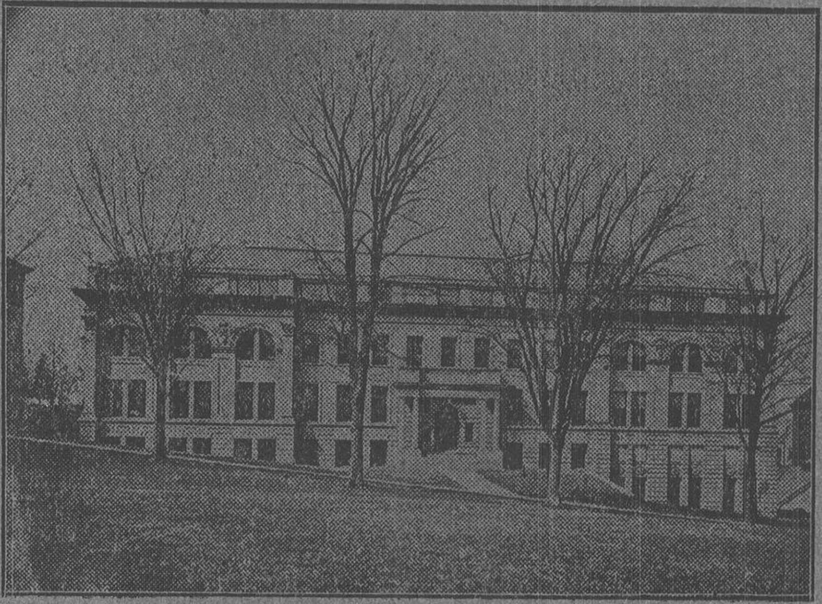
The Wisconsin engineer. Vol. 7, No. 4 June 1903

Madison, Wisconsin: Wisconsin Engineering Journal Association, [s.d.]

https://digital.library.wisc.edu/1711.dl/7P3DBZ6M5SIJV8I

THE
WISCONSIN ENGINEER

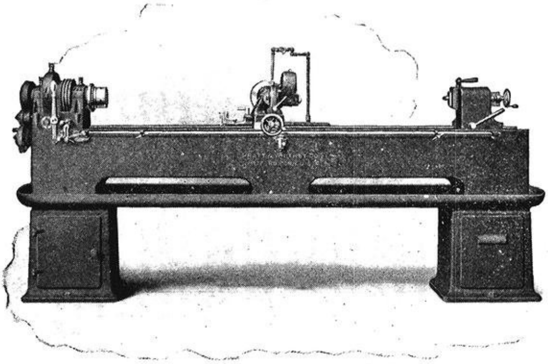
Vol. 7 JUNE, 1903 No. 4

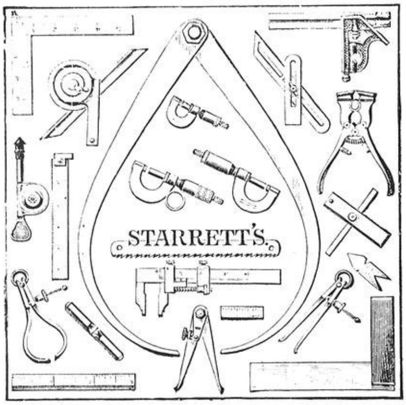


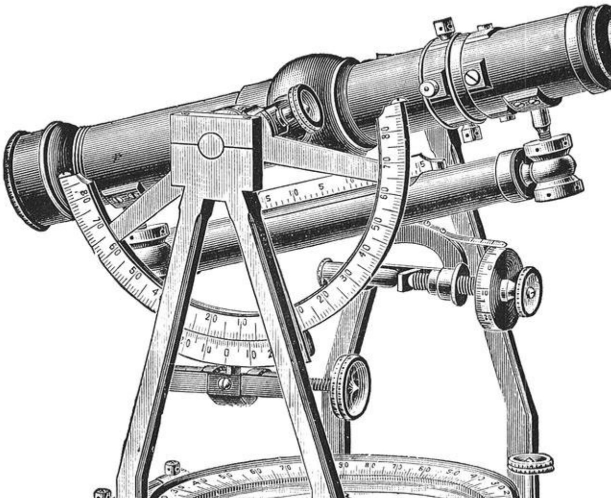
Published Four Times a Year by the University of Wisconsin
Engineering Journal Association

MADISON, WISCONSIN

TRACY, GIBBS & CO., PRINTERS




STARRETT'S.


W. & L. E. GURLEY TROY N.Y.

LEARN TO WRITE ADVERTISEMENTS

Learn by Mail

Five years ago the universally acknowledged first school of advertising in the world was founded by EDWARD T. PAGE and SAMUEL A. DAVIS. During this time they have placed scores of graduates in remunerative positions, and taught hundreds of business men the correct methods of advertising.

Send for Proofs

Learn from the "original school" you hear so much about. It is conceded by leading merchants that it is the one factor to strengthen a young man's prospects. There is no better stepping stone to promotion than a knowledge which will increase your ability to improve the business of your concern.

THESE FACES MEAN SOMETHING

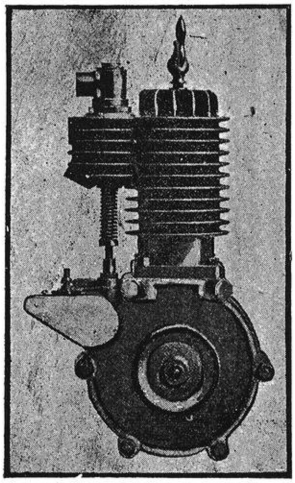
They are the faces of men and women who have answered our advertisements during the past five years with a full appreciation of the fact that advertising is the foundation upon which a business man's success must be built. Learn from the oldest, biggest and most substantial institution of its kind in the world. Learn from the founders themselves. Do you realize the full significance of these facts to you? When we say, we can **positively teach you advertisement writing by mail** we simply reiterate what those who have graduated and profited by our instruction are saying for us. Our lessons are for each individual, and just as personal as if you were the only student.

Notice to Employers: **Concerns desirous of engaging competent advertisement writers capable of earning $25 to $100 per week are requested to communicate with us. We have placed successful ad-writers and ad-managers in some of the largest houses in the world.**

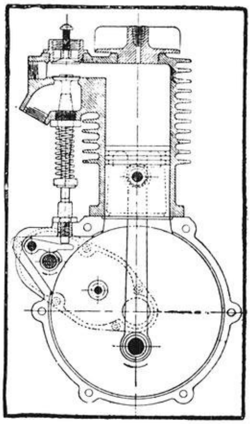
When you enroll in the PAGE-DAVIS ADVERTISING SCHOOL you are not experimenting or being experimented upon. If you write we will send you our 64-page prospectus and a bundle of affidavits from our students **free.**

Page=Davis Co.

Suite 95, 90 Wabash Ave., Chicago



1¾ H. P. Motor Complete.



Section of 1¾ H. P. Motor.

COMPLETE MOTORCYCLE FOR $23.50.

For **$23.50** and a little of your spare time and mechanical skill, you can have a motorcycle equal to any first-class machine on the market.

For the above price we supply complete set of castings, and full detail blue prints, for 1¾ H. P. air cooled bicycle motor same as cut, and all the accessories; the induction coil, spark plug, and cut gears, are finished and ready for use, and we give you all the other parts in the rough, with full detail blue prints, for finishing them. If you are interested, we will be pleased to send you our printed matter, giving full particulars, and prices of castings, accessories and finished motors, both for bicycles and automobiles. Send us your address today. We will please you.

THE EUREKA MFG. AND SUPPLY CO.,
BOX 81, ST. PAUL, MINN.

Send for Sample Copy of

The Engineering Record

Civil, Municipal Building and Industrial Engineering, also Reliable News of Projected Work in these lines.

114 Liberty St., New York City

FREE Catalogue of Architectural, Scientific and Technical Books. Prospectus for 1902, for "Architects and Builders' Magazine," monthly $2 a year.

WM. T. COMSTOCK, Pub., 23 Warren St., N. Y

OLSON & VEERHUSEN

The.... BIG Store.

Clothiers, Hatters, Furnishers and Tailors

We specially cater to the U. W. patronage.

Please mention the Wisconsin Engineer when you write.

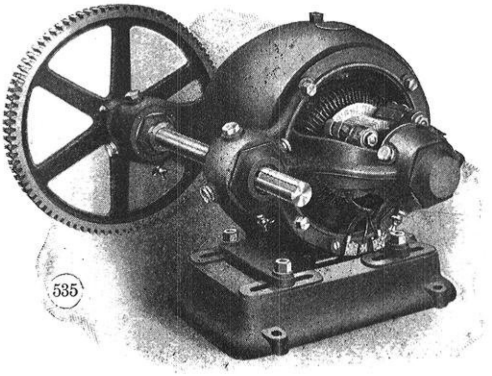
WANTED!

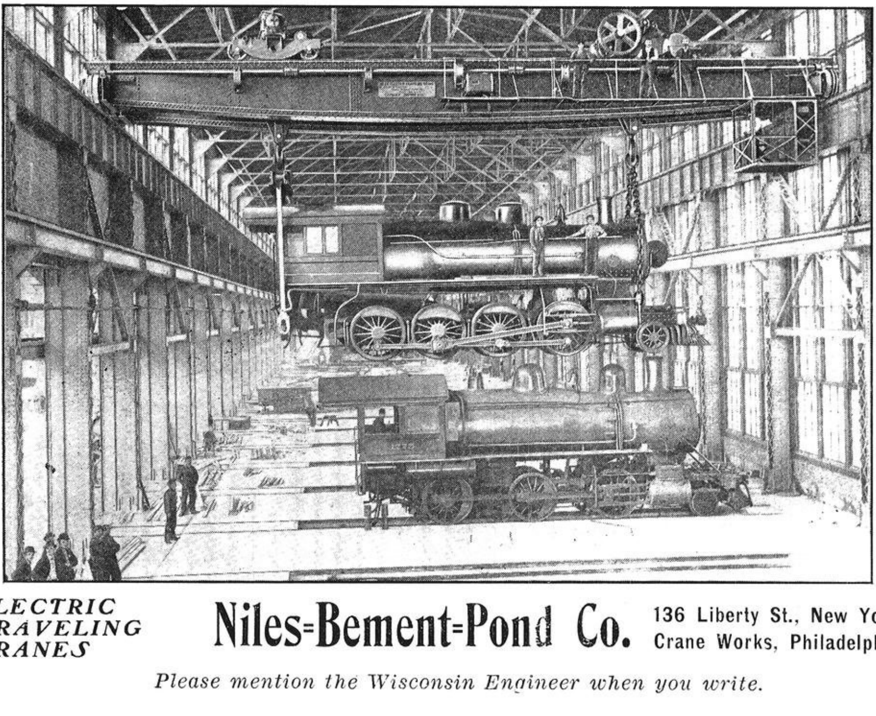
The following numbers of the Wisconsin Engineer:

Vol. I, No. 2
Vol. II, Nos. 2 and 4
Vol. VI, No. 1

If you have any other numbers let us know, we have calls for them and may be able to sell them for you. Write, stating terms.

WISCONSIN ENGINEER.


535



The Wisconsin Engineer,

Published Quarterly by the Students of the College of Engineering,
University of Wisconsin.

Vol. 7. **Madison, Wis., June, 1903.** **No. 4.**

TERMS;

$1.00 if paid before February 1st; after that date, $1.50. Single copies, 35c.
Entered in the postoffice at Madison as matter of the second class.

CONTENTS.

2—Eng.

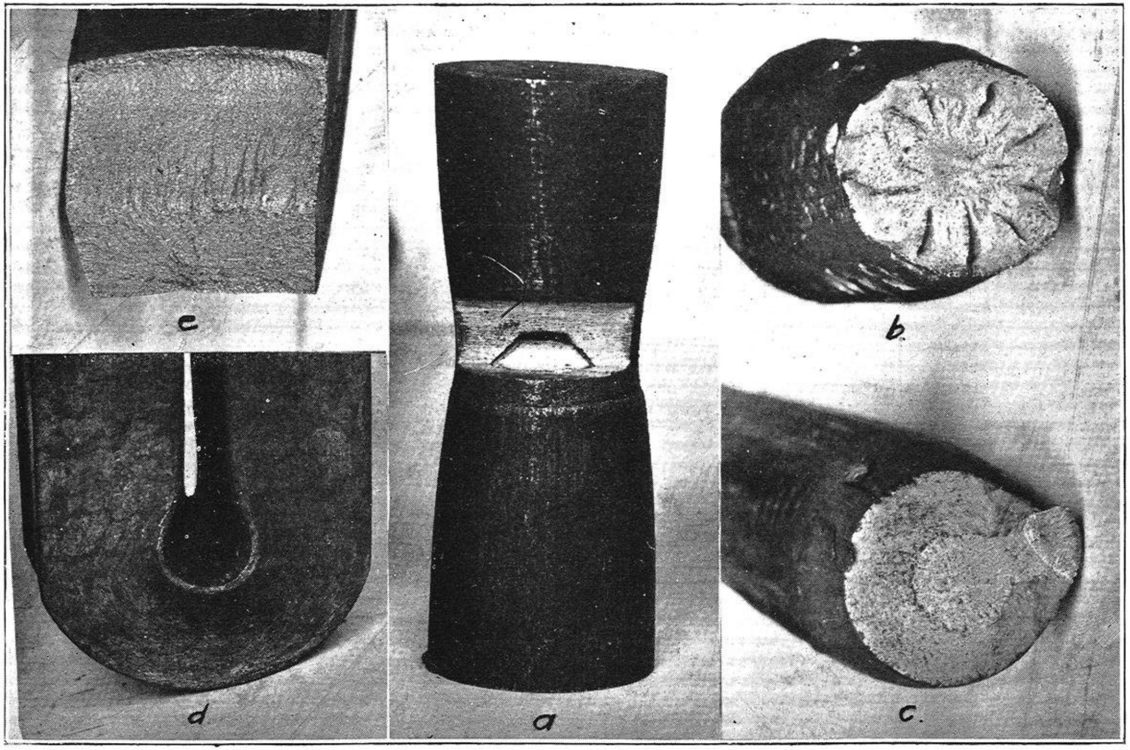


PLATE I.

THE WISCONSIN ENGINEER

VOL. 7. JUNE, 1903. NO. 4.

TENSION FAILURE PHENOMENA, THEIR MEANING AND CAUSE.

RUDOLPH HARTMAN, B. S. C. E., '01.

The various phenomena which accompany the failure of the materials of construction, as regards mechanical force, can all be classed under the two heads: phenomena due to yielding simply, without actual rupture; and phenomena due to actual rupture. From the standpoint of the stress-strain curves the material in the first case is stressed beyond the "yield point" but not up to the final breaking load, the latter case being the final point itself. We may thus look upon actual rupture, for any certain part of a specimen, as the limit to yielding and yet, if we consider the specimen as a whole, yielding may go on after actual rupture has begun. In other words both kinds of failure may go on at one and the same time in any given specimen.

This failure takes place under various conditions and these have been classified into the so-called cases of tension, compression (short-block and long column), cross-bending, torsion, shear, punching, stamping, etc. etc., or into combinations of these.

To most of us the tension and short-block compression cases are simple and easily understood and are almost always looked upon in the light of the "Apparent Theory of Elasticity" only, namely: that if we cut a right section of any body subject to the above tension or compression, then *all* the stress acting upon that section will be of *equal value per unit of area* and will act in the *same direction as the direction of* *the external load applied.* These results follow if *the longitudinal deformation only* of the body is taken into account.

By reasoning evolved in the mechanics it has been shown (if the necessary assumptions made are all granted, as they generally are; and if the facts that bear on the question are borne in mind) that long-column compression, cross-bending, torsion, shear, punching, stamping, etc., etc., can all be resolved in their stress values into the simple ones of tension and compression mentioned.

We thus get simple conceptions of *all the cases* and often feel satisfied with our knowledge of them, and believe that we possess the power to use them in actual engineering practice in a rational way, both in designing and in explaining all phenomena which may come before us.

There are those of us, who, knowing that the foregoing conceptions are not correct as to reality, have sought to get correct impressions by adding the weight of the fact of lateral deformation to the preceding one of longitudinal deformation which gave us the so-called "Apparent Stresses," and we thus come to what are termed "True Stresses" and this, thus completed experimental basis it is which, coupled with the higher mathematics, gives us the elaborate and far-reaching "Theory of Elasticity" *in its entirety.* This lateral deformation gives us the so-called "*implied*" lateral tension and compression stresses.*

By taking this lateral deformation into account (not, however, as in the preceding manner, but as will be shown later) we find that the compression failure becomes a tension failure and thus *all* failure is resolved down to *tension* as its cause. That is one reason why the title of this paper is written as it is. Another reason is that by far the most phenomena noted here are those observed in "tension" tests, the others being given to complete the presentation of the first.

Before taking up the phenomena themselves, I shall, briefly give a list of the men who developed the "Theory of Elastic-

---

*Page 291 Merriman's Mechanics of materials.

ity" and the dates of their work. Only the mile-stones will be given. They concern beam analysis mainly, but as such stand for the whole well enough for the purpose of this paper.

The following men never knew what our conception of a molecule or an atom was:

1638. Galileo: First attempt at beam analysis.
1678. Hooke: Hooke's experimental law.
1680. Mariotte: Experimental proof that beam extended on bottom side and compressed on top side.
1702. Varignon: Second attempt at beam analysis.
1694–1705. J. Bernoulli: Applied Mariotte's law.
1713. A. Parent: Assumed the neutral axis was in the center of the cross-section of a beam.
1759. Euler: Column formula.
1773. Coulomb: Re-affirmed Parent's conclusion.

The following men never mentioned an atom or a molecule as affecting the "Theory of Elasticity" in the least.

1807. Young: Young's modulus of elasticity.
1811. Poisson: Poisson's ratio (lateral deformation).
1824. Navier: Gave beam analysis its final form.
1824.† Lamé: Various formulas as for guns, etc.
1857. Saint-Venant: Final analysis for elastic stresses and ultimate stresses.

The following list of men and the dates of their work in the field of chemistry will also be given to compare with the foregoing list.

1806. Proust: Law of constant proportions.
1808. Dalton: Law of multiple proportions.
1792–1802. Richter: Law of reciprocal proportions.
1808–1827. Dalton: Law of reciprocal proportions.
1805. { Gay Lussac: Law of gaseous volumes.
Humboldt.
1811. Avogadro: Avogadro's hypothesis.
1819. Dulong & Petit: Law of Dulong & Petit.
1821. Mitscherlich: Law of isomorphism.

