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A TECHNICAL MEASUREMENT OF THE
EFFECT OF A MAGNETIC FIELD ON THE
RATE OF CORROSION OF STEEL WOOL

by

William Harold Burgess, Jr.

A THESIS

Presented to the Graduate Faculty

of Lehigh University

in Candidacy for the Degree of

Master of Science

Lehigh University
1954

This thesis is accepted and approved in partial ful-
fillment of the requirements for the degree of Master of
Science.

_____   _____
        (Date)   Professor in Charge

                              _____
                                  Head of the Department

i.

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Bethlehem Steel Company was very kind to analyze the steel wool.

I would also like to acknowledge Weirton Steel Company for the financial backing of this project.

Finally, my wife, Rita, deserves much credit for her help with the secretarial work.

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PURPOSE

The purpose is to obtain a technical measurement of the effect of a magnetic field on the rate of corrosion of steel wool by dissolved oxygen in water. Measurements are made at two temperatures, $20^{\circ}C.$ and $65^{\circ}C.$

The low temperature rate is determined by an oxygen absorption method; the $65^{\circ}C.$ run uses the weight gained method. The runs are made in quadruplicate and submitted to statistical analysis.

"The close relationship between electricity and chemical affinity on the one hand and that between electricity and magnetism on the other early raised the question whether magnetism would alter the character or degree of a chemical reaction. As early as 1881 Remsen[1] observed that magnetism had a remarkable action on the deposition of copper from solution of its salts on an iron plate. In 1886 Nichols[2] further investigated the action of acids on iron in a magnetic field, and in 1887 Rowland and Loues Bell[3] read a paper at the Manchester meeting of the British Association (September 1887) on An Explanation of the Action of a Magnet on Chemical Action. They explained the protection of iron from the chemical action of hydrochloric acid in lines around the edges of the poles by making use of the fact that the force acting on the particle in any direction is proportional to the rate of variation of the square of the magnetic force in that direction. 'This rate of variation is greatest near the edges and points of a magnetic pole and more work will be required to tear away a particle of iron or steel from such an edge or point than from a hollow. This follows whether the tearing away is done mechanically or chemically.' . . . . . .

Alexandre De Hemptinne in 1900 published an interesting paper in which he showed that although theoretically there is an effect of the magnetic field, experimentally it is too small to be of much consequence." [4]

However, there have been workers in the field who have found experimentally that there is a sizable effect of a magnetic field on chemical reactions. H. Schmid and G. Muhr[5] found that carefully purified styrene when placed in a magnetic field of 16,000 gausses and maintained at $80^\circ C$. for eight hours polymerized, giving 0.56 percent polystyrene. Without the magnetic field but with other conditions the same, 4.9 percent polystyrene was formed. A. V. Solov'ev[6] found that the reaction of nitric acid on iron plate in a

magnetic field is different than without the field. Bhatnagar and Mathur[7] carried out critical experiments on fourteen different homogeneous reactions and found that there was an effect of a magnetic field. They noted that the velocity of reaction is accelerated, unaffected or retarded by a magnetic field according as $\sum_f \chi_M \gtreqless \sum_i \chi_M$ where $\sum_f \chi_M$ is the sum of the molecular susceptibilities of the final products, and $\sum_i \chi_M$ is the sum of the molecular susceptibilities of the initial substances.

There are reactions which are catalyzed by magnetized catalysts, such as the catalytic conversion between para-hydrogen and ortho-hydrogen by nickel wire. Ogawa and Tada[8] report that the activation energy of the ortho- para- hydrogen conversion over nickel was 3000 calories for unmagnetized and 6000 calories for magnetized catalyst. For the hydrogen plus ethylene reaction, they found that at 150-200°C. the magnetic mechanism acted on the ethylene, but not on the hydrogen.

There has been some work on reactions of iron salts in solution and also on reactions of various acids on metallic iron, but nothing on the most common reaction of iron, i. e., corrosion of iron by oxygen saturated water.

THEORETICAL CONSIDERATIONS

General Magnetics.

There are many theories on the causes of magnetic phenomena, most of them variations and refinements on the basic premise that the magnetic properties of matter depend upon the electron configuration of the molecule. The most successful theories are those of Weber[9] in 1854 and Ewing[10] in 1890. Weber's hypothesis is that the molecules of iron and steel are permanent magnets capable of being turned round their centers. The molecules are magnets because they have electrons which are spinning around the center of the molecule and due to this motion develop a magnetic field. Ewing's theory extends the theory of Weber to postulate that there is a mutual magnetic action between the molecular magnets.

Weber's and Ewing's theories are concerned with the nature of magnetism and are not applicable to predicting the effect of a magnetic field on a chemical reaction.

The Collision Theory of Reaction Rates.

The collision theory of reaction rates supposes that there are within a mass of reacting molecules a certain number, which possess at least a certain critical reaction energy. These high energy molecules can react only on collision; furthermore, all of the collisions of the high energy molecules do not result in a reaction. These three ideas are expressed mathematically as $k = PZe^{-E}$, where k is the reaction

constant, P is the fraction of colliding high energy molecules which react, Z is the total number of molecules that collide and e^{-E} is the fraction of the total number of molecules that possess at least the critical energy. The quantum mechanical reaction rate theory has shown that P is an entropy term[11] which describes the probability of the high energy molecules colliding in the proper "phase." For instance in the hydrogenation of ethylene the molecules of hydrogen and of ethylene must have a minimum energy, and must collide such that the double bond of the ethylene is exposed to the molecule of hydrogen. Since the manner in which two molecules collide figures in the rate of their reaction, any agency influencing the manner of collision will influence the rate of reaction. In a gas phase reaction the collisions are random, but in a magnetic field all the molecules tend to line up in the field according to their individual magnetic susceptibilities, i. e., as they like the field or do not like the field. It seems reasonable that if the molecules are oriented so they collide at reactive points more than unreactive points they will react faster. The presence of a magnetic field should affect the probability of collision in any given steric configuration. The degree of molecular orientation in the magnetic field depends upon the magnetic susceptibility, the temperature, and the restrictions to free rotation of the molecules. The effect of a magnetic field on P for the simplest case, i. e., of a gas, has never

been calculated. In the case of the rusting of iron by dissolved oxygen there is no way of estimating the effect of a magnetic field on the steric factor P.

Concentration Cells.

J. J. Weigle[12] showed, in 1928, that theoretically a magnetic field would cause paramagnetic and ferromagnetic salts to concentrate within the regions of strongest field and that diamagnetic salts would concentrate in the weakest parts of a magnetic field. His simplified formula for a mixture of liquids is $n/n_0 = e^{H\sigma/2kT}$ where n/n_0 is the ratio of the concentration inside the field to that outside the field, H is the field strength in gausses, k is the Boltzman constant, T is the absolute temperature and σ is the magnetic moment.

> "When applied to the reduction of chromic acid the formula gives n/n_0 as 20:1 in a field of 2000 gauss. Since the reaction products will be concentrated in a small region near the poles where H is the strongest, their concentration in the rest of the solution will get lower and consequently the forward reaction will proceed faster."[13]

In the case of rusting iron, Weigle's formula could be applied to the ferrous and ferric ions and to the $Fe(OH)_2$, $Fe(OH)_3$, FeO, etc., formed if the amounts of these various oxides and hydroxides were known, and if the magnetic moment of all the reactants and products was known. However, all the data are not available.

Diffusion Rate of Oxygen.

A magnetic field of 10,000 gausses produces a decrease

of $2x10^{-4}$ in the diffusion coefficient of diamagnetic
gases through oxygen.[14] There has been no measurement of
the change of the diffusion coefficient of oxygen through
water, but there is probably some effect. The corrosion of
iron is controlled by the rate of diffusion of oxygen
through water in many cases[15] and the magnetic field would
alter the corrosion in such cases through its effect on
the diffusion of oxygen. In the present experiment, all
the sample is so close to free oxygen that the controlling
factor of the rate is not the diffusion rate of oxygen.

Thermic Effect.

> "Two points in the plane of a semiconduc-
> tor containing two resistances, having the di-
> rection of the corrosion process and of the magnetic
> field show a temperature difference: $T = C_t H\ b/a$
> where C_t is the corrosion-magnetic constant of
> the thermal effect at a given temperature, H the
> intensity of the magnetic field, b the thickness
> between the two points under consideration and a the
> thickness of the semiconductor in the direction of
> corrosion."[16]

This difference in temperature is probably small in
most cases, and since the value of $C_t b/a$ would not usually
be known in a practical corrosion problem could not be cal-
culated.

Electrochemical Theory of Corrosion.

In general terms, the corrosion of iron by aeriated
water can be described as the solution of ferrous ions,
the liberated electrons being used by ionic hydrogen to
form atomic hydrogen. The sites of solution of the ferrous

ions are called anodes and the areas where the electrons
react with hydrogen are called cathodes. The film of
hydrogen on the cathode can cause the corrosion to stop
unless it is removed. Dissolved oxygen reacts with the
atomic hydrogen to depolarize the cathode and permit the
corrosion to proceed. The atomic hydrogen can form molecular
hydrogen which is evolved as a gas. The ferrous ions react
with water and also with dissolved oxygen to form ferrous
and ferric hydroxides. Very little elemental iron is di-
rectly oxidized.[17] Even though the major corrosion products
are known, the products of a given corroding material are
almost impossible to predict.[18]

The electrochemical theory of corrosion rests on the
hypothesis that the elemental iron dissolves and in so
doing gives up two electrons which flow to some site where
they react with ionic hydrogen. An electron flowing through
a magnetic field will experience a force which is proportional
to the strength of the field, the charge of the electron,
and the angle the electronic path makes with the direction
of the field.[19] Assume for the moment that there is a cor-
rosion proceeding with only one anode and one cathode. In
this case the iron goes into solution at the anode and re-
leases two electrons which flow by the path of least resistance
to the cathode where they react with an ion of hydrogen.
If the iron were perfectly pure, the path of least resistance

would be through the iron, in a straight line to the cathode. Now, if a magnetic field is created such that it is perpendicular to a plane through the anode and cathode, then the electrons will be forced to travel in a curved path and therefore must take a longer route from the anode to the cathode. Since the resistance is proportional to the length of the path, the resistance is increased by the longer path. Since the electrons must overcome a larger resistance in flowing within the magnetic field than without the field, the potential difference between the anode and the cathode must be larger for the same amount of corrosion within a magnetic field than without the field. The difference in potential is limited, so the magnetic field should cause a decrease in the reaction rate due to its effect on the flowing electrons.

Theoretical Conclusions.

A magnetic field can influence the rate of a chemical reaction by:

(1) Orienting the reacting molecules so that they tend to collide in either more or less favorable steric configurations.

(2) The magnetic field may cause concentration cells of the reactants and/or products.

(3) The rate of diffusion of oxygen may be changed.

(4) A temperature difference within the sample may be

induced by a magnetic field.

(5) A resistance to the flow of electrons may be induced by a magnetic field.

(6) There is no way of calculating the magnitude of any of the above factors for iron corroding in a magnetic field.

