A CARBON FILM HIGH RESISTANCE; ITS CONSTRUCTION AND CHARACTERISTICS.

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The problem of obtaining at low cost a satisfactory high electrical resistance, that is from 0.1 to 100 megohms, for use in experimental work is one with which many laboratories of physics have been confronted. The most common means of meeting this problem has been to use a graphite line on ground glass or hard rubber with some sort of pressure contacts as terminals. However in Dec. 1902, Prof. A. C. Longden described in a paper in the Physical Review* a new form of carbon resistance in which he used as a resistance material a film of smoke deposited from a flame upon a strip of glass. The terminals which he devised, and which are very satisfactory, consist of a film of silver deposited chemically on each end of the strip. The capillary attraction between the glass and the silvering solution causes the end of the film to be almost infinitely thin. The carbon film, when deposited over the central portion of the glass and onto the silvered ends, forms a very smooth and satisfactory contact. A small copper wire is copper plated to each of the silvered tips to complete the terminals. By treating the carbon film with alcohol vapor, it is sufficiently hardened to permit a thin layer of paraffin or shellac to be flowed over it. A number of such slides may be mounted in a dry wood or hard rubber case which is provided with binding posts.

It is this same type of carbon film resistance, but in a new and perhaps a little more convenient form and mounting, that has been the subject of the present investigation. The construction of the resistance is shown in detail in Fig. 1. Instead of a glass slide, a small soft glass tube, sealed at each end, is used, in which there is a slight constriction near each end. The silver copper terminals are constructed as prescribed by Longden. The silver is deposited chemically by Brashear's process for silvering glass, and the copper is deposited electrolytic-

* Phys. Rev. Vol. XV.—No. 6.

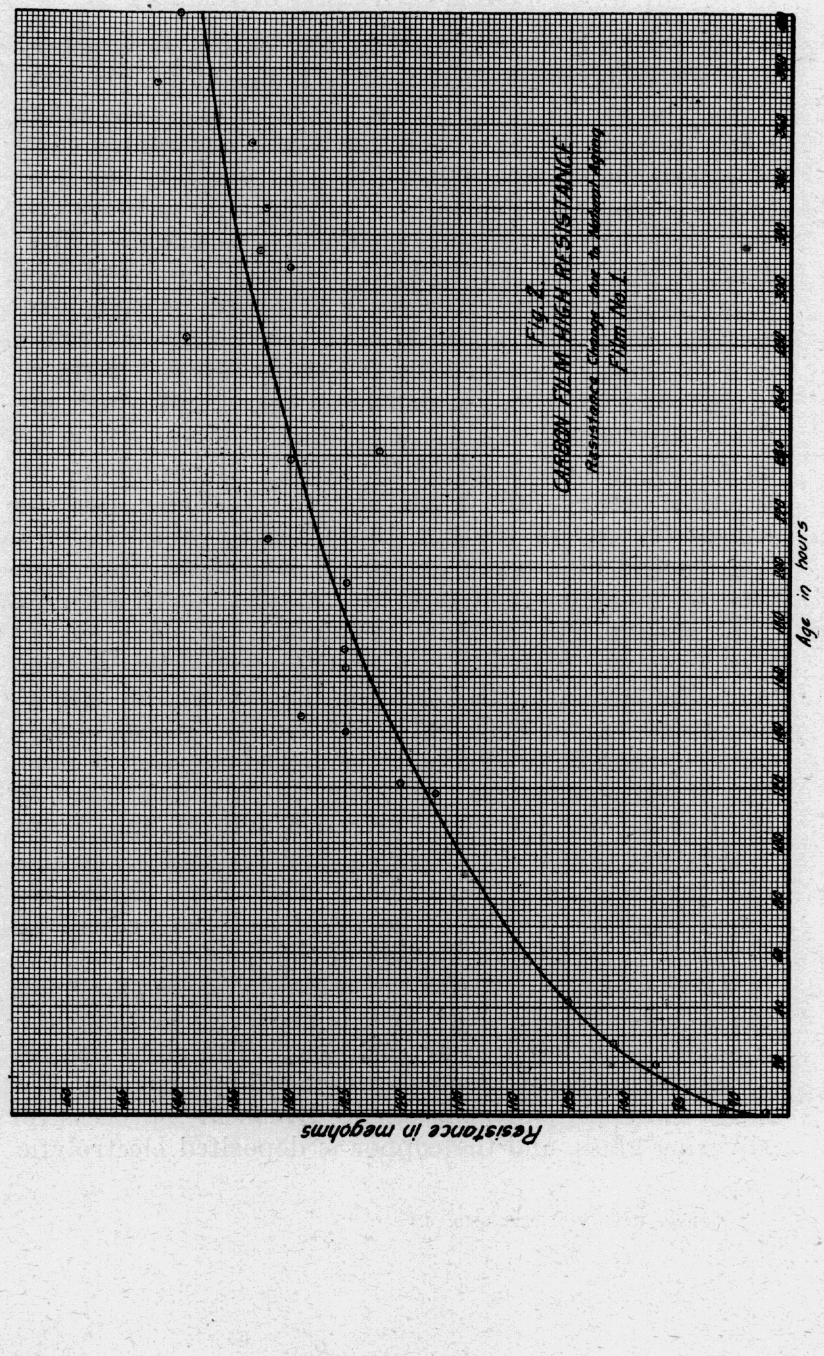
Fig. 2
CARBON FILM HIGH RESISTANCE
Resistance Change due to Natural Aging
Film No. 1
Age in hours
Resistance in megohms