The above group of chemists founded and firmly established the modern ideas of atoms and molecules. From the above lists it is clear that our "Theory of Elasticity" was developed without any considerations with regard to our present conceptions of the constitution of matter.

Most of the foregoing men who developed the "Theory of Elasticity" had ideas either wholly or partially wrong, some of which were found out by themselves, some by others, and some still remain to be detected. Hooke and Mariotte are the experimenters—while the others were the mathematicians in this field. Poisson was much more a mathematician than an experimenter, although he was both. It thus appears that two or three experimenters kept many more than two or three mathematicians busy for 200 years in figuring on the results of their experiments.

Then we come to the modern period of experimentatiod, namely, when about 1854 Lüders, in Germany, first noticen the "breaking-down lines" or the "Lines of Force." From then till now, Bauschinger, Martens, Föppel, Michælis, Rudeloff, Wöhler, Hartig, Bach, Unwin, Kirsch, Kick, etc., in Germany; Tetmajer, etc., in Switzerland; Capt. Hartmann, Tresca, Barba, Durand-Claye, Osmond, Considére, French Commission Reports, etc., in France; Kirkaldy, Hodgkinson, Fairbairn, Anderson, Mallet, Rennie, Andrews, Arnold, Grant, etc., in England, and Johnson, Howard, Gilmore, Thurston, Howe, Keep, Turner, Campbell, Marshall, etc., in the United States, have piled up facts upon facts and mostly within the *last 25 years.*

Do these facts bear up with the "Theory of Elasticity?" Does the "Theory of Elasticity" explain their cause? We shall see.

Most of the most important phenomena thus discovered, mainly as just said, in the last 25 years, will now be presented, beginning with a series of stress-strain curves of various materials tested in tension. In these curves the ordinates represent loads, either actual or unit, and the abscissae represent deformation either actual or unit, and the abscissae represent deformation either actual or unit. In some cases the metric, in others the English system is used, depending largely on the source of information. Those curves not obtained in tension will be labeled as to their origin. The curves in all cases are characteristic curves, for the materials represented.

Figures 1 to 7 are of material more or less of organic origin. It is to be noted that Figures 1 to 4 are concave to the load axis. Figures 6 and 7 are convex to the load axis and Fig. 5 is both. Bauschinger says of wood.* "Der Elasticitäts Modul des Holzes für zug varirt sehr bedeutend mit der Festigkeit, viel mehr, als bei anderen materialien, namentlich bei Eisen und Stahl; er nimmt mit der Festigkeit zu und ab, doch in der Regel bei Weitem nicht in demselben Verhältniss wie diese."

Figures 8 to 12 are of inorganic material not metallic. Figures 8 to 10 are tension, Fig. 11 is a compression curve of brick. No tension curve was obtainable. Fig. 12 is a cross-bending curve of glass. From other sources of information it is known that the tension curves of these substances are similar to those given above.

Figures 13 (a) to 24 (a) inclusive, are of metals obtained by pulling bars or rods finished from *cast specimens* without rolling, hammering or drawing.

So far it is to be noted that Hooke's law has not yet appeared. In the natural unstrained condition in all materials just as it solidifies from the liquid state or just as it grows organically, *there is even no approximation to Hooke's law.*

Figures 13 (b), 15 (b), 16 (b), 18 (b), 20 (b), 23 (b) and 24 (b) are from rolled specimens as well as figures 25, 26, 27 and 28. Figure 29 proves conclusively, coupled with the above curves, that the effect of rolling the metal, or of squeezing the outer surface of the metal, is to give the elastic line its approximate Hooke's law. In Fig. 29 curve 4 is really for metal in the *cast condition* similar to Fig. 24 (a). Note the gradual acquirement of the "drop" as the effect of the rolling is felt more and more. While the effect of the rolling on the

---

* Page 19, 9th Heft. 1883 of the Communications.

soft metals is quite appreciable, yet even on their rolled, and, as seen later, drawn specimens very little of Hooke's law holds. It is on the steel specimens that we get the approximate law nearest to a straight line in value.

Figures 15 (c), 18 (c), 23 (c) and 24 (c) are from hard-drawn specimens, mostly from hard-drawn wires.

The effect of this drawing is to carry the similar effect of rolling one step farther. This will be clearly seen later when the compression present in the tension test is fully understood. This internal compression takes the place of the compression of the rolls. The material becomes much stronger and shows greatly reduced elongation. Hooke's approximate law comes more and more into evidenee as such, but it is well to note here that it was the rolling and the drawing that made it appear at all.

Let us see how testing a material at different temperatures affects Hooke's law. In figures 30, 31, 32 and 33 this is shown, and we see here that its approximate value entirely disappears. The surmise is in order here to the effect that perhaps some of the metals which do not show the least approximation to Hooke's law, at room temperature, may do so at a lower temperature.

As to the effect of the size of the specimen it is well known that the smaller specimens are the stronger. Fig. 34 illustrates this. It may be stated here that the smaller specimens received more rolling or squeezing than the larger ones, and consequently its effects being to increase the strength of the material that this would account for the increased strength. But this latter strengthening cannot explain all the increase in strength as annealed specimens or those of different sizes obtained by one pass through the rolls or those of organic origin, etc., demonstrate. Table XXIX, p. 511, Johnson's Materials of Construction proves this. Again, wires are always stronger than plates of the same material and thickness, and made with the same amount of hammering or drawing. Some wires are stronger than large sections of the same material, even though the ductility of the wire was greater than that of the larger sections. Again, the great strength of spider-web-threads, silk threads, hair, etc., is too well known to need demonstration. Also the strength of cement briquettes varies approximately as the perimeter and not as the area, a fact which again bears out the above conclusion.

But not only in strength (both at the elastic limit and the ultimate) is there a difference in action due to size. Look at the elastic lines in Fig. 34. See how those of the larger specimens begin appreciably, to curve sooner than those of the smaller specimens (they have their so-called "true elastic limit" lower down), and how they make a more sweeping bend and a larger bend up to the yield point!

As to the effect of shape, this is somewhat analogous to that of size. In Fig. 35 a curve of a full size steel eye bar (5.1″x1.02″x25′8″) is given. Note the gradual bend near the yield point. In Fig. 36 we have the curve of a piece of boiler plate steel (1″x$\frac{3}{8}$″x20″). Note the same gradual sweep, only more marked, due to the gauge length being 8″ instead of 260.″ In general also, in case of flat steel specimens, the "drop" comes way beyond the prominent bend in the curve. Compare these with the sharp "drops" in Fig. 24 and Fig. 27 which are also on steels but in "rounds." Again compare Figures 37 and 38, the round wires are always much less yielding than the square wires.

The effect of notching, and the kind of notching, is noticed in Figures 39, 40, 41, 42, 43 and 44. Fig. 45 shows the method of making the test pieces which gave the results in Figures 42 and 43, and Fig. 46 shows that for the results in Fig. 44. Notice the sudden "jumps" in curves 42 and 43 when just under the $\frac{1}{2}$″ length as well as curves 39 and 40 which give similar "jumps." This undoubtedly means that here some new influence begins to be felt and probably that the shoulders make their effects felt markedly since the "Lines of Force" would then take up the full length between shoulders in going across the diameter of the specimen once.

It thus appears that the kind, length and depth of the notch materially influences the strength, etc., of a test piece. It has long been known that a sharp nick or cut is harmful, especially to hard materials, and such must be avoided by rounding all corners where grooves are unavoidable.

As shown, the effect of changing the length between shoulders has also been slightly known, but the effect of depth of groove, or rather of varying height of the collar rings, has not been known as far as I can find out. This is shown in Fig. 44.

Do any of these facts bear up with the "Theory of Elasticity?" Remember that some of these effects are at the "elastic limit."

It is appropriate here to say that the stress-strain or load-deformation curves of other tests, as cross-bending, shear, punching, torsion, etc., give curves which, if they vary any from those presented on tension, almost always diverge still more from straight lines than do those, and consequently differ still more from Hooke's law than do the above in tension.

All autographic diagrams give elastic lines convex to the load line whether the connecting apparatus be string, wire, chain or direct-connected levers. Fig. 47 shows one obtained by Henning's pocket recorder, a direct-connected lever machine.

Again let me ask, where is the "True Elastic Limit" in any of the 45 preceding curves? When we say "True Elastic Limit" do we mean an approximate elastic limit? If so, then why do we define *the "True Elastic Limit" as the point of the elastic line where the curve ceases to be straight?* Is this point to depend upon the scale with which we plot our curves? The preceding curves illustrate this point in question. Furthermore, is the "True Elastic Limit" to depend on the accuracy and power of our measuring apparatus? If so, listen to what Prof. Martens has determined with regard to results measured with what he writes is a machine measuring accurately to 0.0000013 of an inch. Prof. Martens* concludes that even then he was unable to find the point where the curve began.

---

* P. 604, Martens' Hand-book by Gus Henning.

I maintain there never was such a point. The only definite, *real* elastic limit is the yield point in those materials which have a "drop," and even this point can be changed by time, rate of loading, rolling, drawing, etc. For those materials having no "drop" the "elastic limit" is still more indefinite. Those experimenters who have sought to define the elastic limit as "that point where permanent set begins," have been puzzled and amazed to find this begins sometimes *way inside of the yield point* (see Figures 19, 25 and 51) and often inside of the so-called "True Elastic Limit." Yes, and they have been still more amazed to find that this permanent set, when obtained, has, after awhile, partly or *entirely disappeared;* and that in some few cases the specimen has even *contracted!*

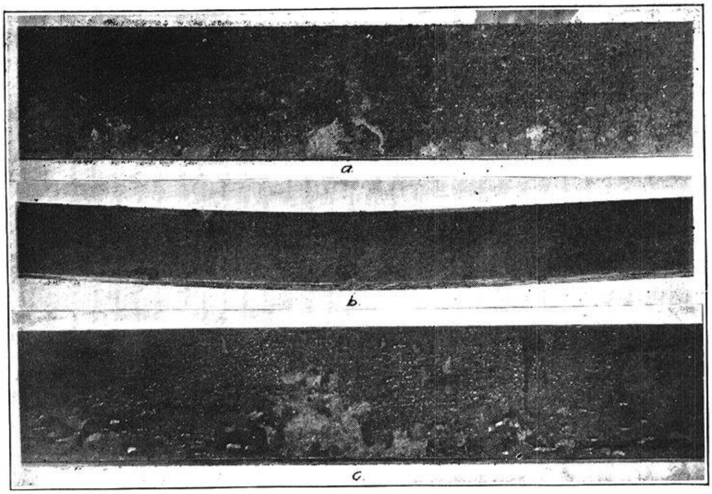


PLATE II.

The "drop" of the weighing beam is accompanied by peculiar phenomena.

If the specimen possesses a scale, this peels off, beginning at one or both ends, and continuing under the same or even less load until the scale is all off, when a sudden stiffness of the specimen manifests itself and the curve becomes steep again. If the scale is thin and smooth, as on some tool steels, it can be seen coming off in streaks, both longitudinal and oblique, mostly oblique, and if the angle these streaks make with the direction of the axis of the piece be measured, it will be found to be the same as that made by the "Lines of Force" (mentioned immediately) with the axis of the piece.

Prof. Martens says * scaling takes place because of the *different extensibility* of the scale from that of the metal underneath. Plate II will prove that this is not true in the case of a cross-bending test, and Plate III, coupled with the significance of Fig. 49, in the case of a tension specimen with collar rings. On the other hand, Plate II shows that scaling takes place, in these cases at least, due to the *different compressibility* of the scale from the metal underneath. In Plate II (a) is the top, (b) the side, and (c) the bottom of the cross-bending test piece which in this case was tool steel 12″ supports, $\frac{3}{4}$″ x 1″ in cross-section tested flatwise. Notice the transverse cracks on the top in (a), the longitudinal cracks on the bottom, and the transverse cracks on the top of the side in (b) and the longitudinal cracks on the bottom in (c). Here we have the *same effect* in scaling on top that we have on the bottom only the directions of the cracks are at *right angles to each other.* (A light effect makes the longitudinal cracks show up best, the light coming down on the specimen; but if the specimen had been changed 90°, and the photograph then taken again, the transverse cracks would look just like the longitudinal cracks, (c) is not in as good focus as (a) or (b).)

If these cracks be studied in detail it will be noticed that the scale comes off like "the roof of a house" with the ridge pole formed by the cracks seen in the plate. I conclude therefore that they mean *compression* caused them. If this is true on the top of the beam it also holds for the bottom, and hence we have *compression present transversely in the tension side of a beam.* By analogy and from other facts we can easily see tension must be present transversely in the compression side of a beam. On the collar rings Fig. (a), Plate III the scaling came off mainly in longitudinal streaks

---

*P. 86, Martens' Hand-book by Gus Henning.

and this coupled with the fact of *no stretch*, or practically none, of the rings as proven by Fig. 49, proves that they must be in compression. On a very few places they came off at angles to the direction of the axis of the test piece but then always *at angles much less* than those of the streak on the main part of the specimen. Fig. (a) Plate III shows this dimly as seen by eye but easily seen with a lense. This fact tends to show that the "Lines of Force" which are underneath the scaling *need not form at a constant angle* for a given material, regardless of shape etc., as some experimenters, notably Commandant Hartmann*, have tried to prove, this will be treated again immediately.

If the specimen has no scale, but is polished the so-called "Lines of Force" or "Breaking-down Lines" or "Lüder's Lines" develop. These form at angles with the direction of pull and vary for the materials from 53° for lead to 65° for nickle-steel and have been shown by Commandant Hartmann to be complimentary to those formed in compression tests of the same materials. These lines can be seen in various books, notably Commandant Hartmann's (although his are sketches), Johnson's Materials of Construction, Prof. Martens' Handbook of Testing Materials, translated by Gus Henning, and in the Berlin Testing Laboratory Communications of 1901.

Fig. (b) Plate III, coupled with the scaling fact mentioned above and others not mentioned here, shows that they need not always form at constant angles to the direction of pull as it seemed at one time they must. The statement that those "Lines" which appear curved were *originally straight* and were pulled into curves is met by the fact that in Fig. (b), Plate III, such lines at times *curved more than the total stretch* between the centers of the round holes there shown. The fact that these "Lines of Force" are oblique in direction shows that *the internal stress must also be oblique in direction.* This conclusion, backed up by other facts as oblique scaling, oblique fractures, etc., upsets the assumptions made as a

---

*L. Hartmann Distribution des déformations dans les métals.

basis in the "Theory of Elasticity." There, there are two sets of stresses at right angles to each other but *no oblique connecting bond* between is mentioned.

The idea of the shape of the foregoing test piece was derived from a study of Theodore Cooper's article* on scaling phenomena from which Fig. 48 is taken.

The yielding beyond the elastic limit goes on in a peculiar, oscillatory manner. The stress-strain curves, as ordinarily obtained and drawn, are erroneous, in that the inertia of the weighing levers, etc., absorbs these oscillations due to the real action of the material. This was lately demonstrated by M. Bacle.† Fig. 50 is a reproduction of his tension curve obtained by utilizing the deformation of the reaction frame of his testing machine itself, thus eliminating the inertia of a combination of heavy levers. To show that the machine itself did not cause the oscillation it should be stated that in punching tests no oscillations were obtained.

As to what happens if the load (beyond the yield point) is kept constant for a period of time, see Figures 25, 19 and 51. Some of these approach very closely to being within the elastic limit, for example, Figures 25 and 51. Note also the wonderful resilient action at zero load *where a contraction* is recorded in Fig. 51.

The conclusion that yielding is possible below the yield point or other elastic limits need not scare us. President C. R. Van Hise states that he has known of slabs of stone to gradually, after long periods of time, bend *with their own weight solely as load*, as in marble slabs in a cemetery. Then just lately Prof. Babcock, in weighing ice, hermetically sealed in glass jars, suspended by wire in water, noticed that the jars kept on *decreasing in size for months*, as indicated by the increasing weight of the jars, all being at 0 degrees centigrade.

---

*Theodore Cooper in Proceedings of the American Society of Civil Engineers 1878.

† M. Bacle, in Communication of the 1900 Meeting, International Congress at Paris, p. 62, Vol. II.

These cases are of *materials stressed way below the elastic limit.* There is thus no definite, fixed elastic limit. More facts on this point will come up from time to time.

What happens if we take load off from a specimen at any stage of a test?

If the point from which we "go down" from the curve is within the yield point, we either go back to zero deformation or we record a "permanent set" which may in some cases disappear later. If we "go up" again, no permanent set having been observed, we find the modulus of elasticity *has been increased.** This phenomenon I take to mean that the previous load pulled the material into line, just as a crooked, kinked wire is stretched out, and the second time these kinks being taken out, naturally a greater resistance, or less deformation for a given pull, results.

If the point from which we go down is beyond the yield point, or stated in a more general way, after the first appearance of the "Lines of Force" inside the measured gauge length, we notice peculiar phenomena. Our return curve becomes concave to the load axis as in Figures 51, 52, 53, 54 and 25. This is caused by a resilient or recovering action which goes on even after all load has been taken off, as in Fig. 51.

In this connection it might be appropriate to call attention to the similarity of these curves to the well-known hysteresis curves obtained in electro-magnetic tests.

The resilient effects of the torsional pendulum and of loaded rubber are all related to the above and explained by them. Similar curves to those given are noticed in the 1881 Watertown Arsenal Reports for torsion by R. H. Thurston, and also in the 1889 Reports, of which Fig. 56 is one specimen.

When the load is again applied we get curves which are very much convex to the load line and the modulus of elasticity *has decreased.* See Figures 9, 51 and 53, and also Fig. 424, p. 510, Johnson's "Materials." Note in Fig. 54 the recovery of the original modulus of elasticity in time.

---

* See P. 509, Johnson's "Materials."

We have thus made a "loop" as the Figures 25, 51, 52, 53 and 54, etc., show.

If we compress the specimen after pulling it beyond the yield point the curves as in Figures 56 and 57 will be obtained, that is, the specimen has entirely lost even the slightest semblance to Hooke's law, by such treatment. Fig. 426, p. 523, Johnson's "Materials" also shows this. If we had waited a period of time before going up, again, it is probable the effect would have been as in Fig. 58, that is, the elastic limit or rather yield point would have been "raised up" above the point from which we started "down off the curve." This rest would also have raised the maximum or ultimate strength of the material as is generally known.

Repetitive and reversal limits as determined by Wöhler and others show that material may be made to yield and fail far below the limits of static single application loads.

Does the Theory of Elasticity explain *any* of the above facts? If not then let us get one which will. An attempt to do so will appear later.

