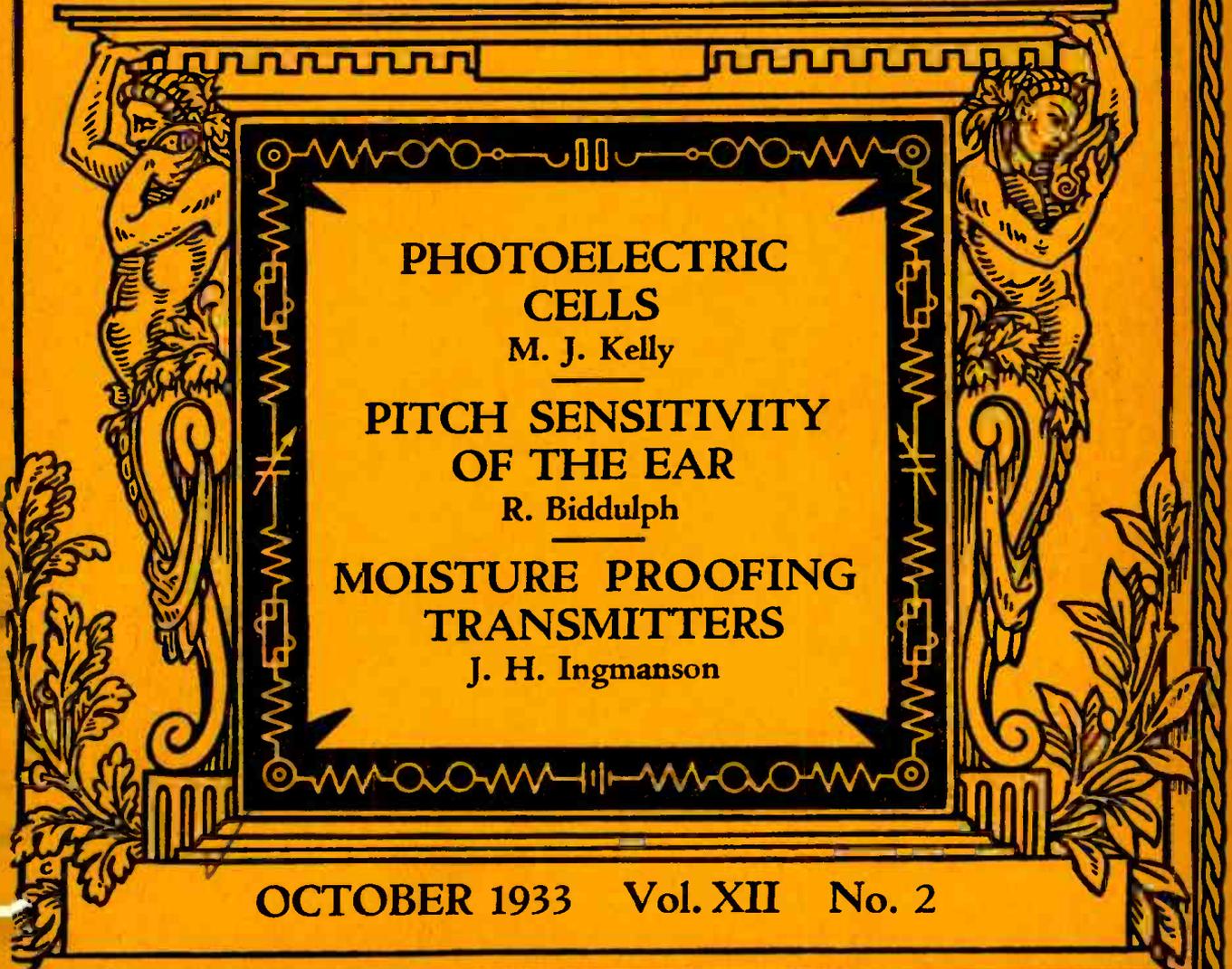


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# BELL LABORATORIES RECORD



PHOTOELECTRIC  
CELLS  
M. J. Kelly

PITCH SENSITIVITY  
OF THE EAR  
R. Biddulph

MOISTURE PROOFING  
TRANSMITTERS  
J. H. Ingmanson

OCTOBER 1933 Vol. XII No. 2

# BELL LABORATORIES RECORD

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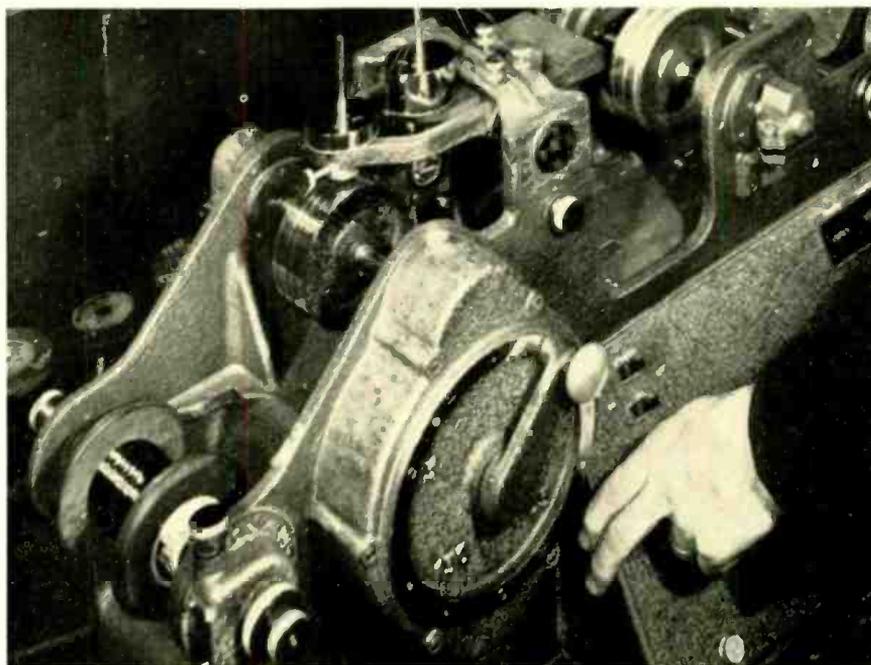
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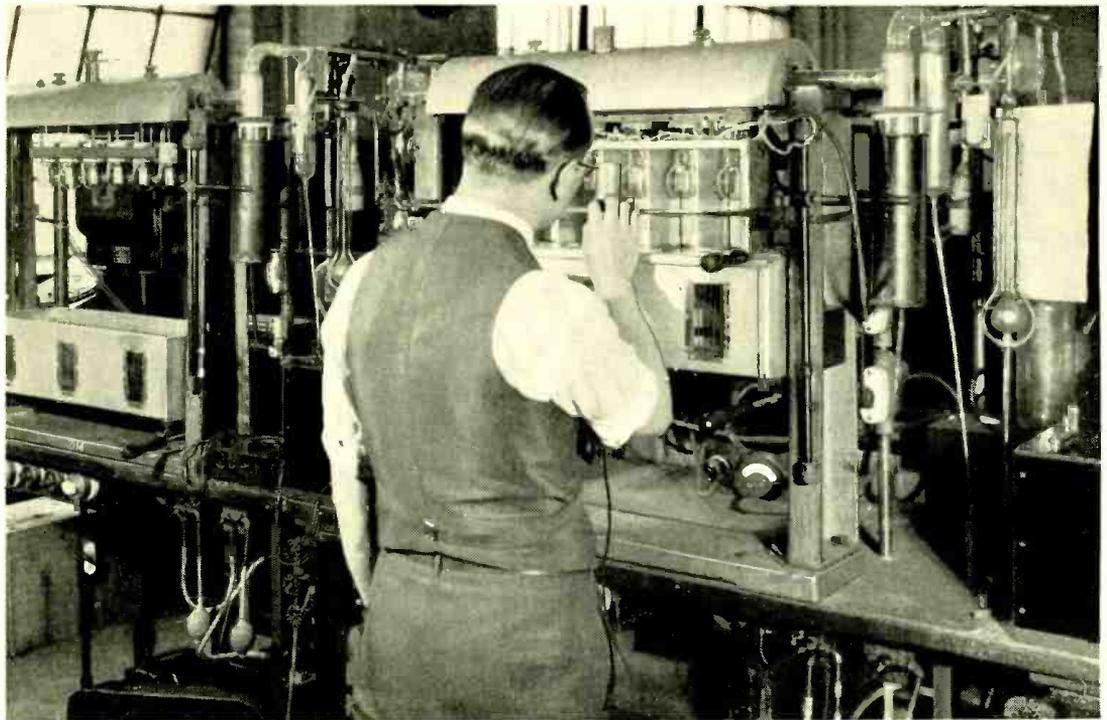


VOLUME TWELVE—NUMBER TWO

*for*

OCTOBER

*1933*



## The Caesium-Oxygen-Silver Photoelectric Cell

By M. J. KELLY

*Vacuum Tube Development Engineer*

A photoelectric cell is a two-element vacuum or gas filled electron tube with a cathode so sensitized that electrons are emitted when light falls on its surface. The number of electrons emitted is directly proportional to the quantity of incident light, and it is this characteristic that makes the photoelectric cell a linear converter of variations of light flux into variations in strength of electric current. In recent years the photoelectric cell has been put to a wide variety of uses, among which might be mentioned the electrical transmission of pictures and sound picture systems. Improvements in these systems have made necessary,

and have in turn been made possible by, the development of more efficient photoelectric cells.

During the past three years the photoelectric cells of the potassium-hydride-cathode type have been replaced by cells employing a new and more highly efficient cathode. This cathode has a core or base of pure silver upon which is formed a matrix of caesium oxide, silver oxide, and finely divided silver. This matrix is covered by an adsorbed layer of caesium of atomic dimensions and in equilibrium with a small amount of strongly absorbed free caesium in the matrix. With an incandescent lamp as a light source, as is used in sound-

picture and picture transmission systems, this cathode is more than fifty times as sensitive as is the potassium-hydride-cathode previously used. The relative response of the two types of cathodes to tungsten light of color temperature  $2710^{\circ}$  K over the spectral range from 3,000 to 11,000 Angstrom units is given in Figure 1.

This complex photoelectric cathode has many elements of similarity to the thermionic cathodes of our long life telephone repeater tubes. Both have a metal core, the thermionic cathode core being a platinum-nickel alloy while the photoelectric cathode core is silver. The cores are both covered by a matrix, the thermionic matrix being barium oxide, strontium oxide, and finely divided platinum and nickel; while the photoelectric matrix is caesium oxide, silver oxide, and finely divided silver. Both matrices are covered by a metallic film of atomic dimensions in equilibrium with absorbed metal in the matrix. The metal is barium for the thermionic

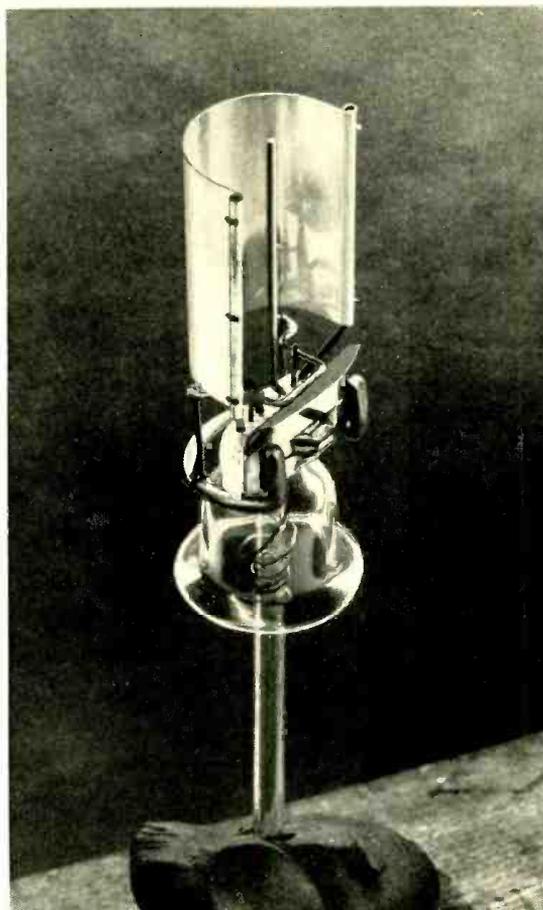


Fig. 2—Arrangement of the caesium pellet and shield used in activating the cathode

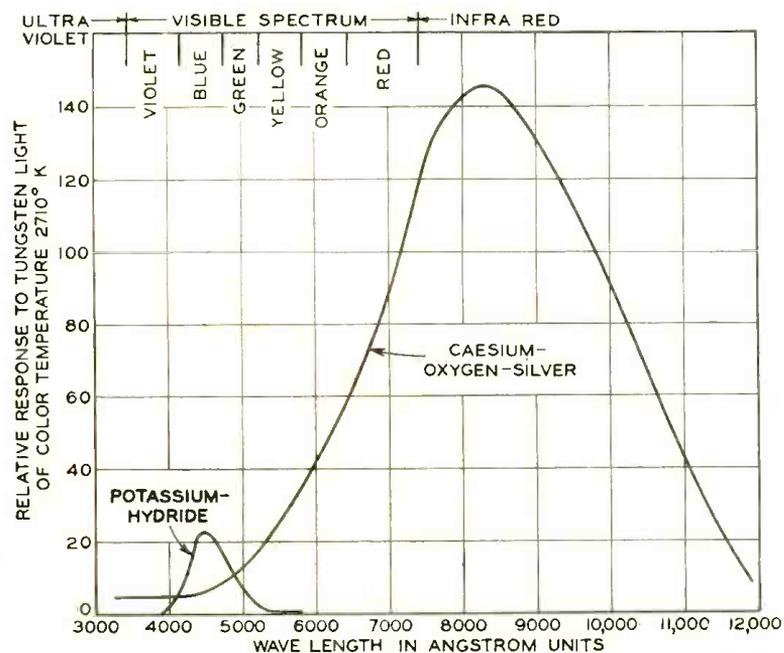


Fig. 1—Photoelectric characteristics of potassium-hydride and caesium-oxygen-silver cells

cathode and caesium for the photo-electric cathode.

