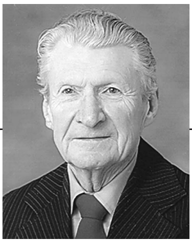
Retrospectroscope

the history of magnetophosphenes



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On 1 October 1831, Michael Faraday observed that a changing magnetic field induced a current in a conductor lying in the field, and a galometer was the detector. Such a current is called an induced current. The critical word in producing the effect is "changing." In other words, the induced current is the first time-derivative of the magnetic field. It was not long before it was recognized that living tissues were conductive, and studies were begun to test the effect of changing magnetic fields on excitable tissues. An interesting property of magnetic fields is that when applied transcutaneously, there is less skin sensation than is encountered with skin-surface electrodes.

Magnetophosphenes

A phosphene is a bright spot in the visual field. When the bright spot is caused by a varying magnetic field, it is called a magnetophosphene. It was Arsonne d'Arsonval, physician and physicist, who first demonstrated that a changing magnetic field could stimulate excitable tissue [6]. He passed substantial 42-Hz current through a coil in which the head was placed. He wrote, "There occurs, when one plunges the head into the coil, phosphenes and vertigo, and in some persons, syncope… The alternating magnetic field modifies the form of muscular contractions, and produces in living beings, other effects that are easy to demonstrate and of which I am pursuing the study of at this time." His comment about phosphenes indicates that either the retina or the visual cortex or both were stimulated. The mention of muscular contractions indicates stimulation of the head muscles, motor cortex, or both. He gave little information on his coil, other than stating that it was made of thin-walled brass tubing. He did state that it was excited with 110 V, and the current was 30 A. He devised a thermocouple ammeter to measure the alternating current.

Apparently, unaware of d'Arsonval's article, Beer reported a flickering light sensation due to a magnetic field [2]. His article contains no quantitative information on the coil or the field strength used.

Magnetically induced phosphenes became the subject of considerable interest at that time when alternating current was being developed for commercial sale. Sylvanus Thompson [14], the pioneer of electrical engineering, also became interested to explore the same. Dunlap [7] and Magnusson and Stevens [11], [12] all carried out studies on magnetophosphenes. Thompson, apparently unaware of d'Arsonval's article, constructed a stranded copper wire coil of 32 turns (cross-sectional area of 0.2 in^2), with an internal diameter of 9 and 8 in. He applied up to 500 A, which produced an rms field strength of 1,000 cgs units at the center of the coil. At the mouth of the coil, the field strength was about two thirds of this value. With the subject in a darkened room and the eyes closed, insertion of the head into the coil produced "a faint flickering illumination, colorless, or of a slightly bluish tint, being brighter in the peripheral field." Even in daylight with eyes open, the visual sensation could be perceived. Some of the subjects reported a taste sensation.

Dunlap suspected that the phosphenes reported by Thompson's subjects might be due to the suggestion produced by the loud hum from the supply transformer when the current was applied to the coil [7]. To investigate this, he constructed a stranded wire coil of 27 turns (37 strands, each 0.082 in diameter); the coil was 8 in long and elliptical in cross-section (9 × 10.5 in minor and major axes). The coil was suspended from the ceiling and could be lowered over the subject's head. With 200 A of 60-Hz current, all subjects perceived the flickering, as reported by Thompson. (Note that the number of ampere turns was slightly less than that used by Thompson.)

To settle the matter of sound-induced phosphenes, Dunlap plugged the subject's ears, and the loud transformer hum was produced with and without current in the coil. The hum without current in the coil surrounding the head was produced by switching the transformer to a load resistor carrying the same current as was passed through the coil. He concluded that the flickering-light phenomenon was genuine, and stated that it could be perceived with the eyes closed and open in a moderately lighted room. Additional tests were conducted with 440 A (60 Hz) applied to the coil; the flickering was more distinct and perceived even by subjects who could not see it in the first tests. When the frequency was changed to 25 Hz and with 480 A flowing in the coil, the response was striking: the whole visual field appeared illuminated. Flickering could also be perceived with the head below the coil, and the sensation was described as disagreeable. However, none of the subjects reported any other sensation.

Magnusson and Stevens [11], [12] carried out studies with a large coil that could be lowered over the subject's head. Not surprisingly, no phosphenes were perceived when direct current was flowing in the coil. However, phosphenes were seen when the direct-current flow was initiated (make shock) and interrupted (break shock). With the make shock, the phosphenes consisted of a horizontal luminous bar moving downward. With the break shock, the bar was dimmer and moved upward. Reversing the polarity of the field did not change the direction of movement of the light bars. They then carried out a series of studies directed toward the importance of frequency and field strength in producing phosphenes in human subjects.

