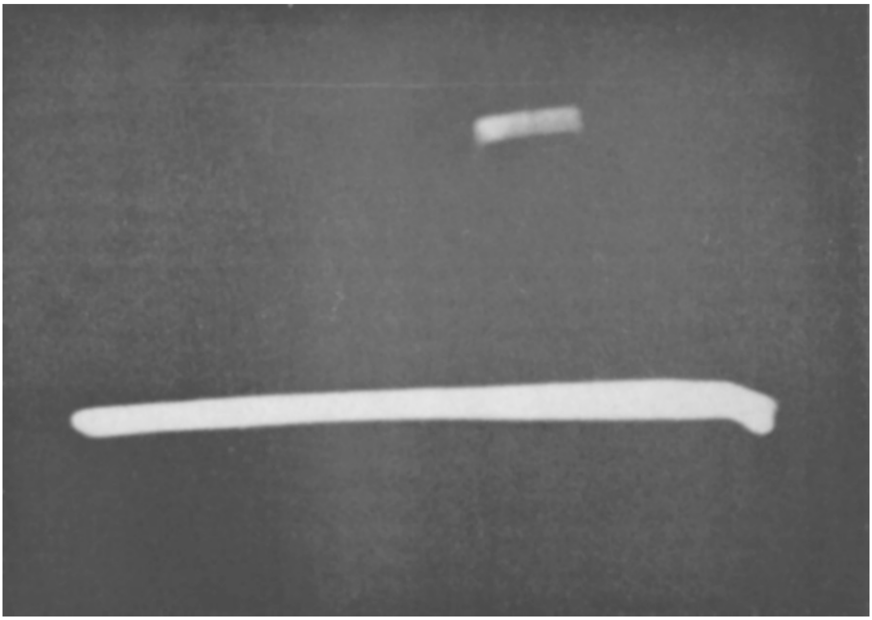

Fig. 1.
Cathode ray oscillographic tracing of stimulus of 5 milliseconds duration, showing square wave form.

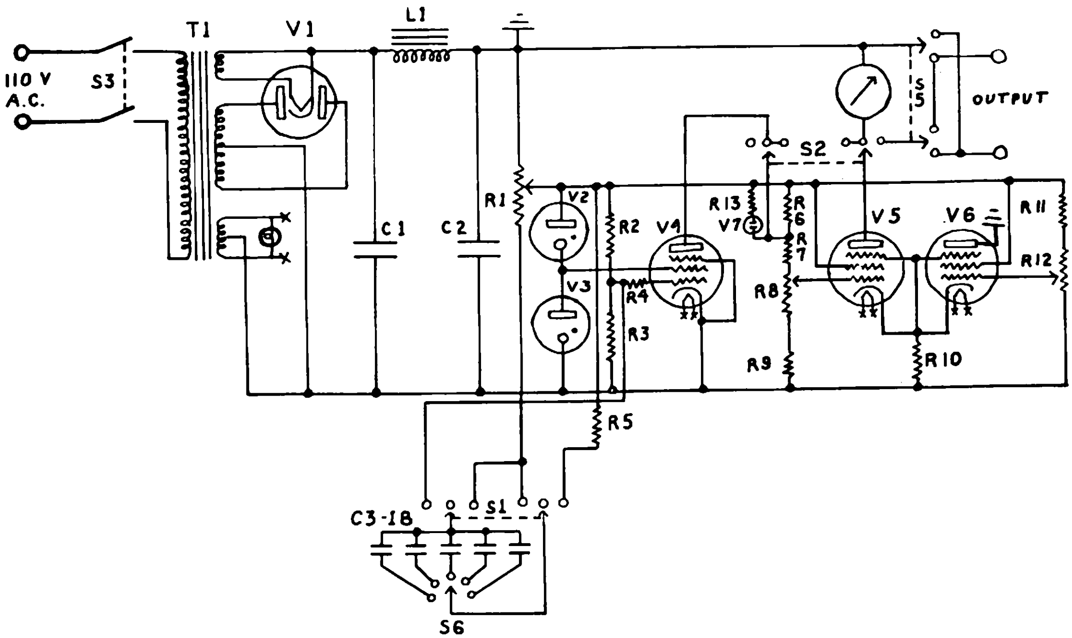

Fig. 2.