For the new photoelectric cell the cathode is a sheet of silver in the form of a segment of a cylinder which is mounted rigidly on a glass stem by three vertical nickel rods. The anode is a nickel wire mounted along the axis of the cathode. From supports mounted on the stem is suspended an open ring of heavy copper wire, shown in Figure 2, between the ends of

which is crimped a tube rolled from thin sheet molybdenum and containing a pellet for the production of caesium. A nickel shield is placed between the pellet and the cathode to deflect the caesium vapor evolved by the pellet, onto the wall of the bulb in front of and below the cathode.

The cathode surface is prepared after the photoelectric cell is sealed to the vacuum pumping system, and its preparation involves the quantitative control of a number of chemical

ed by charging a condenser of known capacity to a definite voltage, and then discharging it through the cell. The discharge is in the proper direction for oxidation of the cathode. A double contact telegraph key is used for charge and discharge of the condenser, and the number of taps given to the key is thus a quantitative measure of the oxidation of the cathode. After the requisite oxidation of the cathode, the next step is the evacuation of the system.

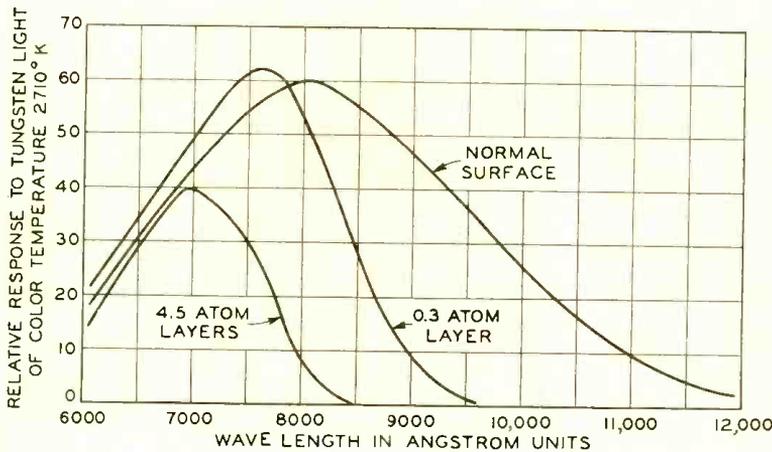


Fig. 3—Effects on the photoelectric sensitivity of various thicknesses of the outer layer of caesium

reactions in vacuum. Three essential steps are taken in succession. A silver oxide film is first formed on the surface of the cathode, then the free caesium is prepared from the pellet already referred to, and finally the caesium is made to combine with the silver oxide surface.

The cells are sealed to a high vacuum exhaust system and after a complete baking of the parts in vacuum at a high temperature, to remove occluded gases, pure oxygen is admitted and the silver cathode is oxidized by a glow discharge between cathode and anode. It is necessary to combine an exact amount of oxygen with the silver of the cathode. This quantitative oxidation is accomplish-

ed by charging a condenser of known capacity to a definite voltage, and then discharging it through the cell. The discharge is in the proper direction for oxidation of the cathode. A double contact telegraph key is used for charge and discharge of the condenser, and the number of taps given to the key is thus a quantitative measure of the oxidation of the cathode. After the requisite oxidation of the cathode, the next step is the evacuation of the system.

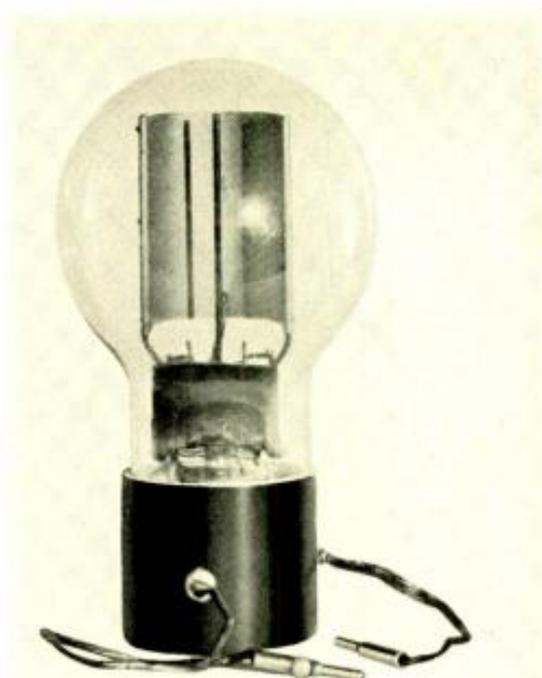
It is as necessary to control the amount of caesium made available for combination with the surface as it is the amount of oxygen. The caesium is obtained by a high temperature chemical reaction. A suitable weight of a quantitative mixture of caesium chromate, chromic oxide, and powdered aluminum is compressed into a pellet with

a die. This pellet is placed in the molybdenum housing described above. After the oxidation of the surface, the pellet is heated by high frequency induction to its kindling temperature. An exothermic reaction involving a great rise in temperature then takes place, which causes the immediate and complete expulsion of all the caesium. The caesium travels in straight lines from the pellet housing and is condensed on the glass wall of the bulb.

The transfer of the caesium to the cathode surface and its reaction with the silver oxide film is accomplished by a rapid heating of the glass wall of the bulb while the cathode remains relatively cool. The cell is placed in a glass chimney and a stream of hot

air, at an accurately controlled temperature, is passed through this chimney. The air stream heats the glass bulb without correspondingly heating the cathode, and causes the caesium to evaporate and to condense on the cathode, where it combines with the silver oxide. The quantities of caesium and oxygen are so adjusted that after the caesium has combined with all but a small amount of the silver oxide to form caesium oxide and powdered silver, there remains a sufficient excess of uncombined caesium to provide a small amount of absorbed caesium in the matrix, which is in equilibrium with a surface layer of caesium approximately one atom thick. After the caesium is transferred from the wall to the cathode, the cell is cooled and sealed from the exhaust system, if a vacuum cell is desired, or filled to the required pressure with an inert gas, usually argon, if a gas filled cell is desired.

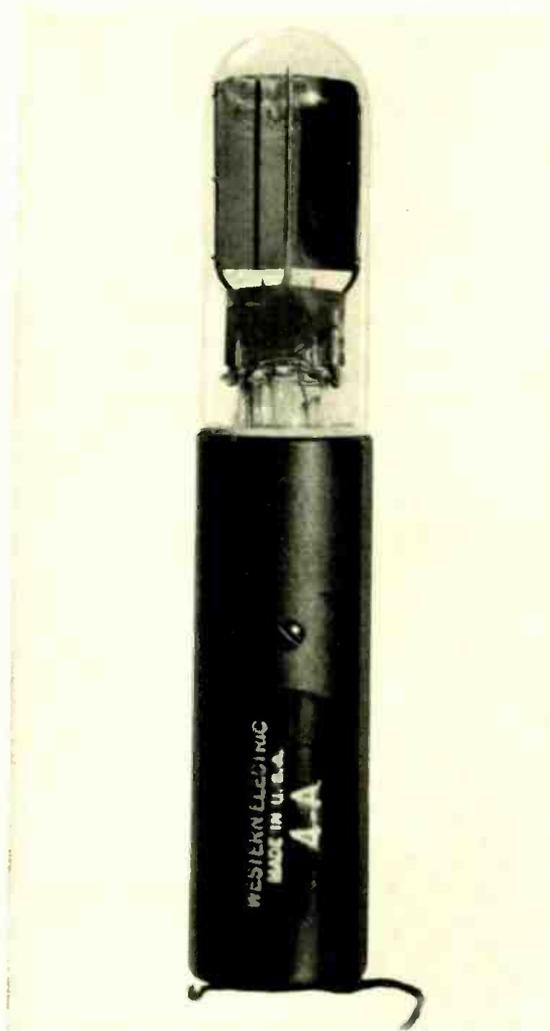
To obtain a highly sensitive cathode surface, and one whose long wavelength limit extends so far into the infra-red, it is very essential that the residuum of caesium in excess of that necessary to combine with the silver oxide be held within extremely close limits. Studies have been made of the effect of additional amounts of caesium on the photo-sensitivity of the surface. In these studies the spectral response of a normally prepared surface has been obtained, and then additional caesium allowed to condense on the cathode surface at such a slow rate that the change in sensitivity of the surface with added caesium coverage could be observed. Typical results of this kind are shown in Figure 3. From this figure it can be seen that the long wave-length limit recedes from about 12,000 Å. to 9,600 Å. by the addition of about 0.3



*Fig. 4—The 3A photoelectric cell is used for sound-picture work*

layer of caesium. When 4.5 layers have been added to the surface, the long wave-length limit has receded further to 8,400 Å. The integrated area under each curve is proportional to the total sensitivity for that surface condition. For 0.3 of an atom layer added, the total sensitivity is reduced to 60% of its initial value, and for 4.5 layers it is further reduced to 25% of its initial value.

The 3A photoelectric cell, Figure 4, has been standardized for sound picture applications. Its cathode is of the caesium-oxygen-silver type. A still higher output is desired from this cell than the increased sensitivity of its cathode makes possible. To further increase the sensitivity, the cell is filled with argon to a pressure of a few hundredths of a millimeter of mercury. With anode potentials of less than 20 volts the behavior of the cell is identical with the high



*Fig. 5—The 4A cell is employed in picture-transmission systems*

vacuum one. For anode potentials greater than 20 volts the anode current rises above that of the vacuum cell and diverges rapidly from it. At 90 volts potential the anode current is approximately three times the vacuum value. This increase is due to ionization of the argon by the photoelectrons emitted from the cathode. A three-fold amplification of the cathode sensitivity is thus obtained by gas ionization. If the anode potential is increased to approximately 150 volts, the anode current will vary in a discontinuous manner and will no longer be directly proportional

to the intensity of the light. It is necessary to operate the cell with anode potentials well below this unstable condition, and ninety volts is the value usually chosen.