EXPERIMENTAL APPARATUS AND PROCEDURE

The rate of reaction is determined at the low temperature by the oxygen absorption method in which the sample, damp with distilled water, is exposed to thermoregulated, pure oxygen gas. The gas is contained over water in a vacuum-tight apparatus shown in Figure 1 . Any hydrogen evolved during the run is measured by catalytically burning it[20] and measuring the ensuing change in volume. The catalyst used is a red-hot platinum wire - 3 on Figure 1 . The hydrogen collection chamber is in the highest part of the system and is provided with a platinum wire to ignite the hydrogen. The platinum wire is heated by the passage of an electric current.

The amount of volume change due to the absorption of oxygen is measured periodically and, after being corrected for changes in cooling water temperature and atmospheric pressure, is used to follow the rate of reaction.

In the high temperature run, the weight gained by the sample is used to determine the rate of corrosion. The volume of oxygen absorbed method requires such precise temperature regulation that it is not used at the higher temperature.

Sample Preparation.

Steel wool (see Table 23 for specifications), in each instance from the same pad, is cut in approximately one-half

① — COOLING WATER
    DELIVERY TUBING

② — HIGH PRESSURE
    RELIEF VALVE

③ — PT WIRE FOR IGNIT-
    ING HYDROGEN

④ — CORK

⑤ — GLASS HOOK

⑥ — SAMPLE

⑦ — TEFLON JOINT

⑧ — SAMPLE TUBE

⑨ — COPPER TUBE

⑩ — BURET

⑪ — MANOMETER
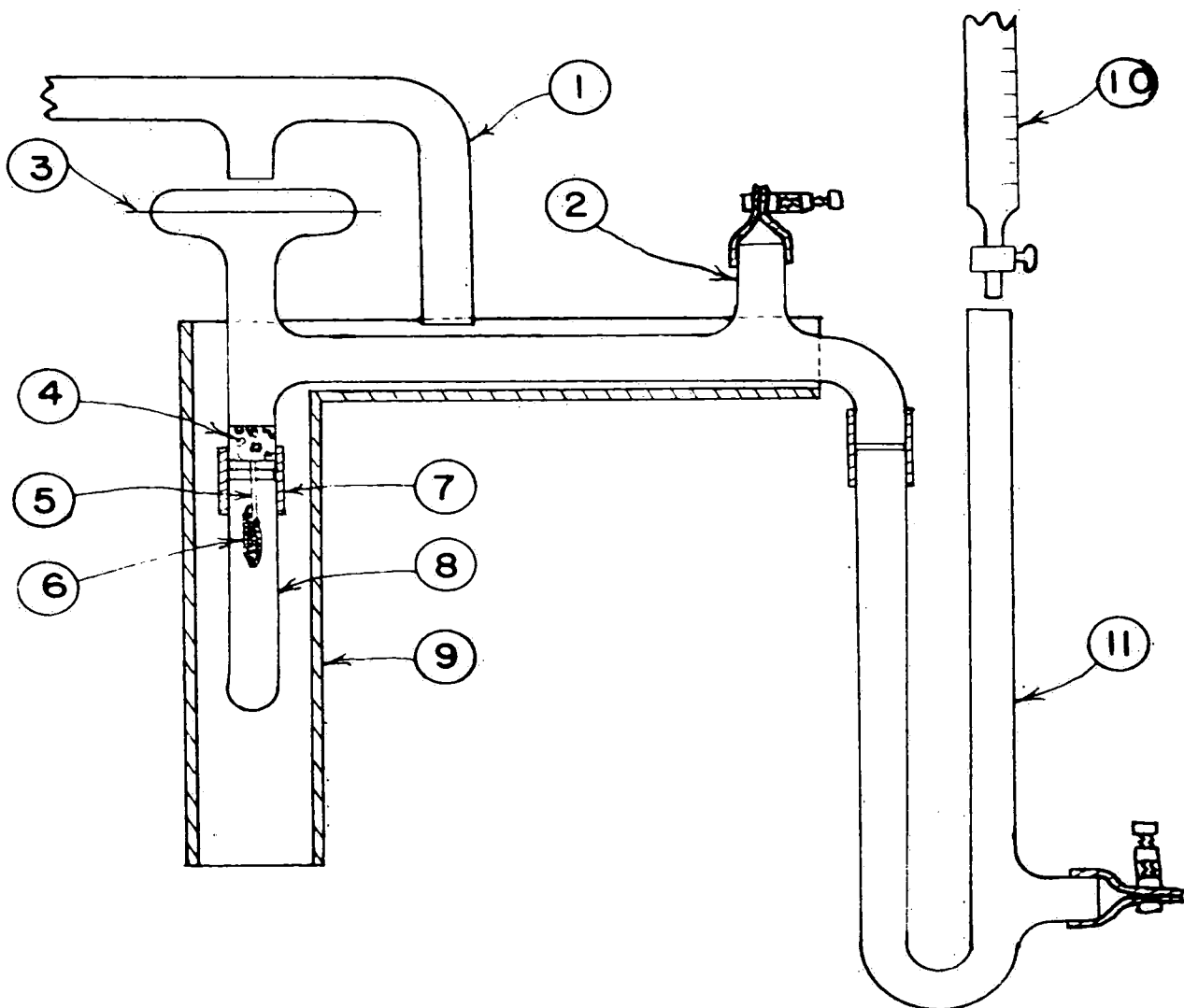
EXPERIMENTAL APPARATUS

FIGURE I

inch squares with tin snips. The wool is rolled between
the fingers into a column about one and one-half inches
long and a hole is pierced in one end for the glass
hook - 5 on Figure 1 . The column of wool is weighed and
cut until it weighs within ten percent of the other four
samples, then placed in absolute alcohol for two hours.
The alcohol is drained off, the samples touched to absorbent
paper and then placed in a vacuum desiccator over sodium hy-
droxide for two days or more. When the samples are needed
they are accurately weighed and used.

Description of the Apparatus for Low Temperature Run.

The equipment consists of ten millimeter glass tubing
with joints of teflon - 7 on Figure 1 . One leg of a water
manometer (11) is connected through a teflon joint to the
reaction tube; the other leg is open to the air. A change
in volume is measured with water added from the buret (10).
The reaction tubing is equipped with a valved port (2) to
facilitate the start-up of a run. The sample is hung on
a glass hook (5) which is embedded in cork (4). The cork
is shaved on two sides to permit freedom of movement for
oxygen throughout the tube.

The temperature regulating system consists of delivery
tubes (1) which deliver a continuous stream of constant
temperature tap water to the reaction tubing. A stream of
water flows over the reaction tubing and oxygen filled leg

of the manometer, to be collected by the copper tube and trough (9) and discharged to the sewer. The copper tube also excludes light from the sample.

There are four separate reactors with one between the poles of a large D. C. electromagnet. This arrangement gives one sample corroding in the magnetic field and three control reactions. The magnetic field is constant at 19,200 gausses. (See Calculation 3 in the Appendix.)

Procedure.

After the sample is prepared, all of the glass tubing of the reaction tube and manometer is clamped in a convenient position and the valve (2) is opened and the tube (8) is removed. The sample is hung on the glass hook and oxygen is bubbled through water in the manometer, displacing the air in the tube with saturated oxygen. Valve (2) is closed and as oxygen continues to bubble, the glass reaction tube (8) is put into place. When the reaction tube is in place, the oxygen pressure in the apparatus increases until it equals the pressure in the oxygen tank valve, i. e., about 5 psig. This positive pressure is used as a test to determine whether the apparatus is leaking. If, after a few minutes, the manometer water levels do not change - indicating there are no leaks - the apparatus is put into place and brought to the temperature of the reaction. After about one-half hour to allow for thermal equilibrium, the water menisci in

the manometer legs are leveled by momentarily opening valve (2), thus exposing both legs to atmospheric pressure. At this time, the atmospheric pressure and temperature, cooling water temperature and the time are recorded.

As the reaction proceeds, measurements of the oxygen absorbed are made. The data taken at each measurement are: temperature of the cooling water, atmospheric pressure, atmospheric temperature, time and the volume of water delivered from the buret which causes the water levels in the two legs of the manometer to be equal. Temperature of the cooling water is measured with a mercury thermometer in the discharge line. Atmospheric pressure is measured on a mercury barometer in the physical chemistry laboratory.

At the end of the run, all samples are visually observed.

High Temperature Run.

It is very difficult to regulate the temperature within the limits required for accurate gas measurements at the temperature (65°C.) used in the high temperature run, so a different method of following the rate is used. The weight gained by the sample is used to determine the rate of corrosion. A new sample must be used for each time increment, but as found in the low temperature run there is a large deviation in rate from sample to sample, therefore only one time element is used. The overall average rate is defined by this single measurement. Four samples are tested simultaneously; one in the magnetic field and three outside the

field.

High Temperature Apparatus.

The reaction tubes and arrangement are the same as in the
20°C. runs. However, the sample is placed in the bottom of
the reaction tube instead of being suspended from a glass
hook, because in several trials at 65°C. the hook loosened
and fell from the cork.

The temperature of 65°C. is obtained by heating water
in a five-gallon can with twenty-five psig. steam to approxi-
mately 66°C. and then allowing a 1000 watt fenwal thermo-
switch to maintain the temperature at about 67 ± 1°C. This
water is pumped to all four reaction tubes through a mani-
fold to insure equal temperature in all samples. The water
drops from 67°C. to 65°C. in transit from the heater to the
reaction tubes. The temperature at the sample is measured
with a mercury thermometer and is continuously measured and
recorded by a Leeds and Northrup temperature recorder. The
temperature variation of ± 1°C. is too great to use the gas
absorption method of measuring the corrosion rate, but it
is satisfactory as a temperature control for the reaction it-
self[21], since variation of the reaction constant with tempera-
ture at 65°C. is small.

High Temperature Procedure.

A prepared and accurately weighed sample is put into a
weighed reaction tube. Distilled water is poured into the
tube and then emptied out, leaving a wet sample in the bottom

of the tube. The reaction tube is placed on the oxygen filled apparatus and the heating water started. When the sample has reacted for the desired time, the sample tube is removed and placed in a drying furnace at $105^{\circ}C$., and dried for three hours. Dry nitrogen is used as a continuous purge to reduce oxidation of the sample at the high drying temperature. Upon cooling to room temperature, the weight of the combined sample and tube is found. The amount of reaction is determined by the difference in weight between the combined weight of sample and tube before and after reaction.

RESULTS

The rate of corrosion of sixteen samples of steel wool at 20°C. has been measured using the volume of oxygen gas absorbed as the method of measurement. All volume measurements are corrected to standard temperature and pressure and reported as milliters of oxygen absorbed at standard temperature and pressure per unit of sample weight in grams. The experimental data including measured volume change, corrected volume change, atmospheric temperature and pressure, temperature of the cooling water, and the differential time elements are given in Tables 1-16. The grand total rate means for the 20°C. and 65°C. runs are given in Table 22, together with the mean of the rates of the magnetic and the non-magnetic samples. Table 22 also gives the ninety-nine percent confidence limits for the four means just mentioned. Curves of the differential rates of the first four samples are plotted against time (Figure 3) and against milliters of oxygen absorbed (Figure 2). The curve of the average of the differential rate curves of all sixteen samples is given (Figure 11) and the integral plot (Figure 12) of this average differential curve is presented. The integral plot is fitted to an equation of the form $y = A \left(1 - e^{-tk}\right)$ - see Table 17 - where y is the oxygen absorbed in t hours, A and k are constants.