The highest load a specimen will stand is one which comes at different points of the stress-strain curves for different materials. For soft ductile materials it may come at the yield point, as in Fig. 16 (b) for zinc. For hard semi-ductile materials it may come at a higher point than the yield point and before the so-called "final" point, as in Figures 23, 24, for steels, etc. For brittle materials it may come almost at the same time as the yield point or elastic limit, and at the same time it may be the final point as in Fig. 23 for cast iron, etc. Often in the semi-ductile materials the high load is a lime, that is, the weighing beam stands still for a quite appreciable period of time, while the specimen draws out. This is only true of curves where the inertia of the levers prevents the oscillatory action.

At this high point, local necking down begins. From now on to the final load (if it have both), the stretching is concentrated around this local spot (see Fig. 10, p. 22, Johnson's "Materials"), and it may be that the rest of the specimen even contracts as is seen in Fig. 47, where the specimen in the second curve failed outside of the gauge length.

At this high point also, in materials with the proper fixity of its constituent matter, fracture begins. All semi-ductile materials forming cups do this. In ductile materials a bend occurs in the curve strictly analogous to this high point, and here also fracture begins forming the cup, (see Fig. 16 (b)).

With material with such fixity of matter that no cup forms, and if they be of homogenous composition, either one of two things happens, either they break right off at the high load like cast iron, or they draw out into points or lines like Fig. 59.

Wrought iron (containing much slag, etc.), can be looked upon as a composite affair, and its necking down, if it develop no cup, indicates innumerable small failures as in Fig. (c), Plate III.

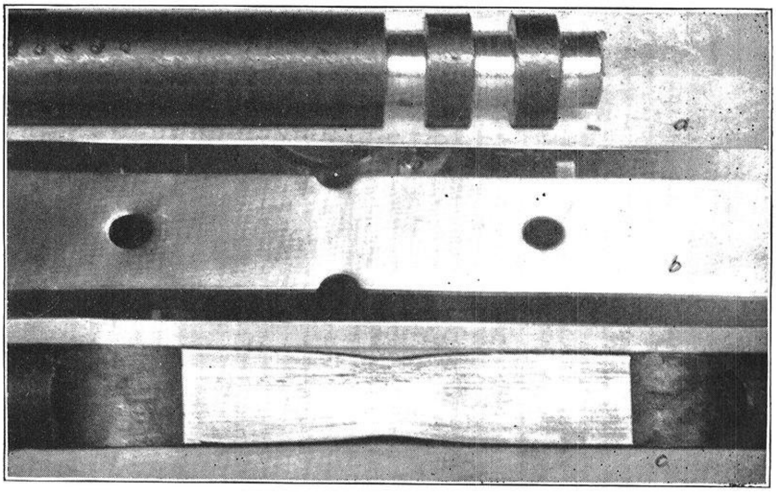


PLATE III.

As to proof that in those materials forming a cup, fracture begins at the hign load, see Fig. 60 taken from Marten's Hand-book; Fig. 61, taken from ordinary boiler-plate failures; Fig. 62, showing a dark spot in the center by reflected light if a tool steel specimen, this same dark spot showing at a punch mark in Fig. 63 and on the tension edge of a cross-bending specimen in Fig. 64 and Fig. (e), Plate I (notice the "rip" lines from the dark spot to the bottom of the cup or outside of the specimen). Fig. (a), Plate I (=Frontispiece), also conclusively proves this, the fractured ends of a 1¼" round mild steel specimen being fitted together and the notch filed in as shown. Howard * and Martens † also concede the same as true.

This center failure first, means that either the stress is greatest in the center or that the material is less resistant in the center, or both of these; I think both, are true, as will be seen later.

If the specimen is a very thin plate it will fail in one of the ways shown in Fig. 65.

If it is a tube it will fail like Fig. 66.

After the first center failure we get generally the cup started, and it forms, in a good example, like Fig. 67 or like Fig. 68, although the latter is of rare occurrences.

Prof. Martens ** says that the ideal cup failure would be like Fig. 69, but I disagree with him for the reason that Fig. 69 is impossible. Fig. 69 could only be possible by *instantaneous* failure, which is contrary to fact as proven by the curved cups and center break.

In the case of notching a specimen, local failure may take place on the *outside first*, like Fig. 70 (a), but this failure need not cause the failure of the specimen, for in the case of Fig. 70 (a) this actual failure took place *in the center* of the specimen and worked toward the outside just as in any cup break. Fig. 70 (a) represents a case of mild steel. In tool steel the outside shoulder failure might cause the actual failure, as it generally does, as in Fig. (a), Plate III. Also see the failure at the punch mark in Fig. 63.

Notice the complete "smashing" break of Fig. 70 (b). This length between shoulders was at the critical length (see jog

---

* Howard, Iron Age, .890, p. 585.

† Martens' "Hand-book of Testing Materials," p. 96.

** Martens' Hand-book, p. 10 Vol. II.

in curve, Fig. 42) where the transverse action first comes prominently into evidence. The longer and shorter lengths gave cup breaks, the longer being normal and the shorter having *shallower* cups. These were all cut *from the same rod.*

In connection with cups, I may say a peculiar phenomenon presents itself, especially when machinery steel is tested, or in a high mild steel. The phenomenon referred to is the radial cracking in the bottoms of cups. The same phenomenon also shows itself in a pronounced way in pulling a medium mild steel *for the second time.* Such is Fig. (b), Plate I. This specimen was originally a $1\frac{1}{4}''$ rod and stood actually about 83,000 pounds, givingthe fracture appearance. Fig. (c), Plate I. Rested a week, the larger piece remaining was pulled again and stood about 94,000 pounds actual, giving break Fig. (b), Plate I. This last figure is the end which fits on to the other end of the piece of Fig. (c), Plate I.

Notice that these cracks *do not go to the center of the specimen, neither do they go to the outside of the specimen,* but stop a little farther toward the outside than where the cup begins.

I take these radial cracks to be direct proof of the presence of compression in the tension test piece. Furthermore they show this compression must be small in the center of the test piece, (later shown theoretically to be zero). This is seen thus, that the *release* of this compressive stress in the cracked zone as the *center failed first,* coupled with the resilient action brought to play on the cracked zone by the enormous compression outside of this zone, caused enough tensile stress to be suddenly generated to do the cracking. *Tension only* can directly cause the cracks to form. Notice also that these cracks formed *without allowing any flow transversely in the direction of the tensile forces* as is generally to be expected in mild steel.

A precisely similar phenomenon is shown in Fig. (d), Plate I. This is a piece of mild steel $\frac{3}{4}'' \times 1'' \times 13''$ bent cold. When the pressure across the bend (from 40,000 to 50,000 pounds) *was released,* a crack was developed in the bend as shown. The crack formed very audibly and *never formed except by release of load.* It also formed *without flow across the crack or in the direction of the tensile forces generated.*

Doesn't this mean that the compression across the crack produced during bending and by the load, was *changed into tensile stress* and that probably, the resilient spring of the tensile forces on the outside of the bend added enough help to rupture the steel? Here the tension of the bend takes the place of the compression of the outside ring in the tension test. Otherwise conditions are exactly similar.

In both cases the material is changed, hardened by the flowing (as drawn wires, etc.), and fails in tension without flowing in the direction of the tensile force as would be expected from the normal action of a mild steel rod.

Let us again recall the scaling phenomena of Figures (a), Plate III, and (a), (b), (c), Plate II, etc., and the meaning of Fig. 49, etc. There is no space here to dwell on the opposite case of compression, in which strictly opposite facts and conditions hold.

All these facts prove a compression present in the tension test, *but not in the least like the "implied" compression of the Theory of Elasticity.*

Once more I ask, "Are any of the foregoing facts explained by that theory?"

In general designing with metals and some other materials the compression modulus of elasticity and the compression elastic limit or yield point are taken equal to the tension modulus and yield point. Is this true? In Johnson's "Materials," pages 490, 491 and 492 are given enough data and curves to prove conclusively that the compression values are in both cases greater than the tension values, although the difference is not very great. The reason for this difference can be seen when the true force relations of both tests are understood as will be shown later.

We have seen how testing a material at different temperatures affects the stress-strain curve. Curves Fig. 30–Fig. 33 were obtained by adding heat to or taking heat from the specimen and by surrounding the specimen with the desired temperature. In Fig. 71 we see the temperature change of the specimen *due to internal action as it is pulled.* A compression curve is also given. These were obtained by Turner* by thermo-electric measurement. Notice that at first the specimen in the tension case cools and then that it gradually, in fact so gradually *that its beginning cannot be detected,* heats up.

Does not this indefinite beginning stand against the idea of a "True Elastic Limit?" It would be interesting to see what becomes of the work done in stretching a specimen: how much is lost in heat, how much is stored up temporarily and how much permanently, etc., but space forbids the discussion here. The data at this point is also very meagre. In this connection the magnetic and electrical effects should be borne in mind.

Annealing, in its effects on strained material, simply forces all or most of the induced stresses to disappear and thus, if we anneal a specimen at any stage of a test, we will get a resulting specimen whose properties will be the same as if we had cut our original material into the shape into which we pulled the annealed specimen before it was annealed, providing our original material had been thoroughly annealed. Fig. 56 illustrates this point. Table XXIX p. 511, Johnson's "Materials" illustrates the same. Annealing cold-worked material brings it into the hot-worked condition, this of course is included in the above statement.

While pulling a specimen, its electro-motive force changes with the stress induced and the resulting stress—E. M. F. curve resembles, in some cases, the ordinary stress-strain curve, see Hambuechen†. This change is to be expected, in the light of electrical theories, etc., since drawing a specimen changes its constitution somewhat as in the cases where mild steel cracked without yielding.

---

*C. A. P. Turner in Proceedings Am. Soc. C. E. Jan. 1902.

†C. Hambuechen Bulletin No. 42 Engineering Series University of Wisconsin, 1900.

The magnetic properties of steel also change with the stress. An end of a broken specimen will pick up vastly more iron filings than will a piece of annealed metal cut into the identical shape of the broken specimen end. This should follow if we look upon the phenomenon of magnetism according to the theory of the same. The pulling and drawing *lines up the units of material*, as we shall see later, by giving them a chance to line themselves up and this lining up is the essential of the magnetic theory.

I have thus about covered the phenonena discovered which accompany tensile failure and especially is this true for the metals, among which steel takes the most important place, as it should.

Do *any* of the whole number of facts presented bear out the "Theory of Elasticity?" Does this or can this "Theory" explain any of them? The answer in all cases must be a very emphatic "no". The discrepancies between the facts and the "Theory" are too great, within as well as without the elastic limit or yield point (in the case of torsion, that of the extension of the outer fibre *at the elastic limit*, as much as 1000 per cent. *difference.*) There is no definite point or limit up to which it does, or it does not hold.

Let it be remembered here that the "Theory of Elasticity" *must have* Hooke's law and Poisson's ratio as fundamental experimental facts to start on. Look back over the list of facts presented and their meanings. Hookes' law is no general, no real law, *not even a special law for steel*, as many suppose.

There is no "true elastic limit," conseqnently, we in practical designing *must adopt* some general "*empirical elastic limit*" and I for one, cast my choice for "Johnson's elastic limit" as the *simplest to obtain;* and in other ways as good as any other.

As for commercial testing records, simply to check the grade of material, I unhesitatingly would use the "drop-in-beam" method for obtaining the yield point of those materials which give one. If the material or test piece has a scale on it, this point cannot be raised. If it possess no scale it should be polished for a small part of its surface near where it *first begins to yield* and then the "Lines of Force" will prevent any mistake being made. For materials possessing no "drop" dividers or a small autographic recorder, the last by far the best, can be used to detect the yield point, in all cases helped by the scaling and "Lines of Force," to avoid mistakes.

As for Poisson's ratio, it is easily seen that this ratio, as used in the "Theory of Elasticity" can only be true, *as a fact*, for *infinitely long specimens.* For a specimen 20'' long the elastic contraction at the middle of the specimen may be about this ratio, but going toward the ends of the specimen it must decrease until it becomes zero near the ends. Many commercial sizes of material come under the same classification as that of a test piece. The statement may be made that it is only necessary to have *one right section* where Poisson's ratio holds, especially if that be the weakest section, and that the "Theory of Elasticity" could be so applied as to change for every section. In answer I will again recall the fact that this "Theory of Elasticity" does not do so, and furthermore that it "*implies*" compression. I ask, *where is the area upon which this compression acts?* and *how large is this area?* Also, *where did the "implied" compression come from?* since the Theory furnishes no connection between the pull or longitudinal tensile stresses and the transverse "implied" compression stresses. These questions cannot be answered seriously.

Also we have seen that while we have undoubted compress present in the tension test piece, while under pull, it is not of a *uniform kind* either considered transversely or longitudinally, and also that we have a *transverse tension* which the "Theory of Elasticity" never considers at all.

It would seem, therefore, that while we undoubtedly will retain designing formulas developed as to form by the "Apparent Theory of Elasticity" and completed by the addition of properly evaluated empirical constants, (and it is proper that we should do so as long as such formulas satisfy the demands made in practice upon them), it is high time we were stopping the usless expenditure of energy of those who seek to apply the higher mathematics to assumptions which in themselves are *farther from the truth* than the error involved in solely using the simple mathematics. It would seem furthermore, that a knowledge of the real actions going on would be of inestimable benefit in determining the variables to be used in a formula, even though this action could only be determined qualitatively, and it was with the object of finding some of these that I began some two years ago to study up the attempts by others to do this, or to show how the "Theory of Elasticity" could be made to conform to fact.

Commandant Hartmann[1] advises discarding the "Theory of Elasticity" and sole reliance on the testing laboratory. The following complete attempts to harmonize the "Theory" with fact, were analyzed by me namely: Prof. Rejo's,[2] M. de la Noés,[3] Captain Duguet's as completed by M. Mesnager,[4] and the following part attempts by Prof. Martens,[5] Prof. Rudeloffs,[6] Prof. Kirsch's[7] and some others not complete enough to mention.

The result of this analysis (given in my baccalaureate thesis of 1901) was that I could not see my way clear in any of them to a rational explanation of the foregoing facts, but that, on the contrary, they each and all of them *failed and failed absolutely.* Is it strange, therefore, that I felt lost for a while? However, this lost feeling was soon dispelled. It struck me that none of these workers ever seemed to think of trying to cut loose from the "Theory of Elasticity" and to *begin with material in the unloaded condition,* just as our best modern chemists and physicists conceive the matter to actually exist.

In the Universal Encyclopedia I find under Elasticity: "No

---

[1] L. Hartmann. Same as foot note, p. 229.

[2] Baumaterialen Kunde.

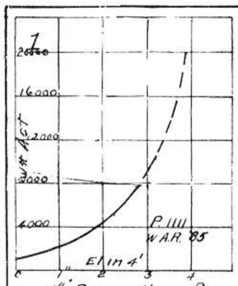
[3] Ponts et Chaussèes.

[4] 1900 Communications of the International Congress at Paris.

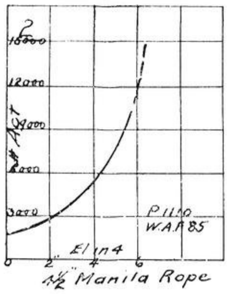
[5] Marten's Hand book of Testing Material, translated by Gus Henning.

[6] Berlin Testing Laboratory Communications.

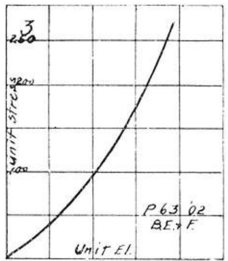
[7] Marten's Hand book of Testing Material, translated by Gus Henning.



