Confinement and Shaping of Electric Fields By Current-Carrying Conductors

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ELECTROSTATIC field pictures, such as for a condenser, are familiar to anyone who has taken even freshman physics. It is not so well known, however, that similar electric fields can be produced with arrangements of current-carrying conductors. Some experimental studies of the electric fields of current-carrying conductors, and the possibilities of shaping and confining these fields in chambers with current-carrying walls, are reported in this paper.

By employing the basic electric field laws, we find that in a rectangular chamber with electrodes for end walls and semi-conducting side walls carrying uniform current (Figure 1) the electric field is $E = V/d$ (V is the applied voltage; d is the length of the side walls). We, therefore, expect the field to be uniform throughout the chamber, and to be confined by the chamber so that an external charged body will have no effect on this field. The experiments reported here were designed to test the validity of those expectations.

EXPERIMENTAL METHODS AND RESULTS

A radioactive alpha-source was used to ionize the air at the point where the field was to be measured. The alpha-source acquired the same potential as the field at that point. The potential was measured with an electronic electrometer connected to the alpha-source.

For our first field measurement, we employed a wooden frame (shown in Figure 2) supporting graphite paper strips as walls and aluminium foil as electrodes with 80 volts applied to them. The agreement of measured field with predicted field was reasonably good (Figures 2a, 2b). Unfortunately, the conductivity of the graphite paper was not uniform in spots. This introduced distortions into the measured field. Attempts to trim the paper to produce uniform conductivity were not entirely successful, but did show conclusively that non-uniform conductivity was the only essential reason for deviations from the predicted field.

For our second measurement, we used a simple rectangular frame (Figure 3), but employed undeveloped photographic film in place of the graphite paper. The applied voltage again was 80 volts. The conductivity of the film was much more uniform than that of the paper, and as a result, the field was much more uniform also. The measured field agreed with the predicted one almost exactly (Figure 3). The field outside the chamber was on the whole quite symmetric, with some deviations due to stray fields in the room. The confinement of the electric field within the chamber was proven by placing a metal disc connected to the 80-volts terminal outside. The field outside the chamber became radically different, but the field inside was affected not at all (Figure 3b).

Reprinted from *Proceedings of the West Virginia Academy of Science 1962,* (Volume 34)

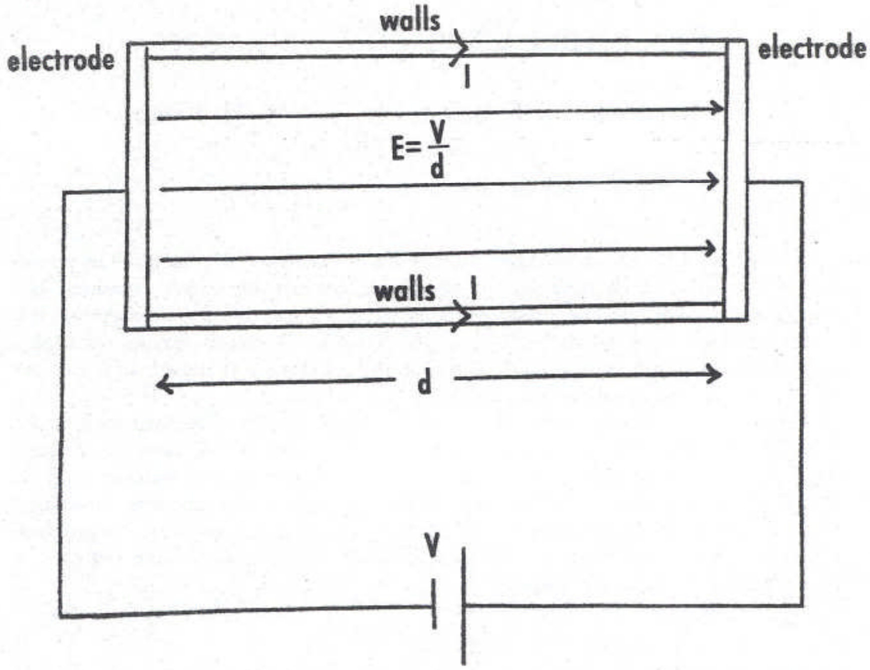

FIGURE 1. Typical rectangular chamber with current-carrying walls.

DISCUSSION

During the course of the experiment we came upon a particular interesting detail, which was rather surprising even though it was anticipated. In the graphite paper, the current was measured to be 50 milliamperes, while in the film the current was only 4 microamperes. Yet, in both cases the confinement and shaping of the fields was exactly the same. Therefore, for practical application of these fields, the poorer the conductor used for the chamber walls, the better, because with poorer conductors less energy is needed to maintain the field. Of course, the poorer the conductor, the longer is the time required for the field to establish itself in equilibrium. Thus for rapidly varying fields, walls made of a better conductor would be needed.