The data for each of the four runs, each run having four samples, is given the three sigma control limit test

(Figures 5,6,7,8) to determine if there are any variations among the four groups which are greater than can be ascribed to random error. Similarly, all sixteen individual samples are given the three sigma control limit tests (Figures 9 and 10). The t-test (see calculation 2 in Appendix) is used to determine the significance of the difference between the mean of the magnetic samples and the non-magnetic samples.

The control charts included in this paper are:

Charts for the four groups: (1) Two charts for the means of the groups, including the plot of the means and the plot of the standard deviations of the means - Figures 7, 8; and (2) Two charts for the standard deviations of the samples within each group, including the plot of the means of the standard deviations and the plot of the deviations of these means - Figures 5 and 6.

Curves for the sixteen individual samples: (1) The chart for the means - Figure 9; and (2) The chart for the deviations - Figure 10.

High Temperature Run.

The data for the single high temperature run is given in Table 21.

DISCUSSION OF RESULTS

In order to compare one sample's rate curve with another sample's rate curve, an average of the differential rates from time zero to seventy-five hours is computed for each sample. Plots of rate versus milliliters of oxygen absorbed such as Figure 2 have shown that there is no correlation between rate and the amount of corrosion, so the rate over a set time is used as the basis of correlation. It is assumed that the only errors that occur are purely random errors. If this is the case, then the experimental curves differ because of random inequalities, such as differences in sample surface, temperature, etc. Since the samples were obtained from the same pad of steel wool and treated identically, and since the runs were made with controlled conditions, the variations of the average rates should be random.

The three sigma control chart method of analyzing data is given in the A.S.T.M. <u>Manual</u> <u>on</u> <u>Quality</u> <u>Control</u> <u>of</u> <u>Materials</u> (Special Technical Publication 15-c)[22] and is a statistical method which enables one to test a controlled set of data to determine if there is any variation of the data which is too large to be merely random. Charts 5, 6, 7, and 8 were constructed (see Calculation 4 in Appendix) to determine if any group of runs varied too much from the mean of the groups and also if the degree of variation within

RATE VS ML O₂ ABSORBED - FIRST RUN

FIG. 2

● — SAMPLE NO. 1
○ — SAMPLE NO. 2
Φ — SAMPLE NO. 3
θ — SAMPLE NO. 4

RATE - ML/GRAM,HOUR

ML O₂ ABSORBED

FIG. 3

RATE VS TIME - FIRST RUN

● — SAMPLE NO. 1
○ — SAMPLE NO. 2
Φ — SAMPLE NO. 3
θ — SAMPLE NO. 4

RATE - ML/GRAM, HOUR

TIME - HOURS

FIG. 4

ML O$_2$ ABSORBED/GRAM
VS
TIME — FIRST RUN

● — SAMPLE NO. 1
○ — SAMPLE NO. 2
◐ — SAMPLE NO. 3
⊖ — SAMPLE NO. 4

ML O$_2$ ABSORBED/GRAM

TIME — HOURS
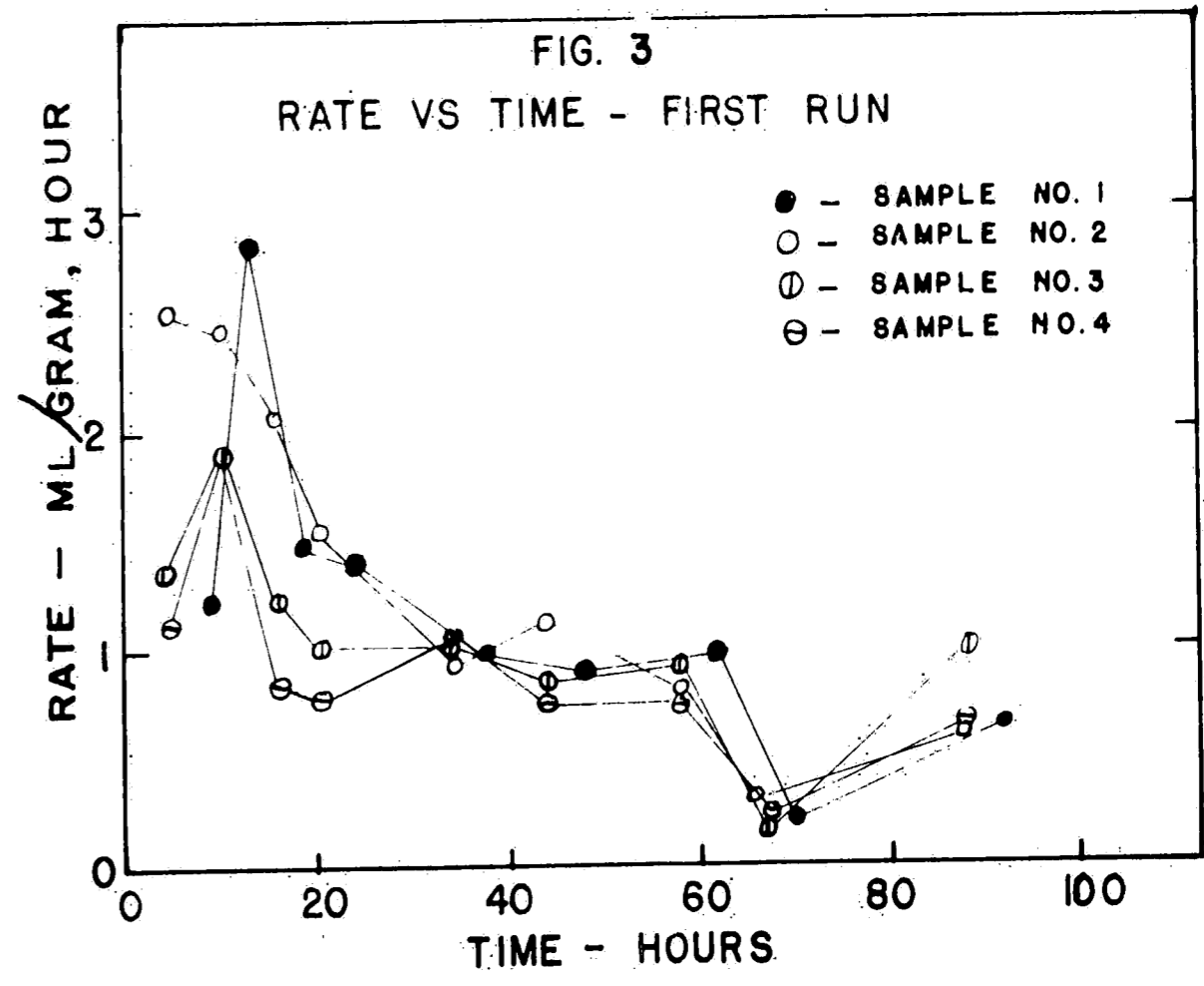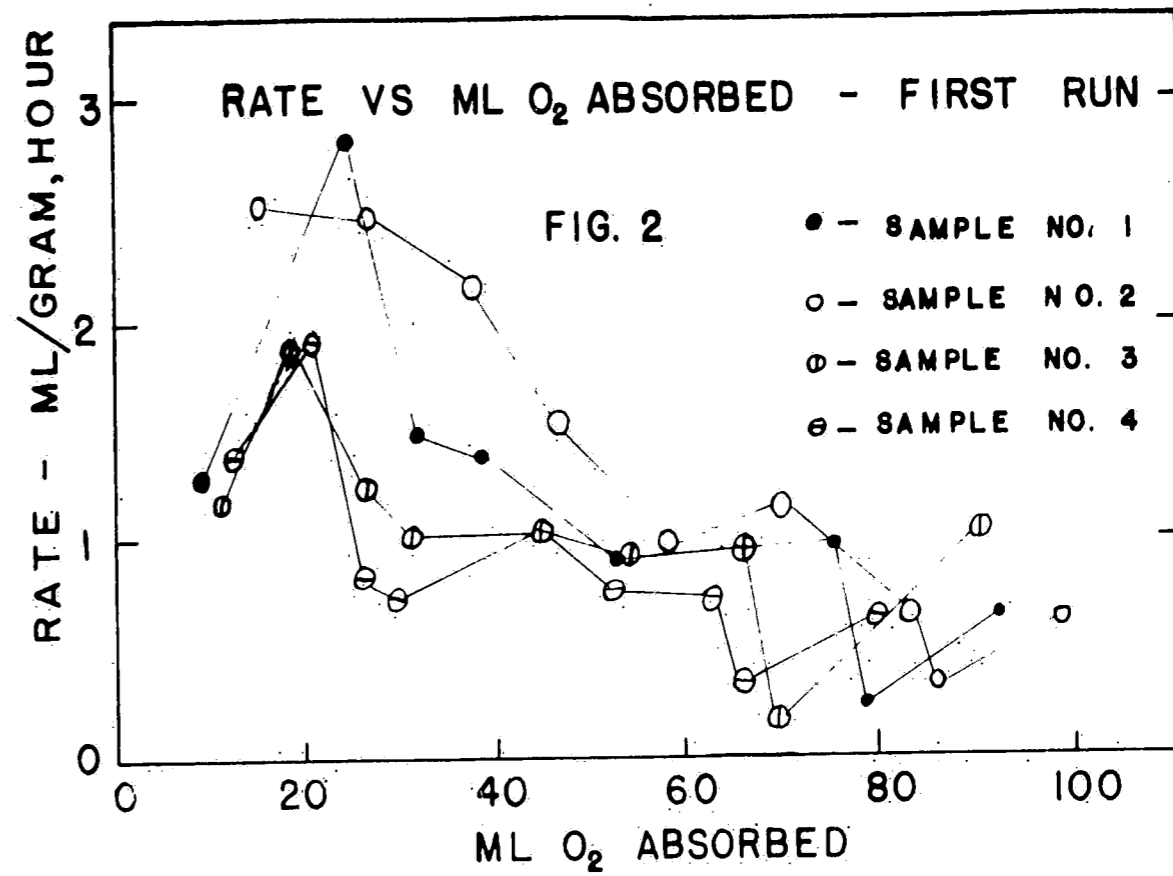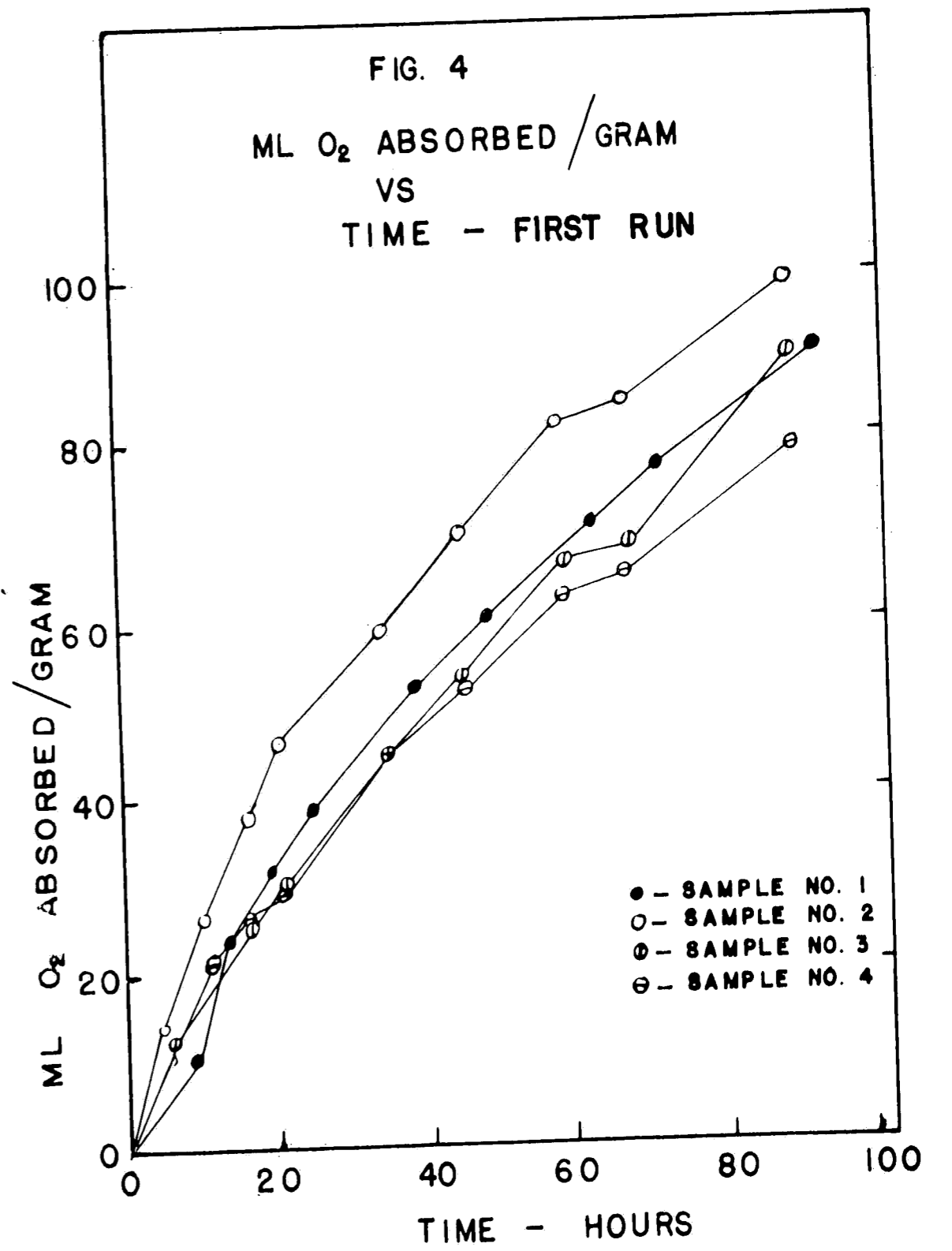
THREE-SIGMA CONTROL CHARTS FOR
DEVIATIONS WITHIN GROUPS

