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In This Issue

John Parker, Editor
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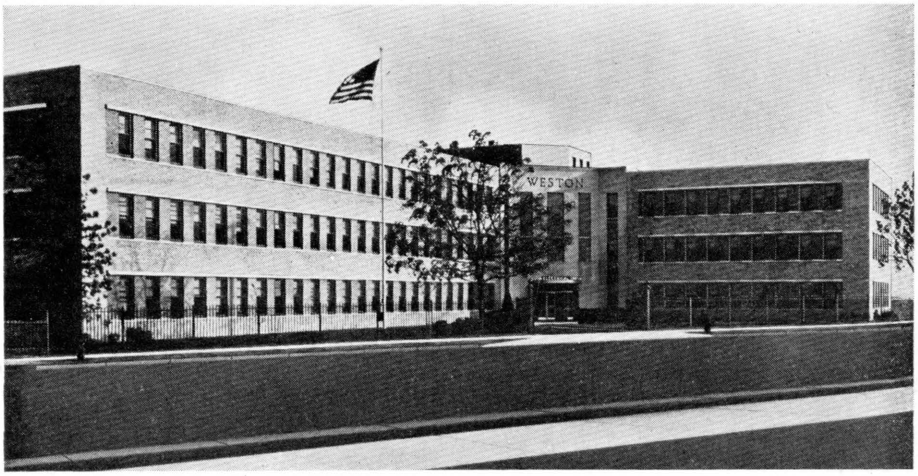
ENGINEERING-ADMINISTRATION BUILDING HOUSEWARMING—OCTOBER 24, 1947

THE HOUSEWARMING of the new Weston Engineering-Administration Building was held on October 24, 1947, and was attended by a large number of guests, among whom were many industrially prominent engineers and executives. While actual occupancy of the new quarters was early in July, the intervening period appeared necessary to get all of the laboratories and facilities into shape. Further, such a program inherently requires a number of displays, all of which took a certain amount of time on the part of our engineers.



The new Engineering-Administration Building.

Our guests were welcomed in the lobby by Mr. E. F. Weston, Past President and Board Chairman; Mr. Caxton Brown, Past President and Chairman of the Executive Committee; and Mr. E. R. Mellen, President, assisted by other officers.

The visitors were first conducted through our Model Shop, where experimental parts, devices and, indeed, complete instruments are built from parts made directly from raw material. Three departments in the factory were next visited, the large instrument assembly, the screw machine department, and a small parts department where thermoelements and Weston Y-bearings are made, along with the printing of scales. Returning to the Engineering Building, the various laboratories were visited and in each an engineer spent from five to six minutes discussing some particular phase of his development work.

The entire trip required two hours and groups were started through at scheduled times from 9:30 a.m. until late in the afternoon.

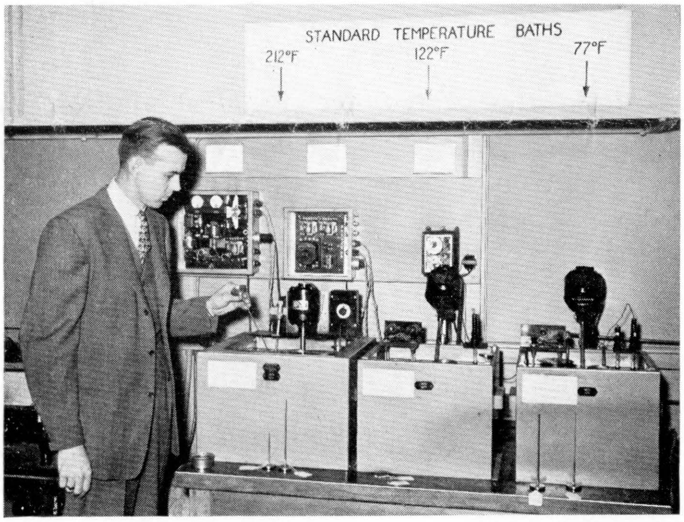
A buffet luncheon was served in the executive area from 12 to 2 p.m. and at the conclusion of the tour and luncheon, or the reverse for those coming in late, an exhibit of the Company's products was looked over. As our guests left the building they were presented with

Demonstrating a bank of similar instruments with widely varying ballistic characteristics.

one of our new pocket thermometers; the smallest bimetallic thermometer manufactured commercially. The head is approximately one inch in diameter and the thermometer was equipped with a clip and holder for carrying on the person.

One of the high spots of the guided tour was the Thermometry Laboratory with various temperature-controlled baths, held to a high degree of precision, in which thermometers could be checked. Baths were shown, among others, held to —100 F, 212 F, and 1,000 F, the latter being of a special salt which, while looking quite innocuous, would ignite a wood splinter or a piece of paper immersed in it.

In the Screw Machine Department an enlarged pivot base made to a scale of 50 to 1 was shown to give an idea of the detail machining on the tiny pivot bases, samples of which were given out. Some of our guests were quite intrigued over the possibility of placing the small hexagon nut on the pivot base, the nut being machined from 3/64 inch hex brass stock with a 0.030 inch −200 thread.



In the temperature laboratory — a group of baths maintained at various temperatures for experimental thermometer testing.

In the Commercial Engineering Group a panel was shown with 25 different Model 801 instruments to illustrate the breadth of ballistic characteristics possible. With natural periods varying from ⅛ of a second to 1.5 seconds, and damped various degrees from almost totally undamped to an overdamped condition, the response varied rather enormously when a telegraph key was depressed. The fastest instruments were literally faster than the human eye and actually only suitable for photographic recording. The slowest instrument would hardly respond to pulses made by tapping the key at only a moderate rate.

The original Riefler clock used by Dr. Weston in his original frequency meter standardization was set up and running. With it were displayed some other historical items, such as the standard meter bars from Switzerland with their certificates from the Bureau International Des Poids Et Mesures. An original Kelvin balance, one of a set obtained in the late 80's, was exhibited and is in full working order. Quite a variety of Wheatstone Bridges, potentiometers and calibrating devices as made for the Bureau of Standards around the turn of the century was also shown.

In the photometric area a most complete display was made of exposure meters, there being something over 100 varieties of domestic and foreign manufacture, all different, and all fundamentally stemming from the invention of Mr. W. N. Goodwin of this Corporation and functioning through the use of the barrier layer photoelectric cell developed by our engineers in 1929 and 1930.

Also in the photometric area was a densitometer for photographic use, along with an example of a color separation print showing the use of complete instrumentation in this photographic process.

There were displays of manganin, of standard cells, of the basic tube tester, of aircraft instruments, of tachometer generators, and of resistor bulbs.

The Research Division showed circuit studies leading to certain of the newer applications and we still have mentioned only a part of what was shown. It is unfortunate that more time could not have been spent and it was with the greatest reluctance that the tour was held down to the necessary two-hour limit imposed by the sheer capacity of the space available.

To those who did not take the tour we wish to say come and see us, as we are certain that whatever your interest may be in the field of measurement, there is some phase of our activities which we believe will be helpful.

E. N.—No. 39 —*J. H. Miller*

THERMAL PROBLEMS RELATING TO MEASURING AND CONTROL DEVICES

Mr. W. N. Goodwin, Jr., who has been successively Chief Engineer and Engineering Vice-President of the Weston Corporation before his recent retirement, is well known for his contributions to the electrical industry in the measurement field.