Schematic diagram of stimulator. The following components are required:

T1—Transformer, 800, 5.0, and 6.3 volts.
L1—Choke, 12 henrys at 100 ma.
C1, 2—8 fd. 600 valts.
C3 to 18—0.75, 0.5, 0.25, 0.1, .05, .025, .01, .005, .0025, .001, .0005, .00025, .0001, .00005, .000025, .00001 fd.
R1—20,000 ohms, 25 watts, voltage divider.
R2—6 megohms, ½ watt.
R3, 4—1 megohm, ½ watt.
R5—100,000 ohms, 1 watt.
R6—100,000 ohms, 5 watts.
R7—750,000 ohms, 1 watt.
R8—250,000 ohms, variable.
R9—80,000 ohms, 1 watt.
R10—1,500 ohms, 5 watts.
R11—750,000 ohms, 1 watt.
R12—500,000 ohms, variable.
R13—100,000 ohms, ½ watt.
V1—Rectifier, 5Z4.
V2—Voltage regulator, VR 150.
V3—Voltage regulator, VR 105.
V4—Pentode, 6SJ7.
V5, 6—Pentodes, 6F6.
V7—Miniature neon tube.
S1, 2—Ganged 2P3T switches.
S3—Power switch.
S5—2P2T reversing switch.
S6—1P16T selector switch.

sistance is kept below 15000 ohms. The duration of the stimulus may be varied in 16 steps from 0.02 to 1500 milliseconds, and its intensity accurately determined prior to administration by means of a conventional milliammeter. A switch provides for reversal of polarity. Thus it is possible to determine strength-duration curves, rheobase and chronaxia, relation between cathodal- and anodal-closing thresholds, and galvanic tetanus ratio.

The circuit, shown schematically in Fig. 2, is derived, with considerable modification, from a basic circuit described by Bauwens.[1] Automatic administration of shocks at fixed intervals was abandoned in favor of manual administration of single shocks, since this was found to be much better tolerated by human subjects. Grounding of the positive output terminal affords some protection from accidental shock.

The time during which the stimulating current flows is determined by the capacity chosen from the bank of condensers C3-18, controlled by switch S6. The function of the pentode V4 is to clip the wave form of the condenser discharge and to apply this voltage in an essentially square form to the grid of pentode V5, the amplitude of this voltage being controlled by the variable resistance R8. Because of the characteristics of the pentode V5, its plate current, which is also the stimulating current, is wholly dependent on its grid voltage so long as the plate voltage does not drop below about 100

[1] Bauwens, P., *Proc. Roy. Soc. Med.*, 1941, **34**, 715.

volts. This condition is satisfied so long as, with full output of 20 milliamperes, the output resistance does not exceed 15000 ohms, a condition easily met in practice.

By employing a common cathode resistance for tubes V5 and V6 their total plate current, and thus the load on the power supply, is kept constant whether a stimulus is being applied or not, eliminating the necessity for elaborate regulation of the power supply. Resistance R12 is adjusted so that with the intensity control R8 at maximum and switches S1 and S2, which are ganged, in the charging position, the milliammeter indicates 20 milliamperes. Thereafter R12 need not be adjusted further.

In operation, the duration of the stimulus is selected by S6, with S1-S2 in the center position to avoid sparking at the contacts of S6. Then S1-S2 is thrown to the charging position, charging the desired condenser. In this position the plate circuit of V4 is open, while the plate circuit of V5 is connected through the milliammeter. R8 is adjusted so that the meter indicates the desired intensity of stimulus, and then the stimulus is delivered by throwing S1-S2 to the stimulating position. This maneuver closes the plate circuit of V4, cutting off plate current in V5; then connects the plate of V5 through the subject rather than the milliammeter, and finally delivers the condenser discharge to the grid of V4, which clips it to square form and impresses it on the grid of V5, the resulting square wave of current in V5 being the stimulating current.

In practice, a large indifferent electrode is used, with the stigmatic electrode of 1.0 sq cm area placed over the nerve or motor point of the muscle to be tested. The threshold stimulus is then determined, first for currents of the longest duration available, and then for those of successively shorter duration until no further response can be obtained at maximum intensity. The values of threshold intensity so obtained are plotted against a logarithmic scale of duration, the result being a strength-duration curve. From this curve chronaxia may easily be determined. Galvanic tetanus ratio is arrived at by first establishing the threshold at which a simple muscle twitch is produced with a current of 1.5 seconds duration, and then increasing the intensity until a tetanic contraction persisting for the duration of the stimulus is secured. The ratio between these 2 intensities is the galvanic tetanus ratio.

Polarity of output is controlled by S3; the positive side remains at ground potential. Thus the relationship of anodal-closing to cathodal-closing thresholds may be easily obtained. In determination of galvanic tetanus ratio, observation of the small neon light, V7, which is extinguished during the passage of the stimulus, is helpful in determining the tetanus threshold, for which purpose it is mounted on flexible leads so that it may be observed at the same time as the contracting muscle.

Summary. A stimulator suitable for the determination of strength-duration curves, rheobase and chronaxia, ratio of cathodal to anodal thresholds, and galvanic tetanus ratio has been constructed of standard radio components. It has given reliable and reproducible results in cases of peripheral nerve injury.