The 4A photoelectric cell, Figure 5, has been designed for picture transmission work. Its cathode is the same as that of the 3A cell but the mechanical dimensions and gas amplification characteristics of the two cells are different. The 5A photoelectric cell, shown in Figure 6, has been designed for light relay and special sound picture applications. Its cathode is the same as that for the 3A and 4A cells, but the cell differs from the others in mechanical



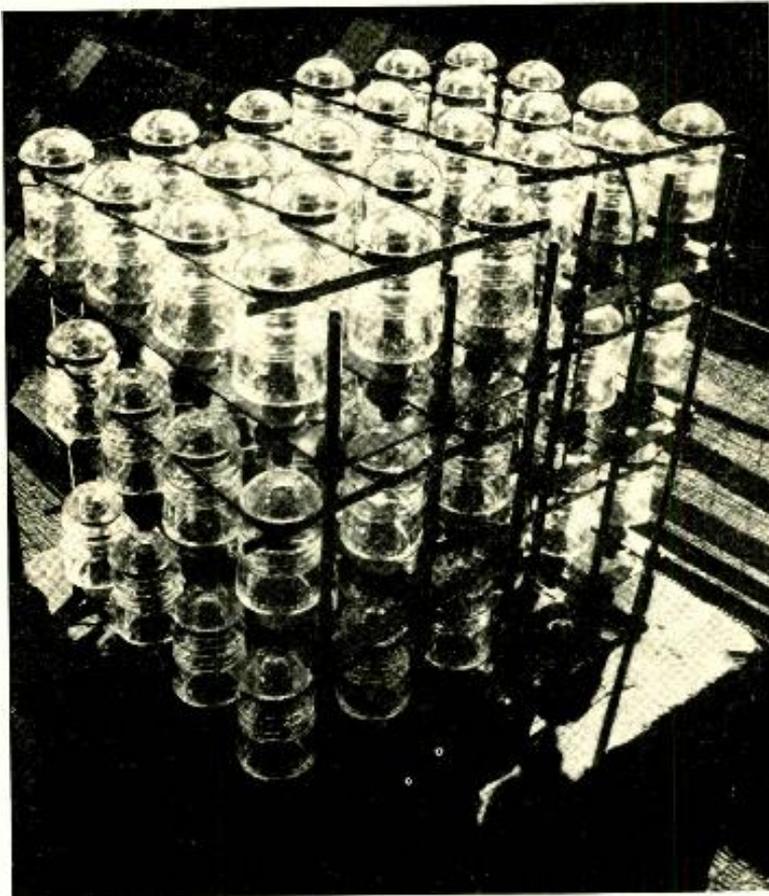
*Fig. 6—The 5A cell has special applications and is of the vacuum rather than of the gas filled type*

dimensions, and is of the vacuum type.

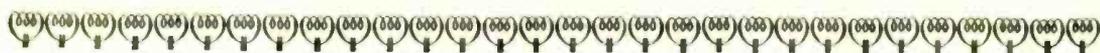
Many thousand photoelectric cells of these types have already been made in the Tube Shop. The precision with which the intricate micro-chemical process of cathode preparation is carried out is so great that the variation in thickness of the matrix on the cathode is not more than 10 molecular diameters and the thickness of the covering thin film of caesium does

not vary by as much as one atomic layer.

C. H. Prescott and M. F. Jameson have carried out the development activities on this photoelectric cathode surface, and J. R. Wilson and M. S. Glass have contributed materially to the standardization of processes and accurate control of quality in the manufacture of the cells employing this type of cathode.



*Insulators on the roof of Section G, awaiting test by methods described in W. A. Yager's article beginning on the following page*



## Electrical Leakage Over Glass Surfaces

By W. A. YAGER  
*Chemical Laboratories*

WHEN the surface of a new glass insulator is moistened, the water tends to form little droplets. After a period of exposure to the elements, the surface loses this characteristic; the droplets of water spread out and finally unite to form a continuous film of moisture. This is but one of many curious habits of glass which are of considerable importance in the telephone plant.

Telephone engineers are constantly striving to minimize and stabilize the attenuation of telephone lines. In contributing to this attenuation, the leakage conductance between the pair of wires is quite important. For this reason the various ways in which insulators permit leakage have been studied in some detail.\* These studies have revealed that there are some seven ways in which leakage takes place, of which two are due to characteristics of glass surfaces or surface films, and it has been found that under many typical service conditions this surface leakage is the most important. It is not only a large factor in attenuation but also by far the most erratic, because it varies widely with changing weather conditions and the aging of the insulators. In reducing this leakage much can be accomplished by properly designing the shape of the in-

ulator,\* but the characteristics of the glass surfaces themselves are at least of equal importance.

How a glass surface will behave toward electric currents depends largely on three factors: the chemical nature of the glass, the moisture and temperature conditions in its environment, and its previous history. The example already cited illustrates the interaction of these factors in a simple case. Apparently the surface tension of water is greater than the forces causing the water to spread, probably because of a very thin contaminating surface film, and thus the water stands in droplets on such a surface. On exposure to the weather, this film is destroyed, and the water slowly dissolves some of the soluble constituents of the glass, leaving a surface of amorphous silica with far stronger adsorptive properties. As a result, the droplets spread into a film of electrolyte.

If the glass is now washed clean and dried, the adsorptive surface of amorphous silica remains. When this surface is exposed to a humid atmosphere, it will adsorb a film of moisture. The thickness of this film varies with the humidity, in the manner shown in Figure 1. According to McHaffie and Lenher a monomolecular layer is first formed at fifty per cent relative humidity; the film thickness then increases with the humidity at a moderate rate up to sixty-five per

\*Such studies, conducted by the Department of Development and Research of the A. T. and T. Company, were described by L. T. Wilson in the *Bell System Technical Journal*, October, 1930, p. 697.

\*RECORD, March, 1930, p. 321.

cent humidity, and finally very rapidly to a layer ninety molecules thick at ninety-seven per cent.

If the glass is allowed to remain in the humid atmosphere, however, more water will be progressively adsorbed in the passage of time. The film of moisture presumably proceeds to dissolve the glass, and the increasing concentration of dissolved constituents lowers the vapor pressure of the solution. In order to maintain equilibrium between the vapor pressures of the solution and of the moisture in the atmosphere, water condenses on the surface, diluting the solution and increasing the thickness of the film. Figure 2 shows a typical example of how this thickness increases with the period of exposure of a glass surface to a saturated atmosphere.

If after any such period of exposure the surface of the glass is dried without being washed, the dissolved constituents will be dried onto the surface

of the glass, remaining there in a readily soluble form. When the glass is again exposed to a humid atmosphere, moisture will be rapidly adsorbed until the film is again as

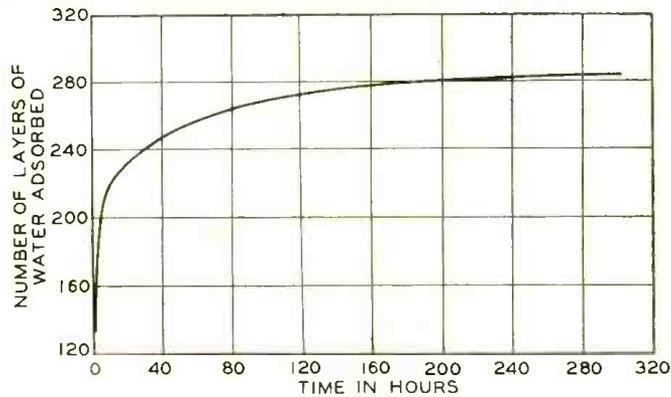


Fig. 2—A smooth curve drawn through Stromberg's data shows this typical increase with time in the thickness of the film of moisture adsorbed on a glass surface exposed to a saturated atmosphere

thick as it was before the surface was dried. The process of slow solution of the glass and slow increase in thickness of the film will then proceed as before.

It is to be expected that the thickness of the film of moisture on a glass surface would be a large factor in the electrical leakage that might take place over the surface. To investigate the influence of this and other factors on leakage, the apparatus shown in Figure 3 has been used for measuring the variation in the current conducted across a glass surface under varying conditions. In it two conducting tapes plated on the glass form parallel spirals around a glass tube, and the current conducted across the glass between the spirals is measured. By thus providing a leakage path of short length and large area, small changes in the environment are made to give relatively large changes in leakage. Unfortunately the process of plating the glass appears to introduce some electrolytic impurities

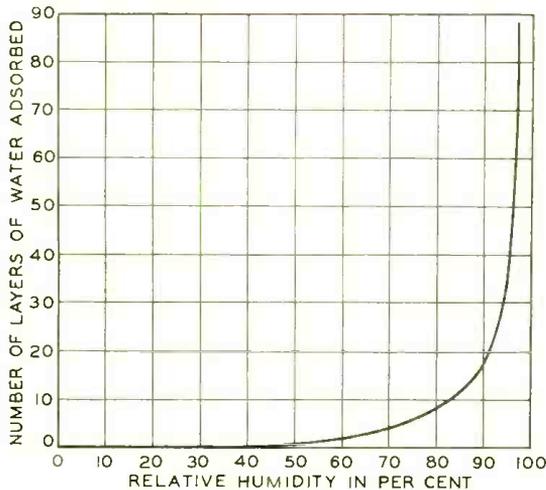


Fig. 1—McHaffie and Lenher have shown that a clean washed surface of glass adsorbs a film of moisture whose thickness in terms of molecules varies with the humidity as shown above

which affect conductivity. Qualitatively however the effect of adsorbed moisture is not disturbed by their presence.

When leakage so measured is plotted against humidity, curves (Figure 4) strikingly similar to those of film thickness against humidity are obtained. In the cases shown, the first measurable leakage occurred at about fifty per cent relative humidity, where according to adsorption data a monomolecular film is first formed. The increase in leakage at higher humidities follows closely the increase in film thickness.

When the glass is allowed to remain in the humid atmosphere, the change in leakage with time depends in its earliest stage largely on the rate at which a film of moisture is adsorbed. As the soluble constituents of the glass dissolve, the leakage is further augmented because the increasing concentration of electrolytic materials in the film increases its conductivity. When the process of solution reaches the point where moisture would be expected to condense on the film in order to maintain equilibrium between it and the atmosphere, the increase in film thickness again largely controls the increase in leakage. The three processes described in the three preceding sentences merge to produce a smooth curve of increase in leakage.

The process of solution sets up barriers to its own progress, however, for it diminishes the supply of soluble constituents near the surface of the glass, and leaves an impeding layer of amorphous silica. After a while the rate of increase in leakage dimin-

ishes, and ultimately the leakage reaches a saturation or final value, dependent on the relative humidity, where all the active factors attain equilibrium. If the surface film is dried and the glass is then exposed to a lower humidity, a lower equilibrium value is attained in a relatively short time. If the glass is exposed to a higher humidity, "aging" proceeds further until a new and higher equilibrium value of leakage is established.

If after it has been aged the surface of the glass is washed thoroughly with distilled water and then reexposed to a humid atmosphere, the remaining barrier of amorphous silica and the dearth of soluble constituents reduces the rate of increase in leakage with time. The effect of five successive washings and reexposures in one case is shown in Figure 5. More exposures and washings gave in this case but little further improvement.

The correlation of these laboratory results with field experience is complicated by the presence of many casual factors in the field. Glass exposed out of doors, especially near an industrial center, is subject to contamination which may produce an increase in surface leakage far outweighing that caused by decomposition of the glass. Deposits of dirt containing electrolytic impurities may accumulate on the surface, and the oxides of sulphur and carbon present in industrial atmospheres may react with the water of the surface film to form conducting solutions of sulphuric and carbonic acids.

Furthermore not all laboratory tests favor the various types of leakage in the same relative degrees as do the

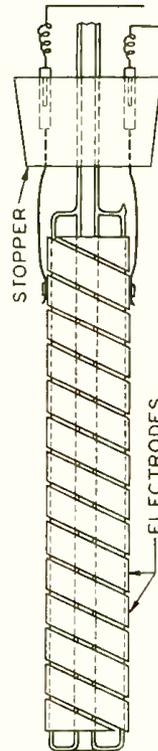


Fig. 3

conditions in the field. It is fairly apparent, for instance, that the leakage measured by the apparatus shown in Figure 3 is primarily due to direct conduction through the surface film. It seems probable, however, that much of the leakage permitted by an insulator in the field can be regarded as occurring in high-resistance surface films, considering the insulator to be a "condenser" whose "plates" are formed by these surface films and the mounting pin. In any case the surface characteristics are of greater importance than the volume characteristics, and the results of the tests are useful in determining the variation in the resistance portion of a path which may be considered as consisting of a resistance and a capacitance in series.