The series of articles on thermal problems in measuring and control devices, the first of which appears in this issue, are the result of many years of study of the subject by Mr. Goodwin, who gives his own introduction below.

The Editor.

1. Introduction

THIS initiates a series of articles on the general subject of thermal problems encountered in the design and use of measuring and control devices. These are developed from the author's notes on the subjects, resulting from many years' experience as an instrument engineer. The principal questions considered will be rates of heating and cooling, time constants, response time, and temperature lag of various types of apparatus, with especial reference to these effects upon accuracy and the safety of the devices.

This article will consider the simplest form of heating and cooling, namely, that of a simple body following Newton's law of cooling. Some of the fundamental problems given in this initial article are already known and may be found scattered in the literature, but they are given here for completeness and as a basis for original work by the author included in this and succeeding articles.

2. Heating and Cooling of a Simple Body Immersed in a Medium Between Which and the Body, Heat Is Exchanged at a Rate Directly Proportional to the Difference in Temperature

A "simple body" is here defined as one which has such a high thermal conductance relative to its surface contact conductance to the surrounding medium that the temperature throughout its mass is essentially uniform at all times and equal to the surface temperature.

Examples of such bodies are: Sheets and tubes of metals or other materials, instrument cases, resistor sheets, long bus bars, and some forms of thermometers. Simple bodies would also include, in practice, relatively large masses of metal in air or other gases, which have high thermal conductivities.

Three conditions of heating and cooling will be considered, assuming a linear convection law.

2*a*. *Temperature of a simple body immersed in a constant temperature cooling medium, at any time, when heated at a constant rate.* If the initial temperature is the same as that of the medium θ_o, then at any time t after the initial application of the heat, the temperature increase above that of the medium, when heat is applied at a rate W watts, as will be proved later, is

$$\theta = \frac{W}{h}\left(1-\epsilon^{-\frac{t}{t_0}}\right) \qquad (1)$$

where $t_0 = \dfrac{Ms}{h}$ is defined as the time constant in seconds, as it is the time required to make the exponent of ϵ equal to -1.

M = Mass of body; grams.

s = Heat capacity per gram; joules per gram per 1 deg. C.

W = Rate at which heat is applied to mass M; watts.

h = Rate at which heat is exchanged between the medium and the mass M per degree difference in temperature; watts per 1 deg. C.

From Equation (1) by making t infinity, the final temperature increase becomes,

$$\theta_m = \frac{W}{h}$$

Therefore Equation (1) can be written

$$\frac{\theta}{\theta_m} = \left(1-\epsilon^{-\frac{t}{t_0}}\right) \qquad (2)$$

which gives the ratio of the temperature increase θ at any time t after heating starts, to the final or maximum temperature change θ_m.

This equation is shown graphically as the ascending curve in

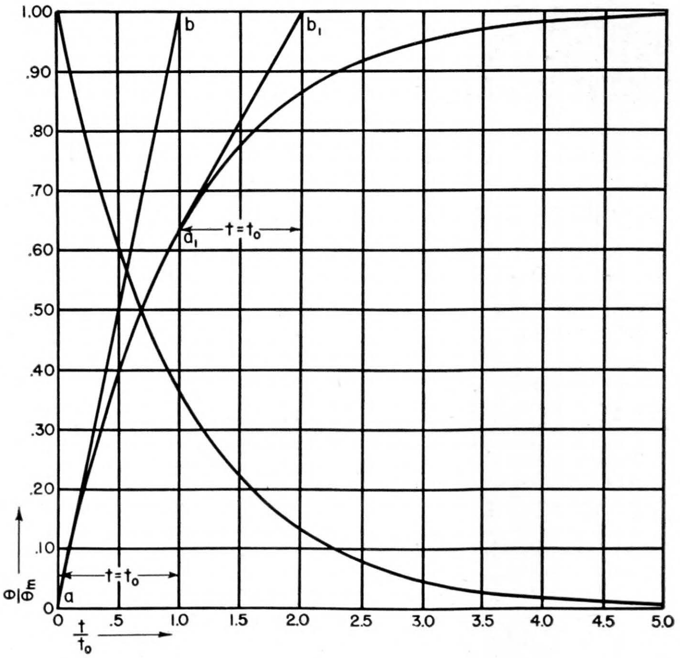


Figure 1—General heating and cooling curves for a simple body, in which time is given in terms of the time constant t_0.

Figure 1 in which the co-ordinates are θ/θ_m and t/t_0. As these are dimensionless, the curve can be used in general for any problem in this class, since the time constant t_0 may have any value. For example, the curve shows that the temperature of any simple body heated at a constant rate in a constant temperature medium will have changed say 90 per cent of its final change in a time equal to 2.30 times its time constant for that medium.

Equations (1) and (2) are derived as follows: The heat added in time dt is Wdt. The heat absorbed by body in dt during which time the temperature changes $d\theta$ is $Ms\left(\frac{a\theta}{dt}\right)dt$. The heat dissipated to the medium in dt is $h\theta dt$. Then, since the heat added must equal the heat absorbed plus that dissipated to the medium, during the same time,

$$Wdt = h\theta dt + Ms\left(\frac{d\theta}{dt}\right)dt$$

or

$$W = h\theta + Ms\frac{d\theta}{dt} \qquad (3)$$

which when integrated becomes

$$\frac{ht}{Ms} = -\log\,(W - h\theta) + C$$

Now when $t=0$, $\theta=0$, since it was assumed that initially the body has the same temperature as that of the medium. From this condition, the constant C can be determined and we have

$$\frac{ht}{Ms} = \log\left(\frac{W}{W-h\theta}\right)$$

or

$$\theta = \frac{W}{h}\left(1-\epsilon^{-\frac{ht}{Ms}}\right) \qquad (4)$$

Now the final temperature increase $\theta_m = \frac{W}{h}$, and since $\frac{Ms}{h}$ has the dimensions of time, let us designate it as the time constant, $t_0 = \frac{Ms}{h}$ and we have

$$\frac{\theta}{\theta_m} = \left(1-\epsilon^{-\frac{t}{t_0}}\right) \qquad (5)$$

which proves Equations (1) and (2).

2*b*. *Cooling of a simple body suddenly immersed in a medium at a constant temperature lower than that of the body, when no heat is supplied.* In this case the ratio of the temperature difference θ between the body and the medium at any time t, to the initial temperature difference θ_m is, as will be proved later,

$$\frac{\theta}{\theta_m} = \epsilon^{-\frac{t}{t_0}} \qquad (6)$$

which shows that the cooling curve has the same form as the heating curve but is reversed. This curve is shown in Figure 1 as the descending curve which is also of universal application in this class of problems.

The proof of this equation follows: In this case the heat removed from the body comes from the heat stored in it as its temperature is reduced. The rate of heat dissipated to the medium is $h\theta$. The rate of heat lost by the material resulting from a drop $d\theta$ in temperature of the body is $-Ms\,\frac{a\theta}{dt}$, then

$$h\theta = -Ms\,\frac{d\theta}{dt}$$

which when integrated yields

$$t = -\frac{Ms}{h}\log\theta + C$$

When $t=0$, the initial temperature of the body above that of the medium is $\theta=\theta_m$ from which C can be determined. Then,

$$t = \frac{Ms}{h}\log\left(\frac{\theta_m}{\theta}\right)$$

or

$$\frac{\theta}{\theta_m} = \epsilon^{-\frac{ht}{Ms}} = \epsilon^{-\frac{t}{t_0}} \qquad (7)$$

which proves Equation (6).