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The phosphenes appeared to follow the magnetic field frequency below 25 Hz. For a given field strength, the phosphenes appeared brighter with 20–30-Hz current. The threshold field strength corresponding to 60-Hz current was 3,000–4,000 A turns. Above 90 Hz, the phosphenes became faint, even with several-fold higher field strength.

After more than three decades of disinterest in magnetic stimulation, Walsh et al. presented an article on retinal stimulation in man using alternating-current fields having frequencies ranging from 5 to 90 Hz, with field strengths up to 900 G [17]. The familiar peripheral-field flickering sensation was reported. When the coil was close to the eye, maximal flickering was perceived. When the coil was over the occipital visual cortex area at the back of the head, no flickering was reported. The flickering diminished with constant stimulation. Prolongation of the effect could be achieved by moving the eyes. Recovery occurred within a few seconds of cessation of stimulation. They reported that the sensation was similar to that when 100-Hz current was passed through the head using directly applied electrodes.

Magnetophosphenes were also described by Barlow et al. [1] by using a coil of 397 turns of 16-gauge copper wire. The coil had 10.5 cm of inner diameter and 20.7 cm of outer diameter and was 7.3 cm long. A laminated core of 5.3 × 2.9 cm in cross section and 37 cm long was placed into the coil. The core was placed a few centimeters from the side of the forehead. Phosphenes were perceived with 20 A of 60-Hz sinusoidal current. The stimulus produced by 7,940 A turns corresponded to a magnetic filed strength of 900 G, which was measured by a search coil.

To illustrate that the phosphenes were due to electrical stimulation of the retina, Barlow et al. [1] placed an active electrode on the side of the forehead and a reference electrode on the back of the forearm. Phosphenes were perceived with 0.3 mA of 60-Hz current. They reported that with the magnetic field and with the electrodes, the duration of perception of the phosphenes outlasted the stimulus in proportion to the stimulus strength.

Barlow et al. [1] stated that the phosphenes were usually colorless, but occasionally they appeared bluish and sometimes slightly yellowish. No phosphenes could be perceived when the core of the coil was placed over the occipital area, the site of the visual cortex.

Soon, magnetic stimulation was applied to other types of excitable tissues. It was Reginald Bickford, an electroencephalographer, who described the use of a pulsed magnetic field to stimulate peripheral nerves in man [3]. Artificial respiration in the dog and man were reported by Mouchawar et al. [13] and Geddes et al. [9], who stimulated the cervical phrenic nerves. The coil was unique in design and consisted of a long strip of tinned copper braid inside a thick-walled, flexible plastic tube that was wrapped around the neck to form a coil of five turns. With trains of pulses (25/s) lasting 1 s, inspiration was produced. The tidal volume depended on the peak voltage applied to the coil.

When applied to man, a mild tingling sensation occurred, and tidal volumes in excess of normal tidal volume (500 mL) were produced. There was a mild tightening of the neck muscles during inspiration.

Stimulation of the cardiac muscle was carried out in the experiments by Irwin et al. [10]. The ability of a pulsed magnetic field to pace the closed-chest dog heart was reported by Bourland et al. [4]. To prove the point, the heart was arrested by right vagal stimulation. A record of the electrocardiogram and arterial pressure confirmed effective stimulation.

Conclusions

Although magnetophosphenes are an interesting sidelight in the history of stimulation, these studies clearly demonstrate the practicality of using pulsed magnetic fields to stimulate a variety of excitable tissues, notably nerves. When it is applied transcutaneously, there is little skin sensation. Despite this desirable feature, magnetophosphenes did not attract clinical attention.

It is interesting to note that the first magnetic stimulation studies occurred in the early 1900s, and there was a considerable gap in time for use of this electrodeless stimulation technique to recur.

Coil design is important for efficiency. The unique double-ring coplanar air coil design reported [15] makes it possible to concentrate the magnetic field by arranging the coils so that they came in contact at a point on the perimeters and current flows in the same direction at the perimeter point of contact.

The clinical applications of magnetic stimulation are described elsewhere [5]. In addition to the clinical applications, there are chapters on the theory of magnetic stimulation and coil design.

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