Measurements of the alternating-current leakage permitted by carrier-current insulators under various conditions have been made in these Laboratories, and by the American Telephone and Telegraph Company on experimental pole lines at Phoenixville, Pennsylvania. The laboratory tests so far conducted on insulators do not show evidence of deterioration, such as was observed with the apparatus shown in Figure 3, on exposure to high humidities for comparable times. Presumably this difference is due to the fact that the leakage with the testing tube is predominantly direct surface leakage, whereas the leakage with the insulators may take place mostly by the "condenser" mechanism described above. On the initial run the thirty-kilocycle conductivity increased by a factor of twenty-five when the environing humidity was increased from zero to ninety-six per cent. But the conductivity remained practically constant while the insulators remained

exposed to high humidities for 234 consecutive hours. After soaking the insulators in cold tap-water over a week-end, the conductance varied by a factor of only 3.5 over the range of humidities, but again 138 hours of humid exposure produced no change in conductance. Finally the insulators were scrubbed with soap and water, soaked in hot cleaning solution, exposed to live steam and rinsed in hot distilled water. The conductance increased by a factor of 6.4 over the humidity range, and still 142 hours of exposure at ninety-six per cent humidity did not increase the conductivity. The insulators are now

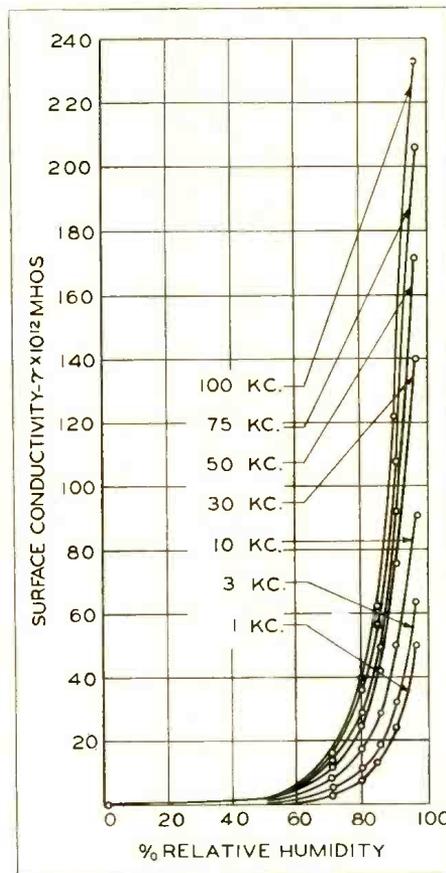


Fig. 4—When surface leakage is plotted as a function of environing humidity for various frequencies, the curves bear a striking resemblance to that in Figure 1

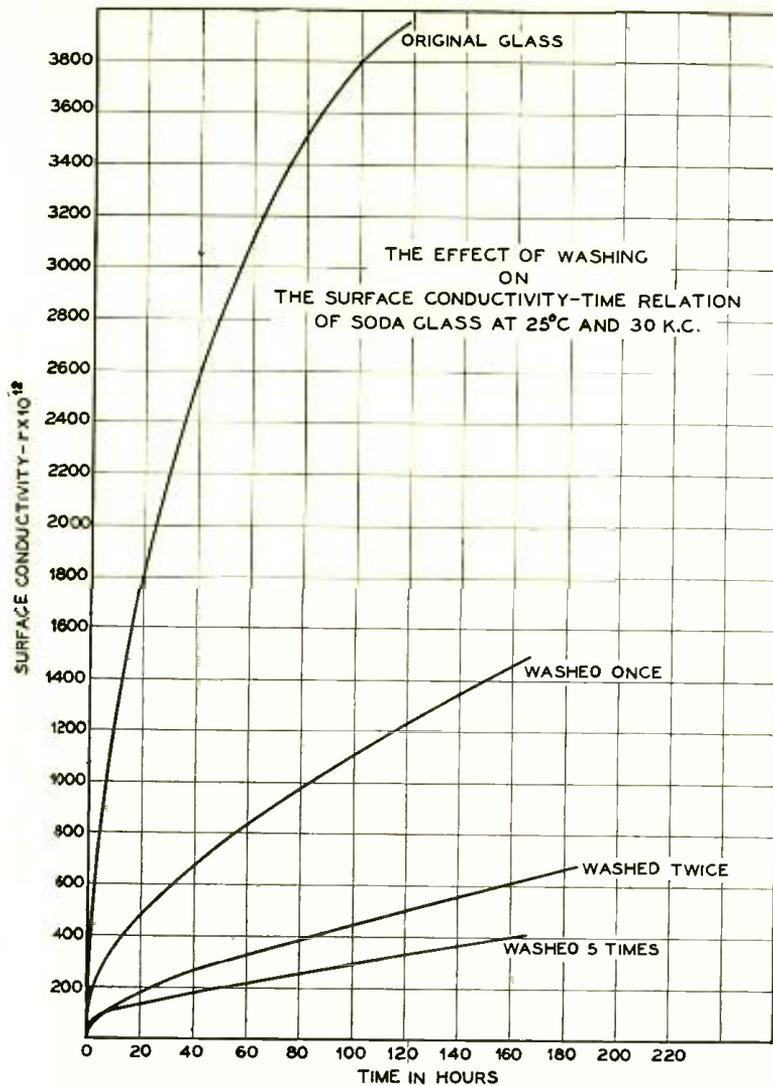


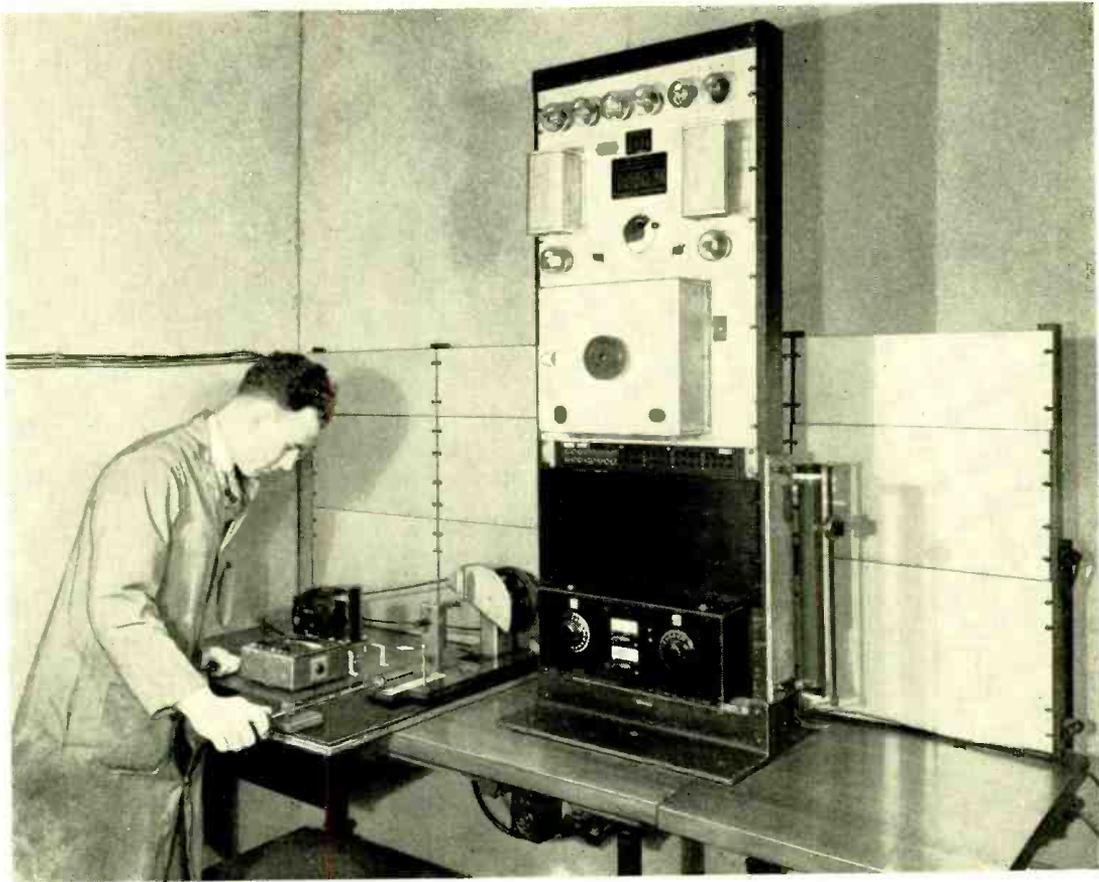
Fig. 5—Washing has a large effect on the rate at which the conductivity of a glass surface increases with time of humid exposure. These curves are for soda glass at 25°C and 30 kc

exposed on the roof, as shown on page 39, awaiting further tests.

Since the surface leakage of a glass,

even under controlled laboratory conditions depends so largely upon the condition of its adsorbing surface and its previous history of exposure, it is meaningless to compare the surface characteristics of various glasses unless they have all received the same treatment from the time of manufacture to the time of measurement. Tests have shown a sample of borosilicate glass, which had been exposed to a humid atmosphere for a long time, to be greatly inferior to a new sample of soda-lime glass, although the borosilicate type is much the more stable chemically. Tests at Phoenixville, moreover have shown that borosilicate insulators are initially superior to those made of alkali glass, but after expo-

sure to weather over a period of time, it appears that a considerable part of the advantage is lost.



## Differential Pitch Sensitivity of the Ear

By R. BIDDULPH  
*Acoustical Research*

**I**MAGINE yourself stationed near a straight railroad track along which a locomotive, with whistle continuously sounding, is rapidly approaching. If the train travels at constant velocity your ear will assign a definite pitch to the sound emitted by the whistle. This pitch will remain constant until the instant the train passes you when it will then appear to abruptly decrease. This phenomena is termed the Doppler effect. It is due to the fact that the apparent frequency of a sound depends upon the number of sound waves striking the ear of the listener per unit time. Given the speed of the

train, the true frequency of the whistle, and the velocity of sound in air, the apparent frequency change observed by a listener stationed at a point along the track may be calculated.

This change is greatest when the velocity of the source is high. If the train were to pass the observer repeatedly, each time at decreased velocity, a minimum velocity will eventually be reached below which the observer will not be able to detect the change in frequency as the whistle passes. If a source of sound producing single frequency tones of controllable intensity is substituted

for the whistle, and the minimum velocity at which a frequency difference of the source is apparent is determined, we shall have evaluated

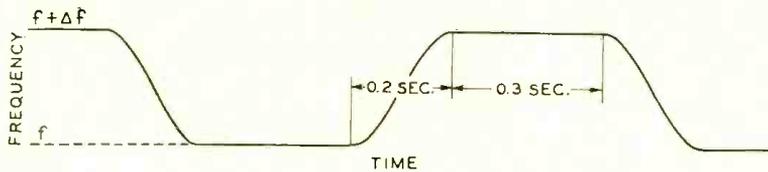


Fig. 1—Cycle of frequencies employed to determine differential pitch sensitivity

one of the fundamental characteristics of the human ear. It is called differential pitch sensitivity and is defined as  $\frac{\Delta f}{f}$  where  $\Delta f$  represents the smallest change in frequency  $f$  that the ear can detect. An accurate determination of these values requires apparatus and technique much more refined than those indicated above, and necessitates the transference of the problem to the laboratory where such refined means are available.

Historically the necessity for determination of the differential pitch sensitivity of the ear first arose in the field of psychology. A law of sense perception formulated by the psychologists Weber and Fechner states that the increase of a stimulus necessary to produce a just discernible increase in the resulting sensation bears a constant ratio to the total stimulus. This law has been shown to be approximately true of the visual and tactile senses, and more recently of the hearing sense with certain restrictions as to frequency and sensation level ranges. To both scientists and engineers the problem has certain specific interests; to the former they are largely academic and theoretical involving problems

of ear function and hearing theory, while the data assists the latter to set requirements for frequency stability in recording, reproducing and transmission systems. Because of this basic nature of the data, an experimental investigation was undertaken by the Acoustical Research Department to

determine differential pitch sensitivity values for the human ear more completely than had heretofore been done.