2*c*. *Heating of a simple body when suddenly immersed in a medium having a higher temperature than that of the body when no heat is supplied.* Let the temperature of the medium be θ_m higher than that of the body when it is suddenly plunged into the medium, and let θ be the temperature increase of the body at any time t, thereafter.

The heat added to the body from the medium in the time dt is $h(\theta_m-\theta)dt$. The heat absorbed by the material in the body by a change in temperature $d\theta$ in time dt is $Ms\left(\frac{d\theta}{dt}\right)dt$. Then since these are equal

$$h(\theta_m-\theta) = Ms\,\frac{d\theta}{dt}$$

which when integrated gives

$$t = -\frac{Ms}{h}\log\,(\theta_m-\theta) + C$$

But when $t=0$, $\theta=0$, from which C may be found. Then,

$$t = \frac{Ms}{h}\log\left(\frac{\theta_m}{\theta_m-\theta}\right)$$

or

$$\frac{\theta}{\theta_m} = \left(1-\epsilon^{-\frac{ht}{Ms}}\right) = \left(1-\epsilon^{-\frac{t}{t_0}}\right) \qquad (8)$$

which is shown in Figure 1 as the ascending curve, and is the same as found for the problem where heat is added, namely, Equation (5).

3. Rapid Experimental Determination of Final Temperature Change

To determine experimentally the final change in temperature of a simple body heated at a constant rate, subject to the linear law of cooling, in a constant temperature medium, without waiting until the temperature becomes constant, the following procedure may be followed. Observe the temperature increase θ_1, after any elapsed time t_1, and then again after double this time, $2t_1$, observe the temperature increase θ_2. Then for the heating condition, the maximum final change in temperature, if heating continued, would be, as will be proved later,

$$\theta_m = \frac{\theta_1^2}{2\theta_1-\theta_2} = \frac{\theta_1}{2-\frac{\theta_2}{\theta_1}} \qquad (9)$$

In the case of cooling, the initial temperature elevation θ_m of the body above the temperature of the medium if not known may be determined in a similar manner by observing the elevation in temperature θ_1 above that of the medium at any time t_1 after cooling starts, and again observe the elevation θ_2 at double the time, $2t_1$. Then the initial temperature elevation was

$$\theta_m = \frac{\theta_1^2}{\theta_2} \qquad (10)$$

Example:

Assume that one wishes to make a preliminary measurement of the maximum temperature reached in a device which is a simple body or can be considered so approximately, for a certain heating rate. Let the temperature increase in 8 minutes be 49.6 deg. C., and in 16 minutes, 71.8 deg. C.

Then, if the heating continued, the maximum increase in temperature would be, from Equation 9

$$\theta_m = \frac{\theta_1}{2-\frac{\theta_2}{\theta_1}} = \frac{49.6}{2-\frac{71.8}{49.6}} = 91.5 \text{ deg. C.}$$

For this measurement, it is necessary, of course, that the thermometers used have a negligible lag, or a known one. For rapidly changing temperatures it is often necessary to employ thermocouple thermometers having small couple junctions.

Proof of Equation (9) for Heating. From Equation (5), the temperature increase θ_1 at time t_1 is

$$\theta_1=\theta_m\left(1-\epsilon^{-\frac{t_1}{t_0}}\right)$$

and at time $2t_1$, the temperature increase is

$$\theta_2=\theta_m\left(1-\epsilon^{-\frac{2t_1}{t_0}}\right)$$

Then,

$$\epsilon^{-\frac{t_1}{t_0}}=1-\frac{\theta_1}{\theta_m}$$

and

$$\epsilon^{-\frac{2t_1}{t_0}}=1-\frac{\theta_2}{\theta_m}$$

Therefore,

$$\left(1-\frac{\theta_1}{\theta_m}\right)^2=\left(1-\frac{\theta_2}{\theta_m}\right)$$

from which

$$\theta_m=\frac{\theta_1^2}{2\theta_1-\theta_2}=\frac{\theta_1}{2-\frac{\theta_2}{\theta_1}}$$

which is Equation (9).

Proof of Equation (10) for Cooling. In a similar manner to the heating problem, Equation (6) yields

$$\theta_1=\theta_m\epsilon^{-\frac{t_1}{t_0}}$$

and

$$\theta_2=\theta_m\epsilon^{-\frac{2t_1}{t_0}}$$

from which

$$\theta_m=\frac{\theta_1^2}{\theta_2}$$

which is Equation (10).

4. Properties of the Time Constant

The time constant of a simple body has been defined as the time $t=t_0$ which makes the exponent of ϵ in the heating and cooling equations equal to -1. The time constant thus defined has several interesting and useful properties. These are as follows:

4*a.* If the initial rate of increase in temperature of a simple body were maintained constant, then the maximum temperature normally attained exponentially would be reached in a time equal to the time constant. This is shown in Figure 1 as the line *a b* which is tangent to the heating curve at zero time and temperature, and therefore corresponds to the initial rate. It will be noted that it reaches the maximum temperature at $t/t_0=1$. This is proved as follows: The rate of increase in temperature at any time is found by differentiating Equation (5) from which the rate is

$$\frac{d(\theta/\theta_m)}{d(t/t_0)}=\epsilon^{-\frac{t}{t_0}} \qquad (11)$$

The rate of increase in temperature at $t=0$ then is

$$\left.\frac{d(\theta/\theta_m)}{d(t/t_0)}\right]_{t=0}=\epsilon^{-0}=1$$

from which

$$\left.\frac{d\theta}{dt}\right]_{t=0}=\frac{\theta_m}{t_0}$$

If this rate could be maintained constant, then the increase in temperature in a time equal to the time constant t_0 would be the rate multiplied by the time or,

$$\frac{\theta_m}{t_0}\times t_0=\theta_m$$

4*b.* The same result as given in 4*a.* when starting from zero follows when starting from any part of the heating or cooling curve, namely, the time required to reach the maximum temperature from any part of the curve, if the rate at that part remained constant, is equal to the time constant t_0. This is illustrated as the line $a_1\ b_1$ in Figure 1, and is true for any part of the curve. This is shown as follows: From Equation (11), the rate of increase in temperature at any elevation in temperature θ is

$$\frac{d\theta}{dt}=\frac{\theta_m}{t_0}\epsilon^{-\frac{t}{t_0}} \qquad (12)$$

The additional change in temperature above θ to reach the final temperature change θ_m is $\theta_m-\theta$. Then from Equation (5)

$$\theta_m-\theta=\theta_m-\theta_m\left(1-\epsilon^{-\frac{t}{t_0}}\right)=\theta_m\epsilon^{-\frac{t}{t_0}} \qquad (13)$$

and the additional time to change from θ to θ_m, if the rate of change at temperature θ remained constant, is the change given in (13) divided by the rate given in (12), that is

$$t=\frac{\theta_m\epsilon^{-\frac{t}{t_0}}}{\frac{\theta_m}{t_0}\epsilon^{-\frac{t}{t_0}}}=t_0$$

which proves the general statement.

