MECHANICS OF THE CAMBERED BRAKE-BEAM.

BY IRVING P. CHURCH, C.E., ITHACA, N. Y.

By "brake-beam," in this paper, will be understood the *trussed* beam shown in diagrammatic form in *Fig. 3*, consisting of a prismatic bar or beam AOB , a short post or strut, OD , and two prismatic tie-rods or tension-members, GD and $G'D$, meeting the post at the joint D . By "cambering" this brake-beam is meant forcing together the extremities B and G (and A and G') until they meet, and permanently fastening them in this position. In the assumption of this constrained form the elastic limit is not supposed to be passed in any member. This constrained or "cambered" form is shown by the full continuous lines in *Fig. 4*, in which the vertical dimensions of the whole frame, and the amount of bending of the bar AOB , are much exaggerated.

This state of initial constraint, brought about before the brake-beam is put to use, occasions a certain initial tensile force (T_0) in each of the tie-rods, and a thrust (Q_0) in the post, and subjects the bar AB to combined flexure and thrust. It is the object of this paper to determine the stresses induced in the various members of the brake-beam when employed in pressing the brake-shoes at its extremities against the car wheels; and also the deflection of the middle point, C , at the same instant.

As preliminary to the final object, it will be necessary to recall certain relations between the various quantities concerned in the case of an elastic prismatic bar of homogeneous material under combined flexure and thrust, as shown in *Fig. 1*. Let the length of the bar (originally straight) be $2l$, and let it be pressed against a single support B , at the middle, by two oblique equal forces, P and P , applied at the extremities O and O' , at equal angles α with the tangent line drawn at B to the elastic curve thus produced. Let the sectional area be F square inches, the modulus of elasticity of the material E pounds per square inch, and the moment

of inertia of the cross-section I (referred to an axis containing its center of gravity and perpendicular to the plane of flexure), and Q pounds the reaction of the support.

$$\text{Evidently } Q = 2 P \sin. a \quad (1)$$

According to the ordinary and well-known theory, the bar will be shortened by an amount

$$2 c, \text{ where } c = \frac{(P \cos. a) l}{F E} \quad (2)$$

while the deflection d (see figure), unless the angle a is very small, is given by the formula

$$d = \frac{(P \sin. a) l^3}{3 E I} \quad (3)$$

We note in the figure that the right-hand extremity of the bar has been displaced a distance c longitudinally, and a distance d laterally, from its original position A . A similar statement, holds, of course, for the other extremity.

FIG. 1.

FIG. 2.

[NOTE A.—It will doubtless be of interest to mention more exact relations in connection with the bar in *Fig. 1*, for the benefit of those who would like to follow up the matter with greater theoretical accuracy.

A more exact expression for the deflection d can be obtained by treating the elastic curve OB according to a method similar to that outlined on p. 545 of Professor Bovey's "Theory of Structures," for an obliquely loaded and bracketed column; that is, by writing the bending moment, or "moment of stress-couple," at any section $= (P \sin. a) x + (P \cos. a) y$, instead of $(P \sin. a) x$.

This leads finally to the form

$$d = (\tan. a) \left[\sqrt{\frac{EI}{P \cos. a}} \cdot \tan. \left(l \sqrt{\frac{P \cos. a}{EI}} \right) - l \right] \quad (3a)$$

Incidentally, it may be remarked that if the angle α were zero, the deflection d would also be zero, *unless*

$$\tan \left(l \sqrt{\frac{P}{EI}} \right)$$

were infinite, in which case d would be indeterminate, but

$$l \sqrt{\frac{P}{EI}}$$

would have to be

$$= \frac{1}{2} \pi, \text{ or } \frac{3}{2} \pi, \text{ or } \frac{5}{2} \pi, \text{ etc.}$$

In other words, we are led to Euler's formula for a slender column.