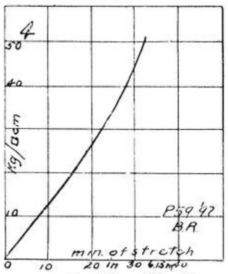
4½" Russia Hemp Rope



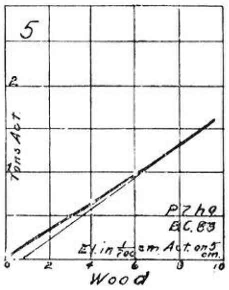
4½" Manila Rope



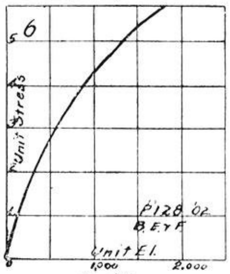
Leather



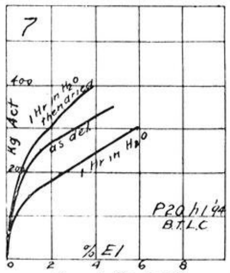
Cotton Belt



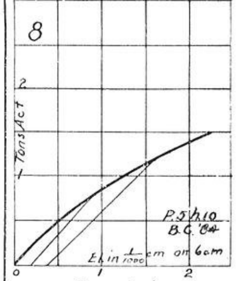
Wood



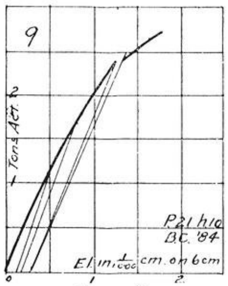
Rubber



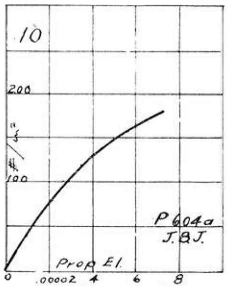
Card Board



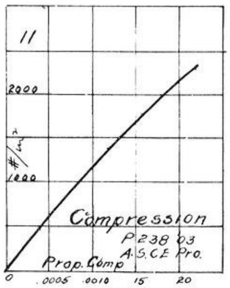
Sandstone



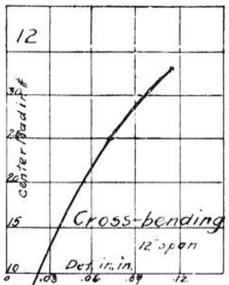
Granite



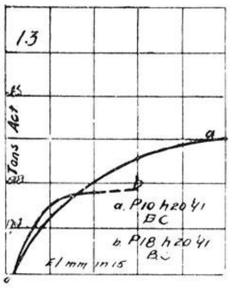
Concrete



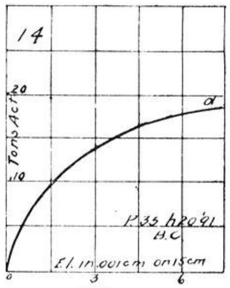
Brick



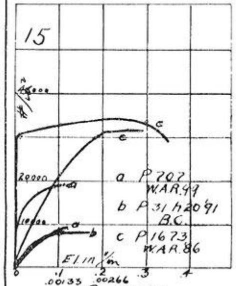
Glass



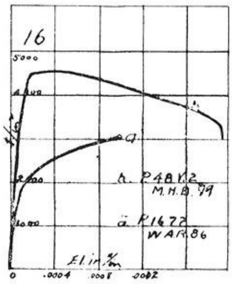
Lead



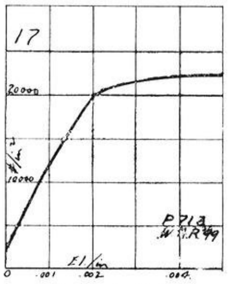
Tin



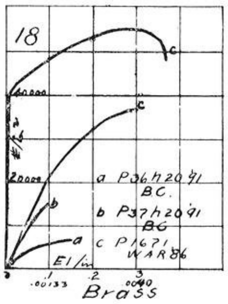
Copper



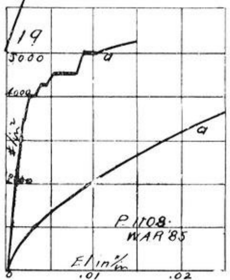
Zinc



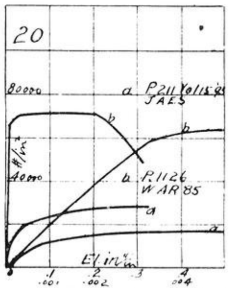
"Lumen" Metal



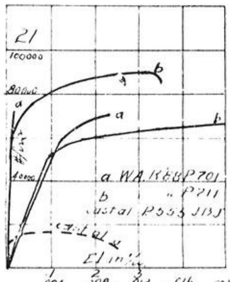
Brass



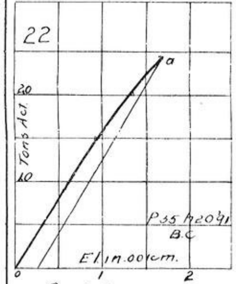
Solder



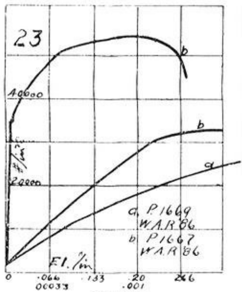
Phosphor Bronze



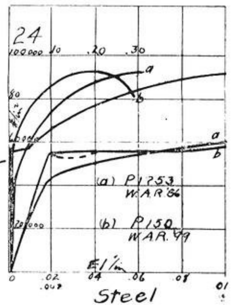
Aluminum Bronze



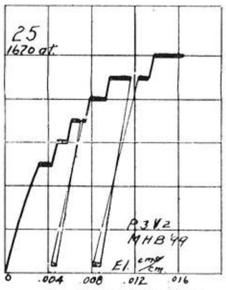
Cast Bronze



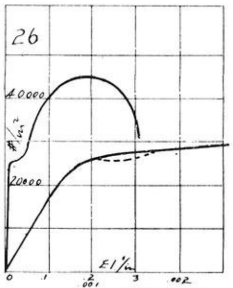
Iron



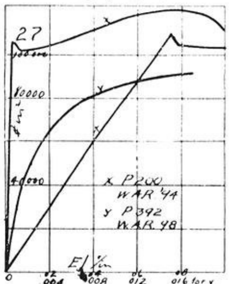
Steel



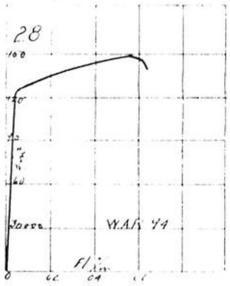
Magnesium



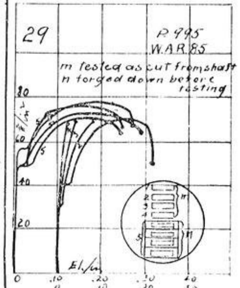
Swedish Iron



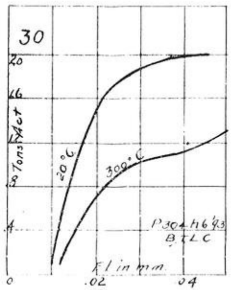
Nickel Steel



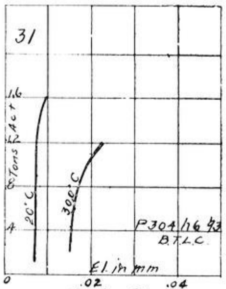
Rifle-barrel Steel



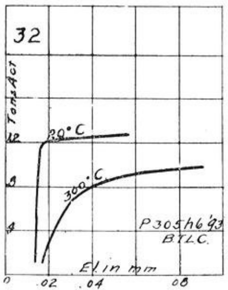
16" Forged Steel Shaft



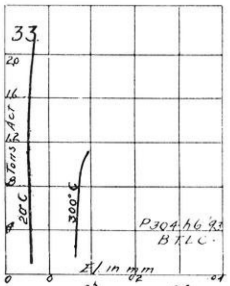
Copper



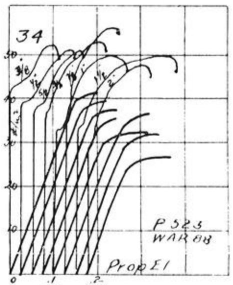
Weld Steel



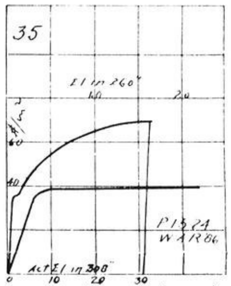
Delta Metal



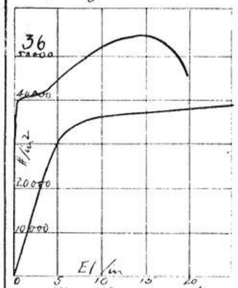
Martin Steel



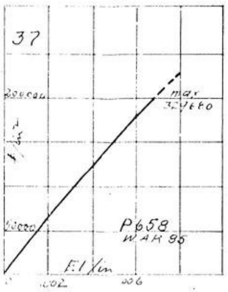
Wrought Iron



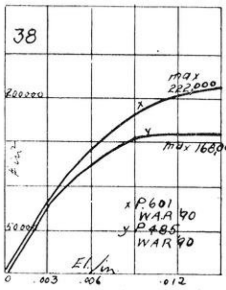
Eye-bar 25'8" (steel)



Steel Boiler Plate

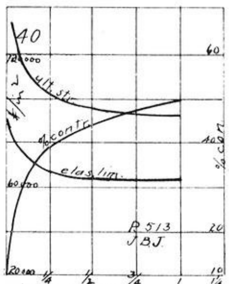


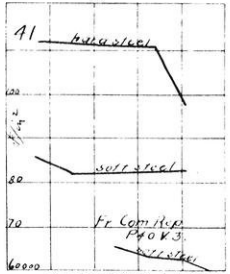
Round Steel Wire



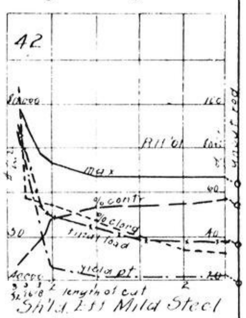
Square Steel Wire

Shoulder Effect, Wrt I.

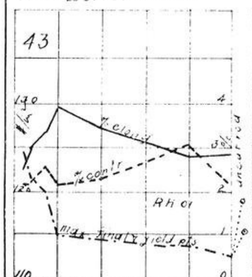




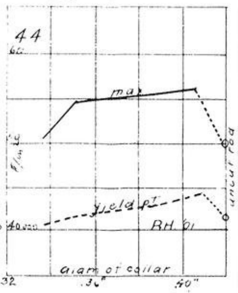
Shoulder Effect, Steel



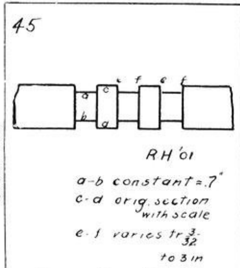
Sh'ld Eff Mild Steel



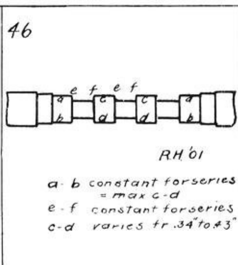
Sh'ld Eff Tool Steel



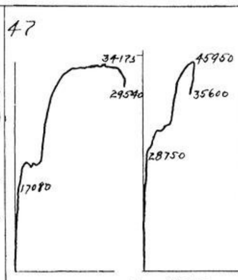
Collar Eff Wrt. I.



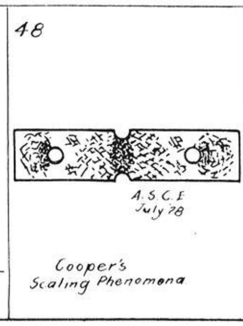
Spec. for 42 + 43



Spec for 44



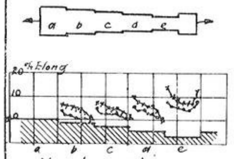
Eng News
G. Henning



Cooper's
Scaling Phenomena

W.A.R. = Watertown Arsenal Reports
J.B.J. = Johnson's "Materials of Construction"
B.C. = Bauschinger's Communications
B.T.L.C. = Berlin Testing Lab Communications
B.R. = Bach's Reports of 1897
B.E.&F. = Bach's Elasticität und Festigkeit
M.H.B. = Martens' Hand Book tr by G Henning
R.H. = R Hartman B.S. Thesis 1901

49



No elongation on Shoulders

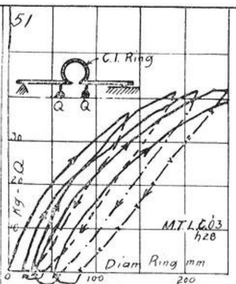
BTLC h1'01 P52

50

1900 Communications International Congress, Paris P62 V2

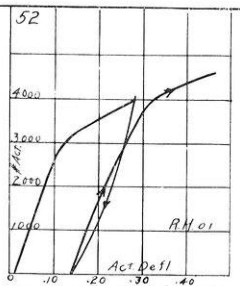
Oscillatory Effect

51



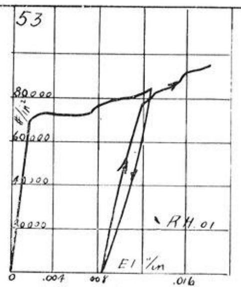
cross bending cast iron

52



cross bending toolsteel

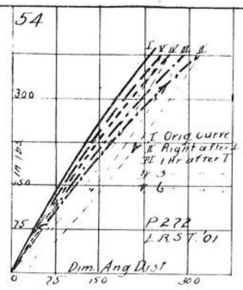
53



tension tool steel

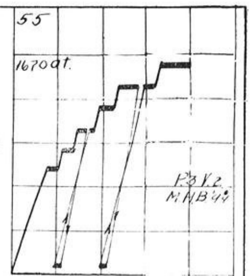
Resilient Loops

54



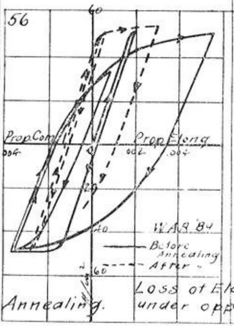
Res. Recovery Ethd

55



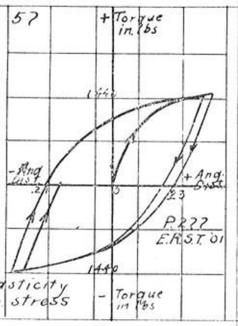
Magnesium

56



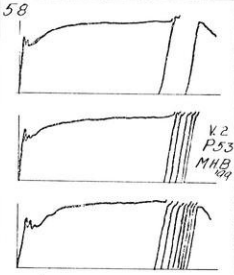
Annealing.

57



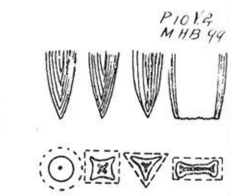
Loss of Elasticity under opp stress

58



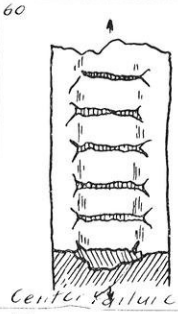
Raised Elas. Lim

59



Fractures
Very Ductile Mtls

60



Center Failure

61

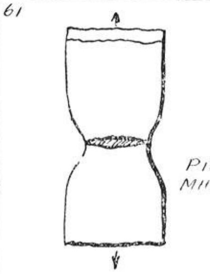
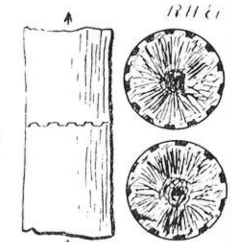


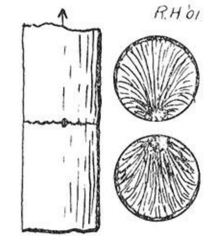
Plate Failure

62



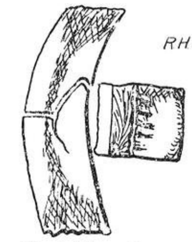
Tool Steel
Center Failure

63



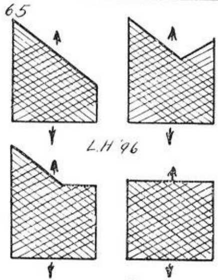
5/8 Tool Steel
Punch Mark Failure

64



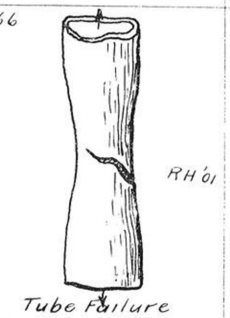
Tool Steel
Column Failure

65



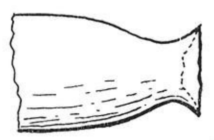
Thin Plate Failures

66



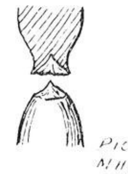
Tube Failure

67



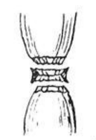
Cup Failure

68



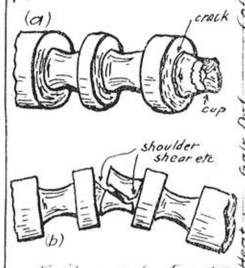
Cone Failure

69



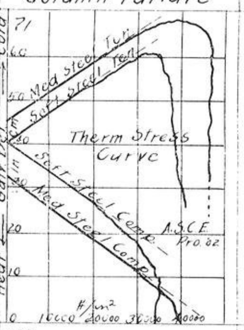
Martens
Theoretical Cup

70

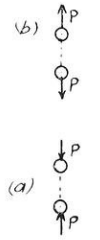


Failures for fig 45

71

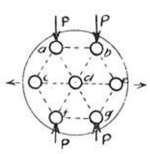


72



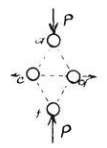
RH'01

73



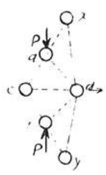
RH'01

74



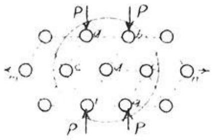
RH'01

75



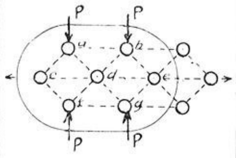
RH'01

76



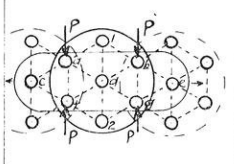
RH'01

77



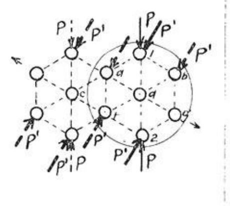
RH'01

78



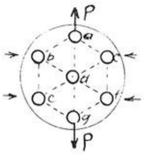
RH.'01

79



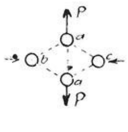
RH'01

80



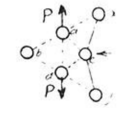
RH'01

81



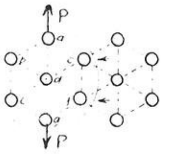
RH'01

82



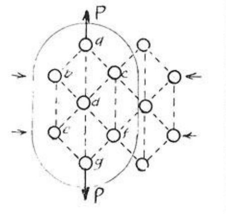
RH'01

83



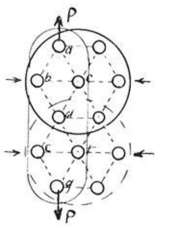
RH'01

84



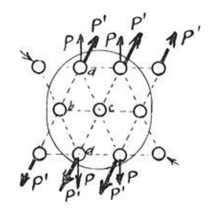
RH.'01

85



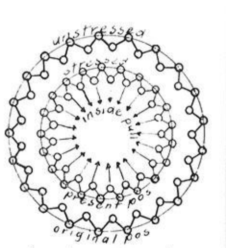
RH.'01

86



RH.'01

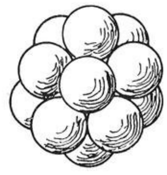
87



Arch Effect

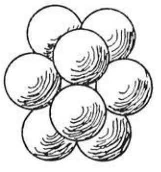
RH.'01

88



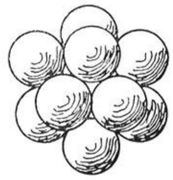
RH.'01

89



RH.'01

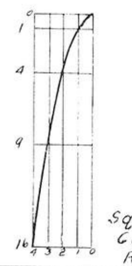
90



RH.'01

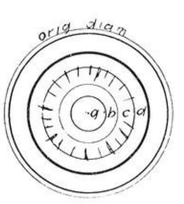
Solid Unit Group

91



Square Curve
RH.'01

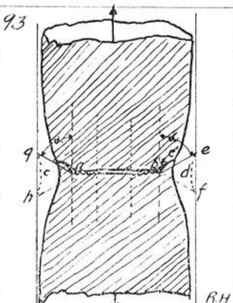
92



Cup Formation

RH'01

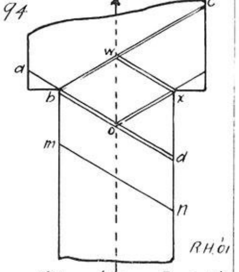
93



Cup Formation

RH'01

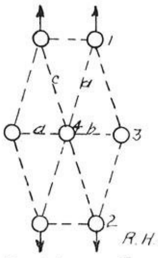
94



RH'01

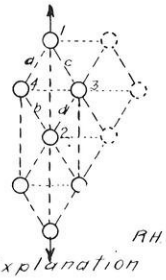
Shoulder Break Formation

95



R.H.'01

96



RH'01

Rubber Contr Explanation

MHB Martens' Hand
Book II by G. Henning
E.R.S.T. Edinburgh Royal
Soc Trans '01
B.T.L.C Berlin Test Lab
Communications '01
M.T.L.C. Munich Test Lab
Communications '02
L.H Com L. Hartmann
"Dist des Def" Paris '0
W.A.R Watertown Arsenal
Reports
A.S.C.E Am Soc Civ Eng Pro '02
C.A.P. Turner
RH R. Hartman
B.S Thesis 1901

theory of elasticity founded on any assumed hypothesis as to the molecular constitution of matter has as yet been found satisfactory when applied to solids. In this case, therefore, the theory of elasticity is best investigated without resorting to any such hypothesis." This partly explains why some of the workers mentioned have not begun as I shall in the following pages, where I hope to do the thing which the above quotation shows has not yet been accomplished.