In the laboratory study, the apparatus for which is shown in the photograph at the head of this article, two successive tones of differing frequency obtained from an oscillator equipped with appropriate filters to insure tone purity were presented to observers by means of telephone receivers designed to produce a minimum distortion. Each observer reported whether a frequency difference was discernible between the two tones. Then, by continually decreasing the frequency difference of the tones presented for observation, the minimum detectable frequency

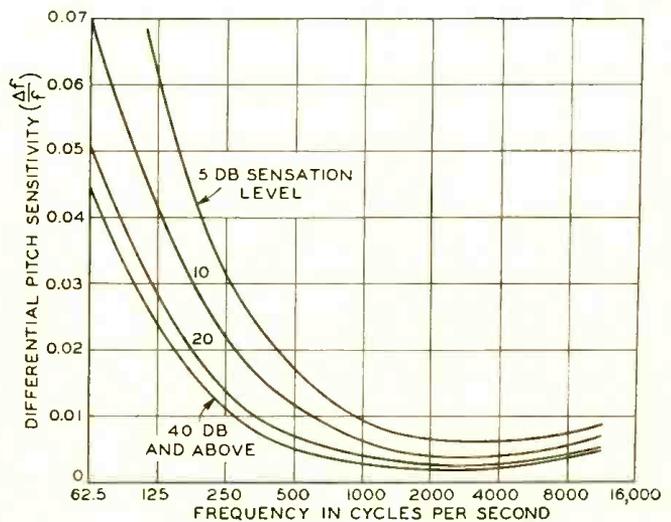


Fig. 2—Experimental values of differential pitch sensitivity for the human ear

difference was determined for each observer, and the mean value taken as the measure of differential pitch sensitivity of the human ear.

The majority of previous determinations, the first reported in 1827, were made using tuning forks and organ pipes as a sound source. Knudsen performed the only measurements using a modern oscillator. His results indicate that tone purity, adequate pitch and intensity control, and the method used to produce a frequency change from  $f$  to  $f + \Delta f$ , are factors influencing results obtained. Tone purity and intensity control are requirements met long ago by the telephone industry; hence

the principal problem lay in devising a satisfactory method of transition from one frequency level to its companion level. Analyses indicate that the generation of interfering harmonics is minimized when the transition is made as a sinusoidal function of time. To accomplish such a transition, an auxiliary condenser was designed to change the frequency of a heterodyne oscillator in a manner shown graphically by Fig. 1, and thus to provide the two recurrent companion tones. The magnitude of frequency change, represented by  $\Delta f$  was made continuously variable, and the time of repose at each frequency equal.

Differential pitch sensitivity is found to be a function of two variables describing the sound—the frequency of the tone and its sensation level. Figure 2 represents the values found. Were the Weber-Fechner law a true

statement of fact throughout the audible frequency range, these curves would be straight lines parallel to the axis of abscissae. Above a frequency of 800 cycles the curves are approximately horizontal; below this value the differential pitch sensitivity rises rapidly but in such a way that the

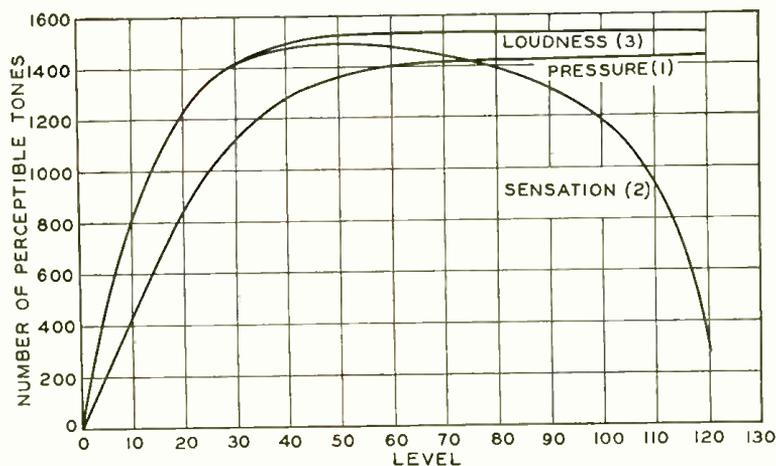


Fig. 3—Number of different perceptible pitches integrated over three paths through the auditory area

absolute detectable frequency difference remains constant. These data indicate the ear to be extremely sensitive to frequency differences; the human ear, for example, can distinguish a frequency difference of 0.3 per cent in a 1000 cycle tone at a sensation level 40 db above the threshold of audibility, or expressed in musical notation it distinguishes a difference of approximately  $\frac{1}{16}$  semi-tone in the tone two octaves above middle C of the piano. Translated into terms of our railroad problem, at all velocities of the locomotive in excess of 1.2 miles per hour a frequency difference would be discerned by the observer if a pure 1000 cycle source were substituted for the locomotive whistle.

It is of interest to compute the number of pitches separately discernible in passing from the lowest

to highest frequencies sensed by the ear. This number will obviously depend upon the path taken through the auditory sensation area since, as

in the ear canal is kept the same for all frequencies, and thus the path—curve 1—is indicated by a horizontal straight line. Along that of constant

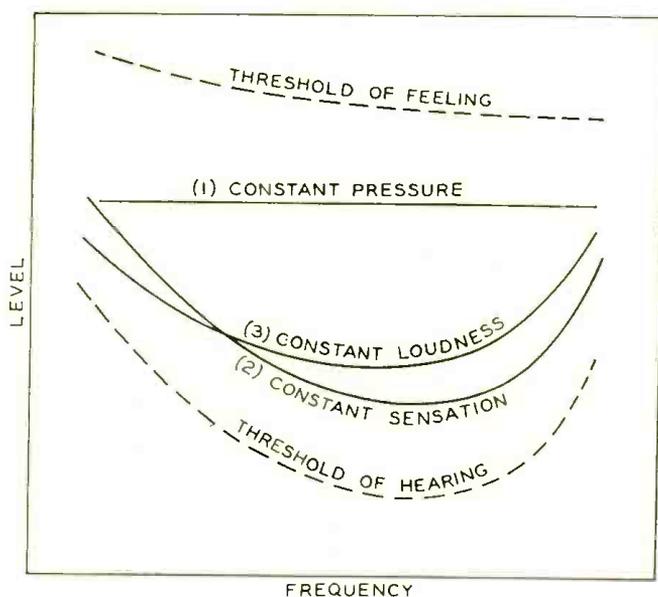


Fig. 4—When tones of all frequencies are maintained at a constant pressure, the path is indicated by a horizontal line, as shown by curve 1. Along curve 2, the tones are all the same number of decibels above the threshold, and along curve 3, they are of equal loudness

has been pointed out, differential pitch sensitivity is a function of the intensity of the tone as well as of the pitch. Figure 3 indicates the number of pure tones separately perceptible along three selected paths of particular significance. One path of each type is indicated in Figure 4. Along that of constant pressure, the pressure

is adjusted so that tones of all frequencies sound equally loud. The curve of constant sensation level—curve 2—represents tones which at each frequency are the same number of decibels above the threshold of hearing. From curve 2 of Figure 3 it is seen that 480 separate tones may be distinguished by the ear if each tone is at a sensation level 5 db above audibility, corresponding approximately to the faintest perceptible sound, whereas if the level be raised to 70 db, corresponding to the optimum level for best articulation of speech over a telephone system, the human ear is capable of distinguishing 1440 separate pitch levels.

Although our ears are in constant use during our conscious hours much still remains to be learned regarding the details of their response in the hearing process. However, continued investigations of ear characteristics coupled with detailed studies of ear structure will eventually formulate a complete answer to the question: How do we hear?

*News notes for October, ordinarily found on a tinted paper insert at the center of the RECORD, will be deferred from this issue. They will appear in combination with similar notes of later date in the November issue.*



# Wetting of Solids by Liquids

By D. A. McLEAN  
*Chemical Laboratories*

AS this is being written, the ink flowing from the pen leaves a thin, even track on the paper. If blotting paper were used instead of writing paper, however, the ink would spread rapidly in all directions, leaving a ragged and uneven line, while if waxed paper were used, the ink would draw up into globules behind the pen, depositing a series of drops instead of an even line. These are observations of typical wetting phenomena, which are important in many processes such as in impregnation, the flotation of ores, grinding and dispersion of pigments, and lubrication. In the manufacture of telephone apparatus, wetting phenomena are encountered in the formation of impregnated dielectrics, such as the paper of condensers, and the insulation of cables, in the treatment of telephone poles with preservatives, and in the lubrication of machinery. Because of the importance of the subject extensive studies of wetting phenomena are carried on in the Laboratories.

In general wetting is a function of the relative attraction between molecules in the wetting liquid, and between the wetting liquid and the surface with which it is in contact. A molecule at the surface of a liquid is attracted strongly by the adjacent surface molecules and by those in the main body of the liquid. The condition in a cross-section of an isolated drop of liquid is represented schemati-

cally in Figure 1. The forces on the surface molecules differ from those on interior molecules. The latter are attracted equally from all sides, while those on the surface are attracted only to those adjacent to them on the surface and to those within. The result is in many ways equivalent to the formation of a strong surface film, the strength of which is called "surface tension". It is this elastic like film that we picture as causing an isolated drop to assume a spherical shape.

When such a liquid drop is brought in contact with a solid surface, the attractive forces between the molecules of the liquid and solid overcome the surface tension to some extent, and the drop assumes the form shown in Figure 2. Other things being equal,

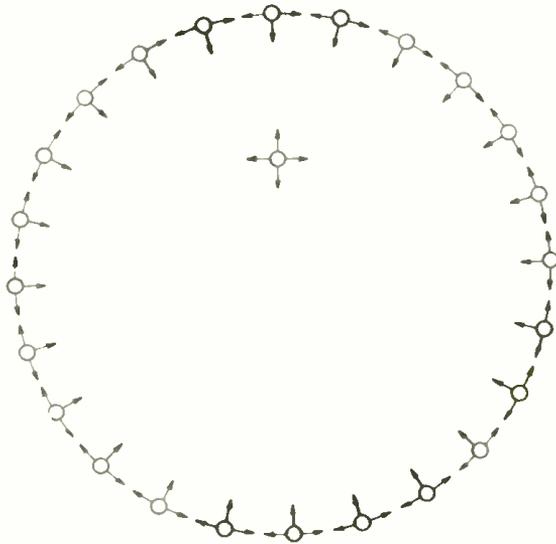


Fig. 1—Schematic representation of intermolecular forces in a drop of liquid

the greater the attraction between liquid and solid, the larger will be the area of contact, which is the surface

there is no wetting, to  $0^\circ$ , when the wetting is complete—such as occurs in blotting paper. Figure 3 illustrates

an approach to this latter condition, while Figure 2 shows a much lesser degree of wetting.

The wetting phenomenon is well illustrated by the action of liquids in capillary tubes. Adhesion exists between the liquid and the sides of the tube so that for any particular liquid and tube material there exists a characteristic angle  $\theta$  as shown in Figure 4. If  $\theta$  is less than  $90^\circ$ , the liquid will move in the direction of the arrow as long as the attraction between solid and liquid is not balanced by some extraneous force. If  $\theta$  is greater

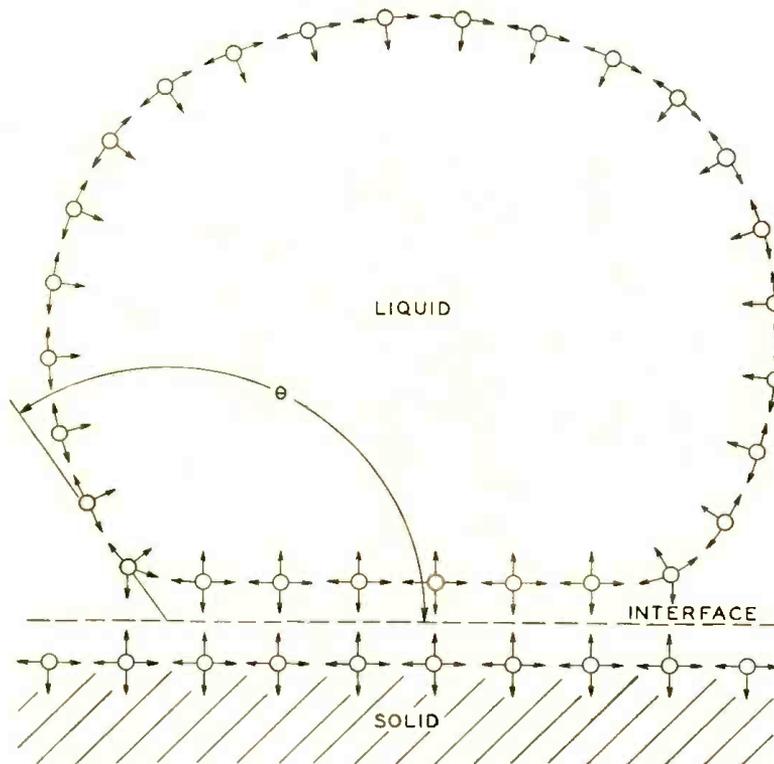


Fig. 2—When a drop is placed on a solid surface, the surface tension is partially overcome by the attraction between liquid and solid

wetted. Wetting is thus a function of the relative value of adhesion—the attraction between liquid and solid—and surface tension, the attraction between molecules within the liquid.