FIG. 5 — SIGMAS WITHIN GROUPS VS GROUP NUMBER

FIG. 6 — DEVIATIONS OF SIGMAS WITHIN GROUPS VS GROUP NUMBER

THREE-SIGMA CONTROL CHARTS FOR
DEVIATIONS AMONG GROUPS

FIG. 7 — MEANS OF GROUPS VS GROUP NUMBER

FIG. 8 — DEVIATIONS AMONG GROUPS VS GROUP NUMBER
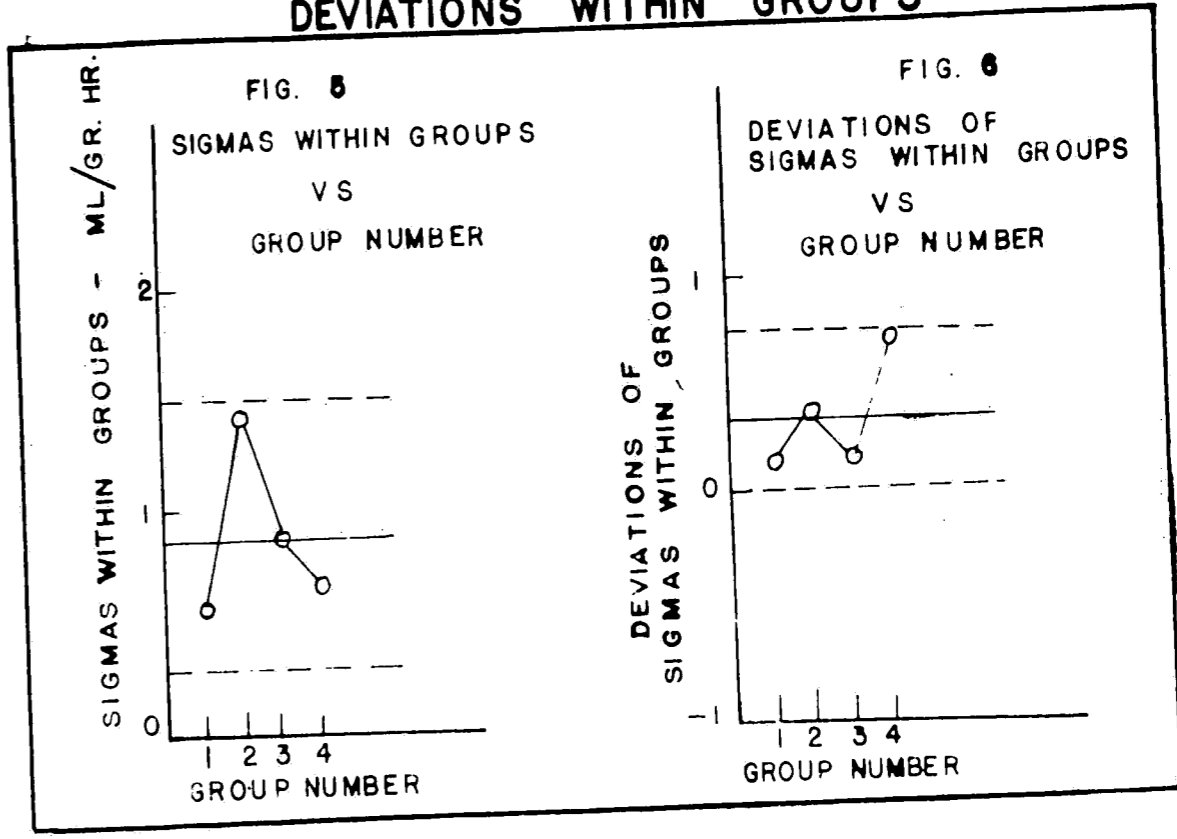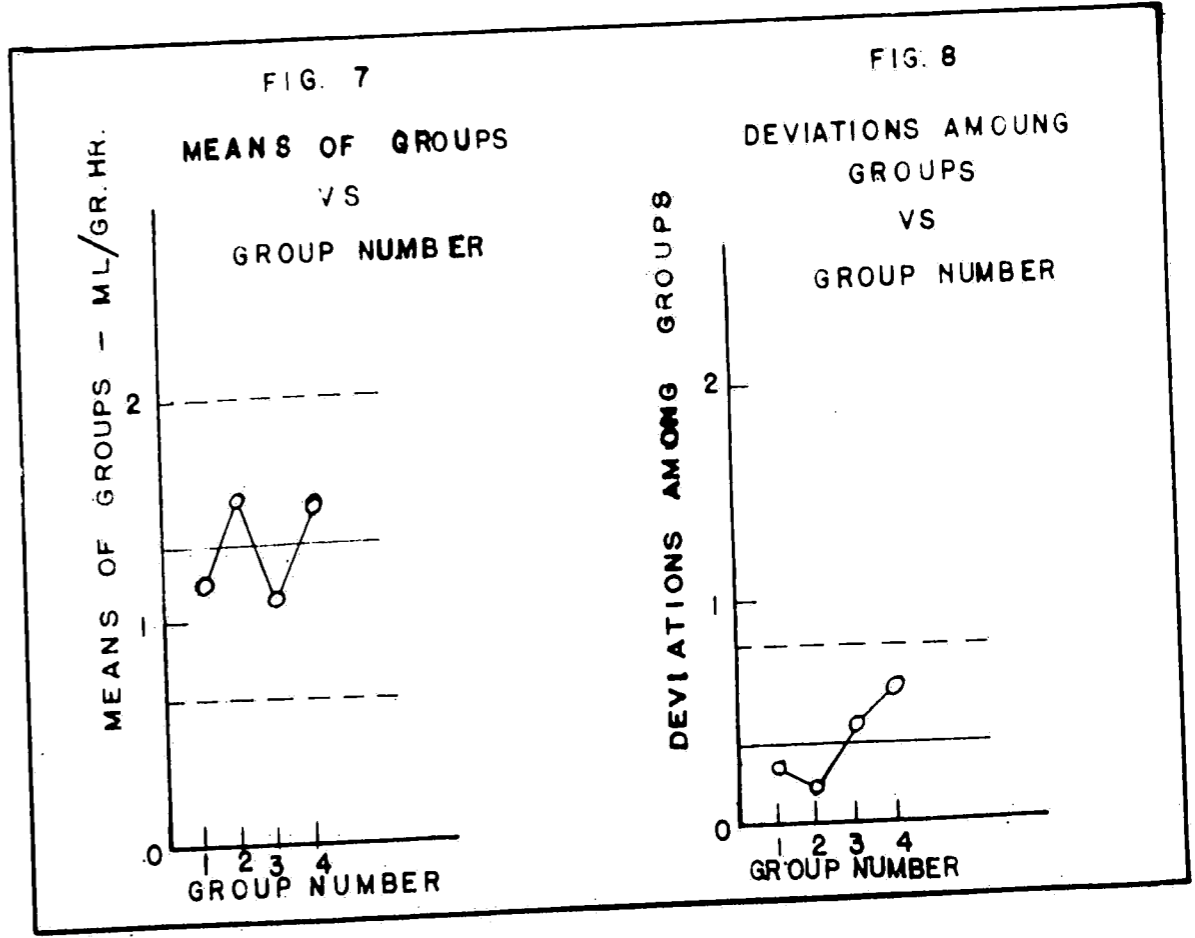
each group (standard deviations) was other than normal. The charts show that not one single point lies on or above the three sigma control limit, and therefore the four runs are all considered to be within the limit of random error; hence, from the same universe of possible rates. All groups are significant.

The data (Figure 9) for the sixteen samples show that in no case is there an average rate which exceeds the limit of random error. Therefore, there is nothing acting on any one sample which is not acting on all samples. But a magnetic field is acting on four samples. Therefore, any effect the magnetic field has on the rate is too small to be significant to this experiment. This does not exclude the possibility that there may be an effect after more corrosion product has been formed or for a different surface treatment of the sample, etc., but it does show that in the initial stages of corrosion at room temperature the effect of a magnetic field is so small that it cannot be measured with an experimental apparatus having more than a twenty-eight percent coefficient of variation. The coefficient of variation is the standard deviation of a variable expressed as a percentage of the variable.