The experiments reported here suggest some possibilities for practical applications of the fields of current-carrying conductors. For example, a uniform electric field 10 meters long is impractical with an ordinary condenser; the plates would have to be as wide as the front of a house. Using arrangements of current-carrying conductors, however, it would be simple to produce a uniform electric field 10 meters long and 1 centimeter in diameter confined in a tube, simply by coating the inside of a 1-centimeter insulating tube with a uniform semi-conducting film. There is no reason why systems of current-carrying conductors should not find wide application for producing electric fields where usual electrostatic fields are impractical or impossible.

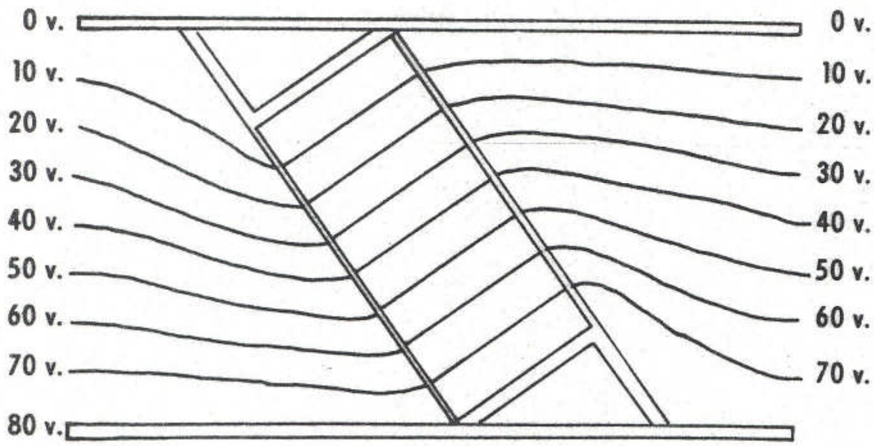

FIGURE 2a. Predicted field.

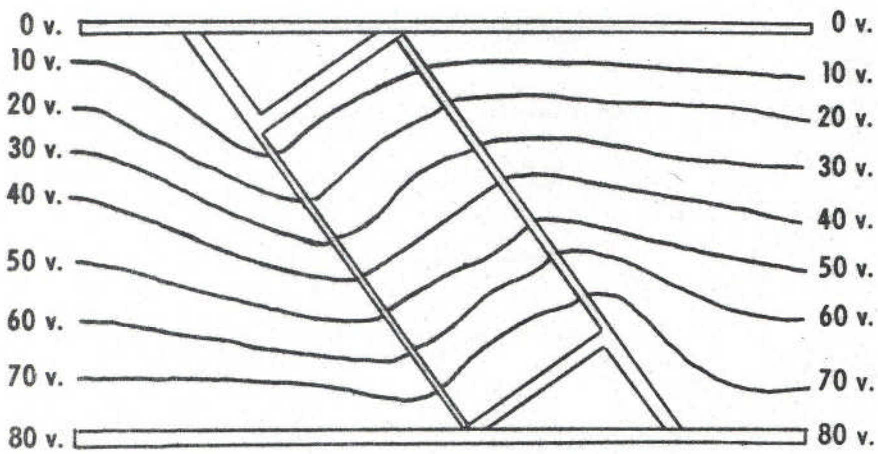

FIGURE 2b. Reproduction of measured field.