This idea of beginning with a unit basis it was which gave birth to the following theory. I thing it is called for since all others have failed and since there seems to be a great necessity for a rational and correct theory to help out the steel-concrete industry in particular. The comparison of dates at the beginning of this paper will be of interest here.

The theory as completed was not conceived of all at once, it is on the other hand a growth. One vital idea was essential outside of the foregoing and that was to see the enormous significance of the "arching-effect" mentioned later. This idea struck me one day as I was trying to see how Prof. Retjo's force-net diagram could be revolved to form a solid cylinder without changing its essential characteristics. And then I considered, in this connection, the action of the collar rings in Fig. (a), Plate III.

I claim no more for this theory than that, if the assumptions and facts upon which it rests be granted, then the theory must stand and if these assumptions or facts be overthrown, then the theory must be either modified accordingly or it must fall. In the light of present knowledge of material, the assumptions and facts are admitted and hence *it must stand.* All theories are of value only in so far as they help the advance of knowledge of the facts connected with the subject in hand. When they outlive this usefulness they had better be dropped. On this basis the "Theory of Elasticity" as a true one, had better be dropped. And on this basis also, the theory now to be given should be adopted, since it has already lead to the discovery of a number of facts which are not yet in shape to give out, but which will appear in due season.

Furthermore this theory explains *all of the facts* given in this paper. The assumptions and fundamental facts upon which this theory rests are seven in number and are as follows:

1. The material is presumed to be composed of separate units between which all forces act, that is, between which stress acts.

These units may be looked upon as molecules although it is not necessary for the purposes of this theory for them to have all the characteristics ascribed to molecules. The characteristics necessary will be stated as separate assumption or facts. Since the units are separate they conform to laws of light, heat, magnetism, etc.

2. *Homogeneous material in all directions in the unstrained state is presumed.*

If this was not presumed the analysis would become too involved; while it is possible to use other material, the simplest only is used here. This assumption means that each unit is identical to every other unit; that each unit has a center of symmetry which is its center of mass, and consequently that each unit affects its twelve adjacent neighbors equally. This spaces the units equally in the solid. This spacing is not affected as to whether they are in motion as per Kinetic theory or not, since in case they are, their average positions can be taken. Some amorphous substances easily come under these assumptions in the light of present knowledge, with the possible exception of the units being identical; but this isn't radical enough to change results since here also averages might be taken.

3. The material we deal with is compressible and extensible, facts known and admitted by all.

This means that there are both repellant and attractive forces acting between the units, both of which can be changed by external loading and so give us deformation. Either force alone cannot explain the facts and laws of materials, as is easily seen when tried.

4. In compressing and extending the material the effect is assumed as changing the distance between the centers of the units.

This assumption is almost a fact, it being an assumption merely because the units themselves are assumed. Number four is admitted by all.

5. While the material remains in the natural state, (i. e. unstrained by external forces) the property of fixity of position or of average position of the centers of the units with relation to each other is assumed.

This assumption is almost included under number (2). It is simply introduced here to limit the theory to solids, which it does. Tension of liquids or gases has only scientific value, while compression is of both scientific and practical value.

6. During the application of external load, the centers of units move with relation to each other according to assumption (4), and this motion is further assumed to follow the laws of attraction and repulsion as generally conceded in physics and chemistry, i. e. the force varies inversely as some logarithmic function of the distance between the units.

This assumption has abundant backing and is admitted by all. For the attractive forces this relation is a much lower power curve than for the repulsive forces, in fact the difference is somewhere from the square or cube function for attractive force to one very much higher, and even *infinite* for the replusion forces, for it is impossible to conceive of failure by *universal compression.*

The "start off" of these curves measures the rigidity of the material and though great for tension is enormous for compression, in fact a liquid or solid of density unity can barely be compressed at all after a little load has been on. These rigidity curves are strictly the stress strain curves for pulling or compressing two units, and hence cannot be obtained practically. In this theory, therefore, the repulsive forces will be taken as being infinite as far as the stresses of practical loa ding are concerned.

One more fact which helps out this last assumption or fact is, that while in tension the force gets weaker as the units move in the direction of the acting force, in the case of compression they become stronger still.

7. *The total volume in any test piece is taken to be a constant for all stages of a test, after residual and elastic forces have ceased to act, that is, all units are and remain the same distance apart for all such stages.*

This is the law of conservation of weight and volume. M. De la Noe[1] usesit, as does also M. Mesnager[2], Cooper[3], Prof. Martens[4] and others. In fact Prof. Martens there records an *increase* in volume in one case of *compressing* a lead cylinder.

This last fact is one proof of the statement made earlier in this paper that the socalled compression test can be shown to fail in tension.

The above seven assumptions and facts are admitted by all modern thought in physics, chemistry and mechanics as sound and rational. They form the basis of the following theory and since this theory formed upon this rational basis explains all the phenomena recorded in these pages, it seems in no way out of place to call it a rational theory.

Both tension and compression cases will be given and thus will their complimentary character be shown. The latest complimentary proof of facts we have is that of "Lines of Force" as mentioned before. Take two units Fig. 72 (a) and compress them. They approach each other but no failure can result. A simple stress-strain curve results.

Take two units Fig. 72 (b) and pull them. They separate until the attractive force between them is overcome and rupture occurs. So much for two single units.

Passing to units equally spaced in a plane or units whose centers, are all in one plane, take seven units as in Fig. 73 and compress them. (The solid spacing will be taken up later.) These form a group of six equilateral triangles. Fig. 74 shows two of these, the simplest combination possible. Apply load P as shown in Fig. 76, unit "a" approaches "f"

---

[1] Annales des Ponts et Chaus sèes, 1900, part 1, 2nd trimester.

[2] 1900 communications of the International congress p. 144.

[3] Proceedings Am. Soc. C. E., 1878.

[4] Marten's Hand book of Testing Materials by Gus Henning.

and "b" approaches "g" and since the repulsion force "a–c" is so great (basis 6) "c" separates from "d" and "d" from "e" also in Fig. 75 "c" separates from "d". If "d" is in the surface of a cylinder (assuming for the time being that the plane-spacing is possible in a solid) the separation just mentioned becomes directly a tensile stress and "d" moves *out of the surface* as in Fig. 75, the attractive forces "x–d" and "d–y" being small. If "a," "f," "c," "d" are interior units as in Fig. 78, "c" and "e" move outwards and push "m" and "n" outwards. "m" and "n" resist and the more so the nearer they are to the axis of the test piece. Thus if load P is applied to every unit in the line a–b the maximum tensile effect across units "c", "d" and "e" will be on the outside edge of the cylinder since "c" and "d" would be separated there the most. Similarly "a" and "f" would be farther apart in the axis of the test piece than in the outside edge thus showing that the compression effect would be greatest in the axis of the piece. (The less, two units approach each other in compression under a given load the greater is the resistance and the more load will they get and vice versa for tension, this being the well known principle of mechanics in anylizing flitched beams, etc.) Now if all the units in the line "a–b" are brought down *the same distance*, that is the ends of a test piece remain parallel, it follows that the tensile stress must *be greatest on the outside edge of the cylinder* and the compression stress *greatest in the axis of the same.* But we have a factor to deal with which has not been mentioned, namely, in the transverse sense we have other units holding on to "d" Fig. 75. These being at the original distance from "d" would have their strong attractive relations with "d" strained and thus we would get the whole *outside* surface of the cylinder under *transverse tensile stress.* This stress is also seen to be a *maximum on the outside, decreasing to zero theoretically in the axis of the test piece.* Let us continue compressing Fig. 76. The action noted continues until distance "a–f" becomes equal to distance "c–d" as in Fig. 77. Here is the critical point for this group of units. A little more compressing will allow a sudden change to the condition in Fig. 78 (providing the units "m," "n," Fig. 76 allow, as on the outside of a cylinder they do) that is, as "c–d" becomes greater in distance than "a–f" the attractive force "a–f" is getting stronger and stronger and that of "c–d" weaker and weaker *thus both helping the load.* If "c" Fig. 77 is an outside unit we see the elementary cause to the *ridges* of the "Lines of Force" as they form in the compression case. Of course they come actually by group action and thus give us visible phenomena. Notice that now we have in Fig. 78 a spacing which occupies *exactly the same volume* that Fig. 76 did, thus fact (7) of the bases of this theory is upheld. In Figures 76, 77 and 78 the light full circle or oval is always drawn around the original group of units discussed. Notice that in Fig. 78 the full heavy circle is drawn around a group containing all of the original units in the circle of Fig. 76 except two. This is yielding or flowing. Notice also that it is a hexagon with position turned through 30° from that of Fig. 76.

Suppose we keep on compressing "a" and "b," Fig. 78. It is seen that we would he simply taking the original group in Fig. 76 turned through 30°. Let us do this and let Fig. 79 represent the state of affairs. In this case no yielding or flowing can take place as long as all units are lined up as shown and as long as "*P*" *keeps its direction* straight down. Rupture can, however, take place under these conditions, and it will be *sudden bursting* as the attractive forces transversely are overcome. And this is just what happens to *those materials which do not flow.* But if the direction of "P" can be shifted (due to non-homogeneity of material or differential load, etc.), then "P" may take the position "P′" and repeat the conditions analyzed before. This is the more probable in that the compressive force from units "1" to "a" and "b" is enormous and serves to delicately balance "1" between "a" and "b" and thus conditions are always ready to made the shift required.

Note in the above analysis that all flowing or *yielding follows the magic angle of 60° theoretically*, all units are situated along lines making this magic angle with each other and remember in tension tests that the "Lines of Force" make angles with the direction of pull varying from 53°–65°, consequently right through this magic angle of 60°!

In the case of tension we have precisely analogous and opopposite relations presented.

Let Fig. 80 be one unit group. As "a" and "g" are pulled by "P," "a" and "d' separate, and "b" and "c" approach each other, Fig. 81. If "c" is in the outside edge of the cylinder, "c" moves *inwards*, "x" and "y" resist this action by tensile force, but another force much more powerful keeps "c" from moving inwards, it is namely the "arching effect" shown in Fig. 87. By similar analysis to that in the compression case, it is seen that in the tension case we have (in the longitudinal plane sense) *a maximum tensile stress in the axis of the test piece and a maximum compressive stress in the outside edge, while (in the transverse solid sense) we get an enormous transverse compression in the outside edge which diminishes to zero, theoretically, in the axis of the test piece.*

The group shown in Fig. 83 is easily followed through the critical stage, Fig. 84, and equal space group of Fig. 85. In Fig. 84 a part of the reason is evident why we get a "drop" in a rolled tension test piece of steel and not such enormous "drops" at least, in compression, if any at all. In Fig. 84, "b" and "c" are ready to rush together, but are held back by the "arching effect." This effect, in material of the right fixity of units, is enormous (machinery steel and higher carbon steels of the semi-plastic type) and hence *when the arch is once broken*, the first "drop" must be very large, as it is in fact. In compression, on the other hand, there is transverse tension and no such effect is possible, while also, in interior groups, "m" and "n," in Fig. 76, resist any sudden action. A group of units acting like "c," Fig. 82, would form the "Lines of Force" which in tension are *furrows*.

Note the *magic angle of 60°* again and remember that Commandant Hartmann proved them complementary for compression and tension.

If we keep on pulling Fig. 85 we see the case of Fig. 83 turned through 30°. If there be no differential action of the units surrounding our unit group, we shall get no more yielding or flow, as from Fig. 84 to Fig. 85, but instead, we shall get rupture. If there be differential action, we get conditions like those in Fig. 86, obtaining, and we see here the conditions just analyzed.

Thus all cases are covered, for any other positions of our unit hexagons are but combinations of the above two positions.

In materials *which do not flow* the break should be straight across the specimen deduced from Fig. 85 and it is in fact as is seen by glass, rubber, etc., fractures. Notice the fact that these considerations of flow, as shown by Figs. 84 and 77, require an oscillatory action in the specimen. This action is shown in Fig. 50.

But I have analyzed a condition which is not quite true.

The real solid spacing of units is shown in Figures 88, 89, and 90 giving the three distinct views possible. Let us see how this spacing would affect the results deduced by the plane spacing.

In a group of 12 spheres around a 13th, no plane section will cut the centers of 7 units as Figures 83 and 76 show, but such a section can be passed to cut 7 units, one through its center and the others having their centers about $\frac{1}{6}$ of the distance between units from that plane. However strictly analogous actions to those analyzed hold.

Group Fig. 88 corresponds to Fig. 80; group Fig. 89 to Fig. 73 and group Fig. 90 is one intermediate between that of Fig. 88 and that of Fig. 89. That of either of these last two figures *must pass through that of Fig. 90* in oscillating from one to the other. This oscillatory action is clearly shown in Fig. 50, as noted before. Fig. 89 shows the most stable group and the one where rupture probably most always occurs especially in those materials which yield or flow before rupture; yet, in the solid spacing, each one of the three groups is stable, *if isolated, and pull is applied to the top units* ("1," "1" and "2," or "1," "2" and "3") only.

Fig. 88 is in a very delicately balanced state and would yield with the least differential action upon it by outside units. Fig. 90, although more stable than Fig. 88, would also quite easily be made to yield.

A thorough analysis of these solid groupings has shown me that the conclusions arrived at as announced, drawn from plain relations, hold in a qualitative sense in the solid groupings, which is all I claim for this presentation.

The magic angle here also is 60° approximately. The "arching effect" and opposite case of "tensile ring" hold just as before.

The "drop in the beam" in tension, and barely noticeable in compression, also holds.

The "Lines of Force" also hold.

All the other phenomena presented in this paper will now very briefly be reviewed and looked at from the basis of the theory presented.

From the theory presented it is seen no Hooke's law is either true or necessary. How and why should we expect a combined action of units of material to give us a straight line when the action between the separate units themselves is one expressed by some logarithmic function? Look at Fig. 91, which is the graph of a simple "square curve." Does not this curve express the approximate reality of the stress-strain curves presented in all the materials? See how straight it starts out and how sharp it turns over, just like actual curves. And then with the cube curve we get still better approximations to Hooke's law.

It is also easily seen now that there is no "True Elastic Limit."

The "drop" was explained.

Yielding under a constant load is explained by appreciating the fact that the "arch," etc., once broken, it can be kept up more easily, especially for materials like zinc, Fig. 16 (b), with little fixity of units.

As the units in the center of the rod flow and load the "arch," we see that they form themselves into new stable groups while the "arch" becomes stressed up higher and higher. The result is that when "we go down off the curve" *the "arch" springs back* and bends the return line toward the load axis, see Fig. 50. At zero load this effect may continue, see Fig. 51 (the same is true for tension tests).

If we rest here the "arch" recovers more and more. Is it strange then that on going up again we get a "raised elastic limit" and a "higher ultimate strength?"

Why in going up *without rest*, do we get a line curved from the load axis or a decreasing modulus or an elastic limit under the point from which we "came down?" Because the "arch" is compelling some of the central units to oscillate back again and not having given it time to do this we have these central unit groups *helping the load.*

Why, in the case of changing from compression to tension do we get no Hooke's law at all (see Fig. 56)? Because, suppose we had pulled a specimen, its "arch" is trying to *contract* the specimen, and if we also compress the specimen we simply help this "arch" along.

Scaling, "Lines of Force" and their complementary action are all explained as we have seen.

The effect of rolling is to make this "arch" stronger; and drawing as we have seen has the same effect only more pronounced.

At different temperatures the units, by the heat theory, are farther apart, their attractive forces are less, hence Figures 30 to 33 should follow.

As to size, the smaller the "arch" the stronger, which is borne out in fact, and the quicker it yields after getting started, also a fact, that is, the larger the specimen the more gradual the yield.

As to shape, a "flat" is a poor shape for an "arch" effect and this holds true. Also it is easier to start the yielding *when the outside units are in a plane.* This is the same reason why an arched floor is stronger then a flat floor.

The effects of notching are all explained by the transverse action of the stress in the specimen. The "jumps" in Figures 39, 40, 42 and 43, stand out clearly now. The "arch" in Fig. (a), Plate III, is more clearly seen. The effect of making this arch stronger, Fig. 46, is clearly understood, etc., etc.

Repetitive and reversal limits and yielding below the so-called "elastic limit" are all demonstrated as possible. Theoretically some of the unit groups may be ready to yield as they cool from the melted state, or come from the annealing oven, that is at zero load. *Everything yields and adjusts itself to circumstances.* In the material world, just as in human life, continual, everlasting application and reapplication of the same thing conquers in the end and gains the day.

We see our way clear to the center failure first, Fig. 62. Also as to the cracks of Fig. (b), Plate I. In this case the zone (a), Fig. 92 had most tensile stress and least resistance because of the compacted "arch" and failed first, zone (b) then "ripped" (see "rip" line Fig. (b) and Fig. (e), Plate I), the sudden release of the "arch" in the cracked zone (c), and the rip zone (b), helped by the sudden spring of the "arch" in (d) which was under enormous load, due to the transverse tension across (a), (b) and (c), caused them. After this release the zone (d) is under peculiar action, being partly analogous to a tube, *on one side only, however.* To me, the action after the cup starts, is like in Fig. 93. After "ab" is ruptured the crack follows from "b" to "e" by a peculiar action which I call a combination of shear, tension and splitting (taking these in the ordinary meanings), during which time the metal in "e d f" is drawn in and "b x é" forms with a tendency to follow along at the angle "ϑ" which is the angle the "Lines of Force" make with the direction of pull.

If the specimen has shoulders as in Fig. 94 failure may begin at the corner "b" as in Fig. 70 (a), and if the material is brittle or very hard this may cause actual failure of the test piece as in Fig. (a), Plate III, but it need not necessarily do so in soft materials, for in Fig. 70 (a) and similar cases the real failure started in the center of the test-piece. Failure in the first case would begin at "b" and run toward "w" or "o," as the material was harder or softer (see Fig. (a), Plate III, and Fig. 70 (b)), (the shear, etc., action being correctly indicated by double lines only), and this would take place by the combination action of shear, tension and splitting, just as in the case of the formation of the cup. This action might continue to "d" or "c," or be met at "w" or "o" by singular action from "x," giving us the various plate failures. We also see here why shoulders strengthen, since "a d" or "b c" is greater than "m n." The sudden change from "a d" to "b d" also explains the danger of sharp corners.