4*c.* The time constant t_0 of a simple body is equal to the time required for the temperature change to reach 63.2 per cent of its final change from the initial value. This is the popular conception of a time constant, but as referred to later in detail, it should not be confused with the time constants in heat problems of more complicated bodies, or with those in most electrical and mechanical problems. This is derived as follows: from Equation (5)

$$\frac{\theta}{\theta_m}=\left(1-\epsilon^{-\frac{t}{t_0}}\right)$$

which when $t=t_0$, becomes

$$\frac{\theta}{\theta_m}=(1-\epsilon^{-1})=0.632 \text{ or } 63.2 \text{ per cent.}$$

5. Time Constants in General

The time constant defined as that time required for change of 63.2 per cent of the final change in some magnitude is frequently but erroneously applied indiscriminately to all kinds of thermal, electrical and mechanical devices. The time constant so defined applies solely to changes which follow the simple exponential law. It applies, as derived in this article, to the heating and cooling of a simple body under linear cooling laws. It applies to electrical circuits containing resistance and capacitance only, and also to those containing resistance and self inductance only, in which the time constants are RC and L/R respectively.

The simple time constant also applies to mechanical devices having spring compliance and damping with no inertia or in which the inertia effect is negligible relative to the damping effects. In this case the time constant is G/S where G is the damping coefficient, and S the spring stiffness.

In other more complicated thermal, electrical or mechanical devices, no one definite theoretical time constant exists. In some cases there are quantities of which there are often an infinite number derived in a similar manner to that for the simple exponential condition, one of which may predominate and might be defined as a time constant. The author has actually used such quantities as time constants in some thermal and mechanical investigations as will appear in later articles.

6. Thermometer Time Constants

The so-called chemical thermometers of the mercury-in-glass type, and the bimetal types in a protecting case are not actually simple bodies as their active elements are not in direct contact with the medium.[1] However, as a rough approximation the better forms of these types may be assumed to follow the laws of the simple body. This is illustrated in Figure 2, in which the heavy lines are cooling curves of a mercury-in-glass chemical thermometer, and a Weston bimetal thermometer, experimentally determined in still air.

The light lines are the theoretical exponential cooling curves of true simple bodies derived from Equation (2), which have time constants equal to the time required for the corresponding thermometers to reach 63.2 per cent of their final change in temperature, as shown in the curves. It will be noted that the theoretical and experimental curves follow closely during cooling to 30 per cent, that is through 70 per cent of the maximum change, whereas in cooling to 1 per cent, that is through 99 per cent of the maximum change, the mercury and bimetal thermometers require 37.4 per cent, and 17 per cent more time respectively than would true simple bodies having the same assumed time constants.

It will be noted that the equivalent time constant of the mercury-in-glass thermometer, which is a good quality chemical thermometer, is 160 seconds in still air and that of the corresponding quality and range of bimetal thermometer, 102 seconds. In water these two time constants are 3 and 4 seconds respectively.

7. Computation of Time Constants

In Equation (1) the time constant was defined as $t_0 = \frac{Ms}{h}$. From this we can compute the time constant of a simple body if its mass M, heat capacity per gram s, and convection coefficient h are known. The values of the heat capacity per gram, for various materials can be found in published tables. Most tables give the values of specific heats. These are numerically equal to the heat capacity per gram in calories. In this paper all values of heat quantity are in joules (watt sec.) and rates of heating or cooling in watts. The latter values may be obtained by multiplying the values in calories or calories per second by 4.186.

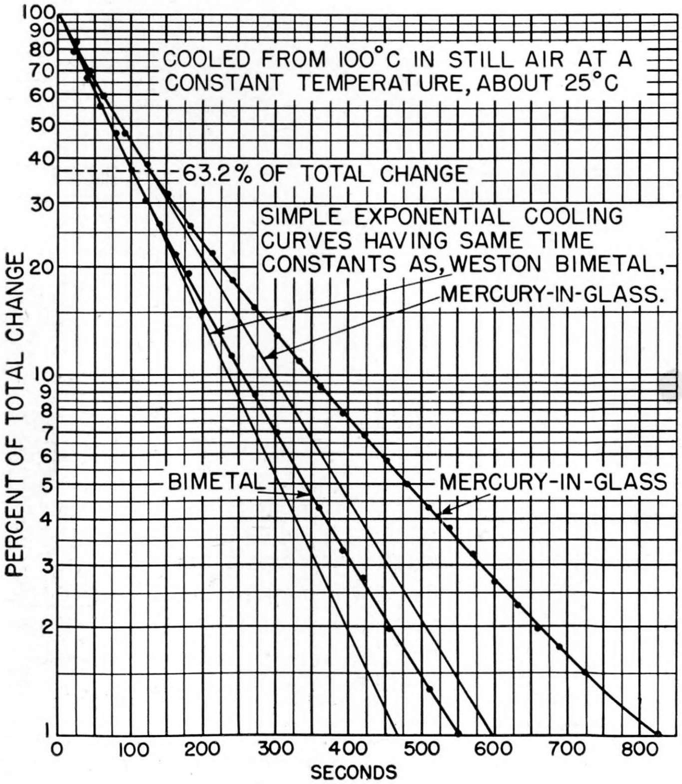


Figure 2—Cooling curves in still air, for a mercury-in-glass chemical thermometer, and for a Weston Laboratory Type Bimetal Thermometer, both having the scale range, —10 to 110 C.

Values of the convection coefficient h depend somewhat upon the shape and size of the object and its orientation with respect to the direction of the natural convection currents. For surfaces mounted vertically, having a height up to about 0.5 inch, the value of h per square inch per 1 deg. C. is 0.0116 watt for still air, and for vertical heights up to 2.5 inches and higher, h per square inch per 1 deg. C. is 0.0071 watt.

Example:

Let us compute the time constant t_0 of a brass metal tube mounted vertically, on which is to be wound a standard resistor. Let its height be 2 inches, and the diameter 1 inch, and its wall thickness 0.030 inch. Let us assume that the mass of the resistor wire and insulation is negligible.

The heat capacity of brass from tables is 0.0917 calory per gram, that is,

$$0.0917 \times 4.186 = 0.384 \text{ joule per gm. per deg. C.}$$

The mass of the tube $M = \text{Volume} \times \text{Density}$. The Volume is

$$V = 2 \times \pi \times 1 \times 0.030 \times (2.54)^3 = 3.1 \text{ cu. cm.},$$

and the density of brass is 8.7, then,

$$M = 3.1 \times 8.7 = 27 \text{ grams.}$$

h = area of surface × coefficient per unit area.

The entire surface area is

$$(2 \times \pi \times 1) \times 2 = 12.6 \text{ sq. inches}$$

Then,

$$h = 12.6 \times 0.0071 = 0.0895 \text{ watt per } 1^\circ\text{C.}$$

Then the time constant is

$$t_0 = \frac{Ms}{h} = \frac{27 \times 0.384}{0.0895} = 116 \text{ seconds}$$

From this value of the time constant, one then can readily determine, by means of the equations and curves given above, the response time and lag of temperature with time, and their effects upon the resistance of the wire on the tube.