Regardless of the size of the drop, a given liquid will spread on a given solid until the angle, measured within the liquid, between the solid surface and the tangent to the drop where it touches the surface, reaches a definite value,  $\theta$  in Figure 2. Depending on the liquid and solid involved, this angle may vary from  $180^\circ$ , when

than  $90^\circ$ , the liquid will move in the opposite direction, that is out of the tube. The important difference between the spreading of a drop on a surface and the entrance of a liquid into a capillary is that in the former case, Figure 2 for example, the spreading cannot continue beyond the condition shown without decreasing

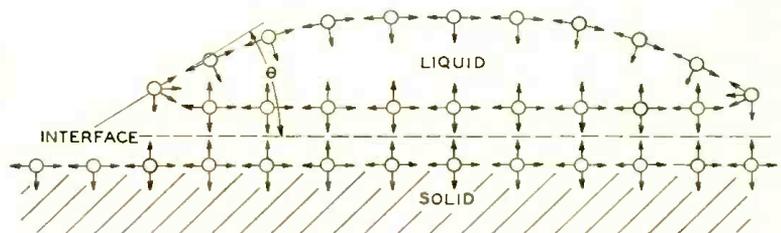
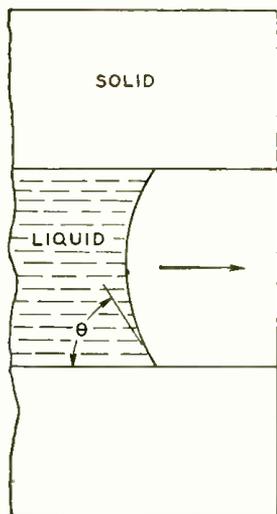


Fig. 3—When the attraction between liquid and solid is large compared to the surface tension, there is a greater wetting effect

ing the value of  $\theta$ , which is fixed for given materials, while in the tube, penetration can continue indefinitely without changing  $\theta$ . As a result a static condition is soon reached with the drop, while with the capillary, penetration will continue until the wetting forces are balanced externally.

For a capillary of any given size, the force causing the liquid to penetrate it is a function of the angle  $\theta$ , which is constant for a given liquid and solid material. The distance the liquid penetrates such a tube in a given time is thus a measure of wetting, and is so used in the Laboratories whenever the solid material is of such a nature that it can be deposited on the inner walls of a capillary. It is particularly suitable for evaluating waxes as inhibitors of spreading. In dial central offices, waxes not readily wet by oils are employed to prevent the spreading of oils along shafts from gear boxes to the friction rolls which they drive. If the inner walls of a capillary are coated with a wax



(a)

Fig. 4—In a capillary tube the characteristic wetting angle,  $\theta$ , determines the movement of the liquid in the tube

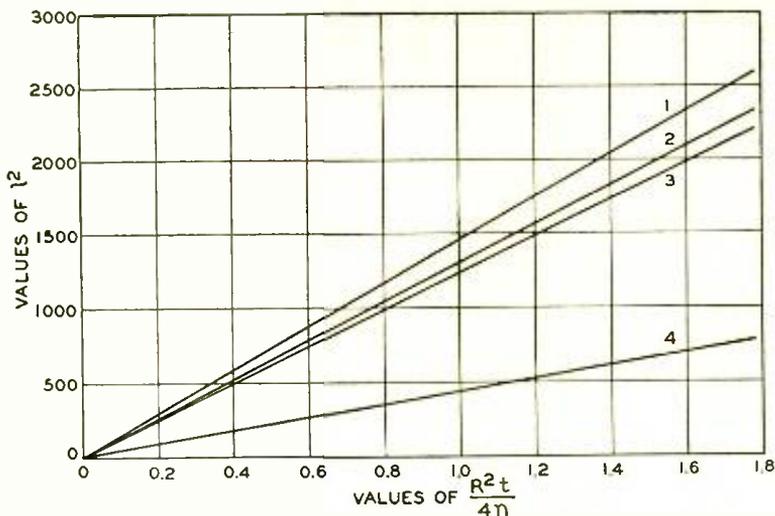


Fig. 5—Typical curves showing the wetting characteristics of waxes

to be tested, the amount of penetration in a given time at once gives a measure of the wetting capacity of the wax.

With the method employed in the Laboratories, a horizontal capillary is used, and the square of the distance penetrated is plotted against time. Such plots are straight lines, and the slope of the line is proportional to the penetration tension of the oil for a particular solid material. A set of such curves is shown in Figure 5. Instead of time, it has been found more convenient to plot  $\frac{R^2 t}{4\eta}$  as the abscissa scale, where  $R$  is the radius of the capillary and  $\eta$  the viscosity of the liquid. The smaller the slope of the curve the better is the wax as an inhibitor of wetting, so that the wax yielding the lowest of the four curves shown is much the best for the purpose. Such a method, however, is not applicable to the study of the impregnation of fibrous materials. A different method has been developed for such purposes therefore, and the apparatus employed is shown in Figure 6.

A strip of paper is suspended so that its lower end dips into the liquid

whose wetting is to be investigated. The liquid rises in the strip by

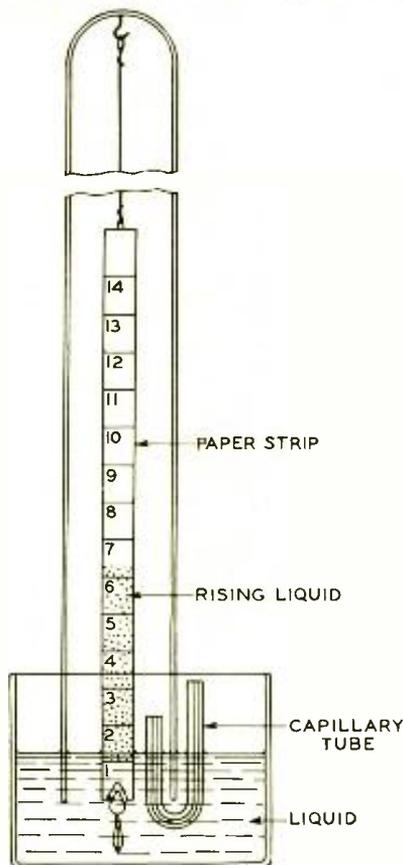


Fig. 6—Wetting of fibrous materials is determined by suspending a strip of paper so that one end is in the wetting liquid

capillary action and the height of rise is recorded as a function of time. Rates of rise, obtained by drawing tangents to a plot of height against time, give straight lines when plotted against the reciprocal of the height and the slopes of these lines are directly proportional to the penetration tension. The rates of penetration depend on the type of paper used but for any one paper the re-

sults are comparable for various liquids.

The property of wetting is especially sensitive to the presence of foreign materials and to the physical and chemical condition of the solid surface. Treatment of the paper with oxygen, for example, greatly lessens the facility with which it is wet by water. This is shown by Figure 7 where the curve for the untreated paper is seen to have a much steeper slope than that for the treated paper. This treatment of paper with oxygen, however, does not affect the degree to which it is wet by benzene.

This difference in the wetting action of benzene and water is shown in Figure 8. Oxygen-treated and untreated paper strips are passed through a water-benzene interface. Since, as pointed out above, benzene has the greater attraction for the treated paper, the benzene is drawn down along the treated paper, at the left, into the water, while water is drawn up along the untreated paper into the benzene. In the former case the benzene, because of its greater adhesion for the treated paper, displaces

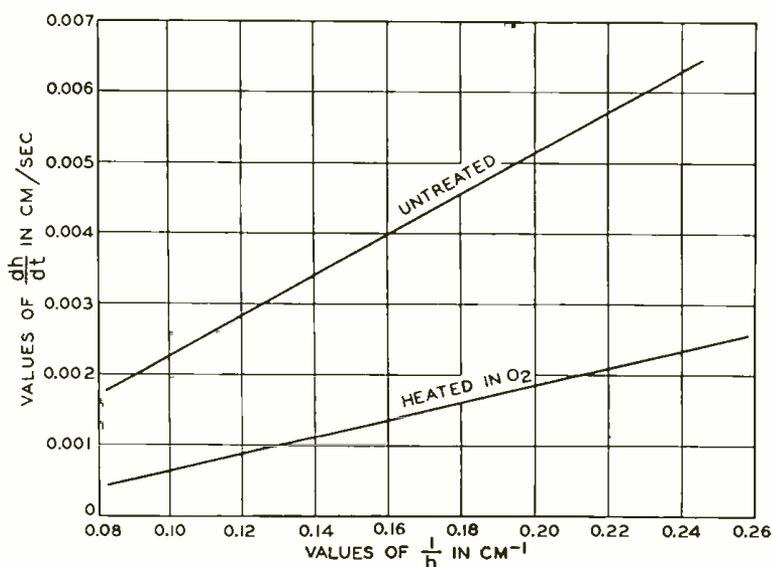


Fig. 7—Treating paper with oxygen greatly reduces its wetting by water

the water, while in the latter, the water displaces the benzene.

A number of such tests are being carried on to determine the interfacial relations between cellulose and impregnating compounds, and attempts

are being made to correlate wetting properties with the characteristics exhibited by impregnated materials in actual service. Much of the work planned, however, is still in the preliminary stages.

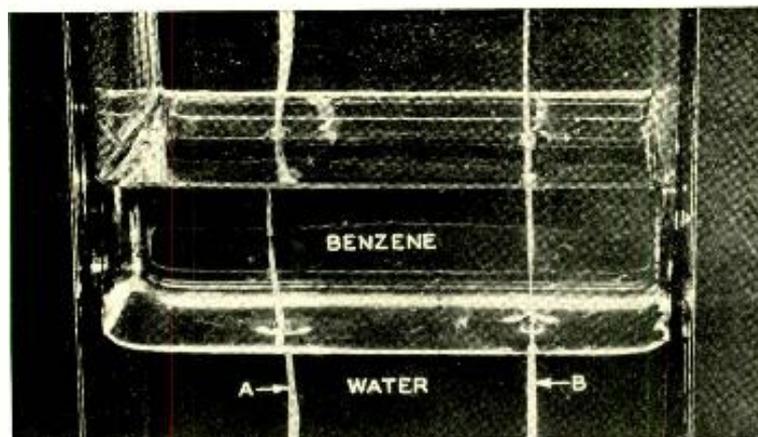


Fig. 8—Comparative action of water and benzene on (A) treated and (B) untreated paper

### *Bound Volumes of Bell Laboratories Record*

*For readers of the RECORD who wish bound volumes, arrangements have been made to supply bound copies of Volume XI, which was completed with the August 1933 issue, at a price of \$1.75 plus prepaid shipping charges. Subject and author indexes are included in the volume. Orders from members of the Laboratories in New York City may be placed through the Personal Purchase Department; orders from all others should be placed on the Blanchard Press, 418 West 25th Street, New York City, before October 20 to secure this price. It is not necessary to return unbound copies as sufficient sets are on hand to take care of the probable requirements. Copies of the index alone may be had gratis on request to the Bureau of Publication.*



# A One-Pair Loaded Emergency Cable

By R. C. DEHMEL

*Outside Plant Development*

THE importance of carrier telephone circuits and their extensive application to open wire lines have made it desirable to provide improved facilities for promptly restoring service when accidents or storms render the lines inoperative. Similar repair facilities are also required when it is necessary to maintain service on lines that must be temporarily broken or diverted during highway changes, cable installations, or retransposition work. To make it possible with a minimum of time to bridge such temporary gaps in open wire lines on which carrier is operated, a one-pair rubber insulated cable has been developed. Each unit length of cable is provided with built-in loading, and has terminating devices at each end for direct connection either to an open wire line or to another section of cable.

Conditions under which the cable may be used are, of course, extremely variable. It may be laid along the ground or it may be strung over cross-arms, as circumstances dictate. Moreover, poor ground conditions often make trucking impossible, and may necessitate the cable being carried by linemen over considerable distances. To meet all such conditions satisfactorily, the cable was designed to be as light as possible and at the same time very strong. Also it is stable electrically and causes a minimum impairment of transmission.