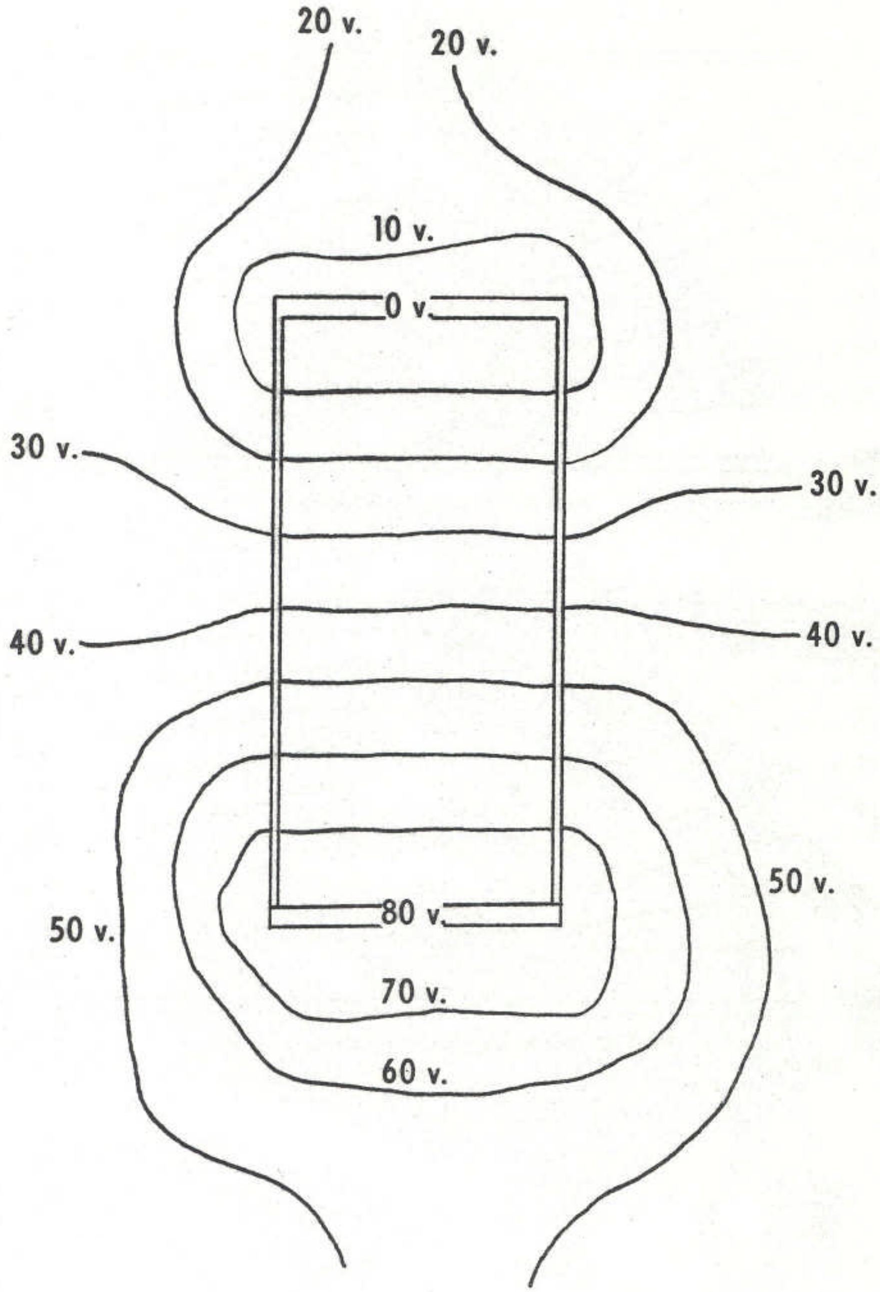

FIGURE 3a. Reproduction of measured field.

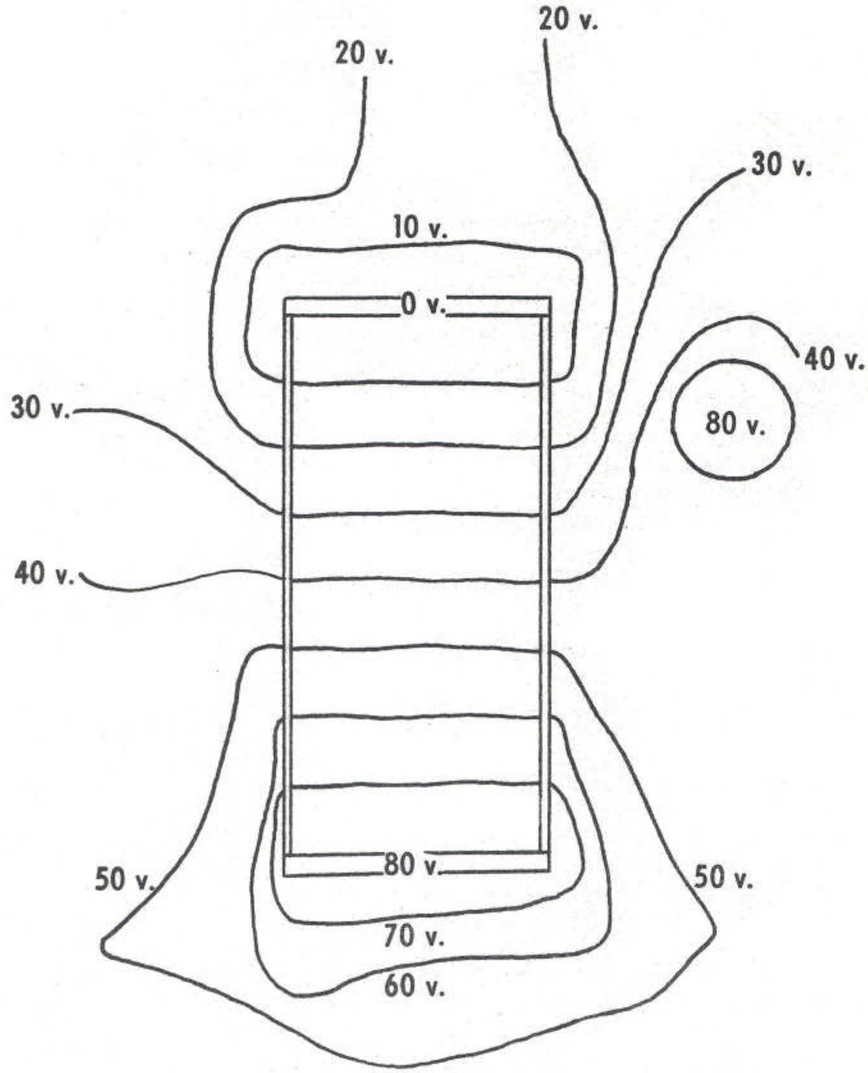

FIGURE 3b. Measured field with 80-volt disc outside chamber.