The t-test adds even more light to the analysis. "A t-test is a way to compare the difference between a mean and an arbitrary value, or the difference between two means,

FIG. 9
THREE SIGMA CONTROL CHART
FOR INDIVIDUAL SAMPLES
MEANS

FIG. 10
CONTROL CHART FOR
INDIVIDUAL SAMPLES
DEVIATIONS
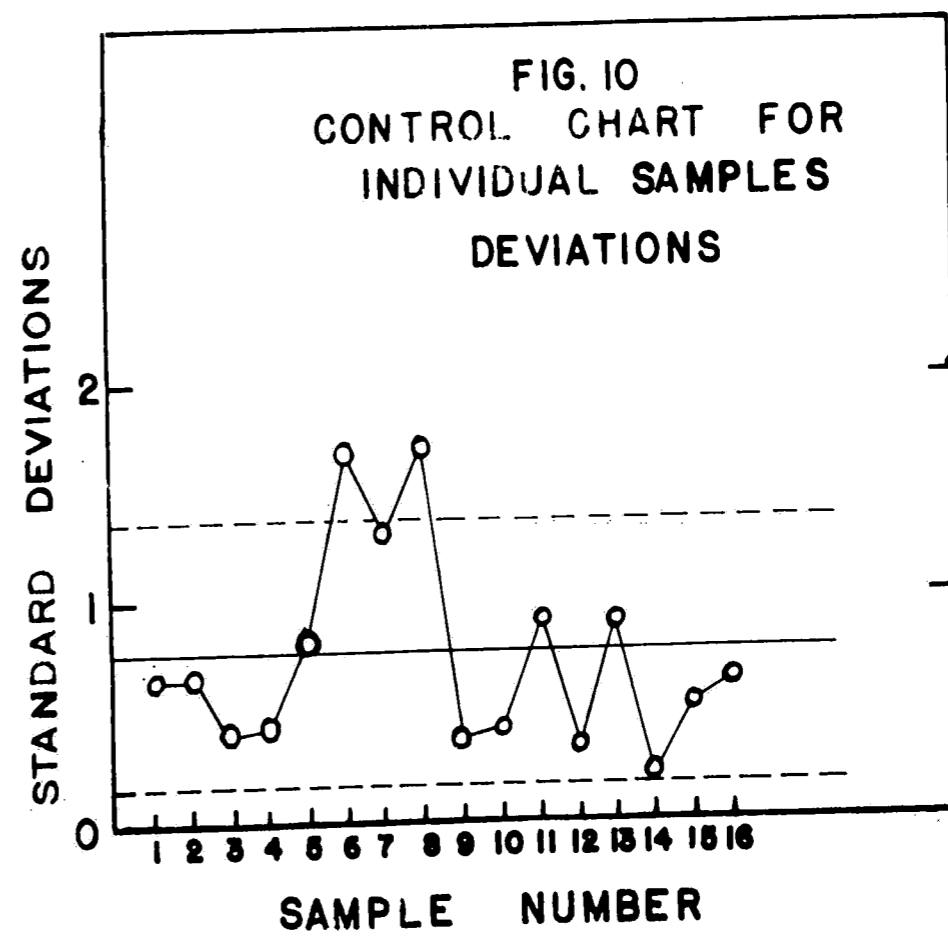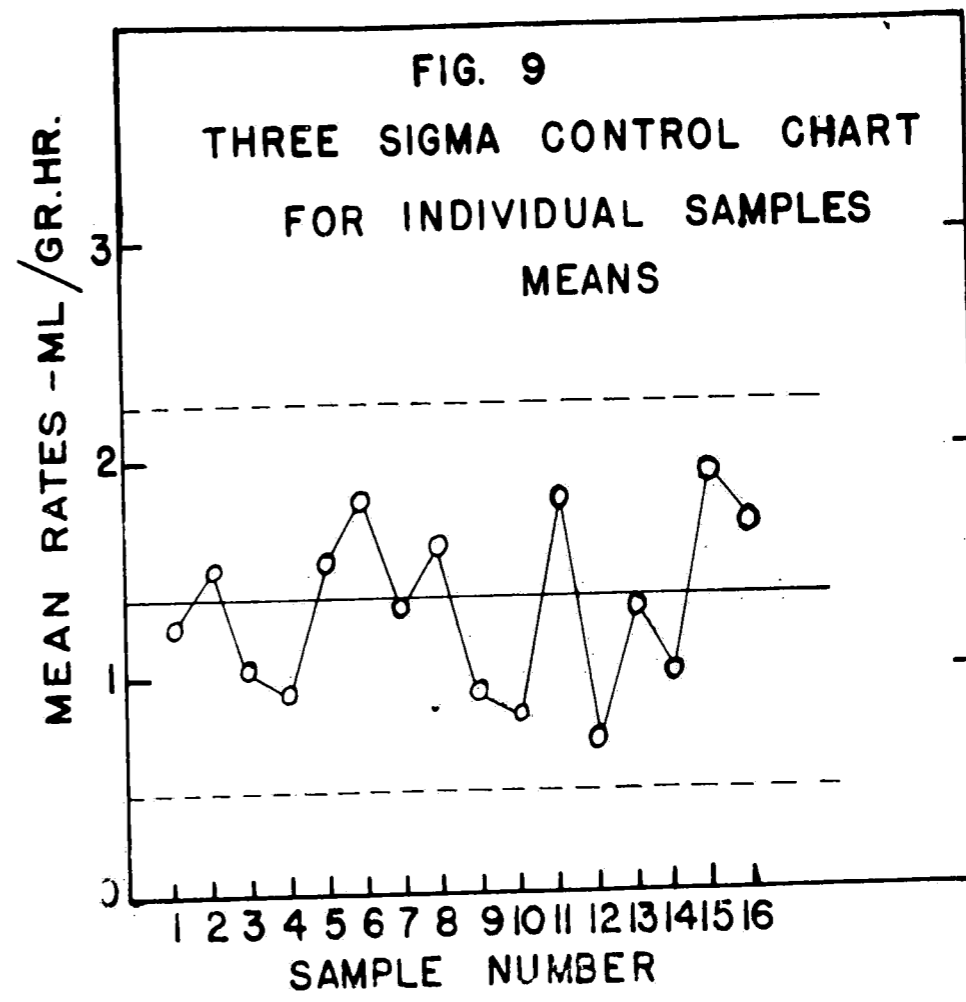
with the experimental error."[23] The value of t is found to be 0.389 (see calculation 2 in Appendix) and the value of the probability associated with this t is 0.705.[24] This means that a value of t as large as that found in this test would be expected to arise as often as seven times in ten, if there were no difference between the samples in the magnetic field and those outside of the field. Therefore, the effect of the field must be very small to have influenced the mean so little.

The grand average rate of 1.348 ± 22% is the average and ninety-nine percent confidence limit, expressed as the coefficient of variation, of the average. The ninety-nine percent confidence limit means that the range 1.348 ± 22% has the probability of including the true average rate ninety-nine times out of a hundred. The true average rate is the average of a large number of runs and may be separated from the absolute average rate because of some systematic error.

According to Whitman and Russel,[25] the reproducibility of corrosion studies is probably no better than twenty-five percent. Newton Friend stated, " . . . . rates of corrosion exhibit marked variation, which may amount to 100 percent, even when the experimental conditions appear to be identical."[26] Variations of twenty to thirty percent are not unusual in corrosion studies.

The control chart for the standard deviations within each sample shows that there is a lack of control in samples

6 and 8. This fact does not destroy the validity of the evidence given by the mean chart. Sample nos. 6 and 8 had very large initial rates which contributed greatly to the extra high standard deviations. The probable cause of these high initial rates was some unusual condition of the sample surface.

The average rate curve (Figure 11) is the average of all sixteen curves, and it is not a smooth function even though it is considerably better than the differential rate curves of the individual samples. Integration of the rate curve gives a fairly smooth curve (Figure 12). The equation of this averaged integral curve (Table 17) is of the form for most immersed corrosion curves and has some theoretical significance.[27]

High Temperature Run.

The data for the high temperature run is much better than the data at 20°C., because there are no chances for cumulative errors. Also, the sample surface anomalies which caused large deviations at 20°C. may not have had much influence at 65°C. Such an anomaly might be the presence of a slight amount of alcohol which would be quickly evaporated at 65°C. Notice that the coefficient of variation is around seven percent as opposed to twenty-eight percent for the lower temperature. There is no significant variation of the reaction rate in the magnetic field at 65°C.