In case of necking-down like Fig. (c), Plate III, in wrought iron, the local failures can be looked upon in the same way as the above failures.

In case of necking-down like candy or Fig. 59 we see the material is so plastic and yielding that *no "arch" of any strength can form*, the units possess little rigidity and hence no chance for a "cup" is presented, and the material draws down to nothing as is there seen.

We also see that *the final load in all cases is zero.*

From a study of the difference between the compression and tension cases it follows that the modulus of elasticity and the yield point should be greater than those in tension, as we have seen is true.

Annealing would give all the stressed groups a chance to adjust themselves to their new surroundings and thus put them back into the unstressed state.

It is seen that in the case of tension *we have expansion of material as long as no appreciable yielding occurs*, and considering the test-piece as a whole, and this would necessitate a cooling of the same as seen in Fig. 71, while the opposite action must obtain in the compression case.

It is seen that, just before breaking, the unit groups in tension take the position of Fig. 85, and are thus, so to speak, "lined-up," giving us increased magnetic effects.

The differences in electro-motive-force must follow as obtained, since we are straining the inter-unit force relations of the material, and the more so the greater the load applied; and from all theories of electricity the condition of the surroundings of the units or molecules is considered as of vital importance.

The resilient loops in other cases of loadings as cross-bending, torsion, etc., are all explained by the "arching effect," etc. In the case of torsion the resilient effect of residuary phenomena in the torsinal pendulum noted by Violle, Wiedemann, Warburg, Pisati, P. M. Schmidt, Martens, etc., is thus also explained when it is borne in mind that the center of the fracture of a mild steel specimen *is crystalline*, a fact which means either *simple tension, or tension as in ripping*, caused the center failure.

Also the phenomena of a weighted rubber tube* contracting when steam is passed through the same is thus easily shown to be that which should follow and from the basis of a *positive coefficient of expansion.* No negative coefficient of expansion in the cubical sense can be demonstrated as true. In the case of rubber we have *enormous deformation without yield* hence Fig. 85 pulls into Fig. 95 and Fig. 83 pulls into Fig. 96, the latter finally getting into the identical combination of Fig. 95 as indicated. Notice that the distances "a" and "b" Fig. 95 are much less than "c" and "d" etc. Now as heat is applied, by the theory of heat in an amorphous material in its unstrained state, expansion occurs equally in all directions. In other words the tendency of the units is to separate equally all around. But in Fig. 95 the effect is felt more in the distances as "a" and "b" than in the distances "c' and "d" and thus "a" and "b" widen out, which separation causes units "1" and "2" to approach, thus giving the contraction noticed. In time the so-to-speak "bond-lines" "1–5"; "4:6" etc. disappear, and on release of load we get the resilient effects noticed in rubber. The application of this theory to rivet-spacing and circular, etc., loaded cover-plates, etc., will be interesting and of value.

Herein we also find satisfactory causes for the angles of

---

*"Elements of Physics" by Henry Crew, 1899.

failure in the compression test and hence we need not invoke the aid of the mythical "internal friction" to help us out as in the formula which says the angle of failure is "45° ± ½ the angle of repose". Again the "*perfectly elastic material*" is supposed to fail in compression by the "Theory of Elasticity" at 45° which has never been obtained in fact.

And then in the so-called "Gravity-fault" in geology we have a *tension phenomenon* which is easily explained by the theory and facts presented and by *no other*.

The above applications including the "Torsional Internal Friction," I have fully treated in my 1901 Thesis. Here I have just space to mention them.

There are many other facts, not as important as those presented, which I have been forced to omit in this paper.

Thus we have a rational theory of mechanical force action, and one which satisfies the most critical mind. The extension of the same to shear, torsion, cross-bending, punching, etc., will undoubtedly clear up many obscure points in the same. I have yet to find the first fact which makes this theory untenable. I have also to find the first fact, coming under the scope of the theory, which is not explained by that theory.

In closing, I would say that many of the conclusions arrived at in this paper, notably the distribution of stress in a tension-test piece with its "arch," etc., are directly proven by the facts presented, regardless of the theoretical treatment later, and that most of the hitherto unexplained phenomena of the tension test, etc., as presented, are consequently explained directly from facts, which are entirely independent of the theory herein given.

I wish to thank Mr. Alvin Haase for his invaluable help in getting the figures of this paper into shape in the short time at our disposal. Thanks are also due to Prof. J. D. G. Mack for the loan of the wrought iron specimen for Fig. (c), Plate III.

I further wish to acknowledge the great help which I received from having access to former Dean J. B. Johnson's private library.

University of Wisconsin, May 28, 1903.

THE NEW TOOL STEEL AND ITS EFFECT ON MACHINE SHOP METHODS.

PROF. C. I. KING.

A writer of a recent magazine article says, "Looking backward through history, not perhaps to primeval times, nor even so far back as the days of Tubal Cain, but only through those centuries in which men have practiced the art of cutting the harder metals, such as iron and steel, by means of hardened steel tools, we find the machine shop has been a school for the cultivation of leisurely pessimism." *

Manufacturing in the modern and best sense of the word has we may fairly say, had its birth in the last half of the nineteenth century. For the past forty years or more, there was a well defined discontent among men of progressive ideas with the methods in vogue, and the results obtained in general machine shop practice. The opinion prevailed that the product of none of the machines in use was up to a standard commensurate with their cost and maintenance. What should the remedy be?

As so often happens in such instances, some invention was sought for which would be revolutionary in character, and which never comes. Many suggestions were made; some of them wise and some other wise. Of the last class I may mention the abrading wheel to grind off the stock, and the cold saw to tear it off, in place of the cutting tool to pare it off, as it was and is used with all of the machine tools.

In its primitive form the lathe, the first of our machine tools, may trace its ancestry back through several centuries, though of its present design there was scarcely a trace.

The wooden bed and the wedged down tool rest and foot stock, gave way to the iron bed, and the foot treddle was

---

*Oberlin Smith, in Engineering Magazine for April, 1903.

superceded by the power driven machine, with the coming of the steam engine.

All turning, however, was done with hand tools until Maudsly, about a century ago, gave us the slide rest. After this invention, progress was made by increasing the weight of the machines and the sizes of the working parts, thereby adding materially to their productive capacity. In the early days while we were making things, and before we had learned how to manufacture, the lathe was the all around tool of the shop, and it was made to do much work which could have been more expeditiously done on a surfacing machine which then was not in existence. But with the demand for it the planer soon came forth, and it was followed by the shaper and the milling machine.

As these tools came into general use, the necessity of further increasing the product and reducing the cost again became pressing, and it forced the process of segregation on until we were given the screw machine, the turret lathe, the boring mill, the pulley lathe, and the automatic gear cutter. All of these tools were made heavier and larger year by year until their limit of production was reached, not on account of the machine itself but on account of the tool steel then to be found in the market. I am not so sure that this steel was wholly to blame for some of the failures which are charged against it, but suspect that a part of them at least were due to lack of knowledge in handling. It was a fact, nevertheless, that in many of the new machines the steel would not stand up to the larger demands put upon it, and so a blank wall seemed to rise up and bar farther progress, which to a certain extent it has controlled for the last quarter of a century. Some increase in the output of these machines was obtained by the use of cooling mediums, such as water, oil, and alkaline solutions, which were allowed to flow on the tools at the cutting points and so carry off some of the heat, and this practice still obtains in some lines of work.

In the efforts to increase the product of the machines as they became more powerful, they were driven at higher speeds, with greater depth of cut and faster feeds until the heat produced at tool point caused it to break down, and it was found that the limit of temperature for the carbon steel was from 450 to 500 degrees.

This steel in hardening is heated to a low, red color, and then quickly plunged in water or other cooling liquid which absorbs the imparted heat in a few seconds of time, and the shorter the time the greater the degree of hardness secured. Cognizance of this led to all sorts of inventions of tempering solutions, but for all around results, nothing has excelled a saturated salt solution. Steel is annealed or softened by packing in powdered lime or charcoal, thus retaining the heat as long as possible.

Why it hardens by the sudden extraction of the heat is not very definitely known. Chemical analysis shows a larger percentage of the carbon combined with the steel, and less in the graphitic form after hardening. Carbon or crucible tool steel is an alloy of iron and carbon, the carbon varying from .05 per cent. to .2 per cent.

The iron is about 99.5 per cent. while small quantities of silicon, sulphur, manganese and phosphorus are present only by sufferance.

In the early practice, to harden steel for tools, we were instructed to heat it to "a cherry red," cool in water, clean off the hardened surface, and again heat until by oxidation the light color was succeeded by shadings from a light yellow to a dark blue, this color indicating a low temper.

That the "cherry red" temperature, as measured by the eye, was a very large uncertainty, may at once be suspected; it may well be doubted if any two persons could measure it alike within a hundred degrees, and the same operator could not do it on two different days if one were clear and the other cloudy. This feature has come to be so well recognized in the large establishments where much hardening and tempering is to be done, that a room is provided for it with curtains on the windows, so that a uniform light shall be secured. It used to be thought necessary to make the steel harder than was required for any particular service, and then reduce it as before described. The later and better practice is to use a lower hardening temperature, thereby avoiding the second process, and I think there need be little doubt that from ten to fifteen per cent more work might have been obtained from this steel had we better known how to handle it at the forge.

With all of the desire and effort on the part of the manufacturing world to increase the output of the tools in use, it is a curious fact that it allowed a new steel to lie within its grasp for nearly forty years without recognition of its value, and which, if properly used, would have increased its product from 25 per cent. to 40 per cent. The new product was known in the market as Mushet steel, being named after the inventor. Mushet was an Englishman who lived in the Forrest of Dean, a locality where much of the charcoal used by the Sheffield mills was made. With the aid of a steelmaker named Brookfield he produced the new alloy which was said to contain two to three per cent. of carbon, and eight to ten per cent. of tungsten. The first alloy of tungston and iron dates back to 1773, and d' Elhuyar & Beirthier are accredited with its production; but at that date it attracted no attention in the industries.

There are two reasons why this steel did not get into extensive use at an earlier date: one, its cost was forty to forty-five cents per pound as compared to the carbon steel at six to twenty cents. The other reason, and by no means the least, was due to the great difficulty in forging it to the required shapes, for if not heated and forged properly by the blacksmith, it would break and go to pieces as easily as cast iron.

A striking characteristic of the tungsten steel, was that it did not have to be hardened; it was always hard when cold, and it could not be annealed. It however, possessed that quality of structure which enabled it to stand from 600 to 700 degrees of temperature before it would break down. This new steel came later to be known as Self hardening steel, and as Air hardening steel from the fact that if subjected to an air blast its lasting qualities were enhanced to a small degree.

The usual surface velocities at which the carbon steel was used varied from 15 to 25 feet per minute, while the tungsten steel would stand from 40 to 80 feet.

On a fractured surface the tungsten steel shows a very close structure; it is darker in color than the carbon steel, and in grinding on an emery wheel it gives off a dark red spark like cast iron, while the other grade shows a bright and scintilating spark. For many years it was supposed that the function of the tungsten was to hold a larger percentage of the carbon in the combined form, and therefore, the steel maker always furnished the toolsmith with positive instruction to work it at a low temperature, and this direction was carefully followed.

Up to comparatively recent dates, all of this steel was imported from England. Finally American manufacturers began to produce it, and while their first attempts were far from successful the American product now is not excelled by any other.

About four years ago a discovery was made which marked a long step in advance in the use of these steels for cutting purposes. Presumably by accident a tungsten steel tool was heated up to the point of combustion or to the melting point.

After cooling off it was put in service, and it caused general surprise by showing much higher efficiency than was ever before attained by any steel. This incident was brought to the attention of a couple of young men, one a chemist, the other an engineer in the employ of the Bethlehem Steel Co., who at once began a series of experiments to determine the cause for these unexpected results. So far as it is known this has not been found, but they did discover some method of treatment which is still a trade secret, by which the steel could safely be raised to this high temperature, and still be on a commercial basis. After this new treatment it was found that the tools would stand from 1100 to 1200 degrees of temperature before failure occurred.

This discovery opened an immense field for improvement along nearly all manufacturing lines, and it also developed the rather astounding proposition, that to get the full benefit of it, all machine tools with which the new steel should be used, must be designed and built especially for it. It was speedily found that none of the tools in use were heavy enough to withstand the extra strain, neither had they sufficient driving power for the increased cuts which the new steel would stand.

That a clearer perception may be had of what this portends, it may be stated that the standard machine tools of average size require from one to six horse power to drive them, while new tools already in the market, and designed especially for this steel, have at a maximum, used fifty horse power.

In the series of experiments made at the works of the Bethlehem Steel company to prove the value of the new process, 200 tons of forgings were used, and $100,000 were expended. Many large forgings are made by this company and in their production, much time and fuel are required, and many men are necessary to handle them; by the old method these forgings were brought as nearly as possible to finished sizes before machining; now they are made only to approximate sizes, and the lathe and one or two men do the rest, and forgings of 36″ in diameter have been reduced to 28″ at one cut.

As a result of this recently acquired knowledge, line shaft speeds have been increased from 90 to 250 revolutions per minute; cutting speeds are increased 180 per cent, depth of cut 30 per cent, and the rate of feed by 24 per cent, and the end is not yet in sight. The planing machine and shaper will probably be the last of our tools to succumb to the new conditions but we may not be surprised to see them driven at speeds approaching 100 feet per minute in the near future.

In contemplation of these results the question at once arises, what has caused this wonderful mutation in the structure or chemistry of the alloy? Frankly, no one knows and for the present at least we must be contented with the results obtained.

It is known, that where the steel contains small percentages of Chromium, and Carbide of Chromium, the last named element is reduced in quantity by about one-half after the steel is treated.

Analysis of what are called the burned portions of the steel showed that nearly all of the carbon had been burned out, and the inference was at once drawn that the carbon was not necessary and so in the new steels only .5 to .6 per cent. is left in.

It may be of some interest to state that the original Mushet steel when worked at the Cherry Red temperature of 1450 to 1550 degrees, gave what was supposed to be its greatest possible service. Between this and 1700 degrees, the value rapidly fell to nearly zero, but from this point up to 1900 it rises sharply to the maximum. It also has been found that some of the new product can be annealed so that it can be machined, and some of it is soft when sent from the mills, this of course opens up a much larger field for its use, and makes it available for milling cutters, dies, drills, etc. Curiously enough, it will not stand shock and jar, and therefore is not suitable for cold chisels, stone drills or any of that class of work.

It also fails in use for finishing work in the machines, where the carbon steel succeeds. Its greatest success has been found in roughing work, and without seeing, it is difficult to believe that it will render service after the temperature has raised until both the tool point and the shaving are red.

Apparently the higher the temperature to which the steel can be raised in treating it for use, without melting it, the higher temperature it will stand in service.

Molybdenum is also used to produce an air hardening steel in place of the tungsten, only about one-half of the quantity in weight being necessary to obtain the same result, and in some of the steels both of these materials are used.

The price of this new product ranges from .50 cents to $1.00 per pound. The manufacturers state that these high prices are due largely to the difficulty in getting a homogenous alloy owing to the greater specific gravity of the tungsten and molybdenum. Neither of these alloys are so efficient in use on cast iron, as on the forged stock, yet they excell the carbon product by 25 or 30 per cent.

ELECTRODEPOSITION ON ROTATING CATHODES.

J. G. ZIMMERMAN.

In the deposition of metals, both in the plating and refining operations, we are limited, by the physical character of the deposited metal, to the use of a current density of comparatively low value. The rotation of the cathode has been suggested as a means for using higher current densities, and it is the purpose to present herein some data and observations obtained from an investigation of such means recently carried on in the Laboratory of Applied Electrochemistry at the University of Wisconsin. The work here described is only preliminary to a more extensive investigation of the subject which it is hoped will be carried out in the future.

The method employed consisted in the rotation of the cathode, a brass tube $\frac{7}{8}''$ in diameter, attached directly to the shaft of a small electric motor, and in varying the speed, the current density and the composition and temperature of the electrolyte.

The work of others along this line seems to have been confined mostly to copper. Mr. Cowper-Coles has described the manufacture of copper tubes by this process and has given some interesting data in regard to his process.* I have endeavored to determine whether the influence of rotation which is so marked in the case of copper, is equally apparent with other metals among which are nickel, zinc and silver.

Copper. In depositing copper it is found that the rotation of the cathode enables the current density to be run up to a high value and at such high values, the physical character of the deposit depends to a great extent upon the speed of rotation. With a comparatively low speed, 700 revolutions per minute, and a current density of 200 amperes per

---

*Jour. of Inst. of Elect. Eng. Vol. XXIX 1900.

square foot, the character of the deposit is at first very good. After a thickness of about .04″ has been reached, the cathode assumes a rough, pebbly appearance, the roughness increasing rapidly as the plating proceeds until finally some of the higher elevations grow out in the form of trees which point in a direction opposite to that of the rotation.

The fineness of the grain is dependent upon the current density, other things being equal, and the fineness increases with the current density until, at a critical value, a powdery deposit will occur. The increase in the number of revolutions per minute increases the critical current density although whether it is exactly proportional, I have not been able to determine. The highest speed which I used was 2500 revolutions, corresponding to 573 ft. per minute, and my observations tend to confirm the statement of Mr. Cowper-Coles that if a peripheral velocity of about 1000 ft. per minute and a current density of about 200 amperes per square foot be used, the copper will plate out with a high polish and to any thickness desired.

Deposition was also made at a current density of 160 amperes per square foot, and at 320. Equal weights were deposited out in each case and other conditions were the same. These samples show that the copper in the second case has finer grain than the former, although the difference in grain is not sufficient to show clearly in a photograph. The speed was 1600 r. p. m. (367 ft. per minute), and the electrolyte, as in all the experiments with copper, was a nearly saturated solution of copper sulphate with ten per cent. of free sulphuric acid. The solution was maintained at room temperature.

Nickel. Nickel, under ordinary conditions of deposition, is more sensitive to the effect of variations of the electrolyte and current density than is copper. A very slight change is sufficient to cause a marked difference in the character of the deposit. These effects are equally marked when a rotating cathode is used. Preliminary tests with the single nickel sulphate and other nickel salts failed to give satisfactory results and the ordinary nickel plating solution, the double sulphate of nickel and ammonia was then employed. It was found that on depositing from a neutral solution through a wide range of current density upon a polished cathode rotating above 1,000 r. p. m. and at room temperature, the deposit was of a dull white, similar to that obtained in ordinary plating.