Reference:

1. RESPONSE TIME AND LAG OF A THERMOMETER ELEMENT MOUNTED IN A PROTECTING CASE—W. N. Goodwin, Jr.—*Trans. A.I.E.E.*—Vol. 64, Page 665, 1945.

E. N.—No. 40 —*W. N. Goodwin, Jr.*

Note: Subsequent articles on this subject will refer to material in this issue. It is advisable, therefore, to retain all copies to preserve continuity.—EDITOR.

THE WESTON ELECTRONIC ANALYZER

IN A circuit where potential is to be measured, the change in potential due to voltmeter loading is a direct function of the circuit impedance and an inverse function of the voltmeter sensitivity in terms of impedance. Since high-resistance or high-impedance circuits are encountered in almost every phase of the electrical industry, particularly in the electronic field, considerable thought must be given to voltmeter power consumption when attempting to measure potentials in such circuits.

Figure 1—The Weston Model 769 Electronic Analyzer.

The new Weston Model 769 Electronic Analyzer, Figure 1, uses a balanced d-c amplifier of novel design as a no-load coupling medium between the high resistance input voltage divider and the 100 microampere d-c meter to provide an effective sensitivity of 5 megohms-per-volt as compared with conventional instruments of 1,000 or 20,000 ohms-per-volt sensitivity; a power gain ratio of 5,000 to 1 and 250 to 1 respectively. The power gain over conventional multi-range voltmeters of fixed ohm-per-volt sensitivity is maximum on the lowest range, but, in general, the lower order of potentials is involved in exceptionally high-resistance networks and maximum sensitivity is desirable in the lower ranges.

The Model 769 is actually a vacuum-tube voltmeter for a-c and d-c potential measurements, an electronic ohmmeter and an analyzer all in one. Power line, audio, and radio frequency potentials through the VHF region can be measured on any one of four ranges using the small diode probe. Six d-c "electronic" ranges and the three highest ohmmeter ranges also operate through the amplifier and meter. Since power is required to energize the amplifier section, the Model 769 must be connected to a 50-60 cycle, 120-volt power line to make use of these functions. Portable instruments, however, are often needed for trouble shooting in locations where power is not available. Under such conditions, the 100-microampere meter is used directly for six d-c voltage ranges at 10,000 ohms-per-volt sensitivity, six a-c voltage ranges at 1,000 ohms-per-volt sensitivity, six d-c current ranges and three ohmmeter ranges. Self-contained batteries supply energy for the ohmmeter. A temperature-compensated copper oxide rectifier (WESTON ENGINEERING NOTES, Vol. 2, No. 1) is used for the 1,000 ohms-per-volt a-c voltage ranges. Thus, an operator using this instrument has available a multi-range a-c and d-c voltmeter, a d-c milliammeter and an ohmmeter without requiring connection to a power line.

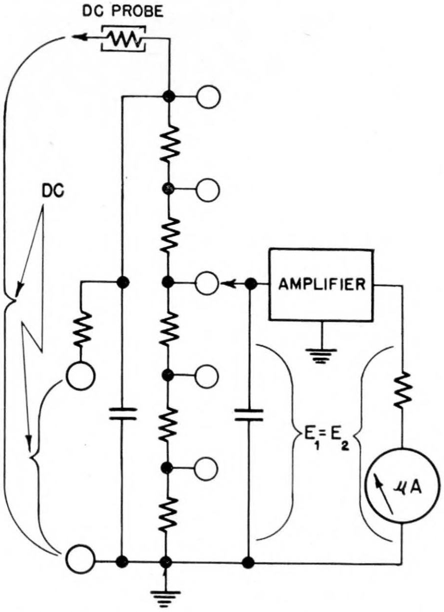


Figure 2—High-Resistance Voltage Divider Network, illustrating alternate use of panel terminals or d-c probe.

Referring to Figure 2, two d-c input terminals are provided for use with conventional test leads. A third terminal is used with a d-c probe or isolation lead to limit capacitive loading of high impedance or resonant circuits when measuring d-c potentials directly at the coil or condenser terminals. This lead contains a 3-megohm resistor in the probe handle mounted as close as possible to the tip, and is supplied with a connector plug which will only fit the special d-c probe pin jack. The d-c input is blocked against a-c potential by the use of divider and amplifier by-pass condensers. The R-C filter thus provided attenuates any a-c component which might be present in the d-c potential applied to the test leads, to a level below meter indication.

A meter-reversing position is included on the "Functional" switch to provide means for reading potentials either positive or negative to chassis or ground reference potential. This is an important feature in view of the fact that, in most equipments where cathode-ray tubes are used, many or all voltages are negative to chassis or ground potential. With the "Functional" switch in the "DC Reverse" position, the Electronic Analyzer may be maintained at chassis potential by connecting the ground lead to the chassis and using the d-c probe for connection to the "hot" terminals in the device under test.

In the measurement of a-c potential across high-impedance components and resonant circuits, power consumption is again a factor to be kept at a minimum, but here all

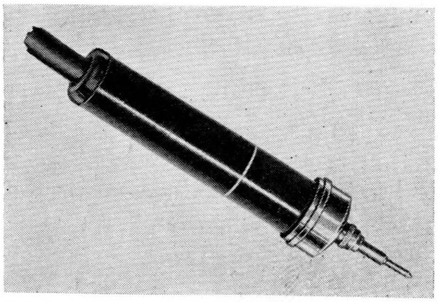


Figure 3—The body length of the a-c probe measures three inches—the diameter is five-eighths of an inch.

components of impedance are involved—resistance, capacitance and inductance. The design of a connecting device usable over a broad frequency range involves a study to approach an optimum probe design with minimum shunt capacitance, minimum series inductance and maximum shunting resistance. These factors must be balanced against the practical phases such as convenience of use, size, insulation, etc. Bulky probe designs are not usable on many HF and VHF devices where, of necessity, components are mounted close together to minimize lead inductance. The a-c probe designed for use with this instrument is shown in Figure 3. A sub-miniature vacuum tube is mounted in the probe head assembly, and is energized through the cable and a six-prong panel connector. The assembly is thus detachable from the analyzer panel, but is always available for use. It is supplied as a part of this model and is regularly stored in the lead compartment.

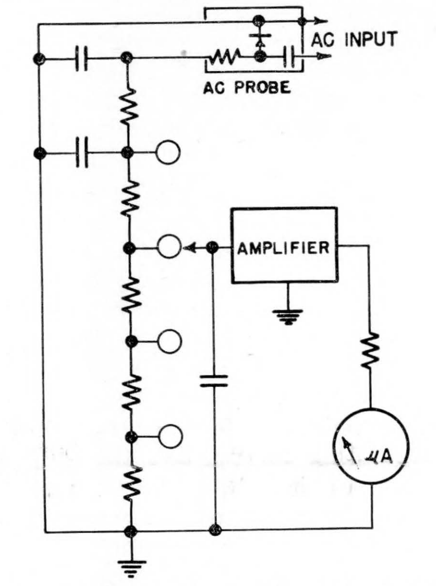


Figure 4—Diagram showing the a-c input and internal probe connections.