Preliminary tests to determine the most suitable cable construction were made with samples containing one pair, one quad, and four pairs. Shielded and unshielded cables were tried. These tests indicated that one-pair cables were superior to the other designs both in capacitance and cross-talk characteristics, as well as in portability. Although shielded one-pair cable was slightly better electrically than the unshielded, the improvement was not sufficient to offset the lower weight, greater flexibility, and lower cost of the unshielded cable.

The distance between the conductors in the cable is much less than that between open wire conductors, and as a result the capacitance is greater and the inductance less. The characteristic impedance of a length of non-loaded cable is therefore much lower than that of an open wire line. Where there is a difference in the characteristic impedance of two connected sections of a circuit, electrical reflections occur which may impair transmission. This is undesirable, of course, and so the impedance of the cable is increased by loading to procure a better matching of the impedances of cable and line. A small 2.7 millihenry carrier loading coil of light weight is employed for this purpose, and is built-in at the middle of each unit length. The coil is potted in a copper container and mounted in a case made up of two

identical aluminum castings bolted together and made waterproof by a rubber gasket.

The parts of the loading coil assembly are shown in Figure 2. The coil case is oval in shape to facilitate dragging along the ground, and the cable enters at the narrow ends through nickel-silver coiled springs to protect the cable at these points. It is necessary for correct functioning of the loading to have a total cable capacitance of about 8000 mmf per loading section. To allow as long a length of cable as possible for each loading section, the conductors are insulated

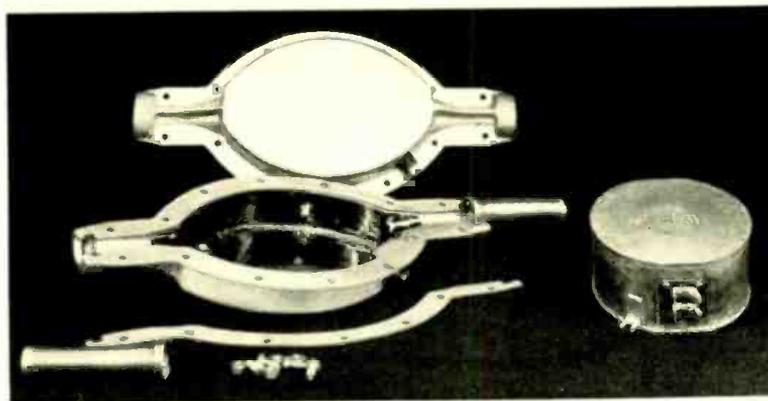


Fig. 2—Disassembled loading unit for single pair emergency cable

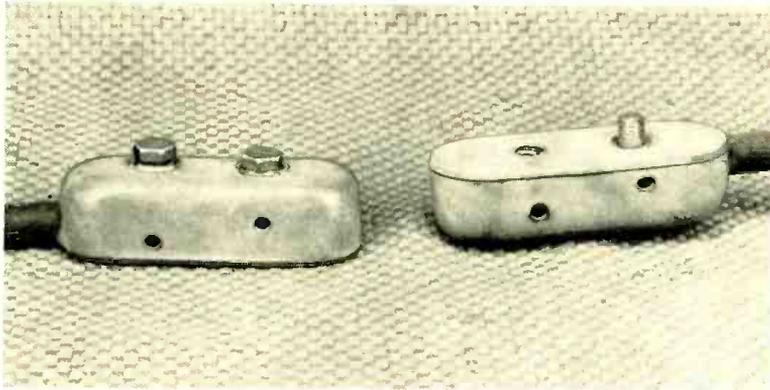
with a recently developed rubber compound of low dielectric constant. The capacitance is such that it is possible to use an average of about 575 feet of cable for each complete unit length of loaded cable. The manufacturing variations in capacitance are allowed for by adjusting the section lengths to provide the total section capacitance required by the loading design.

In the choice of conductor size there were several conflicting requirements which had to be considered. To secure lightness and increased portability, a small conductor was desirable. Although stranded copper wire of No. 19 AWG was found to be satisfactory for carrier transmission under emergency service conditions, a cable of twice the weight and much greater cost would have been required for equally good impedance matching at voice frequencies. Since portability was the controlling factor 19-gauge wire was adopted for the new cable.

Each end of a unit length of loaded cable is provided with a terminal, shown in Figure 3,



Fig. 1—Cable terminals are of moulded rubber with brass bushings and screws



*Fig. 3—In joining two lengths of cable only the long screws are employed*

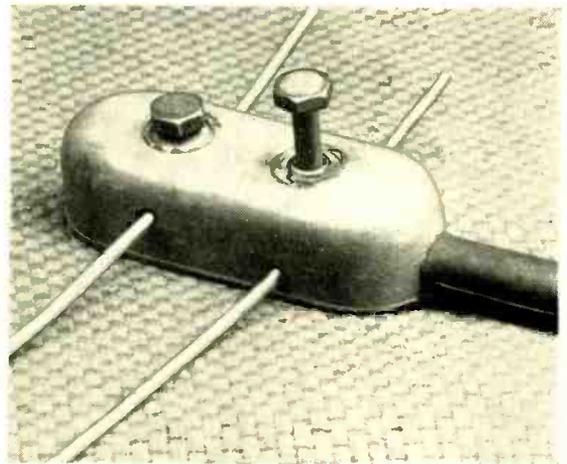
by which it may be connected either to an open wire line or to another length of cable. Two tinned brass bushings are soldered to the cable conductors and moulded into a rubber casing, which is vulcanized to the rubber jacket of the cable. Each bushing is threaded and fitted with a brass screw, the one for the bushing nearer the cable being long enough to project some distance through the bushing. When two lengths of cable are to be connected together, as in Figure 1, the long screw of one terminal engages the bushing containing the short screw of the other, and vice versa. When the cable is to be connected to line wires, the wires are inserted in holes passing through the terminals, as shown in Figure 4, and both screws are used for making the connection.

Each unit length of cable with its built-in loading coil and terminals is shipped in a double wound coil. The complete unit weighs 60 lbs. and may be carried by one man. For installation, the coil is mounted on a drop-wire reel, which is placed midway in

the desired run and the cable is paid out simultaneously in both directions.

The loaded cable is designed to be directly connected to open wire carrier circuits without the use of impedance modifying devices or building-out capacitances. By the loading provided, a good compromise impedance

match is obtained throughout the carrier range with the various types of eight inch and twelve inch spaced open wire lines. Although the loading was introduced primarily for impedance modification, it also reduces the attenuation of the cable. Several



*Fig. 4—In making connection to an open wire line both long and short screws are employed*

miles of loaded emergency cable may be used without seriously impairing operation of the associated carrier system.



# Moisture-Proofing Transmitters with Rubber

By J. H. INGMANSON  
*Chemical Laboratories*

TELEPHONE transmitters are sometimes called upon to function under extremely adverse moisture conditions, such as may be encountered in outdoor mountings. To prevent the ready entrance of moisture into transmitters under such conditions, a rubber membrane has been designed which can be interposed between the diaphragm and the mouthpiece.

To avoid serious interference with the acoustic transmission from mouthpiece to diaphragm, the membrane must be extremely thin and supple. Indeed, transmission requirements indicated that the rubber membrane could not be thicker than about three thousandths inch. Rubber as thin as this has long been commercial, but its life in most cases until recently has been a year or two at most. In a telephone transmitter, a rubber membrane should serve its purpose several times as long. To meet the moisture proofing, transmission and life requirements, a special rubber compound was developed.

The compounding of rubber goods is a highly specialized field requiring an intimate knowledge of a vast array of materials which are admixed with rubber to meet the needs of industry. Aside from sulphur required for vulcanization or curing, the list comprises numerous accelerators and activators to speed up the

cure, softeners to plasticize the rubber, finely divided powders for stiffening, reinforcing or filling as well as pigments for coloring. Each of the numerous materials in each class imparts its own special characteristics to a rubber compound. Since a commercial rubber compound usually consists of a representative material from each group the possible varia-

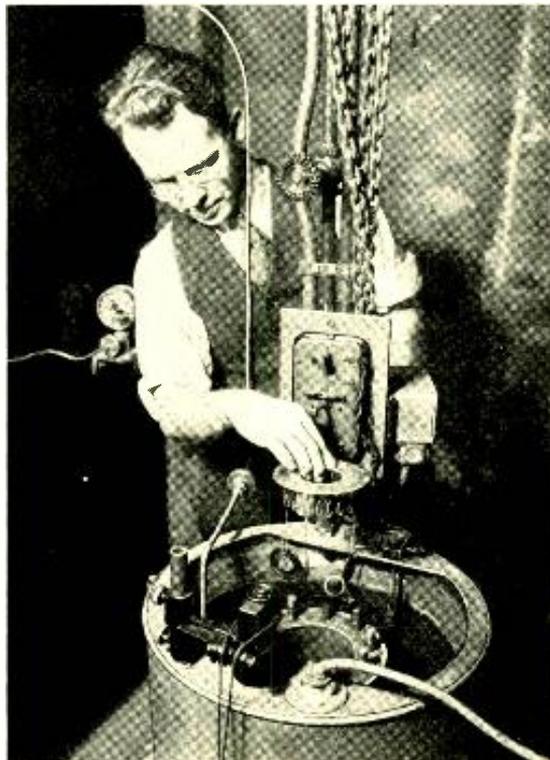


Fig. 1—G. G. Winspear placing samples of moisture-proofing membranes in a bomb where they will undergo accelerated oxidation, to test their life properties



*Fig. 2—Rubber moisture-proofing diaphragm for operator's transmitter*

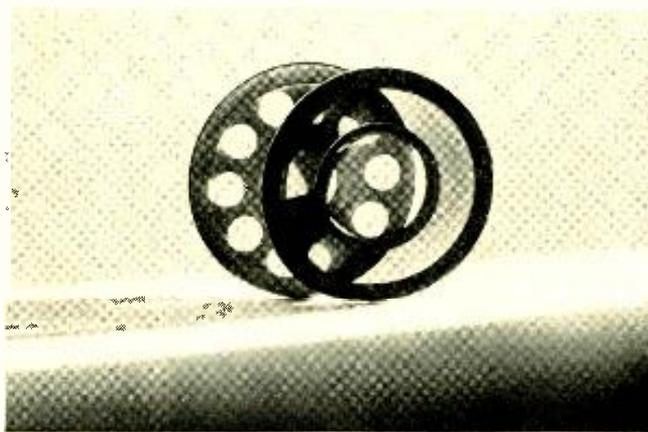
tions are extremely numerous. The function of the rubber chemist is to select and blend these materials in such proportions as to obtain the desired result.

The rubber chemist is also called upon to design compounds for long periods of life, and since in many cases trials cannot be carried on for the desired life period, he resorts to laboratory methods of accelerated aging to predict the period of usefulness of the rubber. Since the oxygen of the air is the principal agent which deteriorates rubber, laboratory methods for testing the life of rubber goods involve accelerating the action of oxygen. In one of the tests found most suitable for this purpose, specimens of rubber are placed for varying periods of time in a vessel of pure oxygen at a pressure of three hundred pounds per square inch and a tem-

perature of 158 degrees Fahrenheit (Figure 1). When subjected to this test, poorly compounded rubber loses its original form, and completely deteriorates as far as further usefulness is concerned, sometimes in less than a day, especially when the specimen is very thin. The rubber compound designed for transmitter membranes, when given this test for ten days, does not show appreciable deterioration and its usefulness for the purpose required is therefore unaffected. Thence may be predicted a service life of many years under moderate conditions of temperature and of protection from ozone and sunlight.

In order to assemble the rubber membrane in the transmitter and obtain a seal against the ready entrance of water, the membrane is formed with an outer edge thicker than the membrane itself, and with a similar inner edge in the case of the annular types, as shown in Figure 3. An adhesive is applied to the edge in order to obtain a bond to the metal parts.