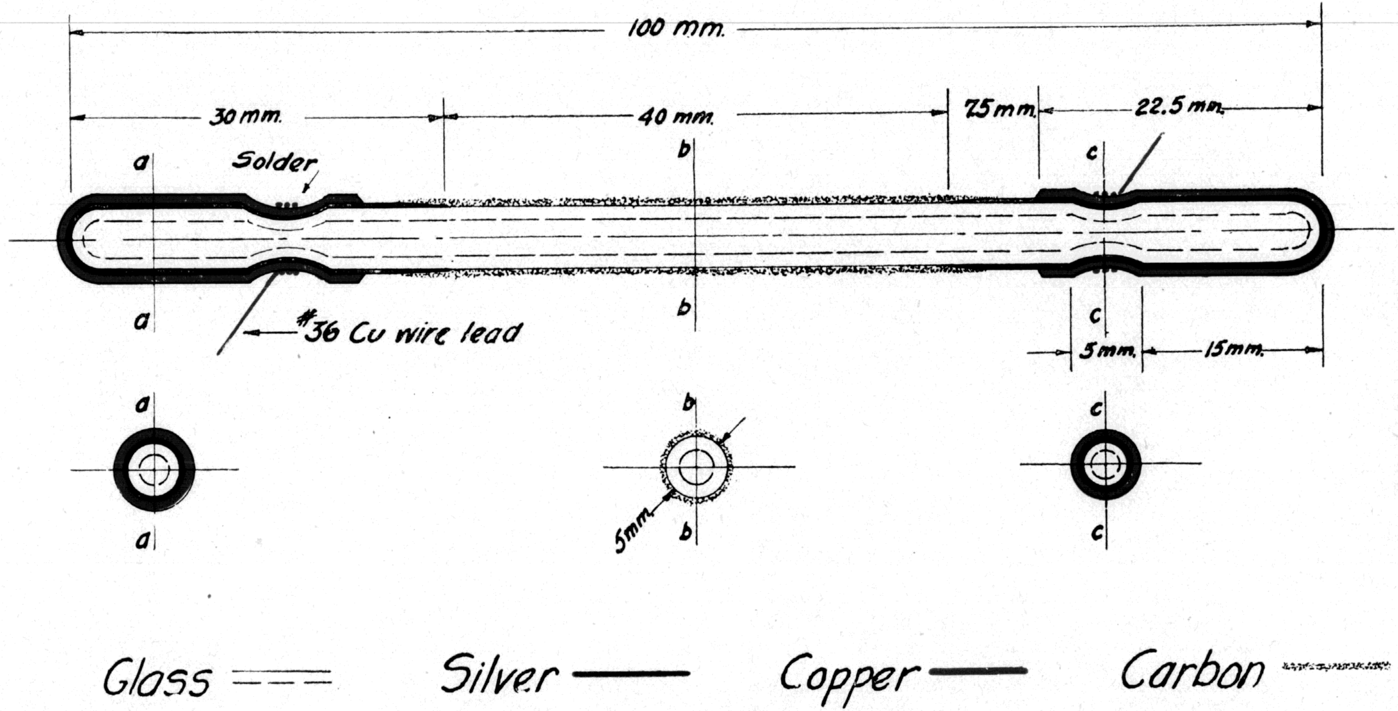

Fig. 1. Detail drawing of a carbon film high resistance.

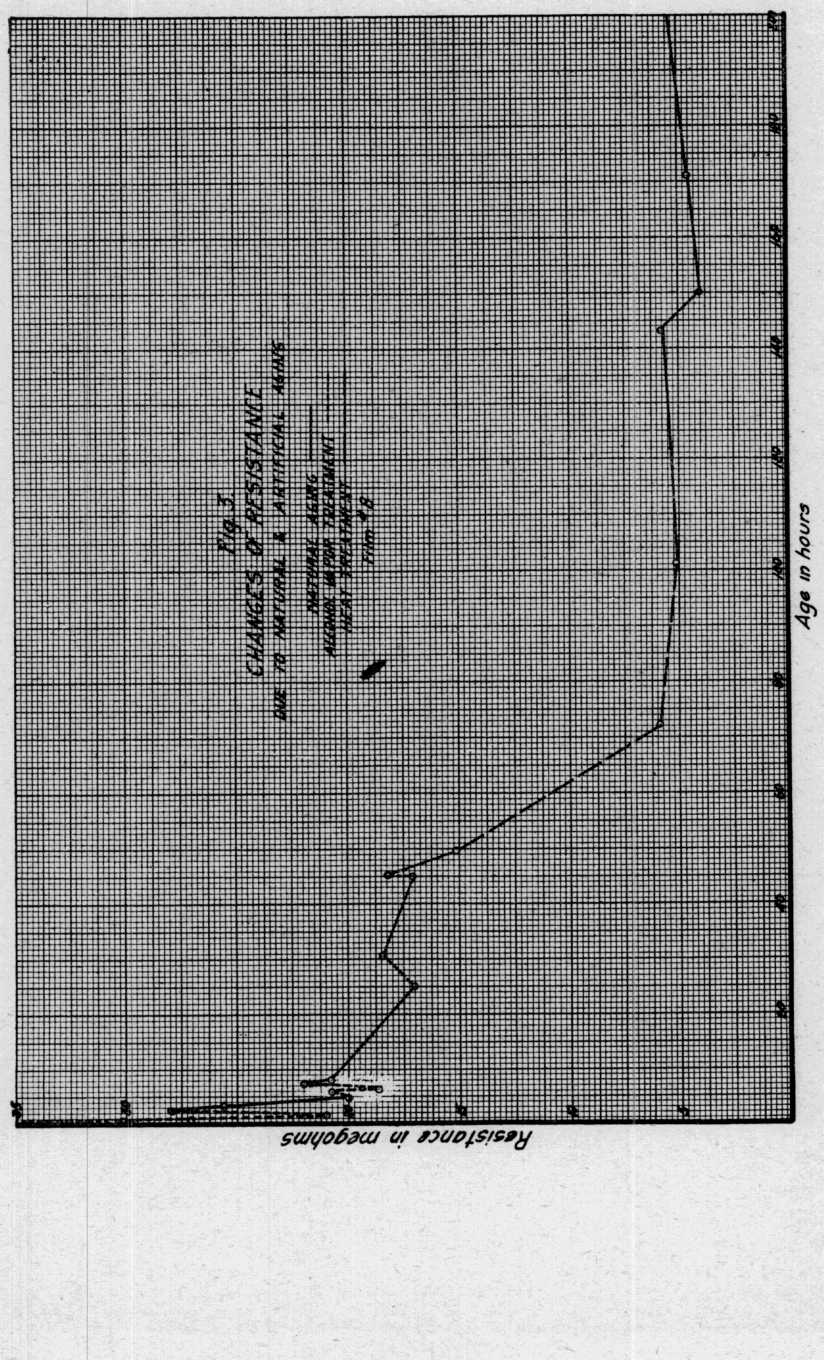
Fig. 3
CHANGES OF RESISTANCE
DUE TO NATURAL & ARTIFICIAL AGING
NATURAL AGING
ALCOHOL VAPOR TREATMENT
HEAT TREATMENT
Film #8
Age in hours
Resistance in megohms