FIG. 11

AVERAGE RATE VS TIME

FIG. 12

INTEGRAL OF
AVERAGE RATE
CURVE
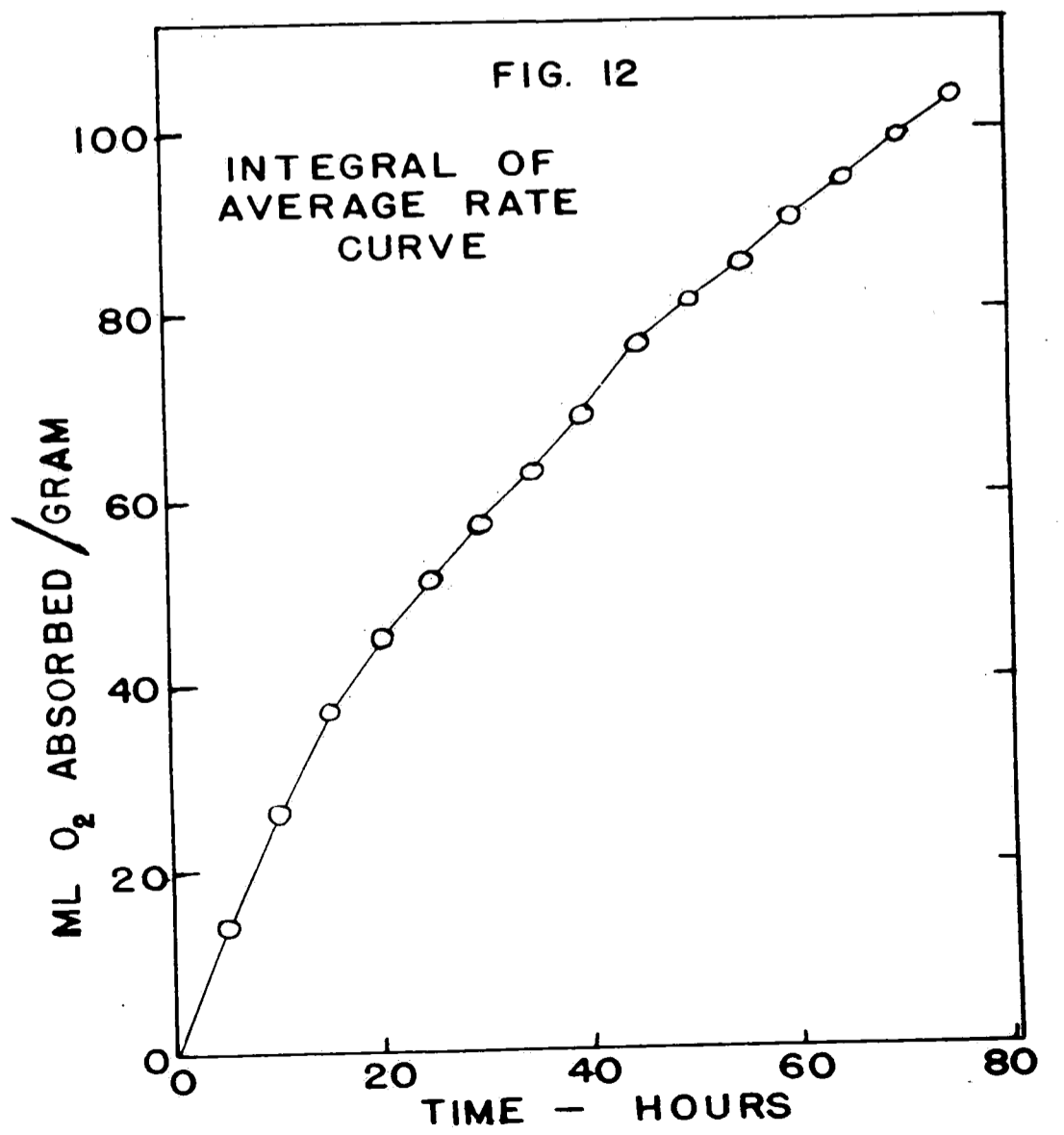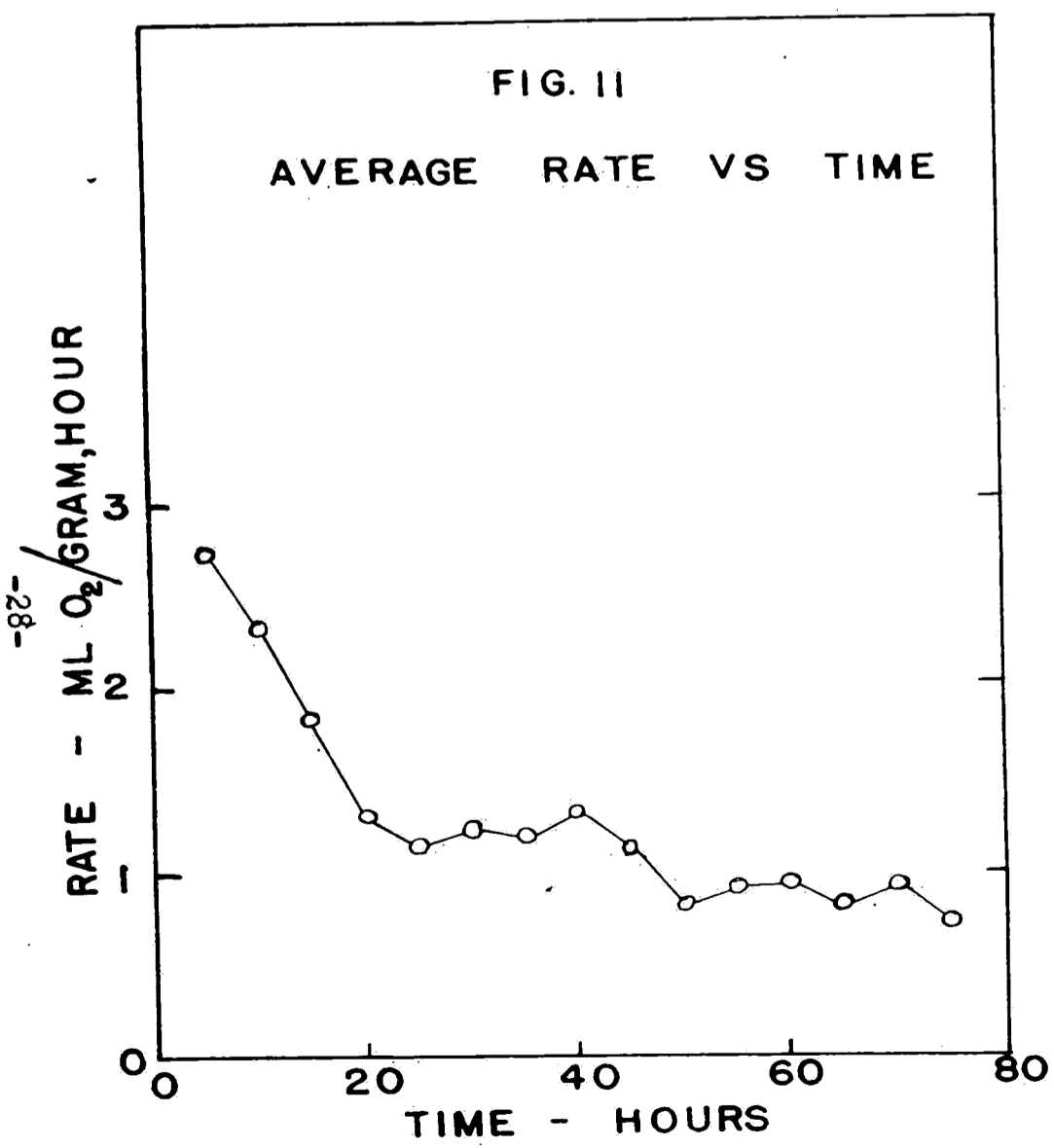
CONCLUSIONS

The conclusions are:

(1) All the means are significant.

(2) The average rate of corrosion of steel wool at $20^{\circ}C$. for the first seventy-five hours is $1.348 \pm 22\%$ ml O_2/gr.,hr. (v = 27.9%, P = .99, n = 16).

(3) The average of the four magnetic samples in a 19,200 gauss field is $1.281 \pm 52.6\%$ ml O_2/gr.,hr. (v = 15.6%, P = .99, n = 4).

(4) The average of the twelve non-magnetic samples is $1.370 \pm 28.4\%$ ml O_2/gr.,hr. (v = 30.3%, P = .99, n = 12).

(5) The difference between the averages could be expected to occur seven times in ten if there were no difference between the two groups.

(6) Any effect the magnetic field has on the corrosion rate is very small at $20^{\circ}C$. and at $65^{\circ}C$.

APPENDIX

DATA TAKEN AT 20°C.

TABLE 1

Run 1
Sample 1 - In Magnetic Field

Weight = 0.1396 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol. ml.(S.T.P.)/gram	Time Elements	Rate ml./gr./hr.
ml.	in.Hg	°C.	°C.		Hours	
0	29.310	–	–	0	0	–
1.90	29.360	–	20.8	10.90	9.08	1.220
2.20	29.390	–	20.5	13.48	4.75	2.830
1.20	29.345	–	20.2	8.25	5.67	1.460
1.05	29.320	–	19.95	0.97	5.00	1.400
2.20	29.410	–	20.2	13.37	13.95	0.960
1.46	29.380	–	19.5	8.93	9.78	0.913
2.65	29.495	–	18.95	14.33	14.48	0.991
0.00	29.470	–	19.7	1.93	8.73	0.221
2.39	29.631	–	20.2	13.72	21.15	0.651

75 hr.avg. = 1.250 ± .699

TABLE 2

Run 2
Sample 2 - Outside Magnetic Field

Weight = 0.1011 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol. ml.(S.T.P.)/gram	Time Elements	Rate ml./gr./hr.
ml.	in.Hg	°C.	°C.		Hours	
0				0	0	
1.47				14.50	5.70	2.540
1.50	The same			12.16	4.87	2.500
1.30		as in		12.29	5.58	2.190
0.83			Table 1	7.56	4.93	1.540
1.52				13.23	13.98	0.950
1.34				11.20	9.77	1.150
1.80				11.99	14.37	0.830
0.00				2.66	8.67	0.310
1.81				13.60	21.03	0.650

75 hr. avg. = 1.501 ± .694

TABLE 3

Run 1
Sample 3 - Outside Magnetic Field
Weight = 0.1568 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr./hr.}$
0				0	0	-
1.77				10.43	9.08	1.150
1.70	The same			9.03	4.75	1.900
1.11				6.83	5.67	1.210
0.85		as in		5.02	5.00	1.000
2.57				14.10	13.95	1.010
1.60			Table 1	8.78	9.78	0.896
2.80				13.61	14.48	0.943
0.00				1.72	8.73	0.197
3.98				21.61	21.15	1.025

75 hr. avg. = 1.038
± 0.445

TABLE 4

Run 1
Sample 4 - Outside Magnetic Field
Weight = 0.2128
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr/hr.}$
0				0	0	-
2.8				12.14	9.08	1.338
2.3	The same			9.25	4.75	1.945
1.02				4.62	5.67	0.816
0.88		as in		3.81	5.00	0.762
3.64				15.00	13.95	1.074
1.81			Table 1	7.36	9.78	0.754
2.99				10.86	14.48	0.753
0.40				2.99	8.73	0.343
3.57				14.10	21.15	0.669

75 hr. avg. = 0.972
± 0.445

TABLE 5

Run 2
Sample 5 - In Magnetic Field

Weight = 0.0734 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr.,hr.}$
0	-	-	-	0	0	-
0.61	29.665	24.8	20.25	7.70	2.47	3.12
2.02	29.641	23.4	20.1	25.80	12.28	2.10
0.90	29.690	25.4	19.4	7.01	6.87	1.02
1.30	29.671	23.6	20.2	20.00	16.14	1.24
0.89	29.722	24.8	19.3	6.10	2.41	2.53
0.00	29.638	26.1	19.5	3.78	9.25	0.41
1.89	29.673	24.4	19.8	23.68	13.18	1.80
0.57	29.616	26.2	19.2	7.06	6.32	1.12
0.00	29.587	26.0	19.8	3.23	5.50	0.59
1.55	29.659	26.0	20.4	19.13	15.30	1.25
0.57	29.602	26.4	19.8	7.05	2.70	2.61

75 hr. avg. = 1.547
± 0.854

TABLE 6

Run 2
Sample 6 - Outside Magnetic Field

Weight = 0.0731 grams
0.37 ml. (S.T.P.) H_2 evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr.,hr.}$
0				0	0	-
1.09				13.77	2.23	6.17
1.75	The same			22.40	12.30	1.82
0.50				1.95	6.84	0.29
0.80		as in		13.72	16.16	0.85
0.90				6.18	2.34	2.64
0.00			Table 5	3.78	8.75	0.43
0.87				10.80	13.20	0.82
0.88				10.98	6.23	1.76
0.43				8.64	5.54	1.56
1.00				12.23	15.28	0.80
0.22				2.64	2.63	1.01

75 hr. avg. = 1.804
± 1.700

DATA TAKEN AT 20°C.