During the operation of the nickel plating with a high current density, the solution heated about 8° C., and from the fact that the nickel would not corrode from the stationary anode as rapidly as it was deposited upon the rotating cathode, the solution became slightly acidified. Under these conditions the deposit had a polish equal to the best that can be obtained by means of a buffing wheel and the dull white appearance was entirely absent. This polished appearance was always obtained after operating the plating solution for some time, provided that it was not kept neutral, and it seemed to be due to a change in the electrolyte, resulting from the incomplete corrosion of the anode. To illustrate the dependence of the character of the deposit upon the length of time the solution had been operating, as well as on the current density, five deposits were made.

The neutral solution was first electrolyzed at a current density of 66 amperes and a velocity of 1,400 r. p. m. The first deposit appeared as a dull white coating. The temperature rose from 22° to 26°, and the solution then was slightly acid. The second deposit was made under the same conditions as at first, with the exception of these changes in the electrolyte, and the deposit then appeared with a high polish, though with a considerable number of specks on the surface. On again depositing a coating with 44 amperes density, at the same speed, the deposit assumed its original dull white appearance, showing the effect of low current densities on the polish.

The temperature was 30° at the beginning and 40° at the end. During an hour's run the temperature was raised to 80°, and the current density gradually rose from 170 amperes per square foot to 300 amperes. A thick deposit of good quality was obtained. This did not show any indications of cracking or peeling. It was, however, dotted with specks of imperfections, although smaller in size and number than in previous case. One hundred and sixty-five grams of nickel per square foot were deposited in an hour, and the indications were that the deposit could have proceeded much longer without becoming loose. Finally, the solution at 80°, after the addition of new salts, was used with a current density of 225 amperes. This resulted in an almost immediate loosening and peeling of the deposited nickel.

The deposit in all these preceding cases, has been discontinued as soon as the loosening or cracking of the coating occurred. A trial was now made to determine the effect of continuing the deposit beyond that point. A hot acid and dilute electrolyte was used; current density 145 amperes per square foot, and the rate of rotation 1000 r. p. m. As a result of this lower current density, the deposit assumed some considerable thickness before any indications of cracking appeared. When portions of the deposited metal became loose and curled away from the surface, they protected the spaces directly back of them from friction with the electrolyte and as a consequence, that part of the cathode received a dark powdery deposit similar to the familiar ''burned" appearance of nickel. On the other hand, the surfaces exposed to the friction of the solution were highly polished, and the unusual appearance of nickel trees on the extreme edges was shown.

An interesting phenomenon in the study of nickel is the obtaining of a perfectly polished surface, under suitable conditions. Just what these conditions are, I have not been able to definitely determine. It appeared, at first, that it might be due to the solution becoming acidified by the incomplete corrosion of the anode, but the addition of an equivalent amount of free acid to the ordinary plating solution did not seem to afford conditions whereby the same coating could be obtained. The effect of the addition of the free acid was to immediately damage the nickel coating, producing in its stead a brown powder. That the acidity does effect the deposit materially is clearly shown. Both deposits of 17 grams each were made under similar conditions with the one exception that the second was kept neutral during the whole time. Both electrolytes became hot and dilute in salts, and still the first was highly polished, while the second was of a dull white. The acidity of the above electrolyte far exceeded that which caused the previously mentioned brown deposit. There seems, therefore, to be some other explanation needed than is afforded by the presence of free acid.

All of the nickel deposits obtained, with but one exception, as before mentioned, showed evidences of cracking or peeling sooner or later when any considerable thickness was obtained, and in general, it was found that the greater the acidity, dilution, and the higher the temperature of the electrolyte, the greater was the tendency of the deposit to break up.

Zinc. The behavior of zinc is widely different from that of nickel when deposited on the rotating electrode. While it is difficult to obtain trees or rough deposits of nickel, it is difficult to prevent them in the case of zinc. There is a strong tendency also for zinc sponge to be deposited. While copper and nickel can be deposited in a state of high polish, zinc cannot be obtained smooth unless special precautions are employed. The smoothest deposit was obtained by increasing the friction of the solution against the metal, through the aid of a partition in the cell which prevented the electrolyte from taking up a circulatory motion to correspond with the cathode. The partition consisted of a wooden slab placed vertically in the electrolyte with the edge near the cathode. The depositions were obtained from a sulphate zinc plating solution and all the coatings were made under equal conditions of current density, temperature and amount of deposit. With no partition, the plating is in the form of high narrow ridges. The result of using the partition at a distance of about $\frac{1}{2}''$ is to decrease the size and number of the ridges. By moving the partition to a distance of $\frac{1}{4}''$ the deposit is considerably smoother than before; and by placing the partition very close, but not touching the cathode, a very smooth deposit was obtained. This phenomenon points to the fact that by employing a much higher speed of rotation, a smooth deposit might be obtained without the partition, but conditions prevented the use of sufficiently high velocities to demonstrate this.

It was found that with an acid solution at almost any current density above 100 amperes per square foot, or a neutral solution at high current density of 225 or over, spongy deposits are obtained.

Iron was more satisfactorily deposited by this device than by ordinary methods; lead was deposited from a plumbate solution as a thin film with a high polish which, however, flakes off as soon as any considerable thickness is attained, and from acetate solutions it was deposited in a spongy form; antimony from a tartrate solution, precipitated to a considerable thickness and with a high polish. This deposit, however, on exposure to the atmosphere for a few days, crumbled to dust. Silver was also plated with great rapidity, and high polish upon the rotating cathode from a cyanide solution.

PERSONALS.

R. C. Cornish, '97, is now assistant superintendent of the new Milwaukee Gas Light Company plant on the west side of Milwaukee.

W. A. Baehr, '94, has been called from the Denver Gas & Electric Company, to the position of engineer for the La Clede Gas Company at St. Louis, Mo.

H. C. Schneider, '98, is superintendent of the Baker Mfg. Co , at Evansville, Wis. He is also one of the directors.

E. H. Ahara, '92, has severed his connection with the Deering Harvester Works, of Chicago, and is now superintendent of the manufacturing department of the Dodge Mfg. Co., at Mishawaka, Ind.

J. R. Hippenmeyer, '02, spent two weeks at his home in Madison. He has been sick for some time, but will soon resume work.

Sherman Moore, '02, is on the U. S. Lake Survey with a party which expects to sweep the western end of Lake Erie.

A. C. Rollman, 01, has resigned his position with the Northern Elect. Co., to take a position with the Arnold Mag. Clutch Co., of Milwaukee. L. D. Rowell, '01, is with the same company.

NOTES.

At a meeting of the students of the College of Engineering, April 15th, the committee appointed to secure a suitable memorial in honor of the late Dean J. B. Johnson, made its report. Chairman H. P. Howland, '03, made a few very appropriate remarks, and on behalf of the student body presented to the College of Engineering the handsome portrait which now so fittingly adorns the west wall of the library of the engineering building, as a perpetual reminder of the man who but lately walked among us, and whom all of us who knew him esteemed most highly.

Among the well chosen words of Mr. Howland, he mentioned the last active service of Dean Johnson, in Madison, that of the superintendence of the searching party seeking the bodies of those so unfortunately losing their lives in Lake Mendota. He was the last man the College of Engineering could afford to lose, and besides being an authority in many engineering lines, he was always a broad-minded man. It was a peculiar circumstance that no student representative has had a voice in former memorial services to his honor, but if actions signify anything then they speak louder than words.

This portrait is our testimonial to his memory, and in it we preserve to ourselves and to those who come after us his splendid example as a teacher, scholar, engineer, husband and father.

Professor Turneaure, as acting Dean, in a brief speech of acceptance, very fittingly closed the meeting. Among other things, he said, "Nothing will tend to perpetuate the influence of Dean Johnson like this picture. He was first of all an educator of the highest degree of excellence, and although now absent from us, yet he is present as an inspiration, and his influence on the faculty, students, and the university, will be with us forever."

From the balance of the subscriptions a bronze memorial tablet will be hung with the picture.

The fifth annual banquet of Tau Beta Pi was held May 14, 1903, at Keeley's Hall. About 34 of the active and honorary members of the fraternity were in attendance. Prof. J. G. D. Mack acted as toastmaster, and the following toasts were responded to: "Wisconsin Alpha," C. C. Douglas; "Then and Now," Prof. W. D. Taylor; "What Next," S. J. Lisberger (presented by H. P. Howland); "The Late Dean Johnson," Prof. D. C. Jackson; "Sketches," L. F. Van Hagan; "The Wide World," A. C. King, and "Engineering Ethics," Prof. F. E. Turneaure. The remarks of Professors Taylor and Turneaure were particularly appropriate and were greatly enjoyed by all.

WHERE THE SENIORS WILL SETTLE DOWN.

CIVIL ENGINEERS.

W. K. Adams will be with the Penn. R. R. at Union Sta., Pittsburg, in the M. of W. Dept.

H. J. Cowie has a position with the Power Development Co., at Niagara Falls, South Ontario, Can.

Howard Dessert will spend the summer in rest and recreation, fishing in the lakes of northern Wisconsin.

A. F. Frendberg is with the Alton R. R., in Chicago.

A. C. Greaves is assistant city engineer at Madison.

J. F. Hahn will work for the Steel Concrete Construction Co., at St. Louis.

G. R. Keachie is in the employ of the Manitowoc Steam Boiler Works.

Olaf Laurgaard is with the U. S. G. S., on irrigation work in the state of Washington.

F. M. McCullough is doing city engineering work at Baraboo at present, and will later go to Richland Center.

W. C. McNown is in the maintenance of way department of the Erie R. R. at Buffalo.

C. H. Perry has entered upon construction work with the Burlington R. R. at Benton City, Mo.

H. J. Saunders will be resident engineer, headquarters at Omaha, on the double track work of the Union Pacific.

J. L. Savage will engage in United States irrigation in Idaho.

W. R. Saxton will enter the United States geological survey in Wyoming.

H. L. Stevens is with the Illinois Steel Co., at South Chicago.

John Wilson, H. E. Brandt and Alvin Haase will work for the tax commission in Wisconsin.

MECHANICHAL ENGINEERS.

A. E. Anderson and C. C. Douglas will enter the steam turbine department of the General Electric Co. at Schenectady. Mr. Anderson will work for the Janesville Electric Co. until January 1st.

A. L. Johnson will be connected with the Johnson Chair Co. of Chicago.

B. F. Lyons will work for the La Clede Gas Light Co. of St. Louis.

H. P. Howland will be instructor in the Steam and Testing laboratories during the summer session, after which he will enter the employ of the Illinois Steel Co.

ELECTRICAL ENGINEERS.

B. C. Adams, J. C. Gapen, R. G. Krumrey and S. J. Lisberger have accepted positions with the Emerson McMillan Co. Mr. Krumrey will be located at San Antonia, Texas.

H. E. Bailey, J. E. Brobst, L. R. Brown, M. E. Haman, F. C. Weber and A. J. Quigley will go to the great works of the General Electric Co. at Schenectady.

J. U. Belling will go to Sioux City, Iowa, in the service of the United Gas Improvement Co.

E. B. Mueller will go to the La Clede Gas Co, of St. Louis.

John Pugh, Jr., will work for the J. I. Case Co. of Racine.

W. J. Rowe will become an employee of the Chicago-Edison Co.

Irving Seaman will enter the service of the Electric Storage Battery Co. of Philadelphia.

Will Spalding will work for the California Gas and Electric corporation at San Francisco.

F. G. Wilson has acccpted an instructorship in engineering at the university of Illinois.

F. P. Woy has left to work for J. G. White & Co., a firm of New York contractors and consulting engineers.

N. O. WHITNEY ENGINEERING ASSOCIATION.

Feb. 27, 1903.

Piano solo—D. P. Falconer.

Paper: "The Coast and Geodetic Survey"—F. A. Potts.

Paper: "Light as a cure for diseases due to bacteria"—Wm. Ungrodt.

Debate: *Resolved*, That the eight hour working day should be adopted by Law.

Affirmative.	Negative.
W. F. Hood,	E. Ducket,
A. M. Hoefer,	C. L. Eustis.

Won by the affirmative.

Singing.

March 6.

Singing.

Paper: "The Gisholt Machine Shops"—R. E. Hagenah.

Report on Periodicals—C. M. Rood.

Debate: *Resolved*, That the State ought to organize and conduct manufactories and commerce.

Decision for the affirmative.

March 13.

Singing.

Paper: "The New Dam across the Nile River"—R. L. Hankinson.

Report on Periodicals—E. W. Galloway.

Debate: *Resolved*, That woman's suffrage is desirable.

Judges—Kowalke, Robertson and Parker.

Affirmative.	Negative.
F. H. Hankson,	M. A. Whiting,
W. H. Hauser.	A. E. Helzer,
	E. G. Hoefer.

Judges decided for affirmative.

March 20.

Installation of officers.

Singing.

Paper: "Profit Sharing"—H. A. Parker.

Meeting adjourned early (for Michigan debate).

March 27.

Report on Periodicals—W. S. Lacher.

Debate: *Resolved*, That the senior engineers should be allowed to elect an equivalent number of fifths in place of a thesis.

Judges were: Hood, Pratt and Griswold.

Affirmative.	Negative.
L. B. Robertson,	G. G. Post,

H. I. Ward,	W. R. Harvey,
N. F. Conrad,	Ed. Zaremba.

Won by the negative.

April 3.

Report on Periodicals—C. A. Hoefer.

Parliamentary practice, led by W. H. Robinson and M. E. Warry.

April 17.

Singing.

Report on Periodicals—W. F. Hood.

Talk on Milwaukee Electric Co.—W. A. Rowe.

Paper: “Printing of Paper Money—M. W. King.

Debate: *Resolved*, That municipalities should own and control their water, lighting and street railway systems.

Affirmative.	Negative.
C. Brenton,	A. T. Stewart,
J. R. Smith,	C. L. Eustis.
B. F. Zinke,	

Judges—C. A. Hoefer, Falconer and Potts.

The decision was for the negative.

April 24.

Paper: “The U. W. Heating Plant”—R. G. Griswold.

Paper: “Porcelain and Clay Work”—O. S. Kowalke.

Report on Periodicals—E. H. Pratt.

Impromptu debate: *Resolved*, That the United States should not retain permanent possession of the Philippine Islands.

Affirmative.	Negative.
H. S. Cole,	D. P. Falconer,
N. F. Conrad,	I. B. Hosig,
M. W. King,	W. R. Harvey.

Won by the affirmative.

May 1.

Singing.

Report on Periodicals—I. B. Hosig.

Talk: “General Electric Company”—H. I. Ward.

Debate: *Resolved*, That the present system of making articles of no commercial value in the U. W. shops not the best training for students.

Affirmative.	Negative.
A. U. Hoefer,	Wm. Ungrodt,
F. A. Potts,	P. W. Morrissey,
	R. L. Hankinson.

The judges were Whiting, King and Pratt.

The decision was for the negative.

Banquet, May 8.

Toastmaster—Edward Zaremba.
"Our Association."—Prof. O. B. Zimmerman.
"Factors of Safety."—Prof. J. G. D. Mack.
"Prospects."—Prof. C. F. Burgess.
"Elements."—Dr. Victor Lehner.
"The Co-eds."—R. G. Griswold.
"Side Shots."—I. B. Hosig.
"The Barbarians."—Dr. G. W. Wilder.

May 15.

Singing by club.
Election of officers.
President—F. H. Murphy.
Vice President—R. G. Griswold.
Secretary and Treasurer—C. M. Rood.
Censor—G. G. Post.
President of Joint Debate League—W. A. Rowe.

BOOK REVIEW.

A NEW WORK ON TRACK.

NOTES ON TRACK. CONSTRUCTION AND MAINTENANCE. 1200 pages, 600 Illustrations. Published by the author at Auburn Park, Chicago, by W. M. Camp, editor of the Railway and Engineering Review; member American Society of Civil Engineers.

W. B. Parson's "Track," published in 1886, was the first book on this subject, written in this country, which treated it from a scientific standpoint. E. E. R. Tratman's work, "Railway Track and Track Work," followed in 1897, and has been the standard authority on this subject, at least for students, since Parson's work went out of print. Both of these works were written by engineers—the latter treating the subject from a standpoint very largely theoretical. But the author's work is an attempt to present the subject, as he tells us in the preface, "from the stand-point of both the track man and the engineer."

Such a presentation is difficult to accomplish successfully, and it is in no wise certain that the author has produced a book that will prove equally interesting and of service to the ordinary track man, to the engineering student, and to the educated engineer.

Much matter usually found in manuals of railway Field Engineering has been brought into this treatise on track, and it is difficult to understand how the ordinary track man is to derive any benefit from the lengthy articles on curves, transition curves, and on the action of car wheels on curves.

Extracts from a single page will serve to show a deal of matter calculated to repel the higher class of readers which the author proposes to reach.

"Knowledge alone, in the sense of mere information, is not always a safe guide, for a certain amount of that can sometimes be picked up in a short time without learning the uses to which it may be put." "There are many people—able to read, to whom tabulated information is practically as difficult as hieroglyphics." "It frequuently happens that an old and well deserving track laborer is purposely withheld from promotion out of jealously or prejudice on the part of his foreman, or from a desire on the part of the latter to aid certain other of his friends."

But the work as a whole is a very fair presentation of the best current practice in track maintenance, and contains much that is now set down for the first time in convenient form for reference.

The author has had wide experience in the line of which he writes. The very language—some of it in English, none of the best—savors of the track.

The author at times is diffuse, and descends to trivial details. But still there are few good points in track maintenance that are not brought out.

The articles treating of culverts, creeping rails, and laying tie plates, are among the most comprehensive and helpful.

BRITISH STANDARD SECTIONS issued by The Engineering Standards Committee, D. Van Nostrand Co. Price $1.00 This pamphlet issued by the above committee and supported by the Inst. of Civil Engineers, Mechanical Engineers, Naval Architects, Electrical Engineers and the Iron and Steel Institute contains the following: Equal Angles; Unequal Angles, Bulb Angles; Bulb Tees; Bulb Plates; Z Bars; Channels; Beams and T Bars. A drawing of each of these sections is shown and a table giving the various dimensions of the sections for different sizes. Each table is supplemented with a column of remarks in which are suggestions for ordering, etc.

FLEXURE OF BEAMS by Albert E. Guy. D. Van Nostrand Co. Price $1.35 net. This work which first appeared as a series of articles in the "American Machinist" opens up a new field. The treatment of this subject in treatises and text books, is almost stereotyped and in spite of the fact that certain methods of action and of failure of beams are well known, no attempt has been made to explain them and recognize them in formulae. The study of the failure of beams by the buckling of the compression side, as taken up in this book, proves to be the central fact in the entire subject. Mr. Guy's experiments disclose the analogy between the failure of the compression side of a beam by buckling and the failure of long columns and show that Euler's formula is at the base of the whole subject.