(If α were greater than 90° , we should have the case of combined flexure and tension treated on pp. 356, etc., of the writer's "Mechanics of Engineering." This case is also given by Prof. James MacMahon, in his chapter on "Hyperbolic Functions," in Merriman and Woodward's "Higher Mathematics." The result for the deflection in this latter treatment (p. 152) is very nearly the same in form as in Equation (3a) above, but contains, instead of

$$\tan. \left(l \sqrt{\frac{P \cos. \alpha}{EI}} \right)$$

the hyperbolic tangent of

$$\left(l \sqrt{\frac{P \cos. (\pi - \alpha)}{EI}} \right)$$

where α still refers to *Fig. 1* of this paper, but is greater than 90° .)

Besides the longitudinal shortening $2c$ of the bar, as due to the thrust component $P \cos. \alpha$, we ought more strictly to consider what might be called a "longitudinal deflection," as illustrated in *Fig. 2*, where a case of pure flexure is shown, the forces P' and P' being perpendicular to the bar. The extremity of the bar having been displaced from O' to O during the gradual increase of the force P' from a zero value, $O'B$ being tangent to the elastic curve at B , the middle of bar, we note on drawing $O'V$ perpendicu-

lar to $O'B$ that a displacement $O'V$ of the extremity has occurred in the direction of the length of the bar, and this we may call a "longitudinal deflection" of extremity, due to the curvature of BO , and not to thrust. The value of this distance $O'V$, $= d''$, can be obtained by a consideration and application of the properties of a curved beam or elastic arch, and is

$$d'' = \frac{1}{15} \cdot \frac{P'^2 l^5}{E^2 I^2} \quad (3b)$$

To avoid complexity in what follows, the stricter relations mentioned in this note will not be observed. The effect of shearing stresses in influencing deflection will also be neglected.]

To determine the initial stresses in the brake-beam, *i. e.*, those due to camber, let us consider *Fig. 3*, which shows in

FIG. 3.

full continuous lines the bar, the post, and the two tie-rods, *under no strain*. For the bar, let the sectional area, its moment of inertia and the modulus of elasticity be denoted by F , I , and E , respectively, and the half length by l . Similarly, for each tie-rod we have F_1 , E_1 , and $l_1 (= DG)$. Conceive a circle to be struck with center at D and radius $= DG$. Denote the difference between the lengths DG and DB by λ ; that is, λ is the amount by which each tie-rod is too short to reach the extremity of the bar without inducing stress. In the production of the camber, the post, which is short and for local reasons is often made very thick, is considered as remaining unchanged in length.

When the ends of the tie-rod and bar on the right (and simultaneously on the left) are forcibly brought together (by screwing up a nut, for instance), they will be found at

some point B' . The end B of the bar has been displaced sideways a distance d ; and also displaced longitudinally a distance c , due to the thrust $T_o \cos. \beta$, T_o being the tensile force induced in the tie-rod; while the tie-rod itself becomes elongated by an amount c_o dependent on T_o . Between the quantities concerned we now have the following relations, from the principles of "Mechanics of Materials:"

$$d = \left(\frac{l^3}{3EI} \right) T_o \sin. \beta = R T_o \sin. \beta \quad (4)$$

$$c = \left(\frac{l}{FE} \right) T_o \cos. \beta = N T_o \cos. \beta \quad (5)$$

$$c_o = \left(\frac{l_1}{F_1 E_1} \right) T_o = N_1 T_o \quad (6)$$

(for brevity's sake R , N and N_1 are used instead of the factors which they are seen to replace); and also, since the sum of the projections of d , c and c_o upon the line joining B and D must equal λ ,

$$c_o + c \cos. \beta + d \sin. \beta = \lambda \quad (7)$$

So far as its use in the analysis of this paper is concerned, the angle between the tie-rod and the tangent-line at middle point O of the bar, is not supposed at any time to vary appreciably from a fixed value, which will be called β . Given all the quantities in these four equations except d, c, c_o and T_o , these last-named can be easily determined; or, if d is known by actual measurement, we do not need to know λ , but can determine T_o directly from equation (4).

We are now ready to consider the cambered brake-beam when subjected to external forces in service. These external forces are the pressure on its middle point, $2W$, and the two reactions, W and W , one from each brake-shoe; see *Fig. 4*, in which the vertical dimensions and the degree of distortion are much exaggerated to secure clearness in demonstration.

