Stimulation of Irritable Tissues by Means of an Alternating Magnetic Field.* (25209)

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Observation of visual sensations not caused by light, by technicians working in the vicinity of large choke coils carrying strong alternating currents, was reported by Thompson (1). He was able to reproduce such an effect by exposing the head of human subjects to an extensive alternating magnetic field generated inside a large coil. This phenomenon ("phosphenes") has also been studied by others(2-5). The stimulation is evidently due to eddy currents induced in the tissues exposed to the alternating magnetic field. No attempt has been made in any of these investigations to localize the stimulus. The nearest approach to a search for local effects of an alternating magnetic field was an attempt by Magnusson and Stevens(4) to stimulate a cat's nerve by disposing it transversely in an alternating magnetic field. The result of this experiment was negative.

Methods. The magnetic fields used in the above-mentioned experiments were obtained with electromagnets excited with low frequency a.c. (below 90 cps) as well as with intermittent d.c. The observed light sensation was monochromatic (bluish white), flickering and strongest near the periphery of the retina.

To obtain a more nearly localized effect in our experiments, a bar electromagnet with a pyramidal pole tip, shown in Fig. 1, was constructed. Distribution of the axial field intensity component is shown in the same diagram. Currents of 2 frequencies have been used to energize this magnet, 60 cps and 1,000 cps. The maximum flux density obtained at the pole tip with the 60 cps source (a.c. line voltage) was 8,740 gauss (rms) and with the 1,000 cps source (motor-generator set), 2,260 gauss (rms). In spite of the lower flux density at 1,000 cps, the induced eddy currents are stronger as compared to those induced at 60 cps due to the proportionality of the induced e.m.f. to rate of change of the magnetic field.

Results. Observations of the phosphenes reported by previous authors have been verified at 60 cps. The flickering light sensation was strongest when the pole tip was held against the temporal area but could still be detected when the pole was placed against the occipital area. No other sensations or effects were observed in varying the location of the pole tip relative to different areas of the cortex.

At 1,000 cps a new effect was observed when the magnet pole was close to the temple. There was an intense sensation of nasal obstruction experienced by all subjects.

It proved possible to stimulate frog nerves intensely at 60 cps as well as at 1,000 cps by winding a nerve about the pole tip to form a closed one-turn loop. The pole tip was well insulated by a cap of acrylic plastic material ("Densoform"). A nerve-muscle preparation of a frog's sciatic nerve attached to the gastrocnemius muscle was used (Fig. 1). Intense tetanic contractions of the muscle were obtained whenever the magnet was excited. Fig. 2 shows a record of the muscle contraction with a simultaneous recording of the pattern of the stimulus. The latter recording was obtained by registration of the e.m.f. induced by the stimulating magnetic field in a loop surrounding the pole tip. The same effect has also been obtained in a substantially homogeneous 60 cps magnetic field of 6,000 gauss rms flux density. It also proved possible to stimulate contraction in excised frog muscles placed in a Petri dish and submerged in Ringer's solution. The Petri dish was placed into the gap of an electromagnet generating a 60 cps magnetic field in a 5 x 15 cm gap of 2.8 cm pole separation. The bottom of the Petri dish was parallel to the horizontally oriented pole faces. Tetanic contractions of freshly excised muscles were observed while

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the magnetic field was on. Stimulation of the irritable tissues by the eddy currents induced in the contents of the Petri dish showed a dependence on their position in the dish as well as on their orientation. The maximum effect was observed when the muscle was placed near the rim of the Petri dish and no effect was seen when the muscle was at the center. With the muscle placed near the rim, the contraction was strongest when the longitudinal axis of the muscle was oriented tangentially and least strong or absent for the radial orientation. These observations are in accordance with the anticipated distribution of eddy currents which flow along the rim of the Petri dish. The stimulating action of alternating magnetic fields depends on the induced eddy current density. It is reasonable to assume that an increase in intensity and, to a limited extent, in frequency of the alternating magnetic field used would lead to observation of effects which were not observed at the eddy current densities produced under the conditions described above.

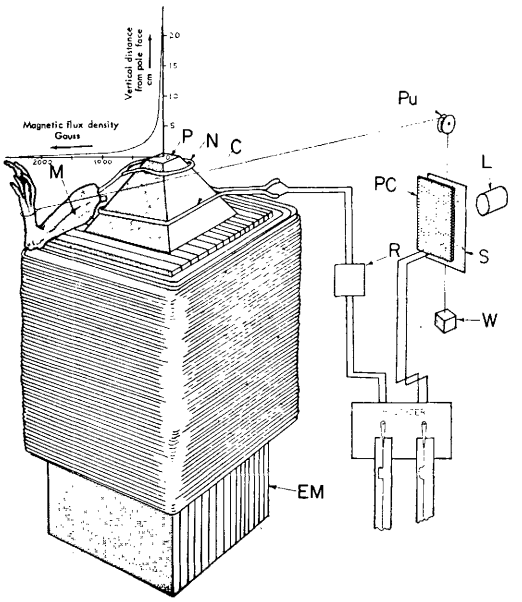

FIG. 1. EM: laminated bar electromagnet generating a non-homogeneous alternating magnetic field the axial component of which is represented in the diagram as a function of distance from the pole face P. N: nerve forming a closed loop in magnetic field. M: frog's gastrocnemius muscle. C: wire loop surrounding pole tip of the magnet. R: rectifier which rectifies the a.c. signal induced in loop C. The rectified signal is recorded by one of the 2 recorder channels. PC: photocell (International Rectifier Corp. type B-10) of the photoelectric device recording muscle contraction. L: light source. S: shutter which can be lifted by the string attached to frog leg. The shutter is actually flush with bottom of photocell PC. It is represented somewhat longer in the diagram to show the point of attachment of the string to which weight W is attached. When muscle contracts, shutter S and weight W are lifted thus exposing an increasing area of the photovoltaic cell PC to light from the source L. Voltage output of photocell is recorded by the second channel of the 2-channel recorder.