TABLE 1

Run 1
Sample 1 – In Magnetic Field

Weight = 0.1396 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr./hr.}$
0	29.310	–	–	0	0	–
1.90	29.360	–	20.8	10.90	9.08	1.220
2.20	29.390	–	20.5	13.48	4.75	2.830
1.20	29.345	–	20.2	8.25	5.67	1.460
1.05	29.320	–	19.95	0.97	5.00	1.400
2.20	29.410	–	20.2	13.37	13.95	0.960
1.46	29.380	–	19.5	8.93	9.78	0.913
2.65	29.495	–	18.95	14.33	14.48	0.991
0.00	29.476	–	19.7	1.93	8.73	0.221
2.39	29.631	–	20.2	13.72	21.15	0.651

75 hr.avg. = 1.250 ± .699

TABLE 2

Run 2
Sample 2 – Outside Magnetic Field

Weight = 0.1011 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr./hr.}$
0				0	0	
1.47				14.50	5.70	2.540
1.50	The same			12.16	4.87	2.500
1.30		as in		12.29	5.58	2.190
0.83			Table 1	7.56	4.93	1.540
1.52				13.23	13.98	0.950
1.34				11.20	9.77	1.150
1.80				11.99	14.37	0.830
0.00				2.66	8.67	0.310
1.81				13.60	21.03	0.650

75 hr. avg.= 1.501 ± .694

TABLE 3

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
				ml.(S.T.P.)/gram	Hours	ml./gr./hr.
ml.	in.Hg	°C.	°C.			
0				0	0	-
1.77				10.43	9.08	1.150
1.70	The same			9.03	4.75	1.900
1.11				6.83	5.67	1.210
0.85		as in		5.02	5.00	1.000
2.57				14.10	13.95	1.010
1.60			Table 1	8.78	9.78	0.896
2.80				13.61	14.48	0.943
0.00				1.72	8.73	0.197
3.98				21.61	21.15	1.025

75 hr. avg. = 1.038 ± 0.445

TABLE 4

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
				ml.(S.T.P.)/gram	Hours	ml./gr./hr.
ml.	in.Hg	°C.	°C.			
0				0	0	-
2.8				12.14	9.08	1.338
2.3	Tne same			9.25	4.75	1.945
1.02				4.62	5.67	0.816
0.88		as in		3.81	5.00	0.762
3.64				15.00	13.95	1.074
1.81			Table 1	7.36	9.78	0.754
2.99				10.86	14.48	0.753
0.40				2.99	8.73	0.343
3.57				14.10	21.15	0.669

75 hr. avg. = 0.972 ± 0.445

TABLE 5

Run 2
Sample 5 – In Magnetic Field

Weight = 0.0734 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol. $\frac{ml.(S.T.P.)}{gram}$	Time Elements	Rate $\frac{ml.}{gr.,hr.}$
ml.	in.Hg	°C.	°C.		Hours	
0	-	-	-	0	0	
0.61	29.665	24.8	20.25	7.70	2.47	3.12
2.02	29.641	23.4	20.1	25.80	12.28	2.10
0.90	29.690	25.4	19.4	7.01	6.87	1.02
1.30	29.671	23.6	20.2	20.00	16.14	1.24
0.89	29.722	24.8	19.3	6.10	2.41	2.53
0.00	29.638	26.1	19.5	3.78	9.25	0.41
1.89	29.673	24.4	19.8	23.68	13.18	1.80
0.57	29.616	26.2	19.2	7.06	6.32	1.12
0.00	29.587	26.0	19.8	3.23	5.50	0.59
1.55	29.659	26.0	20.4	19.13	15.30	1.25
0.57	29.602	26.4	19.8	7.05	2.70	2.61

75 hr. avg. = 1.547 ± 0.854

TABLE 6

Run 2
Sample 6 – Outside Magnetic Field

Weight = 0.0731 grams
0.37 ml. (S.T.P.) H_2 evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol. $\frac{ml.(S.T.P.)}{gram}$	Time Elements	Rate $\frac{ml.}{gr.,hr.}$
ml.	in.Hg	°C.	°C.		Hours	
0				0	0	-
1.09				13.77	2.23	6.17
1.75	The same			22.40	12.30	1.82
0.50		as in		1.95	6.84	0.29
0.80			Table 5	13.72	16.16	0.85
0.90				6.18	2.34	2.64
0.00				3.78	8.75	0.43
0.87				10.80	13.20	0.82
0.88				10.98	6.23	1.76
0.43				8.64	5.54	1.56
1.00				12.23	15.28	0.80
0.22				2.64	2.63	1.01

75 hr. avg. = 1.804 ± 1.700

TABLE 7

Run 2
Sample 7 – Outside Magnetic Field

Weight = 0.0732 grams
No hydrogen evolved

Measured vol. ml.	Atm. Press. in.Hg	Atm. Temp. °C.	Cooling Water Temp. °C.	Corrected vol. $\frac{ml.(S.T.P.)}{gram}$	Time Elements Hours	Rate $\frac{ml.}{gr.,hr.}$
0				0	0	-
0.88				11.12	2.58	4.32
1.71	The same			21.90	12.32	1.78
0.62				3.50	6.80	0.52
0.93		as in		15.37	16.29	0.94
0.80				4.97	2.46	2.02
0.00			Table 5	-	-	-
1.02				16.50	21.90	0.75
0.30				3.67	6.25	0.59
- 0.40				- 1.82	5.57	- 0.33
1.19				14.64	15.22	0.96
0.32				1.17	2.55	0.46

75 hr. avg. = 1.328 ± 1.367

TABLE 8

Run 2
Sample 8 – Outside Magnetic Field

Weight = 0.0733 grams
0.185 ml.(S.T.P.) H_2 evolved

Measured vol. ml.	Atm. Press. in.Hg	Atm. Temp. °C.	Cooling Water Temp. °C.	Corrected vol. $\frac{ml.(S.T.P.)}{gram}$	Time Elements Hours	Rate $\frac{ml.}{gr.,hr.}$
0				0	0	-
1.15				14.54	2.67	5.53
2.14	The same			27.30	12.33	2.21
1.07				9.18	6.83	1.34
1.20		as in		18.78	16.20	1.15
0.80				4.96	2.46	2.02
0.00			Table 5	-	-	-
0.54				10.41	21.85	0.48
0.63				7.84	6.17	1.27
- 0.70				- 5.57	5.59	- 0.999
1.00				12.21	15.26	0.801
0.13				1.52	2.37	0.642

75 hr. avg. = 1.623 ± 1.748

TABLE 9

Run 3
Sample 9 - In Magnetic Field

Weight = 0.0965 grams
0.175 ml. (S.T.P.) H_2 evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	ml.(S.T.P.)/gram	Hours	ml./gr.,hr.
0	-	-	19.7	0	0	-
0.74	29.602	26.4	20.3	18.2	4.75	1.491
1.84	29.663	25.1	20.1	30.4	9.92	1.552
1.00	29.638	27.4	19.9	17.7	8.86	1.096
0.62	29.654	27.0	20.3	10.5	5.39	1.118
1.15	29.666	25.6	20.5	20.1	10.58	1.065
0.26	29.542	27.5	20.6	7.9	7.72	0.665
0.44	29.508	27.2	20.65	7.7	6.70	0.788
1.07	29.500	26.8	20.7	14.9	11.36	1.026
0.50	29.467	27.5	20.75	5.1	8.09	0.101
2.40	29.567	25.4	20.3	28.9	16.30	1.365

75 hr. avg. = 0.989 ± 0.411

TABLE 10

Run 3
Sample 10 - Outside Magnetic Field

Weight = 0.0986 grams
0.832 ml. (S.T.P.) H_2 evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	ml.(S.T.P.)/gram	Hours	ml./gr.,hr.
0				0	0	-
0.71				6.64	4.75	1.396
1.74	The same			14.15	10.00	1.415
1.00				9.51	8.70	1.093
0.75		as in		7.69	5.52	1.391
0.85				8.18	10.36	0.789
0.29			Table 9	5.29	7.87	0.672
0.26				3.49	6.78	0.515
0.47				5.77	11.39	0.507
0.44				0.23	8.05	0.029
1.64				14.62	16.33	0.895

75 hr. avg. = 0.8678 ± 0.459

TABLE 11

Run 3
Sample 11 – Outside Magnetic Field

Weight = 0.0937 grams
Measurement of H_2 not made

Measured vol. ml.	Atm. Press. in.Hg	Atm. Temp. °C.	Cooling Water Temp. °C.	Corrected vol. $\frac{ml.(S.T.P.)}{gram}$	Time Elements Hours	Rate $\frac{ml.}{gr.,hr.}$
0				0	0	–
1.84				18.2	4.92	3.70
3.31	The same			30.4	9.98	3.05
1.78				17.7	8.39	2.15
1.00		as in		10.5	5.63	1.87
1.80				20.1	10.23	1.96
0.53			Table 9	7.9	8.00	0.99
0.67				7.7	6.80	1.13
1.36				14.9	11.37	1.31
0.93				5.1	8.08	0.63
3.04				28.9	16.25	1.78

75 hr. avg. = 1.866 ± 0.940

TABLE 12

Run 3
Sample 12 – Outside Magnetic Field

Weight = 0.0956 grams
0.305 ml. (S.T.P.) H_2 evolved

Measured vol. ml.	Atm. Press. in.Hg	Atm. Temp. °C.	Cooling Water Temp. °C.	Corrected vol. $\frac{ml.(S.T.P.)}{gram}$	Time Elements Hours	Rate $\frac{ml.}{gr.,hr.}$
0				0	0	–
0.72				6.90	4.92	1.400
1.59	The same			13.12	9.98	1.318
0.75				7.41	8.39	0.885
0.22		as in		2.82	5.63	0.502
0.68				6.81	10.23	0.665
– 0.14			Table 9	1.31	8.00	0.164
0.43				5.25	6.80	0.773
0.60				7.20	11.37	0.635
0.56				1.39	8.08	0.172
2.18				20.30	16.25	1.250

75 hr. avg. = 0.724 ± 0.398

TABLE 13

Run 4
Sample 13 - In Magnetic Field

Weight = 0.0946 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
				$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr.,hr.}$
ml.	in.Hg	°C.	°C.			
0	29.528	26.2	20.3	0	0	-
1.60	29.505	25.9	20.4	16.30	5.92	3.755
1.65	29.386	24.1	20.3	19.79	13.38	1.479
0.75	29.404	24.6	20.4	6.56	4.87	1.350
0.79	29.449	23.5	20.1	6.76	5.41	1.250
1.97	29.519	24.0	19.6	16.45	13.34	1.232
0.46	29.479	25.0	20.3	4.21	5.61	0.750
0.15	29.532	24.6	20.2	1.95	5.66	0.344
0.53	29.437	24.4	20.1	7.54	12.25	0.615
1.15	29.408	25.2	20.1	11.77	9.25	1.271

75 hr. avg. = 1.338
±0.930

TABLE 14

Run 4
Sample 14 - Outside Magnetic Field

Weight = 0.0932 grams
No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
				$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr.,hr.}$
ml.	in.Hg	°C.	°C.			
0				0	0	-
0.80				8.60	5.92	1.451
0.57	The same			9.30	13.38	0.695
0.61				5.26	4.87	1.080
0.78		as in		6.76	5.41	1.249
1.25				9.59	13.34	0.719
0.65			Table 13	6.15	5.61	1.095
0.64				6.84	5.66	1.206
0.50				7.35	12.25	0.600
0.90				9.46	9.25	1.023