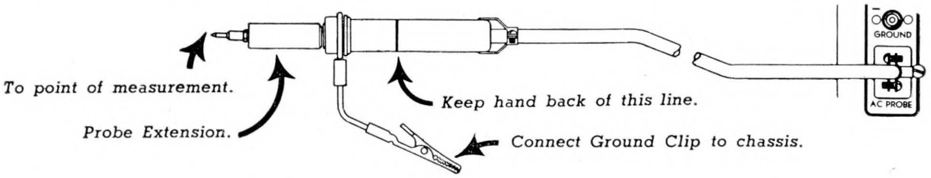
To provide coverage from 50 cycles to 300 megacycles, a combination probe involving an adapter or low frequency extension for the lower audio and power line frequencies is necessary. This evolves from the fact that an a-c probe must be blocked against d-c potential to avoid continuous diode conduction and d-c amplifier influence. This necessitates the use of a blocking condenser in the probe tip. The condenser is charged every half cycle by the recurrent positive peak excursions of the applied a-c potential, where the diode rectifier is conducting, and discharges at a slower rate through the high-resistance input voltage divider. See Figure 4. As the time interval between recurrent peaks becomes larger or in other words the frequency of applied voltage is decreased, the average values of the developed d-c potential also decrease. Satisfactory response in the power frequency range requires a comparatively large blocking condenser. The physical size of such a condenser adds appreciable inductance at the probe tip, with a resultant lowered resonant frequency and increased probe loading in the high-frequency and VHF ranges. To avoid a restriction in frequency coverage, a small blocking condenser is used in the probe proper, with a larger unit mounted in an extension tip. This and the ground lead are removable for high-frequency measurements. For readings in the VHF regions, probe loading of the circuit under test can be further reduced by removing the small tip. One page of the instruction book for the Model 769 is reproduced here to illustrate the flexibility of this combination unit. See Figure 5.

To limit body capacity effects where the operator's hand may be too close to the probe tip or a resonant circuit in contact with the tip, a hand-limit line is engraved on each probe.

When the a-c probe is used, the device is responsive to the peak value of the applied potential. The scale is calibrated in terms of rms volts and, therefore, reads rms or effective values on any sine wave source. Where appreciable harmonic amplitudes are present in the source, or where complex wave forms are involved, the instrument will read .707 times the peak value of the applied potential. Since the presence of harmonics can affect the peak value of any wave, appreciable errors may be noted. If the crest factor or ratio of peak to rms is known, a correction can be applied to the instrument reading. In general, the error will be less than one-half the sum total of the harmonic content in per cent when measuring distorted sine wave voltages.

With pulse modulation, the investigator is usually interested in reading peak voltage, and in such

Audio and Supersonic Frequencies **(Minimum 50 cycles—Maximum 200 kilocycles)**



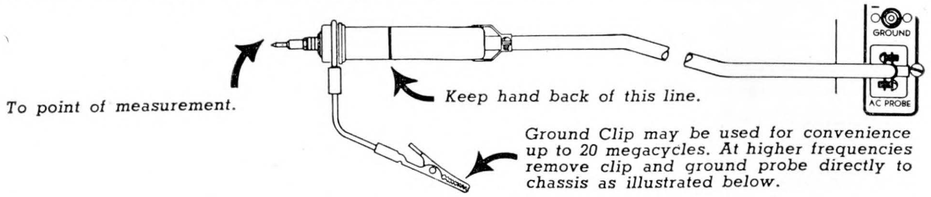
To point of measurement.

Keep hand back of this line.

Probe Extension.

Connect Ground Clip to chassis.

Frequencies Up to 20 Megacycles **(Minimum 1,000 cycles—Maximum 20 megacycles)**

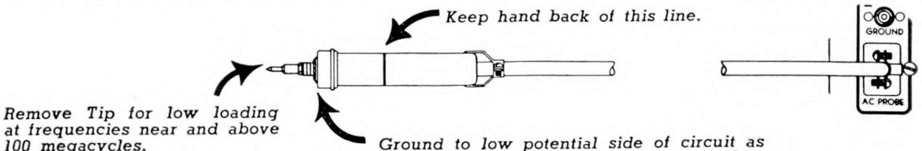


To point of measurement.

Keep hand back of this line.

Ground Clip may be used for convenience up to 20 megacycles. At higher frequencies remove clip and ground probe directly to chassis as illustrated below.

Frequencies Above 20 Megacycles **(Minimum 1,000 cycles—Maximum 300 megacycles)**



Keep hand back of this line.

Remove Tip for low loading at frequencies near and above 100 megacycles.

Ground to low potential side of circuit as close to point of measurement as possible.

Figure 5—Illustration showing correct probe connections for measurements in various sections of the frequency spectrum.

cases the instrument readings should be multiplied by 1.414. If the duty cycle is very short, as applied to radar modulation, the duration of the peaks becomes so short with respect to the fundamental pulsing frequency that the probe input condenser discharges appreciably between peaks. This results in a low reading, with the error increasing as the duty cycle becomes smaller.

The use of a thermionic rectifier in the a-c probe introduces an unavoidable diode curvature predominant on the lowest or 3-volt range. A separate non-linear arc is, therefore, required on the instrument scale for accurate tracking. A linear relationship between applied a-c potential and developed d-c output is rapidly approached at higher input levels, and by the inclusion of compensating resistors, the ranges above 3 volts are made to track correctly on a linear scale arc. Since the 100-microampere instrument also functions as an a-c voltmeter in conjunction with a copper-oxide rectifier, a non-linear scale distribution is necessary for the 1,000 ohms-per-volt ranges. To limit the number of scale arcs, the copper-oxide rectifier network is designed to follow the thermionic rectifier probe response on the 3-volt range. Thus only 3 scale arcs are required for all functions and ranges. See Figure 6. The "B" arc printed in red is used for all 1,000 ohms-per-volt a-c voltage readings and the lowest a-c probe range; all d-c functions and the higher a-c probe ranges operate in conjunction with the "A" scale.

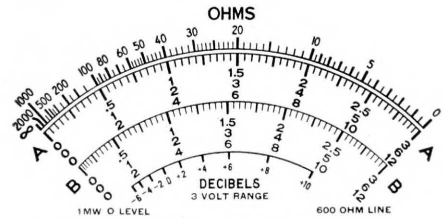


Figure 6—Representative scale distribution.

The ohmmeter function is generally conventional with energy supplied by the two internal unicells. For resistance readings from 0 to 200,000 ohms, the R, R x 10, and R x 100 ranges are used directly with the 100 microampere meter. For higher readings up to 2,000 megohms, the amplifier section is switched into the circuit between the input resistance network and the meter. Readings from 5,000 ohms to 2,000 megohms are readable on the R x 1,000, R x 10,000, and "Megohms" switch positions.

Amplifier Section

The amplifier is a compound feedback circuit combining regeneration and degeneration to obtain over-all stability. Whenever gain stability is desired, it is general practice to employ an amplifier having a gain much larger than the final gain desired and degenerating the excess amplification by reverse feedback. In theory, the higher the gain inherent in the amplifier and the greater the degeneration, the better the over-all stability will be in the face of changing tube characteristics and energizing potentials.