The continuous full lines $A O B D O$ in *Fig. 4*, represent the brake-beam in its cambered condition, with its extremities or joints A and B just touching the brake-shoes (and the latter the wheels), but as yet not under external pressures. As

the pressure $2W$ is gradually applied (*i. e.*, increased gradually from a value of zero to a value of $2W$) the joints A and B experience corresponding pressures increasing to a final value of W at each joint. The dotted lines $A'O'B'D'$ show the members of the brake-beam in their final form and position under the system of three external forces, $2W$, W and W . (It may be that the pressure $2W$ is applied at a point along the length of the post and not at its upper end, but this will not affect the analysis, since the $2W$ would still be a force external to the frame-work or truss.) In reaching this final (dotted) position the joint O has moved through the distance OO' , or "deflection of the

FIG. 4.

brake-beam," which we may call δ . The lower end of the post has moved through an equal parallel distance δ (since the post does not shorten), while the joint B has moved along a line perpendicular to the post to a new position B' and (similarly, A to A' on the left).

As auxiliary lines, draw BB'' equal and parallel to δ and join $D'B''$; draw at O' a tangent line to the elastic curve of the bar, and verticals through B and B' . Let $O'B_0$ represent the unstrained length of the half-bar OB . Describe the short arc $B''K'$ with D' as center. $K'B$ may be considered a straight line and perpendicular both to $D'B'$ and to $D'B''$. Also draw BK perpendicular to $B''K'$.

Before application of the pressure $2W$, the deflection of the bar AB was $=d, = OM$, and the oblique force at its extremity B was T_0 , at an angle β with MB . After application of $2W$, the oblique force acting on the extremity B' of the bar is the resultant P of the new tension T now acting in the tie-rod, and the reaction W ; and the deflection of the bar is $d' = O'M$. P makes some angle α (smaller than β) with MB , but need not be dealt with directly, being fully represented by its two components T and W , in their respective positions; see *Fig. 4*. It is now required to determine both T and δ .

When the bar AB was under initial stress only, the shortening of the half bar was c , and the thrust producing it was $T_0 \cos. \beta$, while the force producing deflection was $T_0 \sin. \beta$; whereas, after the application of $2W$, the shortening of the half-bar is c' , the corresponding thrust is $T \cos. \beta$, and the force producing deflection is $T \sin. \beta - W$.

Again, the difference between the lengths $D'B''$ (i. e., DB) and $D'B'$, in other words the distance $B'K'$, is the excess of the elongation produced in the tie-rod by tension T over and above that due to T_0 .

We are thus enabled to write [referring to equations (4), (5) and (6) for the significance of N, N_1 and R]

$$\left. \begin{aligned} c &= N T_0 \cos. \beta; \quad c' = N T \cos. \beta; \quad d = R T_0 \sin. \beta; \\ d' &= R (T \sin. \beta - W); \quad \text{and } \overline{B'K'} = N_1 (T - T_0). \end{aligned} \right\} \quad (8)$$

We also note that the distance $BB' = c' - c$, i. e.,

$$\overline{BB'} = N (T - T_0) \cos. \beta \quad (9)$$

Projecting BB' and $B'K'$ upon BK , we find that BK , which is $\overline{BB''} \sin. \beta$, is made up of $\overline{B'K'}$ and $\overline{BB'} \cos. \beta$, that is [see equations (8) and (9)]

$$\delta \sin. \beta = (T - T_0) [N_1 + N \cos.^2 \beta] \quad (10)$$

In *Fig. 4* it is evident that $\overline{OO'}$, or δ , the deflection of middle of brake-beam, is equal to the difference between OM and $O'M$; that is, between the value d , of the deflection of the bar AB under initial cambering strain only, and that d'

of its deflection under final strain, which leads us, after noting the values in equations (8), to the relation

$$\delta = d - d' \text{ or}$$

$$\delta = R [W - (T - T_0) \sin. \beta] \quad (11)$$

If, now, we solve equation (10) for δ and equate the result to the right-hand member of (11), we obtain for the value of T the tension in the tie-rod [after restoring the terms represented by N , N_1 , and R , as evident in equations (4), (5) and (6)]

$$T = T_0 + \frac{\left(\frac{l^3}{3EI}\right) W \sin. \beta}{\frac{l_1}{F_1 E_1} + \frac{l \cos.^2 \beta}{F E} + \frac{l^3 \sin.^2 \beta}{3EI}} \quad (12)$$