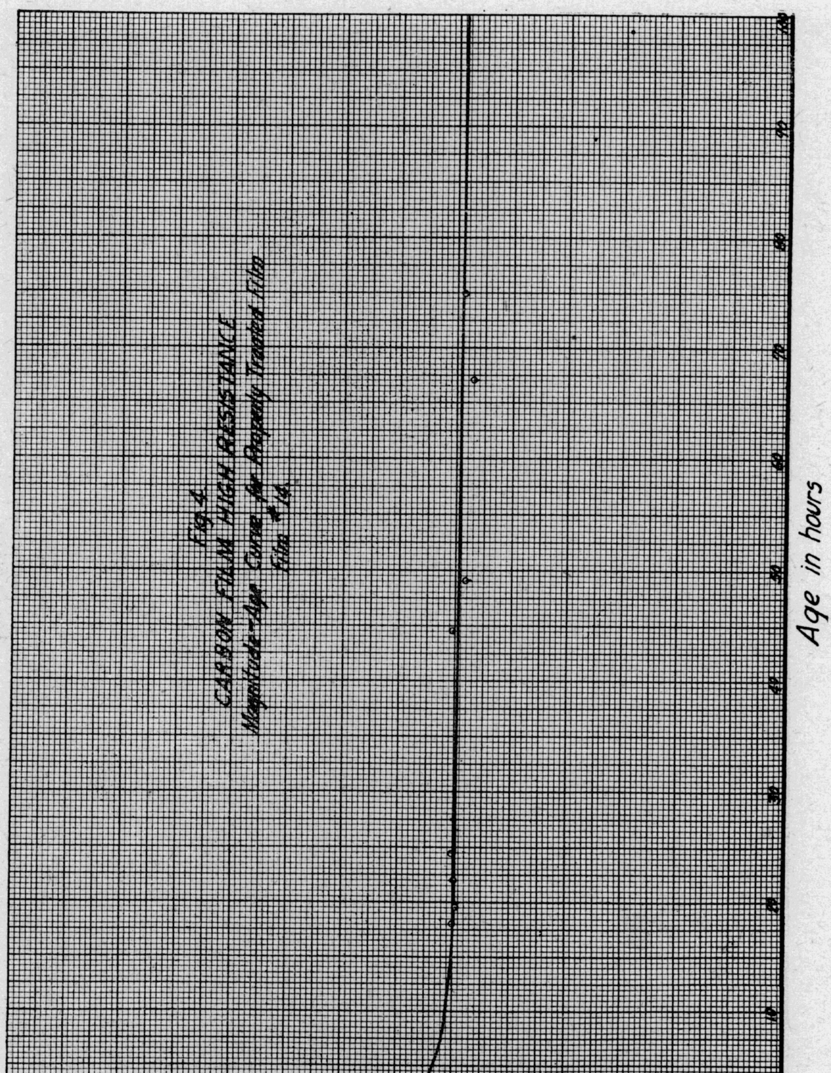
Fig. 4.
CARBON FILM HIGH RESISTANCE
Magnitude-Age Curve for Properly Treated Film
Film #14.
Age in hours
Resistance in megohms