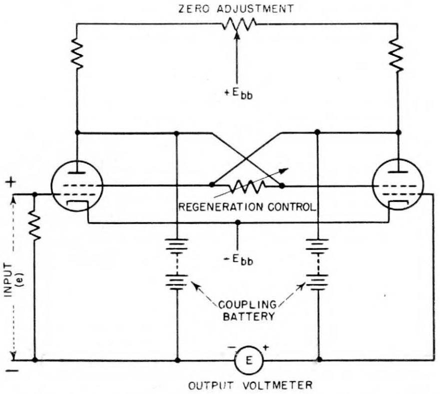


Figure 7—Regenerative feedback to screen grids to obtain increased amplification.

The condition of high gain through regeneration and complete degeneration through conductive coupling is achieved in a four-tube amplifier. This follows the fundamental circuit as described by R. W. Gilbert in *Electronics Magazine,* March, 1947, and is the first commercial application of the "voltage input with voltage output" combination outlined therein. Referring to Figure 7, two voltage amplifier pentodes are used in a balanced circuit with the screen grid of each tube connected to the plate of the opposite tube to obtain regeneration in a manner similar to the action of a multivibrator. By this method a gain ratio for greater than the normal gain of the amplifier tube proper can be realized. Degeneration is obtained by conductively coupling the plate of each tube to its control grid through coupling batteries. In the circuit of Figure 8 the batteries have been replaced by cold cathode gas regulator tubes. To avoid loading of the pentode-tube plate circuits with the gas-tube regulating current and the output load, a pair of buffer tubes is used. Without these decoupling tubes, the degree of regeneration attainable would be limited considerably by the loading of the pentodes.

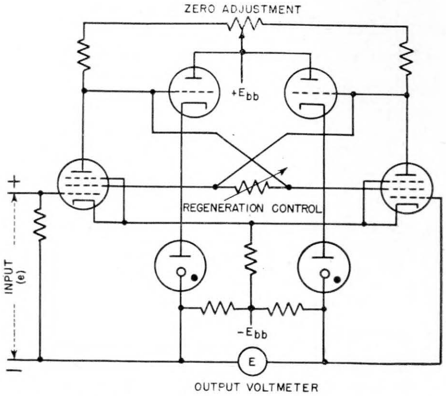


Figure 8—The practical circuit incorporates isolation tubes and gas tubes in place of batteries for maintaining proper biases.

The voltage appearing across the output voltmeter has a polarity opposite to that of the applied input voltage. As the tube gain is increased by regeneration, the difference in magnitude between input and output voltage becomes smaller until the two are equal. This is the point of unity gain and maximum stability where tube coefficients and energizing potentials have a minimum effect on the over-all input-output relationship.

In production, the amplifier chassis is assembled, wired and tested for unity gain, stability with line voltage variation, input grid current, balance, and variation in gain with tube changes before it is mounted on the instrument panel. Two type 6SJ7 tubes are used with a type 6SL7, a 6×5 rectifier and two type 991 gas-regulator tubes. The two separate triode sections of the 6SL7 act as the buffers shown in the diagram.

The complete range complement

of the Model 769 is listed as follows:

POWER REQUIRED

A-C Probe, Volts	D-C Electronic, Volts	Resistance, Megohms
3	3	0 to 2
12	12	0 to 20
30	30	0 to 2000
120	120	
	300	
	1200	

NO POWER REQUIRED

A-C 1000 o.p.v., Volts	D-C 10,000 o.p.v., Volts	D-C Current, Ma.	D-C Resistance, Ohms
3	3	0.3	0-2,000
12	12	1.2	0-20,000
30	30	6.0	0-200,000
120	120	30.0	
300	300	120.0	
1200	1200	600.0	

The Model 769 consists of a heavy gauge drawn aluminum panel on which all components are mounted. It is line insulated on all functions where power is required and doubly fused in the power cord plug. A-c and d-c probes along with standard test leads are carried in the accessory compartment.

E. N. No. 41 —*O. J. Morelock*

CHEMICAL CORROSION OF THERMOMETER STEMS, THERMOWELLS, SEPARABLE SOCKETS, AND ASSOCIATED APPARATUS

CORROSION and related agents of destruction account for one of industry's largest losses and although great strides have been made by alloying, surface coating, and proper selection of metals, much still remains to be done.

This article will concern itself in detail with a limited cross section of the field, i.e.: the problems of the manufacturer and user of thermometers, thermowells, separable sockets, and similar devices. The basic facts discussed, however, may be applied to similar problems wherein one must contend with like chemicals and metals.

Corrosion, we know, damages or destroys metals by weakening or embrittling them, by making them porous and by reducing the weight and cross section, that is, by actually eating the metal away until mechanical failure results.

In most industrial applications corrosion and its allies, erosion, agitation, turbulence, galvanic action, metal-ion cells, oxygen cells, and variances due to concentration and heat, present a complex problem making it nearly impossible to answer apparently simple questions concerning the proper metal or alloy for a given application.

No simple formula or rule of thumb has been evolved nor is it expected that we may some day so simplify the matter; at the present time good judgment, based on past experiences of both kinds and coupled with intelligent use of published data, usually permits satisfactory use, at least in the less difficult applications. Some of the more difficult problems must still be solved by trial and error.

Corrosion in the least complicated form takes place when a piece of metal is submerged in a corrosive liquid contained in a glass tank. See Figure 1. As an example, assume that the liquid is an acid and the metal a stainless steel.

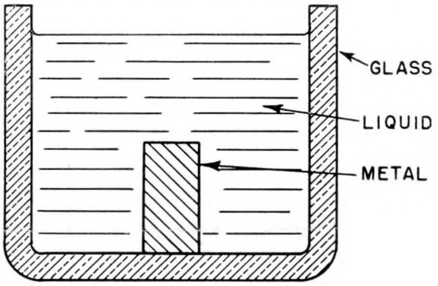


Figure 1—Simple corrosion.

In simple corrosion, as shown in Figure 1, a part or all of the metal may dissolve and pass into the liquid in the form of ions. The rate of corrosion or loss is readily determinable and relative rates for various metals and corrosive mediums are easily established. Our example, however, oversimplifies actual industrial conditions to the point where the results are practically meaningless in the face of the actual results encountered.

In practice, it is found that simple conditions never exist; invariably impurities are met in the liquid, non-homogeneity in the metal, temperature differentials, voltage differentials, agitation and flow. Scores of other conditions prevail and although sometimes beneficial in general the result is corrosion and destruction at a greater rate than the simple test would indicate.

In view of the above and that which follows, it should become apparent as to why it is difficult or even impossible to answer such an apparently simple question as—"Is blank metal satisfactory for use in sulfuric acid?" The answer depends upon whether the temperature is low or high, a motionless or a turbulent liquid, aerated or not, concentrated or dilute, pure or impure, under pressure or not, in a glass or a metal tank, if the metal is seamed or seamless, if polished or rough, if passivated or activated. Mix the above conditions in the variegated pattern met in industry and it is obvious that more details must be known about the application than merely the name of the acid and the metal.

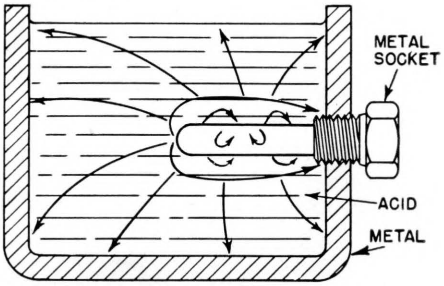


Figure 2—Flow of current (and metal) into solution and away from socket.