This value for T being substituted in equation (10) we determine the deflection of the middle point of the brake-beam under the pressure $2W$ to be

$$\delta = \frac{\frac{l^3}{3EI} \left[\frac{l_1}{F_1 E_1} + \frac{l \cos.^2 \beta}{F E} \right] W}{\frac{l_1}{F_1 E_1} + \frac{l \cos.^2 \beta}{F E} + \frac{l^3 \sin.^2 \beta}{3EI}} \quad (13)$$

In most ordinary cases of metallic brake-beams the last term in the denominator of (13) is so large compared with the first two that the omission of the latter occasions but slight error. Calling these two terms zero, then, we have for the case mentioned

$$\delta = \left[\frac{l_1}{F_1 E_1} + \frac{l \cos.^2 \beta}{F E} \right] \frac{W}{\sin.^2 \beta} \quad (13a)$$

If there were originally no camber in the bar AB , we should have $T_0 = 0$, and the tension T for a given $2W$ would be correspondingly less, but the value of δ would not be affected; in other words, the brake-beam would be no stiffer with a camber than without, except as there might be some looseness at the joints due to faulty workmanship, if there were no camber. (A conclusion different from this might perhaps be reached if the stricter considerations of "Note A" in the first part of this paper were carefully fol-

lowed out.) However, initial camber is doubtless of utility in reducing the bending action on the bar AB , making the character of the final stress upon it almost purely a thrust, and thus rendering possible some economy in material; in other words, if a brake-beam of given dimensions is to be subjected to a given pressure $2W$ at the middle when in service, a certain initial camber can be assigned, such that the bar becomes practically straight when the pressure is applied, *i. e.*, becomes a column, or simple compression-member. This means simply that δ is to be equal to d in Fig. 4, or that $d' = 0$.

Making, therefore, $\delta = d = R T_o \sin. \beta$ from equation (8), we have

$$T_o = \frac{\left[\frac{l_1}{F_1 E_1} + \frac{l \cos.^2 \beta}{F E} \right] \frac{W}{\sin. \beta}}{\frac{l_1}{F_1 E_1} + \frac{l \cos.^2 \beta}{F E} + \frac{l^3 \sin.^2 \beta}{3 E I}} \quad (15)$$

as a special condition for this case. Having solved (15) for T_o in any numerical instance, we can then compute the corresponding value for d from equation (8), and camber the brake-beam accordingly. The final thrust produced in the bar AB will then be $T \cos. \beta$, which $= W \cotan. \beta$ [since d' is to be zero; see equation (8)].

[NOTE B.—The expression for T in equation (12) is identical with that derived by G. P. Ritter, C.E., who has used Castigliano's method of Least Work, in a thesis on the metallic brake-beam, written during his Senior year ('96-'97) in the College of Civil Engineering at Cornell University. Mr. Ritter applied this method as adapted by Castigliano to the case of a framework under initial stress.

This identity was to be expected, since in both treatments the consideration of shearing stresses is omitted and the bending moment in the bar AB is assumed to be independent of the thrust component at the extremity.