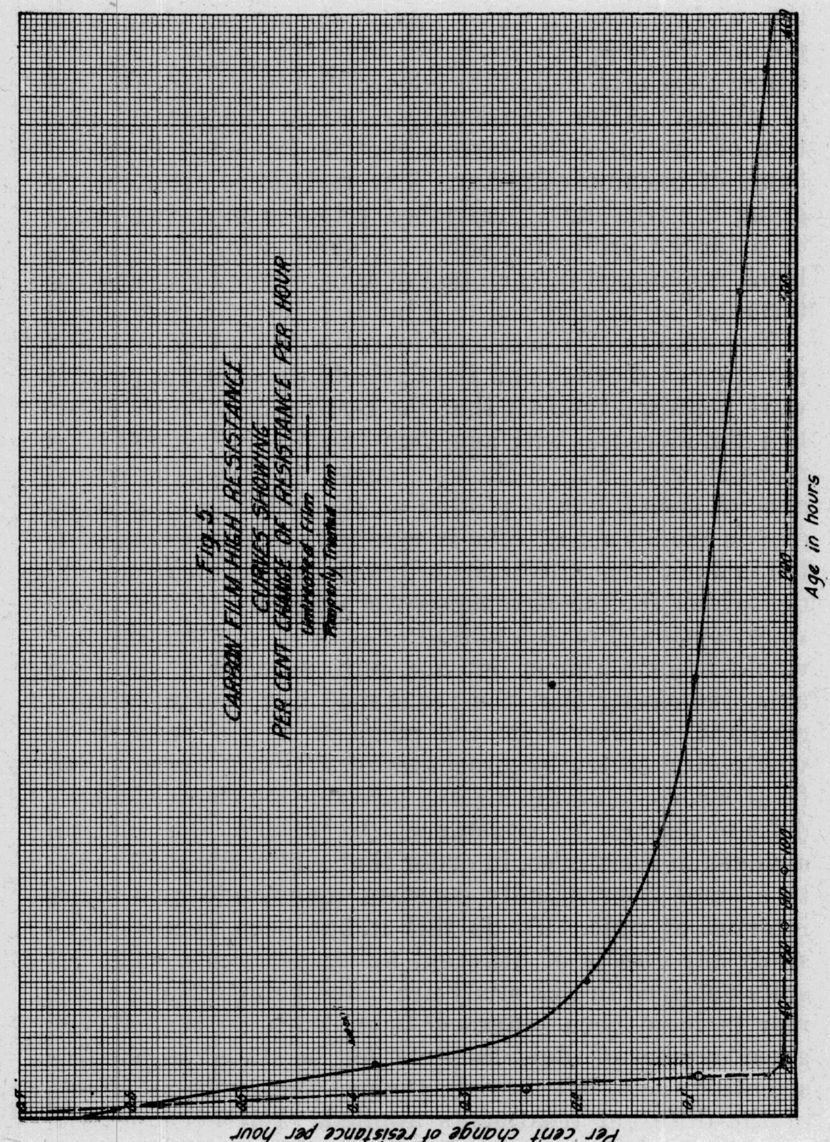
Fig. 5.
CARBON FILM HIGH RESISTANCE
CURVES SHOWING
PER CENT CHANGE OF RESISTANCE PER HOUR
Untreated Film
Properly Treated Film
Age in hours
Per cent change of resistance per hour

ally from a bath of forty parts of saturated copper sulfate solution, one part of concentrated sulfuric acid, ten parts of distilled water and a few drops of a thin solution of gelatine in water. After the copper plate is deposited the copper wire is cut off close to the tube, and a new piece attached at the constriction with a small drop of solder. After thoroughly cleaning the central portion of the tube, the carbon soot is deposited from the flame of burning camphor. The resistance after undergoing the treatment prescribed below is mounted inside of a larger protective tube. A small wooden terminal block is clamped to each end of this larger tube, and the terminal wires soldered to a binding post on each block.

The results of Longden's investigation of carbon film resistances showed, and the data obtained in the present work confirms the fact that the resistance of such a carbon film increases with age, very rapidly at first and later more slowly. Fig. 2 shows a curve in which the resistance of such a film is plotted on the ordinate against its age on the abscissa. The irregularity of the points plotted is due to the difference in temperature conditions under which the measurements were made. If this curve were continued over a period of several hundred days, it would become almost but not quite parallel to the time axis, indicating that the resistance had become almost constant. It has been the purpose of the present investigation to try by processes of artificial aging (artificial aging referring to any process which produces a definite change of resistance) to hasten the natural changes in resistance, in order that a film might be made to assume a practically constant magnitude in a short interval of time. To do this it has been necessary to study the effects of different aging processes. The results obtained in this study are listed below. Since these results have been obtained from work on not a very great number of films, they can not be stated as positive scientific facts, but they do suggest the probable effects of the different treatments applied. Furthermore, the results can be interpreted on a qualitative basis only, since there are a number of indeterminable factors involved in the procedure, such as the exact amount of treatment, the exact thickness of the film and the exact condition of the contacts, etc.