The design of special molding equipment for preparing membranes of the required thickness, form, and accuracy of dimension was perhaps no less



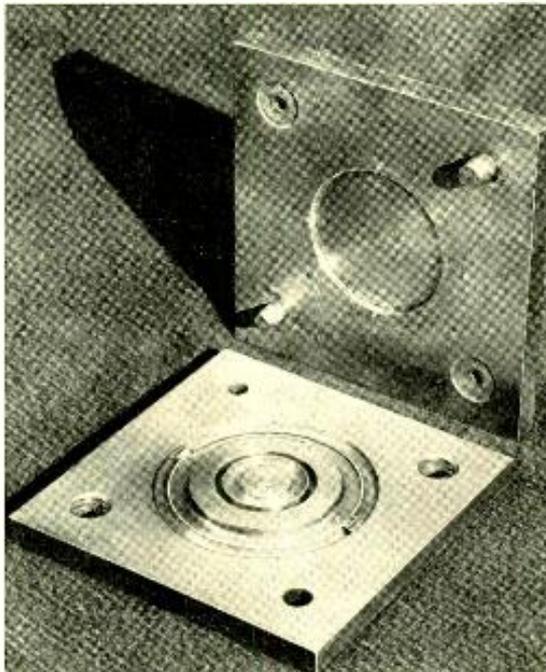
*Fig. 3—An annular type of membrane also finds use in the field*

a problem than the development of the rubber compound. Such parts are necessarily formed in a highly polished steel mold (Figure 4). The mold is shaped to the dimensions of the desired part, with allowance for the slight contraction which takes place in soft rubber when it cools to room temperature. Overflow cavities are connected to the mold cavity itself by a few narrow wedge shaped channels.

The constituents of the rubber compound are mixed to a plastic homogeneous mass between closely-set steel rolls which revolve at different speeds. A quantity of the plastic compound more than sufficient to form the desired part, is inserted in the mold cavity. The mold, consisting of two or more parts, is assembled and placed between the steam-heated platens of a hydraulic press. A pressure of several tons per square inch is applied, and steam at twenty pounds per square inch is circulated in the platens, for twenty minutes. Under the pressure and heat, the raw rubber compound flows, most of it filling the exact shape of the mold, and the excess passing through the strategically located overflow channels into the overflow cavity. At the end of the heating or vulcanizing period, the membranes are removed from the

mold and are ready for assembly.

Such membranes are finding use in handset transmitters installed in exposed locations where moisture conditions are particularly severe, such



*Fig. 4—Typical mold for preparing moisture-proofing membranes from rubber*

as markets, taxi stations, police boxes, and harbor craft. Several thousand operators' transmitters\* also equipped with rubber membranes (Figure 2) have been in use for about two years with satisfactory results.

\*RECORD, February, 1932, p. 182.



# The 80A Amplifier

By R. A. MILLER  
*Special Products Development*

**M**ICROPHONES for such purposes as broadcasting, public address, and sound pictures have received considerable attention in recent years. At the outset the double-button carbon microphone—a modification of the carbon transmitter long employed in the telephone plant—was used for these special services. The condenser microphone, made commercially available later, has the advantage of being free from carbon noise which is present with the double-button transmitter. Since the condenser microphone is a high impedance device, however, and of relatively low efficiency it has the disadvantage that it must be closely associated with an amplifier.\*

The moving coil microphone\*\* on the other hand has the double advantage of having a low impedance and of being quiet in operation. Because of its low impedance it need not be closely associated with an amplifier. Experience has shown that even though the microphone and amplifier be separated by several hundred feet there is little loss in quality and negligible interference from stray electrostatic or electromagnetic fields. Its output, however, is not so high as that of the carbon microphone nor as that of the condenser microphone with its associated amplifier. To adapt the moving coil microphone for interchangeable use

with the other two types, therefore, an amplifier must be inserted between the microphone and the main amplifying equipment.

Although the moving coil microphone can be used with present amplifying systems by proper modifications of the existing equipment, and has actually been so used, the results have not been entirely satisfactory for one reason or another. To provide an amplifier more nearly suited to adapt the moving coil microphone not only to existing amplification systems which may be supplied with batteries, but to systems now in the course of development or contemplated which may be expected to operate on alternating current, a new amplifier, known as the 80A, has been developed.

Since it is designed for use with existing equipment, the new amplifier must be capable of taking its required power from several different types of sources. The cathode heating source available may be a storage battery, rectified and possibly filtered alternating current, or—most severe of all—raw alternating current. The plate circuit, in which is provided means for obtaining “C” bias, may be called upon to operate from dry cells, from a storage battery which may be floated across a charger, or from rectified and filtered alternating current. Regardless of the source of power, however, the requirements of freedom from the introduction of

\*RECORD, *June*, 1928, p. 329.

\*\*RECORD, *May*, 1932, p. 319.

noise, either microphonic, electronic, or from the power supply, must be met.

The 80A amplifier, now in production by the Western Electric Company, is capable of satisfactory operation under any of these various conditions. As shown in Figure 1, it is designed

for mounting on a relay rack, and is approximately  $19\frac{1}{4}$  inches long,  $3\frac{1}{2}$  inches wide, and has an overall depth of  $7\frac{1}{4}$  inches. A rear view is shown in Figure 2. All the apparatus is mounted on the rear of the panel and all internal connections are made under a mat.

As shown in the schematic of Figure 3, the 80A is a single stage amplifier, and requires no separate source of "C" potential. Use of the recently developed 262A vacuum tube\* greatly assists in obtaining the desired characteristics. The am-

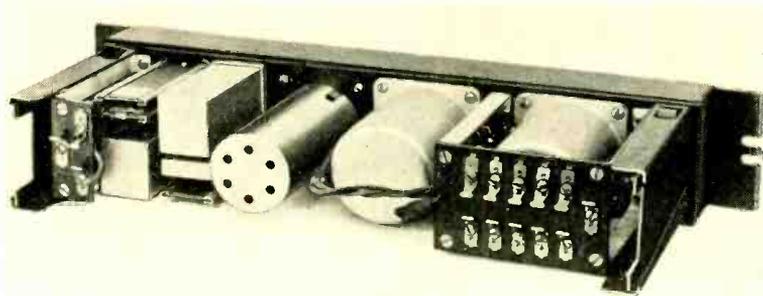


Fig. 2—All apparatus for the 80A amplifier is mounted on the rear of the panel

mended maximum power output is six milliwatts of single frequency or peak power. Where the highest quality transmission is desired, however, a maximum output of not over two milliwatts is recommended. The transmission characteristic is substantially flat over the frequency range of 35 to 10,000 cycles per second.

As already noted, the amplifier is designed to be interchangeable, with regard to power source and output impedance, with existing pick-up equipment. Thus the heater circuit, which requires about 0.3 ampere at

12 volts, may be supplied from any available source of direct or alternating current. Plate power may be obtained from any 200 volt source ordinarily used for this class of work. Most pick-up equipment is designed to work into impedances of either 50 or 200 ohms, and the 80A

amplifier is thus arranged for either of these two output impedances. The selection of the correct output impedance is made by properly strapping the output terminals.

The magnitude of the output delivered to associated amplification

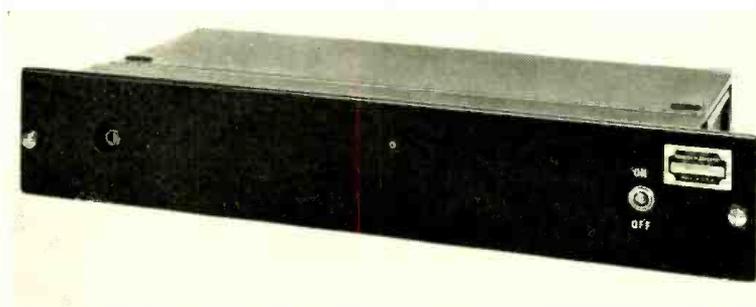


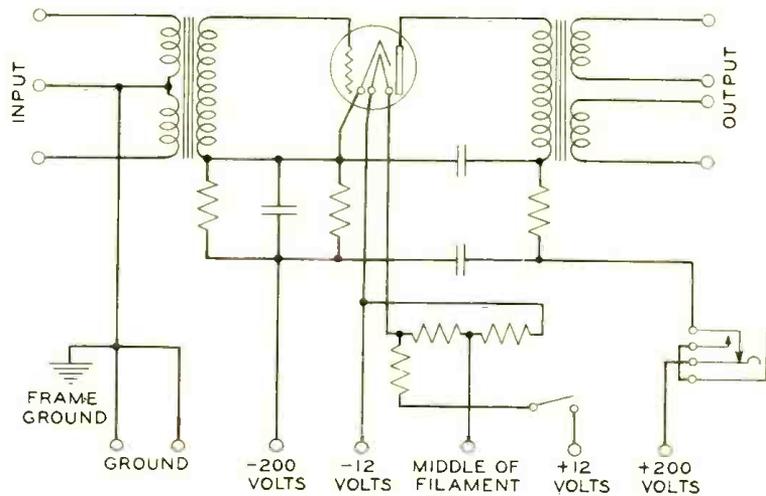
Fig. 1—Nothing appears on the front of the panel of the 80A amplifier but a power switch and a testing jack

plifier operates from the relatively low impedance of the moving coil microphone, approximately thirty ohms, and into output impedances of either 50 or 200 ohms. The gain is approximately 31 db, and its recom-

\*RECORD, February, 1933, p. 158.

systems by the 80A amplifier, is of the same order as that of the two stage amplifiers (Western Electric 53 and 54 types) used with the condenser microphones, or of the carbon microphones (387 and 600 types)

alone. A single 80A amplifier, therefore, is ordinarily all that is required. Provision has been made, however, so that should greater amplification be required, two or more of the 80A amplifiers may be connected in cascade.



*Fig. 3—Simplified schematic of the 80A amplifier*



## Contributors to This Issue

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M. J. KELLY received a Bachelor of Science degree from the University of Missouri in 1914 and a Masters degree from the University of Kentucky the following year. He then studied at the University of Chicago and received a Ph.D in 1919. With the engineering department of the Western Electric Company, which he joined the year before receiving his doctor's degree, he has been continuously connected with the development of thermionic devices of all types. In later years he has also been associated with the development of photoelectric cells, vacuum thermocouples, ballast lamps, and other glass apparatus for communication uses. Since 1924 he has been in charge of both the development and manufacturing activities of the Laboratories in connection with all these various devices.

WHILE A student at Union College, W. A. Yager spent one summer as an assistant in the research laboratory of the General Electric Company in Schenectady working on the development of carboly. On receiving the B. S. degree

in chemistry in 1928, he joined the Chemical Laboratories. Here he has since been engaged in dielectric and surface-leakage studies, and has most recently been investigating the dielectric properties of various materials under controlled conditions of frequency, temperature and humidity.

R. BIDDULPH received a B. S. degree in physics from Brigham Young University in 1925, and spent the years immediately following in teaching and in travel abroad. In 1929 he joined the Research Department of the Laboratories in the group engaged in the development of audiometers and audiphones. The work described in this issue of the Record grew out of the development of heterodyne audiometers for use in measuring the extent and type of deafness. Recently he has been engaged in studies of impaired hearing and in the communication problems of the hard of hearing.

DAVID A. McLEAN received a B. S. degree in chemical engineering from the University of Colorado in 1929, after



*M. J. Kelly*



*W. A. Yager*



*R. Biddulph*



*J. H. Ingmanson*



*D. A. McLean*



*R. C. Dehmel*

which he joined the Technical Staff of Bell Telephone Laboratories. Here he has been associated with fundamental studies of the flow of liquids and soft solids, the wetting of solids by liquids, and various properties of impregnated dielectrics.

R. C. DEHMEL graduated from the University of California in 1927 with a B. S. degree in engineering. He came directly to the Laboratories and simultaneously pursued studies in metallurgy at Columbia University, where he received the Masters degree in 1930. He has continued his graduate program taking work leading to a Ph. D. degree in electro-chemistry. His assignment at the Laboratories is with the wire development group of the Outside Plant Department on problems relating to the design and testing of bare and insulated wires.

J. H. INGMANSON entered the dyestuffs industry with the Sherwin-Williams Company in 1917 and three years later went

with the Conley Foil Company as development engineer. In 1925 he re-entered the dyestuffs field as works manager for the Crown Chemical Corporation, and in 1928 joined the Chemical Research group of the Laboratories. He

holds a B.S. degree in chemistry from the University of Chicago. His work with the Laboratories has been the study and development of rubber and allied insulating materials.



*R. A. Miller*

R. A. MILLER received the B. S. degree in Electrical Engineering from the Massachusetts Institute of Technology in 1920 and immediately joined the Technical Staff of the Laboratories. His first work was in the machine switching laboratory testing dial equipment. He then transferred to the Special Products Department where he has worked on the development of transmission testing equipment, public address systems, and other speech and music amplifying apparatus. More recently he has been engaged in sound-picture developments.