The present writer has also applied a modification of Castigliano's other theorems, involving the "derivatives of internal work," and obtained a value for δ the same as that given in equation (13). Castigliano gives no direct method

for finding displacements of joints in a framework in which there are strains before loading; but if we write out the expression for internal work as due to the *excess* of each final stress over its initial value, the function so formed can be employed for purposes of differentiation, in obtaining displacements, which will be those occurring during the application of the external forces, *after the initial strains are set up.*]

Borrowing a numerical example from Mr. Ritter's thesis (see note B), let us apply equation (13) for deflection, to a steel brake-beam in which the bar or compression-member is a hollow cylinder, whose outer diameter is 2 inches and inner 1.62 inches, and length = 60.5 inches, with round tie-rods of 0.875 square inch sectional area, the angle β being $18^\circ 22'$, and the load 15,000 pounds.

That is, using the units inch and pound, we have $l = 30.25$, $l_1 = 31.88$, $F = 1.08$, $F_1 = 0.875$, $I = 0.447$, $W = 7500$, and may take $E = E_1 = 28,000,000$; on substitution of which in equation (13) we obtain

$$\delta = 0.16 \text{ inch};$$

a result which, to quote Mr. Ritter, "is almost exactly what tests show for such a beam."

THE JACQUES CARBON BATTERY.

BY JOHN W. LANGLEY.

The experimental portion of the investigation of this subject was performed by two students, Messrs. H. S. Rosewater and W. H. Oldham, of the Case School of Applied Science, Cleveland, O., who made it the subject of a thesis, which is here partly reproduced. Some of the tables of readings have been omitted, but their results are represented graphically by curves.

Among those who have been attempting the direct production of electricity from carbon is Dr. W. W. Jacques, of Boston, who startled the scientific world and general public

recently by his broad assertion that he had invented a process of making electricity directly from coal, and that his process was practicable and would revolutionize existing methods. He claimed for it an efficiency of 32 per cent. instead of the present value of only 6 per cent. or 8 per cent.

His apparatus, as embodied in a patent, consists of a closed furnace, which heats an iron pot about 6 inches in diameter and 2 feet deep, which is filled with caustic potash or soda, the alkali being kept in a melted state by the application of heat. The following sketch (*Fig. 1*) will serve to show the general character of his battery. In this melted

FIG. 1.

FIG. 2.

alkali is suspended a rod 3 inches in diameter and 20 inches long, made of coal compressed into sticks of the above size and baked so as to expel the included gases. This forms one plate or electrode of the battery, and is the consumable element.

In order to accelerate the action of the battery a supply of air is to be forced through an iron pipe, which terminates in a rose nozzle. Thus the air keeps the melted hydrate in constant agitation and at the same time supplies oxygen, which Jacques claims is necessary for the chemical action. With a cell of this size a current of 150 amperes at an E.M.F. of one volt is obtained.

A test made on a battery of 100 cells, each 12 inches deep and $1\frac{1}{2}$ inches in diameter, showed that thirty 16-candle-power lamps were maintained for eighteen and three-quarter hours at full incandescence, the average E.M.F. being 90 volts, current 16 amperes, consuming eight pounds of carbon in the pots. The report claimed that "the actual electrical energy obtained from the carbon consumed in the pots was 82 per cent. of the theoretical." This efficiency, however, means nothing and is quite misleading, as it does not include the carbon consumed outside the pot to heat it.

Much discussion has arisen as to the cause of the current. Jacques says "that the electric current is due to the chemical combination of the oxygen of the air with the coke (carbon) there can be no doubt. Qualitative tests showed that oxygen was taken from the air, that carbon was consumed, and that the E.M.F. obtained agreed almost exactly with that which is theoretically obtainable from the combination of oxygen with carbon to form carbonic acid (1.04 volts)."

His opinions, however, have been criticised by men who have experimented a great deal on this subject. Mr. C. J. Reed claims that the action is, as proved by three experiments made by him, thermo-electric, or, rather, thermotropic, which term he applies to a thermo-electric junction between two metals, or two pieces of the same metal at different temperatures, and a solution of a salt or a melted salt, which does not act chemically on the metal immersed in it.

This paper will endeavor to show that no new theory need be put forth to explain the action of this battery, but only an old one applied. With the view of finding the correct reason for this extraordinary current, tests were made in which the following apparatus was used:

A A furnace.

B An iron pot.

C A pyrometer.

D An air blast.

E A gas burner.