The following characteristics of carbon films as high resistances have been noted:

I. Changes in resistance produced by processes of artificial aging are followed usually by a recovery in which the resistance tends, partially at least, to reassume its former magnitude. This phenomenon is illustrated by the curve in Fig. 3. Here a film has been submitted to alcohol vapor and heat treatments.

II. Bathing a carbon film in alcohol vapor produces a decrease in resistance except in the following cases:

(a.) When one or both of the contacts between the carbon and silver are poor, the carbon is washed away from the silver producing an increase in resistance.

(b.) If the alcohol vapor is forced on to the film in such a manner as to disturb the mechanical arrangement of the particles of carbon, an increase in resistance will be noted.

(c.) If the alcohol vapor is applied repeatedly, without intervals of natural recovery between the applications, a limit is reached, after which no decrease can be produced. If the process is carried still farther, the result is an increase similar to that produced by natural recovery, but more rapid. It has been impossible to explain why this occurs, but trials in which the contacts were covered completely with paraffin have proved that these seemingly erratic variations are not due to defects in construction, and may be repeated quite regularly. This effect is shown also in Fig. 3.

III. Heating a film at a temperature from 80° to 110°C. produces a decrease in resistance due probably to the mechanical change in the arrangement of the particles of carbon when the glass and carbon expand and contract. (See Fig. 3.) Heating to too high a temperature usually causes some cracking of the silver copper tips, which will result in an increase in resistance.

IV. Bathing a film in liquid alcohol decreases the resistance except in those special cases described under the alcohol vapor treatment. As with alcohol vapor, an extended treatment in the liquid alcohol produces an increase. It is evident from examination of a film so treated that an extended liquid alcohol treatment washes off all loose particles of carbon and an increase in magnitude necessarily follows. The ordinary decrease noted at first with either treatment is due to the packing and hardening effect of the alcohol on the film. However, in depositing a film from a camphor flame, it is very probable that the particles of carbon in leaving the flame carry with them camphor vapor which is incompletely burned, and which becomes occluded in the film. It is possible that the natural change in resistance of an untreated film is due to physical or chemical changes in this occluded material. This camphor is washed to the surface of the film by the alcohol vapor treatment, and is in a large part removed completely by the liquid alcohol bath. For this reason, the liquid bath is preferable to the vapor treatment.

With this knowledge of the effects of artificial aging on the resistance of thin carbon films, it is possible to prescribe the following treatment in the preparation of such films for use:

It is desirable to cleanse the film as far as possible from all foreign matter and loose particles of carbon, thus bringing the resistance of the film as nearly as possible to its permanent magnitude. This is done most efficiently and quickly by immersing the film in liquid alcohol for ten to twenty minutes, and then drying for a half hour at 60° to 70°C. in an oven. The change in resistance of a film prepared in this way is shown in Fig. 4.

Fig. 5 shows by comparison the difference between an untreated film under the influence of natural aging alone, and a film which has received the above prescribed treatment. Here the per cent of change in resistance per hour is plotted against the age of the film. It will be seen that the change in magnitude of the treated film becomes much less at an early age than that of one which has received no treatment. The finished film should be mounted as described above, for protection and convenience in use. For best results the films should not be covered with paraffin or shellac since these materials cause undesirable changes in resistance with changes of temperature. The carbon film itself has a rather high negative temperature coefficient of resistance, which is, however, easily measured if necessary.

The results of this investigation can be confirmed only after a long interval of time, for time is the important test of the constancy of a resistance material. The points in the above report which have not been completely explained are to be investigated more thoroughly at a later date.

The writer wishes to express his appreciation of the help and criticism of Dr. E. H. Williams under whose direction this work has been carried on.