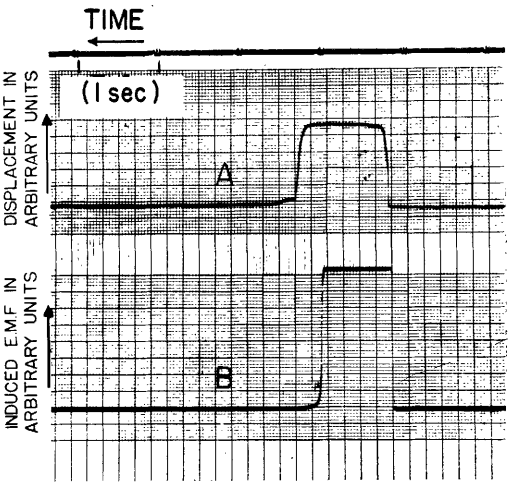

FIG. 2. Temporal relationship between stimulus and response in electromagnetic stimulation. A. Photoelectrically recorded movement of frog leg produced by contraction of the gastrocnemius muscle. Muscular contraction is evoked by stimulation of the nerve N of Fig. 1 through the current induced in it by the alternating magnetic field. B. The stimulus as a function of time in arbitrary units as represented by rectified and filtered e.m.f. induced in loop C of Fig. 1.

Summary. Stimulation of frog nerves and of excised frog muscles submerged in Ringer's solution has been obtained without the use of electrodes by means of sinusoidal alternating magnetic fields. This effect is due to eddy currents induced in conductive tissues and their surroundings. Visual and non-visual sensations have been induced in human subjects by non-homogeneous alternating magnetic fields adjacent to the brain.

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1. Thompson, S. P., *Proc. Roy. Soc. B,* 1910, v82, 396.

2. D'Arsonval, M. A., *C. R. Biol., Paris,* 1896, v48, 450.

3. Dunlap, K., *Science,* 1911, v33, 68.

4. Magnusson, C. E., Stevens, H. C., *Am. J. Physiol.*, 1911, v29, 124.
5. Barlow, H. B., Kohn, H. I., Walsh, E. G., *ibid.*, 1946, v148, 372.

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Cation Specificity of Thrombocyte Agglutinating Activity (TAg) of Canine Plasma.* (25210)

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Canine plasma possesses the ability to agglutinate homologous and autologous platelets rapidly in the presence of Mg^{++} or Mn^{++}(1). This property of plasma has been termed thrombocyte agglutinating activity (TAg). TAg is contained in crude globulin fractions of plasma, but not in the albumin fractions. It is non-dialyzable and heat-labile. TAg appears to be separate from the plasma procoagulants, fibrinogen and antihemophilic factor, as well as from prothrombin and related $BaSO_4$-adsorbable factors. In this study TAg was tested for activity with 15 separate cations. The active ions were studied further to determine the relative amounts needed for prompt agglutination of platelets with TAg.

Methods. Details of the macroscopic platelet agglutination test for TAg have been described(1). The test is done in 2 stages. In the first or incubation stage, canine plasma is incubated for 30 min. with a cation chloride solution. In the second or agglutination stage, a standard suspension of washed canine platelets is added to the incubation mixture and time and degree of agglutination determined. Three types of canine plasma were used. *Resin plasma* was prepared by use of Dowex 50 resin columns(1). *Oxalate plasma* has been described(2). *EDTA plasma* was prepared by mixing 9 parts of whole dog blood with one part of stock EDTA solution(1), previously diluted one to 3.27 with normal saline. Plasma dialysis against 0.154 M NaCl was carried out with Visking casing (18 hr continuous agitation, 4°C). *Adsorbed plasmas* (resin, oxalate, or EDTA) were prepared by adding to each ml plasma 100 mg $BaSO_4$ (Merck) (contact time 30 min, 4°C) and repeating the procedure once. In the prothrombin time test with adsorbed plasmas no clot formed in 10 min. The chloride salts of various cations were used; all salts were Baker A.R., except $FeCl_3$ (Mallincrodt), $PbCl_2$ (Fisher), and $BaCl_2$ (Merck). Solutions were standardized by chloride analyses, and diluted to 0.108 M. For weaker solutions, serial 2-fold dilutions were made with 0.154 M NaCl. Cation concentration in the experiments is expressed as mM cation *added* per liter of plasma incubation mixture. *Platelet suspensions*(1) were prepared from EDTA canine plasma and contained $4 \cdot 10^5$ platelets/cmm. In several experiments, platelet preparation was modified by resuspending the platelets in solutions containing 0.5% bovine albumin (Armour). With this modification the platelet pellet could be resuspended rapidly, and platelet reactivity was unchanged.

Results. TAg and $BaSO_4$ adsorption of plasma. A series of tests were performed to determine the effect of $BaSO_4$ adsorption of plasma on platelet agglutination by TAg. Fig. 1 shows the results obtained with resin plasma before and after adsorption. With either Mg^{++} or Mn^{++}, rapid agglutination occurred, regardless of plasma adsorption or cation concentration used. Only with adsorbed plasma at the lower Mn^{++} concentrations were agglutination times less rapid than with non-adsorbed plasma. With Ca^{++}, on the other hand, no agglutination occurred with adsorbed plasma; with non-adsorbed plasma, clotting occurred in the incubation phase and the resultant serum caused moderately rapid agglutination.

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