75 hr. avg. = 1.013
±0.269

TABLE 15

Run 4   Weight = 0.0934 grams
Sample 15 - Outside Magnetic Field   No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr.,hr.}$
0				0	0	-
1.21				12.67	5.92	2.140
2.67	The same			30.15	13.38	2.255
0.89				8.05	4.87	1.652
1.57		as in		14.60	5.41	2.695
3.00				26.90	13.34	2.020
0.92			Table	8.84	5.61	1.573
0.77				8.14	5.66	1.435
1.21			13	14.39	12.25	1.172
2.61				26.45	9.25	2.863
					75 hr. avg. = 1.969 ± 0.540	

TABLE 16

Run 4   Weight = 0.0967 grams
Sample 16 - Outside Magnetic Field   No hydrogen evolved

Measured vol.	Atm. Press.	Atm. Temp.	Cooling Water Temp.	Corrected vol.	Time Elements	Rate
ml.	in.Hg	°C.	°C.	$\frac{ml.(S.T.P.)}{gram}$	Hours	$\frac{ml.}{gr.,hr.}$
0				0	0	-
1.489				16.05	5.92	2.710
1.340	The same			17.40	13.38	1.301
0.601				5.45	4.87	1.118
1.008		as in		9.50	5.41	1.755
2.155				19.59	13.34	1.467
0.979			Table	9.85	5.61	1.754
0.694				7.65	5.66	1.351
1.146			13	14.16	12.25	1.156
2.660				28.01	9.25	3.040
					75 hr. avg. = 1.739 ± 0.650	

TABLE 17

AVERAGED RATE CURVE

Time Hours	Average Rate $\frac{ml.}{gr.,hr.}$	Integrated Rate $\frac{ml.}{gr.}$	Calculated Integral Rate* $\frac{ml.}{gr.}$	Percent Deviation
0	-	0	0	0
5	2.71	14	12.0	14.3
10	2.31	26.5	23.1	12.8
15	1.84	37.4	33.0	11.7
20	1.30	45.4	42.4	6.6
25	1.18	51.4	50.6	1.6
30	1.24	57.5	58.5	1.7
35	1.20	63.6	65.5	2.7
40	1.32	69.9	71.9	2.9
45	1.12	76.3	77.6	1.7
50	0.828	81.2	83.0	2.3
55	0.929	85.7	88.0	2.7
60	0.954	90.5	92.6	2.3
65	0.833	95.0	96.5	1.6
70	0.931	99.5	100.0	0.5
75	0.745	103.7	103.7	0.0

Avg. = 1.380   Avg. % dev. = 4.05%

* $y = 140 \left(1-e^{-0.018t}\right)$ t is in hours, y is in ml./gr.

TABLE 18

THREE SIGMA CONTROL CHART DATA
for
GROUP MEANS

Group	Mean $\bar{x}$	Standard Deviation of Means	Number in Sample
1	1.190	0.205	4
2	1.576	0.172	4
3	1.112	0.450	4
4	1.515	0.614	4

Avg. = 1.348   Avg.= 0.362

3σ limits:* $\bar{\bar{x}}_m \pm A_1 \bar{\sigma}_m = 1.348 \pm 1.88(.362)$

$$= 1.348 \pm 0.680$$

$\bar{\bar{\sigma}}_m : B_3 \bar{\sigma}_m , \ B_4 \bar{\sigma}_m$

$0 , (2.266)(0.3615)$

$0 , 0.819$

*-Asterisk: See Item 22 in Bibliography.

TABLE 19

THREE SIGMA CONTROL CHART DATA
for
GROUP DEVIATIONS

Group	Mean $\bar{x}$	Standard Deviation of Sigmas	Number in Sample
1	0.573	0.128	4
2	1.417	0.353	4
3	0.870	0.149	4
4	0.657	0.724	4

Avg.0.879   Avg. .328

3σ limits: $\bar{\bar{x}} = .879 \pm .619$

$\bar{\bar{\sigma}}_m = 0, .745$

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TABLE 20

THREE SIGMA CONTROL CHART DATA
for
INDIVIDUAL MEANS

Sample Number*	Mean	R.M.S. Deviation	Number in Sample
1	1.250	0.699	8
2	1.501	0.694	8
3	1.038	0.445	8
4	0.972	0.455	8
5	1.547	0.854	9
6	1.804	1.700	9
7	1.328	1.367	8
8	1.623	1.748	8
9	0.989	0.411	9
10	0.868	0.459	9
11	1.866	0.940	9
12	0.724	0.398	9
13	1.338	0.930	9
14	1.013	0.269	9
15	1.969	0.540	9
16	1.739	0.650	9

Avg. = 1.348   Avg. = 0.785
±0.378

3σ limits: $\bar{\bar{x}}_m \pm A_1 \bar{\sigma}_m = 1.348 \pm .858$

$\bar{\bar{\sigma}}_m = 0.187, 1.381$

* <u>Asterisk</u>: Nos. 1,5,9, and 13 are magnetic samples.

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TABLE 21

DATA FOR HIGH TEMPERATURE RUN

Sample Number	Weight in grams	Weight Out grams	Time hours	Rate gr./gr.,hr.	Rate ml./gr.,hr.
1	0.0982	0.1049	13.75	0.00496	3.48
2	0.0956	0.1011	13.75	0.00418	2.93
3	0.1109	0.1185	13.75	0.00500	3.50
4	0.0973	0.1037	13.75	0.00478	3.34

Avg. = 3.312
± 0.229

TABLE 22

99 PERCENT CONFIDENCE LIMITS FOR IMPORTANT MEANS

Name	Mean $\frac{ml.}{gr.,hr.}$	99% Confidence Limits $\frac{ml.}{gr.,hr.}$	R.M.S. Deviation $\frac{ml.}{gr.,hr.}$	Number in Sample
Grand total mean	1.348	± 0.288	± 0.373	16
Non-magnetic sample	1.370	± 0.388	± 0.415	12
Magnetic Samples	1.281	± 0.674	± 0.200	4
65°C. mean	3.312	± 0.772	± 0.229	4

TABLE 23

STEEL WOOL SAMPLE

Analysis:*

$$C = 0.29 - 0.30\%$$

$$Mn = 0.60\%$$

$$P = 0.058\%$$

$$S = 0.026\%$$

$$Si = 0.10\%$$

General History:

An open hearth steel which has been cold drawn into a wire. The wire is shaved to produce Grade No. 0 steel wool. The wool is a product of James H. Rhodes & Company of New York. This wool is made to Federal specification FF-W-556.

* Through the courtesy of Bethlehem Steel Company

SAMPLE CALCULATIONS

The calculations involved in converting the experimental data into useful quantities involve two formulae -- one to convert the measured volume change into standard temperature, pressure and volume; the other formula to account for the change in pressure and temperature from one measurement to the next. The formulae are:

$$(1) \quad V_M \left(\frac{T_0}{T_M} \frac{P_M}{P_0} \right) = V_{S.T.P.} = 0.914 \frac{P}{T_M} V_M$$

where the subscript m stands for the measured quantity.

$$(2) \quad \Delta V = \Delta N \, R \, T_0 / P_0 = -776 \left(\frac{P_2}{T_2} - \frac{P_1}{T_1} \right)$$

where the subscript 1 refers to the preceding measurement and the subscript 2 refers to the most recent measurement.

Calculation of the first volume change for sample number one is shown:

CALCULATION 1

Measured vol.	Vol. Corrected to s.t.p.	$\left[(-776) \left\{ \left(\frac{P}{T} \right)_2 - \left(\frac{P}{T} \right)_1 \right\} \right]_{=1}$	Total of Corrections	Corrected vol./sample wt.
ml.	ml.	ml.	ml.	ml./gr.
1.9	1.758	-0.237	1.521	10.90

CALCULATION 2

t-Test for Comparison of Means.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where $\bar{x}_1$ = first mean

x_2 = second mean

n_1 = number in first mean

n_2 = number in second mean

$$S = \sqrt{\frac{\Sigma(x_1 - \bar{x}_1)^2 + \Sigma(x_2 - \bar{x}_2)^2}{n_1 + n_2 - 2}}$$

Sample No.	x_1	$x_1 - \bar{x}$	$(x_1 - \bar{x})^2$		Sample No.	x_2	$x_2 - \bar{x}_2$	$(x_2 - \bar{x}_2)^2$
					1	1.250	-0.031	0.00096
2	1.501	0.131	.01716		5	1.547	.266	0.07076
3	1.038	- .332	.11022		9	0.989	- .292	0.08526
4	0.972	- .398	.15840		13	1.338	.057	0.00325
6	1.804	.434	.18836					
7	1.328	- .042	.00176			4)5.124		Sum 0.16023
8	1.623	.253	.06401					
10	0.868	- .502	.25200			Avg. 1.281 = $\bar{x}_2$		
11	1.866	.496	.24602					
12	0.724	.646	.41732					
14	1.013	- .357	.12745					
15	1.969	.599	.35880					
16	1.739	.369	.13616					

12)16.445   Sum 2.07766

Avg. 1.3704 = $\bar{x}_1$

2.07766
0.16023
─────────
2.23789

$$s = \sqrt{\frac{2.23789}{12 + 4 - 2}} = .399$$

$$t = \frac{1.3704 - 1.2810}{0.399\sqrt{\frac{1}{12} + \frac{1}{4}}} = 0.389$$

degrees of freedom = $n_1 + n_2 - 2 = 14$

t for P = .705 is 0.389; Therefore, the probability of having the means differ by 0.089 is 0.705.

CALCULATION 3

Calculation of the Strength of the Magnetic Field.

Measured Quantities:

D. C. Voltage - 129 volts = V

Resistance - 11.6 ohms = R

Turns - 2950 turns = N

Gap - 27/32 inch = l

$$m.m.f. = 1.257 \frac{NV}{R} = 1.257 \times \frac{129}{11.6} \times 2950$$

$$= 41,300 \text{ gilberts}$$

$$H = \frac{m.m.f.}{l} = \frac{41,300}{\frac{27}{32} \times 2.54} = 19,200 \text{ gausses.}$$

CALCULATION 4

Three Sigma Control Chart Calculations.

For Group Means – See Table 18.

The mean of the four groups is 1.348 and the mean of the standard deviations of the four groups is 0.362. The three sigma control limits are placed about the mean of the groups by the formula $\bar{\bar{x}}_m \pm A_1 \bar{\sigma}_m$ where $\bar{\bar{x}}_m$ is the mean of the four groups, A_1 is a constant, and $\bar{\sigma}_m$ is the average of the standard deviations of the four groups. Since there are four items in the average $\bar{\bar{x}}_m$, the value of A_1 is found in the A.S.T.M. Manual on Quality Control[22] to be 1.88. The three sigma control limits on the group means are therefore $1.348 \pm 1.88(0.362)$.

The variations within the four means are tested with the three sigma control chart for standard deviations. The limits are defined[22] by $B_3 \bar{\sigma}_m$ and $B_4 \bar{\sigma}_m$, and for the case with four items in the means B_3 is zero and B_4 is 2.266. Therefore, the three sigma control limits for the standard deviations within the means are $0(0.362)$ and $2.266(0.362)$ which are 0 and 0.819.

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