F Various instruments to be described later.

The furnace was built of brick and contained the pot packed around with fragments of fire brick. A large multi-

ple gas burner, whose gas supply could be very accurately regulated, served as the source of heat, and by it the temperature of the pot could be quite exactly brought to any desired point and maintained nearly constant.

B, the Pot. The pot was made 12 inches in length, of 4-inch steam pipe, with a cap over its lower end. To its upper end were riveted two right-angled irons, which served as handles for the pot and also as one of the terminals of the electric circuit, as shown in *Fig. 2*. As the pot was too short to project through the cover of the furnace, a sheet iron sleeve was made to fit over the pot and between the upright handles. Over these two handles a horizontal iron bar was fastened with set screws. Through the center of the bar a collar passed, which held, insulated from it, a brass tube, to the upper end of which a binding post was fastened, the lower being slotted so as to hold either of the various rods to be experimented upon.

C, the Pyrometer. The temperature of the melted alkali was measured by a pyrometer of the Siemens type, which, as is well known, depends on the variation of the resistance of a platinum wire with its temperature, the wire being included in an electric circuit. The instrument consisted of a piece of $\frac{3}{4}$ -inch iron pipe about 24 inches long, with a plug in its lower end. In the bottom of the pipe, and insulated from it by sheet asbestos, was a coil of platinum wire wound around a clay pipe stem, one end of the coil passed up through the stem, the other on the outside of the pipe stem and separated from the iron pipe by the asbestos. Both ends were fastened to copper leads at the top of the pipe.

Thus keeping the amperes constant in the coil, the volts, which varied directly with the resistance, which, in turn, varied directly with the temperature, were made to read the temperature by being properly calibrated. This was done by having an accurate mercurial thermometer immersed with the pyrometer in an oil bath, readings being taken simultaneously. The thermometer used read to 550° F. The current was kept constant by means of a rheostat at .25 amperes during the entire calibration, and also during all the experiments which follow. Two calibrations were made up to

350° C., at which point the oil took fire. A curve was plotted from these readings with volts and temperature as axes, and a straight line drawn through the majority of the points. A check was made on this line by finding the voltage at which zinc melted, and knowing the temperature a new point was found which agreed very closely with the line.

Compressed air was admitted to the pot by a $\frac{1}{4}$ -inch iron pipe, which descended to the bottom and terminated in numerous small orifices.

The circuit was arranged as in *Fig. 3*. The instruments used were two ammeters, one reading to thousandths and the other to thirtieths of an ampere; also a voltmeter reading to thirtieths of a volt. A battery and rheostat were added for the pyrometer circuit.

By means of a two-point switch the voltmeter could be

FIG. 3.

connected either with the pyrometer circuit or with the pot circuit, thus giving, in the first case, the temperature, and in the second the E.M.F. of the pot.

In *Fig. 3*, *A* is the carbon, iron or copper rod, *B* a battery, *C* the pyrometer, and *R h* a variable resistance. The readings were made in the same order in all of the experiments. (1) The pot voltage was read on open circuit and marked "Volts" in the diagrams. (2) The pot amperes read when the ammeter alone was in the circuit, designated by "Amps" in the diagram. (3) The pyrometer current was adjusted to .25 amperes, and the voltage read and reduced to its temperature equivalent, designated as "Temp" in the diagrams.

In order to avoid ambiguity in the following diagrams, the plus and minus signs are such that when the carbon, iron or copper rod is connected to one terminal of the out-

side circuit and the pot to the other terminal, the flow of current from the rod is the same as though these signs were applied to an ordinary liquid battery having its zinc pole marked "minus." The pot was grounded and, therefore, at 0 potential, always.

Seven experiments were made in the following order:

- 1 A copper rod without the air blast.
- 2 A copper rod with the air blast.
- 3 An iron rod without the air blast.
- 4 An iron rod with the air blast.
- 5 A carbon rod with the air blast.
- 6 A carbon rod without the air blast.
- 7 A carbon rod without the air blast, but with sodium nitrate added to the melted caustic soda in the pot.

