of moisture and the amount of salts in the soil, while the resistance of a foot cube of iron is equal to about 0.0000004 ohms for the resistance of a foot cube of soil, it is seen that soil has no resistance which is of the order of 250,000,000 times as great as a body of iron of the same dimensions; that is to say, the conductivity of iron is 250,000,000 times as good as ordinary soil. It would seem from this that current would flow almost entirely on the good conducting rails and none through the high resistance ground. Resistance, however, varies directly as the length and inversely as the cross-section of a conductor, and with the large surface of rails exposed to the ground, the cross-section of the path of the current through ground is enormously great compared with the cross-section of the path of the current through the rails. As a matter of practice it is found that where the rails alone are used for the return of current, frequently a considerable portion of the total current actually leaks from rails through ground.

From the above considerations it will be seen that the leaking of current from the rails of electric railways, producing stray currents through ground and on underground piping, does not constitute a source of loss to the railway company; as, for instance, would be the case with leakage of gas or water. On the contrary, by allowing the current to return by ground and underground pipes as well as by way of the rails, the total conductivity of the return circuit is increased, and the voltage loss in the return of this current is decreased, so that there is an actual saving of power for the railway company.

During the last few years alternating current has also been used in a number of cases for electric railways which employ the running tracks as a return conductor. Where these rails are in contact with ground stray alternating currents through ground are undoubtedly produced. As already pointed out, such alternating currents may produce electrolysis which varies up to 1 per cent. of that which would be produced by a corresponding direct current. However, no actual case of electrolysis from alternating currents from such railways has been reported, as far as the writer is aware. This may be due to the fact that alternating current electric railways in nearly all cases operate on long distance lines and on their own right-of-way, where they are away from underground piping networks. The author, therefore, does not feel warranted in drawing any positive conclusion as to the positive danger from electrolysis caused by alternating current electric railways where they operate within city limits.

General Effects of Stray Electric Currents on Underground Piping.—The current flowing through the rails from the trolley cars back to the power station produces in these rails a drop in potential; that is to say, points in the rails away from the power station have a positive potential with reference to the rails at the power station. Since potentials are measured relatively it is convenient to consider the negative terminal of the dynamo, which is assumed connected to the rails at the power station, as at zero potential. The distribution of potentials in the rails of a simple electric railway system, and in the underground piping, is illustrated in Fig. 2, in which convenient values have been assumed. It will be noted that the stray current causes the underground pipes to be negative to the rails at points away from the power station, and positive to the rails near the power station. It is also seen that the negative potential of the pipe, plus the drop on the pipe, plus the positive potential of the pipe, equals the drop in the rails. In the case assumed a potential difference of 550 volts is maintained at the power station; of this, 10 volts is lost in the trolley wire, 520 volts is used by the motors of the cars, and 20 volts is left to bring the current back to the power station. If the negative bus-bar and the rails at the power station are considered as at zero potential, the rails at the car in the assumed case will have a potential of ÷ 20 volts. Thus, for practical purposes, the ground with its underground pipes is subjected to a potential difference of 20 volts, and the amount of stray current produced is that due to these 20 volts. If the rails are laid in the usual way—that is, in contact with ground—the 20 volts in the rails will send some shunting current through the ground and through the underground pipe as shown in the diagram. Under the assumed conditions, there is a drop of 8 volts from the rails to the pipe near the car, a drop of 4 volts in the pipe itself, and a drop of 8 volts from the pipe through ground to the rails at the power station. It is, therefore, seen that it is the potential difference or drop in grounded rails caused by the return current which is the cause of stray currents through ground. Attempts should, therefore, be made to keep the potential difference or drop in rails as low as practicable, in order to keep stray currents through ground down to a minimum.

From the explanation of metallic and electrolytic conduction given in the first part of the paper, it will be understood that, where stray currents flow on underground pipes, they do no harm, except where they leave the pipes to flow to the surrounding soil. At such points corrosion of the iron from electrolysis will take place, and theoretically there will be a loss of 20 pounds of iron per year for every ampere of electric current leaving the iron. Some have assumed that, with the low densities at which current generally leaves un-

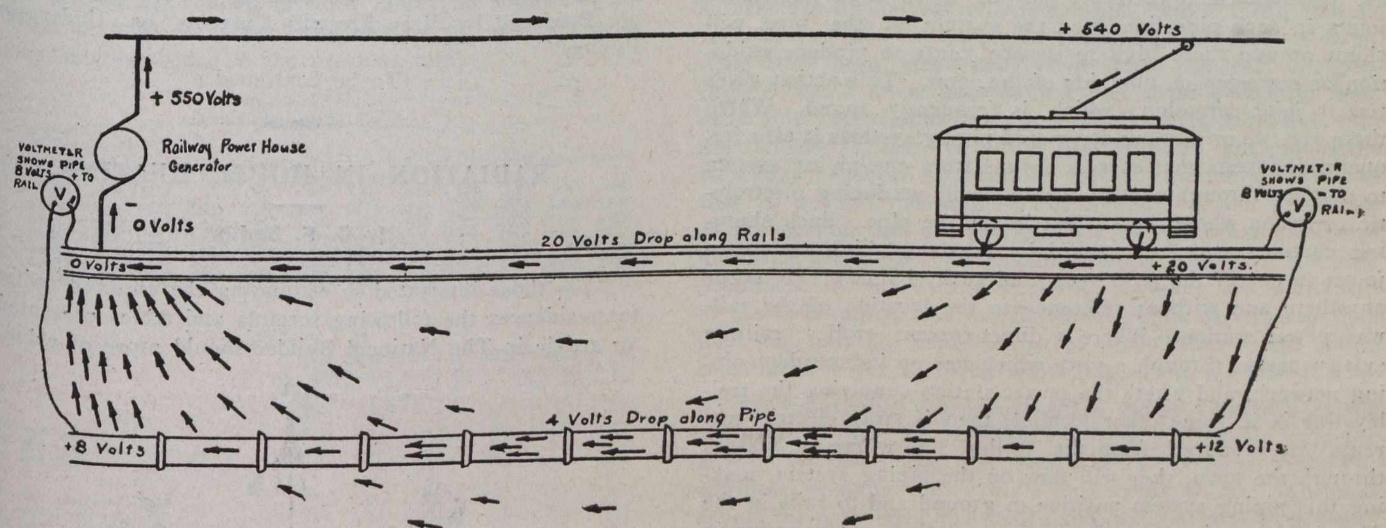

Fig. 2.—Diagram Showing Stray Currents and Assumed Resulting Potentials.