The subject is confusing because the phenomenon of corrosion is very complex and still only a scientific theory and because the conditions at the place of use are so complex and so often are not known accurately.

Presently accepted theory regarding the mechanics of corrosion is that it is entirely electrical and that a flow of current is always involved. In simple or static corrosion a difference of potential exists between the metal and the solution surrounding it. If the metal is not homogeneous (and no alloy is) or if impurities are present in the metal, then small sections take on a potential difference within the small section and also with respect to adjacent larger sections. If the tank wall is made of metal instead of glass, then another potential will exist between the two metals. Thus electric currents, and metal, will be flowing in various directions and usually away from where the metal is most wanted, unless the conditions were and could be planned correctly in advance. See Figure 2. This shows small localized cells due to pits, non-homogeneities and impurities normally present in unpolished commercial metals. Little need be done about these localized conditions other than to use the least affected metal or alloy (See Table No. 2 referred to in this article.) with the proper surface finish. Regarding the flow to the metal tank wall, this can often be reversed so that the metal tends to leave the tank wall sacrificially rather than the socket, or so that little or no potential difference exists, which condition would be nearly ideal.

Table No. 1 lists certain metals and alloys with respect to their potential or electromotive force activity in relationship to each other.

TABLE NO. 1

Electromotive Force Series

Zinc
Aluminum
Steel
Cast Iron
Chromium-Iron (active)
Stainless Steel (active)
Solder
Lead
Tin
Nickel (active)
Nickel-Chromium (active)
Brass
Copper
Bronze
Monel Metal
Silver Brazing Alloy
Nickel (passive)
Nickel-Chromium (passive)
Chromium-Iron (passive)
Stainless Steel (passive)
Silver
Gold
Platinum

The farther apart any two metals are shown in the table, the greater the metal loss from the metal shown uppermost in the table.

Table No. 1 and Figure 3 illustrate the advantage of passivated stainless steel in reducing galvanic corrosion, and frequent reference to this data will tend to prevent totally illogical combinations of metals in corrosive mediums.

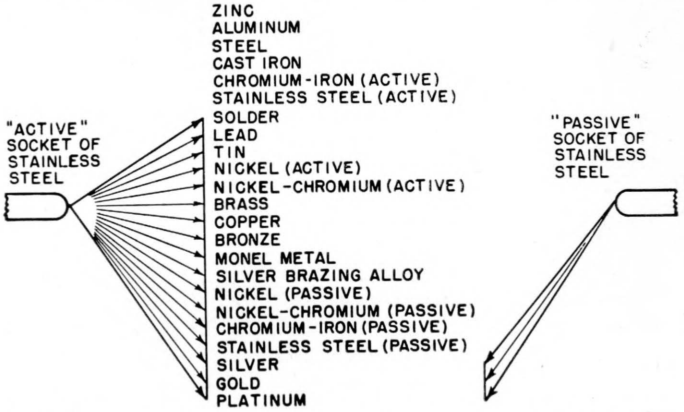


Figure 3—Loss of socket metal to "more noble" metals. Obviously the "passive" condition is to be preferred.

The facts concerning corrosion may be summed up as follows:

1—Corrosion is electrochemical. It manifests itself in the destruction of metals in chemical solutions.

2—The electrochemical action consists of a transfer of metal into the solution in proportion to the discharge of positively charged ions in the solution.

3—Acids are particularly cor-

TABLE NO. 2

CORROSION RESISTANCE OF CERTAIN METALS

G = Good P = Poor VP = Very Poor

Corrosive Medium	Stainless Steels		Monel	Bronze	Bess. Steel
	No. 304	Type No. for (G)			
Acetaldehyde	G		G	P	P
Acetic Acid—5%	G		G	P	VP
Acetic Acid—25%	G		P	P	VP
Acetic Acid, Glacial	G		P	P	VP
Acetic Anhydride	G		P	P	VP
Acetone	G		G	G	G
Acetylene	G		G	G	G
Agar Agar	G		G		G
Air, Liquid	G		G	G	G
Albumen, Egg	G		G	G	G
Vegetable Juice	G		G	G	
Vinegar	G		P	P	
Viscose	G		G		
Water, Sea	P		G	G	P
Wax, Chlorinated	G			G	
Wax, Paraffin	G		G	G	
Whiskey	G		G	G	VP
Wines	G		G	G	VP
Witch Hazel	G			G	
Yeast	G		G		
Zinc Chloride	P		G	P	
Zinc Sulfate	G		G	P	

EDITOR'S NOTE: Copies of Table No. 2 containing the complete list of some 400 corrosive mediums may be obtained by a request directed to the Editor.

rosive due to the presence of excess hydrogen ions.

4—Dissolved air may accelerate or retard corrosion. Oxygen, whether due to an oxidizing agent or aeration, tends to form a surface on stainless steel which is more resistant to corrosion than the metal itself.

5—The velocity of the liquid due to flow, agitation, or turbulence has an effect. Increased velocity more quickly removes the corrosion products and any protective film which would tend to form.

6—Local variations in temperature, rough surface conditions, crevices and cracks, welding and similar conditions cause "concentration cells" with resulting accelerated local corrosion.

7—Corrosion rate is vitally affected by impurities, some of which act as accelerators and some as inhibitors. Pure chemicals are seldom encountered, so varying results may be experienced in what are considered to be like circumstances.

8—Galvanic action must be retarded when possible by proper selection of metals.

9—Stainless steels in particular must have smooth, passivated surfaces to achieve optimum conditions.

Accompanying this article are excerpts from Table No. 2 entitled "Corrosion of Certain Metals." This table was compiled with the assistance of various research organizations and corrosion engineering divisions of large manufacturers of steel, brass, nickel, etc. The table reflects their findings and suggestions as well as our own and combines practical experience over a period of many years with latest theory.

The table is intended to show the approximate corrosion resisting ratings of several metals when exposed to various commonly met mixtures, gases, liquids, and solutions.

The table and values expressed in it are based on tests and experiences and the sources of information are considered to be reliable.

Many conditions may arise in actual use differing sufficiently from those contemplated that results may vary widely and in fact on occasion in certain instances material which would normally be considered "good" and would be expected to last for years might deteriorate to the point of being unusable in a few days or even in a matter of hours.

Table 2 lists some of the more common metals used in the manufacture of sockets and thermowells. There are obviously many other metals and alloys which in specific instances may be more suitable.

Sockets and other parts sometimes are not readily available in the unlisted metals due to the fact that the special metal is frequently difficult to machine or to obtain in small quantity and for various other reasons. In certain other instances the corrosive medium and the condition surrounding its use indicate the inadvisability of using any non-noble metal. Sometimes also, as in certain stripping and plating and deplating baths, large electrical currents are intentionally introduced, of a magnitude which tends to dissolve the stem or socket in a matter of minutes.

In all such instances there are certain non-metal alternatives available as protective sheathings or coatings, such things as glass tubes, plastic tubes, plastic paints and varnishes, "stop-off" lacquers and similar substances.

E. N.—No. 42 —*Anthony H. Lamb.*

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