All the materials used were of ordinary commercial quality, because these only could be economically used in a practical battery; therefore no attempt was made to employ chemically pure materials, as would have been the case if these experiments had been made in the interests of pure science instead of electrical engineering.

In experiment No. 1 a $\frac{1}{2}$ -inch copper rod was used, which was brightened before using, but which became coated with a dark scale, copper oxide, which scale was not disturbed for experiment No. 2.

Referring to *Plate I*, the curves of volts and temperature approach and recede from each other, *i. e.*, when the temperature goes up the volts drop, and when the temperature falls the volts rise; the same being true of the amperes, as shown by curve *V*, of *Plate VIII*.

In experiment No. 2 the same copper rod was used, and just enough air to keep the alkali from splashing. *Plate II*, together with curve *VI* of *Plate VIII*, show the results. The same general outline is observed, the volts falling as the temperature rises, and the reverse. The ampere curve, *Plate VIII*, curve *VI*, acts similarly to that of *Plate II*, except at the end of two hours and twenty-five minutes it rises to the maximum positive reading attained by any of the curves; in this case both curves become negative twice.

In experiment No. 3 a $\frac{1}{2}$ -inch iron rod was used, thus

making with the iron pot a hypothetical battery in which both electrodes or plates were of the same metal (which would exclude ordinary galvanic action), still, an E.M.F. was

PLATE I.

PLATE II.

created and a current circulated, as shown in *Plate III*, and in *Plate VIII* curve *VII*. The latter shows the general characteristics of thermo-electric action, the curve going

within ten minutes from a + value to — 4.5 amperes, the maximum negative value attained by the amperes.

Experiments 4, 5 and 6 show the same general relation

between rise of temperature and fall of volts, and it will be noticed that the E.M.F. produced by carbon against iron is not materially greater than that of iron against iron, as

shown by *Plates III and VI*. This is directly opposed to Mr. Jacques' theory, but to give his hypothesis every chance and to favor chemical action as much as possible, experiment

No. 7 was instituted, in which some sodium nitrate was added to the melted alkali in the pot. It would seem that if the voltage produced was caused by the oxidation of car-

bon, as Jacques asserts, the nitrate acting at a red heat ought to develop it, but *Plate VII* shows a diminished, not an increased E.M.F.

PLATE VII.

PLATE VIII.

That these experiments show the cause of the current to be thermo-electric there can be no doubt. In the first place the general appearance of the curves plotted is that of

characteristic thermo-electric curves by their sudden changes in magnitude and direction. Then the maximum voltage occurs when the difference of temperature is greatest; for such is the case on starting and stopping the gas (on starting, the pot becomes hot while the alkali remains relatively cool, and on stopping, the pot becomes cool while the alkali remains hot), which causes a great difference of temperature between the rod and the pot; this also shows a thermo-electric characteristic.

Also the addition of air would, if the action was chemical or galvanic, add oxygen and cause the curves of volts to become more negative, but this result is disproved in all the curves where air was used, and especially in *Plate VII*, where sodium nitrate was added, which held so much easily available oxygen, the curve being, in fact, positive instead of more negative.

Then again, the addition of air, air much colder than the melted alkali within the pot, would, if the action was thermo-electric, cause the voltage to be greater at starting and stopping the experiments than if it were not used, and also than during the interval between starting and stopping, a result shown just as expected in all the curves where air was used when compared with those in which the air was not used. Mr. Reed also stated that when ordinary illuminating gas was injected into the pot, no different results were obtained. Why should they be? Cold gas will cause the same effect as cold air if the action is thermo-electric, and not galvanic. That it is thermo-electric these experiments seem to conclusively prove.

The E.M.F. shown in this paper is much smaller than that stated by Jacques, and reported by other observers. The cause of this is probably due to the small diameter of the pot used, and to the very gradual and even heat employed, which greatly tended to lessen the differences of temperature between the two electrodes, that is, between the rods and the iron shell of the pot, for it is this difference only which causes the E.M.F. observed, according to the views put forth in this paper.