The author takes up the simple problem of the design of a beam of minimum volume, firmly held at one end and sustaining a load at the other end. He shows how the text book formulae are inadequate in determining the section of such a beam, and that the problem brings up for consideration (1) the transverse shearing, (2) the longitudinal shearing, (3) the deflection of the beam. The author then gives a discussion and tabulation of results of experiments he has performed. He returns to the above simple problem and discusses the best form of section, the central web and the width of the section. This is followed by an example in the use of the formulae established, and a solution of the same. A statement of the author's new law and some practical examples of their application finish the text.

Mr. Guy discloses for the first time the laws of failure of a long beam unsupported laterally as well as the connection by means of definite formulae of long beams and columns. His book is a valuable addition to engineering literature.

ALUMNI DIRECTORY.

The Alumni directory given below is as near perfect as we can make it with the information at hand. A complete and authentic directory is indispensible in a college like ours, and to keep it correct, we need the support and encouragement of both undergraduates and alumni. The names of alumni, whose addresses we are not certain of, are indicated by asterisks (*). Anybody possessing information, as to any change of address, or correction in the directory, will do the ENGINEER a favor by imparting such information to our alumni editor.

Abbott, Clarence E., B. S. M. E., '01. 433 Murray St., Madison, Wis.

Adams, Bertram F., B. S. M. E., '02. Grad. Student U. W. Sigma Ch. House, Madison, Wis.

*Adamson, Wm. H., B. S. C. E., '86. Address not known.

Ahara, Edwin H., B. S. C. E., '92; M. E. '96. Supt. of Dodge Man'f Co., Mishawaka, Ind.

Ahara, Geo. V., B. S. M. E., '95. With Fairbanks, Morse & Co., Beloit, Wis.

Ahara, Theo. H., B. S. M. E., '00. With Fairbanks, Morse & Co., Beloit, Wis.

*Albers, John F., B. S. C. E., '77; C. E., '78. Druggist, Antigo, Wis.

Alexander, Walter B., B. S. M. E., '97. Asst. Mast. Mech., care of C. M. & St. P. Ry., Minneapolis.

Allen, Andrews B., B. S. C. E., '91. Wisconsin Bridge Co., 1022 Monadnock Bldg., Chicago, Ill.

Allen, John S., B. S. E. E., '97. Mgr. Beloit Electric Light Co., Beloit, Wis.

Alverson, Harry B., B. S. E. E., '93. Cataract Power & Conduit Co., 40 Court St., Buffalo, N. Y.

Anderson, Gustave A., B. S. M. E., '02. Western Elec. Co., Chicago, Ill.

*Arms, Richard M., B. S. E. E., '94. Seattle, Wash.

Aston, Jas. B., B. S. E. E., '98. Care of Thomas Aston & Son, Milwaukee, Wis.

Atkins, Hubbard C., B. S. M. E., '01. Allis-Chalmers Co., Milwaukee, Wis.

Austin, W. A., B. S. M. E., '99. Room 1011 149 Broadway, N. Y.

Baehr, Wm. A., B. S. C. E., '84. Engr. for La Clede Gas Co., St. Louis, Mo.

*Baldwin, Geo. W., B. S. C. E., '85. Lumber Dealer, Crete, Neb.

*Bamford, F. E., B. S. M. E., '87. Lieut. U. S. A., Atlanta, Ga.

Barnes, Chas. B., B. S. M. E., '00. Engineering Dept. Sargent & Lundy, 200 Oakwood, Boulevard, Chicago, Ill.

Barr, J. M., B. S. M. E., '99. Westinghouse Elec. & Mfg Co., Pittsburg, Pa.

Bauss, Richard E., B. S. M. E., '00. Western Elec. Co., Chicago, Ill.

Bachelder, Clare H., B. S. M. E., '01. Chicago Telephone Co., Chicago, Ill.

Balsley, Eugene A., B. S. C. E., '02. American Bridge Co., Chicago, Ill.

Barkhausen, Louis H., B. S. M. E., '01. J. I. Case Co., Racine, Wis.

Bebb, Edward C., B. S. C. E., '96. U. S. Geol. Survey, Washington, D. C.

Beebe, Murray C., B. S. E. E., '97. Care of Amber Club, Pittsburg, Pa.

Bennett, Chas. W., B. S. M. E. '92. American Tin Plate Co., Elwood, Ind.

Benson, F. H., B. S. C. E., 91. New Insurance Bldg., Milwaukee, Wis.

Bentley, F. W., B. S. M. E., '98. Stoughton, Wis.

Berg, William C., B. S. C. E., '02. Res. Engr. on L. & N. R. R., Coal Creek, Tenn.

Bergenthal, V. W., B. S. E. E., '97. Stanley Elec. Mfg. Co., Monadnock Bldg., Chicago, Ill. Home address 5,808 S. Park Ave.

Bertrand, Phil. A., B. S. E. E., '95. People's Gas & Elec. Co., Peoria, Ill.

*Berry, Claude, B. S. C. E., '01. Great Northern Ry., St. Paul.

Biefeld, Paul A., B. S. E. E., '94. Prof. of Elec. Eng., School of Heilperghausen, Ger.

Bird, Henry, B. S. C. E., '94. Died Dec. 22, '91. Citronelle, Ala.

Bird, Hobart S., B. S. C. E., '94; LL. B. '96. San Juan, Porto Rico.

*Bliss, Wm. S., B. S. M. E., '80. J. M. Dennis Lumber Co., Williams, Arizona.

Boardman, Harry B., B. S. E. E., '93. Westinghouse, Church, Kerr & Co., New York City.

*Boardman, Horace P., B. S. C. E., '94. Ass't Engr. B. & B. Dept., C., M. & St. P. Ry., 1100 Old Colony Bldg., Chicago, Ill.

Bohan, Wm. J., B. S. E. E., '95. C., M. & St. P. Ry. Shops, Milwaukee, Wis.

Boldenweck, Felix W., B. S. M. E., '02. Testing Dept., Western Elec. Co., 27 Stratford Place, Chicago, Ill.

*Boley, C. U., B. S. C. E., '83; C. E., '99. City Engineer, Sheboygan, Wis.

Boorse, Jesse M., B. S. E. E., '95. Monroe Division of Chicago Telephone Co., Chicago, Ill.

Bossert, Chas. P., B. S. M. E., '88. Pfister & Vogel Leather Co., 55 9th St., Milwaukee, Wis.

Boynton, C. W., B. S. M. E., '98. Ledro-Wolley, Wash.

*Brace, Jas. H., B. S. C. E., '92. Albany, N. Y.

Bradish, Geo. B., B. S. C. E., '76; C. E., 78. Civil Engineer, La Crosse, Wis.

*Bradley, Wm. H., B. S. C. E., '78. Junction Iron and Steel Co., Mingo Junction, Ohio.

*Brennan, Wm. M., B. S. C. E., '94. Wisconsin Central Ry., Manitowoc, Wis.

Broenniman, Arnold E., B. S. C. E., '97. 443 Finance Exchange, New York City.

Brown, Geo. W., B. S. C. E., '86; C. E.,. '90 Gov. Works, Dry Tortugas, Fla. Via Key West.

*Brown, Perry F., B. S. C. E., '97. Kurtz & Brown, Mills Bldg., San Francisco, Cal.

Brown, Samuel L., B. S. M. E., 89. Tacoma Smelting Co., Tacoma, Wash.

*Brown, Thane R., B. S. C. E., '95. Wis. Bridge & Iron Co., Milwaukee, Wis.

Burdick, Wm. C., B. S. C. E., '01. St. Paul Depot, 1015 Sycamore St., Milwaukee, Wis.

Buerstatte, F. W., B. S. M. E., '01. Mech. Dept. C., M. & St. P. Ry. 1440 Park Ave., Chicago, Ill.

Bucey, John H., B. S. C. E., '95. Died Dec. 4, 1896.

Buckley, W. J., B. S. E. E., '99. United Gas & Elec. Co., Long Branch, N. J.

Bump, Milan R., B. S. E. E., '02. Spokane Long Dist. Trans. Co., Spokane Wash.

Burgess, Chas. H., B. S. E. E., '95. Ass't Prof. of Elec. Eng., University of Wisconsin.

Burgess, Geo. H., B. S. C. E., '95. Penn. Lines Chief Engineer's Office, Pittsburg, Pa.

Burkholder, Chas. I., B. S. E. E., '96. General Elec. Co., Schenectady, N. Y.

Burton, Wm. C., B. S. E. E., '93. J. G. White & Co., Limited, 22 A, College Hill, London, Eng.

Buttles, Ben. E., B. S. E. E., '00. 503 W. Adams St., Chicago, Ill.

*Campbell, Bert, B. S. C. E., '98. Chicago, Ill.

Carey, Jas. L., B. S. M. E., '88. 306 Baird Ave., Austin Station, Chicago. Ill.

Carlsen, Chas. J., B. S. M. E., '96. Chicago Telephone Co., Chicago, Ill.

Carpenter, Chas. G., B. S. C. E., '82. 123 N. 40th St., Omaha, Neb.

Carter, B. B., B. S. M. E., '88. 1644 Monadnock Bldg. Chicago, Ill.

Caverno, Xenophon, B. S. M. E., '90. Kewaunee Gas Light & Coke Co., Kewaunee, Ill.

Clausen, Leon R., B. S. E. E., '97. 422 W. Jackson Bldg., Chicago, Ill.

Cochran, Robt. B., B. S. M. E., '97. Cochran-Bly Machine Works, 1 Hill St., Rochester, N. Y.

Cole, Chas. M., B. S. M. E., '02. Detroit Bridge Co., Detroit, Mich.

Cole, Harry W., B. S. M. E., '02. Allis-Chalmers Co., Milwaukee, Wis.

Comstock, Nathan, B. S. M. E., '97. Attorney, Arcadia, Wis.

Connolly, Pat. H., B. S. C. E., '85. City Engineer, Racine, Wis.

Conover, Allen D., Ph. B. C. E., '75. 151 W. Gilman St., Madison, Wis.

Conradson, C. M., B. S. M. E., '83; M. E., '85. American Turret Lathe Co., Fairview and Broadway St., Camden, N. J.

Cook, Thomas R., B. S. M. E., '00. 105 Barr St., Fort Wayne, Ind.

*Coombs, Ed. C., B. S. C. E., '97. A. T. & S. F. Ry., Wanette, Okla.

Cooper, A. S., B. S. C. E., '81; C. E., 83. U. S. Ass't Engr., Savannah, Ga.

Cosgrove, J. F., E. E., '96. Scranton Correspondence School, 919 Pine St., Scranton, Pa.

Cornish, Ross C., B. S. C. E., '97. 1st Ass't Sup't Milw. Gas Light Co.

Crandall, H. R., B. S. M. E., '98. 180 23d St., Milwaukee, Wis.

*Crane, Edgar W., B. S. E. E., '95. San Gabriel Elec. Co., Azusa, Cal.

Crenshaw, Thos. P., B. S. E. E-, '95. Died.

Crowell, Robinson, E. E., '96. Sacramento Elec., Gas & Ry. Co., Sacramento, Cal.

Curtis, Norman P., B. S. C. E., '01. Madison, Wis.

Dean, Chas. L., B. S. M. E., '01, Seymour, Wis.

De Lay, Frederic A., B. S. E. E., '02. Instructor, Mich. School of Mines, Houghton, Mich.

Diehl, Guy E., B. S. C. E., '02. U. S. Steel Corp., Hibbing, Minn.

*Dixon, Fred B., B. S. C. E.. '97. New London, Wis.

Dixon, John E., B. S. M. E., '00. Brooks Locomotive Works, Dunkirk, N. Y.

Dodge, Jos., B. S. M. E., '84. Allis-Chalmers Co., Milwaukee, Wis.

*Dodge, McClellan, B. S. C. E., '84. City Eng'r, Eau Claire, Wis.

Dousman, Jas. H., B. S. C. E., '84. Milwaukee Automobile Co., 73 21st St., Milwaukee, Wis.

Dow, Herbert W., B S. M. E., '02. Instructor, Ames College, Ames, Iowa.

Duffy, Wm. F., B. S. C. E., '84. Asst. Engr S. & R. B. V. Ry., Shreveport, La.

Durand, Samuel B., B. S. C. E., '91; C. E., Stanford, '94. Died at Denver, Col., Oct. 29, 1900.

Dutcher, John E., B. S. E. E., '97. Swift & Co., Kansas City, Mo.

Earle, Roy R., B. S. E. E., '02. Gen'l Elec. Co., Schenectady, N. Y.

Earll, C. I., B. S. M. E., '85. 76 Williams St., New York City.

*Egan, R. A., B. S. C. E., '99. Brooklyn, N. Y.

Ehreke, G. W. R., B. S. E. E ,'02. Gen. Elec. Co., 917 State St., Schenectady, N. Y.

Ehrnbeck, Anton D., B. S. C. E., '02. 22 34th St., Milwaukee, Wis.

*Ela, Edwin S., B. S. C. E., '96. Recorder Gov. Survey, Rochester, Wis.

Ellis, John F., B. S. C. E., '87. Died Evansville, Wis., Dec. 9, 1890.

Elser, R. C., B. S. C. E. Died May 17, 1900.

Emerson, Fred M., B. S. C. E., '00. Milwaukee Bridge Co., Milwaukee, Wis.

*Erbach, Wm. Z., B. S. M. E., '93. Lumber Business, Athens, Wis.

Ericksen, Erick T., B. S. C. E., '88; C. E., '90. Bastrop, La.

*Evans, Ed. M., B. S. C. E., '94. Bridge Inspector, 2277 Paulina St., Chicago, Ill.

Evans, Geo. B., B. S. C. E., '94. 348 Atlantic Ave., Pittsburg, Pa.

Fairchild, David L., B. S. C. E., '90. 17 Columbia Block, Duluth, Minn.

Falconer, Robt. C., B. S. C. E., '95. Vanceburg, Ky.

Farris, Jas. A., B. S. M. E., '00. Whiting Foundry Equipment Co., Harvey, Ill.

Fehr, H., B. S. M. E., '84; LL. B., '86. Lawyer, Empire Bldg, Milwaukee, Wis.

Fisher, John J., B. S. C. E., '76. U. S. Dep't Mineral Survey, Prescott, Ariz.

*Fisher, John R., B. S. C. E., '74; C. E., '80. Lumber Dealer, Beaver Dam, Wis.

Ford, Arthur H., B. S. E. E., '95. Prof. Elect. Eng., Georgia School of Tech., Atlanta, Ga.

Ford, Fred H., B. S. E. E., '93. Northern Electric Co., Milwaukee, Wis.

*Fowle, Fred F., B. S. C. E., '93. Milwaukee Bridge & Iron Works, 120 7th St., Milwaukee, Wis.

Fowle, Harry H., B. S. E. E., '95. Electrician (Fowle & Fowle), Milwaukee, Wis.

Fowler, Myron M., B. S. E. E., '01. Western Elec. Co., Engr. Dep't, 841 W. Adams St., Chicago, Ill.

Fox, Henry, B. S. M. E., '92. Box 311, Hartshorn, Indian Territory.

Frankenfield, Budd D., B. S. E. E., '95; E. E., '96. Care of Nernst Lamp Co., Pittsburg, Pa.

Fratt, Fred W., B. S. C. E., '82. Chief Engr. M. K. & N. W. R. R., Joplin, Mo.

Freschl, E., B. S. M. E., '99. 3405 Wells St., Milwaukee, Wis.

Fricke, August C., B. S. M. E., '01. Milwaukee, Wis.

*Fugina, A. R., B. S. C. E., '98. U. S. Geol. Survey, Cincinnati, Ohio.

*Fuldner, Henry C., B. S. C. E., '97. A. Moensted Cement Co., Milwaukee, Wis.

Funk, Wm. F., B. S. M. E., '91. M. Funk Boiler Works, 1407 Main St., La Crosse, Wis.

Gardner, Stephen, B. S. E. E., '02. Chicago Edison Co., Chicago, Ill.

Gerdtzen, G. A., B. S. M. E., '93. Ass't Prof. of Machine Design, University of Illinois.

Gerlach, T. A., B. S. C. E., '98. Head Draftsman, Paige Iron Works, 15124 Turlington Ave., Harvey, Ill.

Gibson, Wm. J., B. S. M. E., '02. Fuller & Johnson Co., Madison, Wis.

Goddard, A. L., B. S. M. E., '96. Hadden Heights, N. J.

Golder, Lloyd W., B. S. M. E., '95; B. S. E. E., '96. Sullivan Machine Co., Chicago, Ill.

*Gooding, Wm. H., B. S. C. E., '73. Independence, Iowa.

Granke, Leo E., B. S. C. E., '00. U. S. Geol. Survey, Washington.

Gregerson, Louis T., B. S. C. E., '95. C. & N. W. Ry., Boone, Ia.

*Gregg, H. B., B. S. M. E., '92. Engr. of Tests, Santa Fe Ry., San Bernardino, Cal.

Grey, John C., B. S. M. E., '02. Clairton Steel Co., Clairton Pa.

Griffith, John H., B. S. C. E., '93. Cambria Steel Co., 230 Tioga-Westmont, Johnstown, Pa.

Grover, A. J., B. S. C. E., '81; C. E., '83. 1137 Park Ave., Omaha, Neb.

Grover, Allison S., B. S. M. E., '95. Draftsman, Allis-Chalmers Co., Milwaukee, Wis.

Hackney, Robert H., B. S. M. E., '93. Fox Pressed Steel Co., Joliet, Ill.

Hain, Jas. C., B. S. C. E., '93. 1100 Old Colony Bldg., Chicago, Ill.

Hambuechen, C., B. S. E. E., '99; E. E., '00. Instr. Electro Chemistry, University of Wisconsin.

Hamilton, Harvey F., B. S. C. E., '92. G. N. R. R., Great Northern Bldg., S. Paul, Minn.

Hammerschlag, James G., B. S. M. E., '02. Nordberg Mfg. Co., Milwaukee, Wis.

Hancock, L. M., B. S. M. E., '88. Gen. Supt. of Bay Counties Power Co., 234 Third St. San Francisco, Cal.

Hansen, Oscar, B. S. E. E., '94. Western Electric Co., Chicago, Ill.

*Hanson, A., B. S. C. E., '99.

*Hanson, Walter S., B. S. M. E., '95. Walburn-Swenson Co., Shawnee, Okla.

*Hanson, Henry O., 92 W. Jersey St., Elizabeth, N. J.

Hargrave, R. W., B. S. M. E., '99. Zion City Headquarters, Chicago, Ill.

Harrison, C. N., B. S. C. E., '82. Madison, Wis.

*Harriman, F. J., B. S. C. E., '89. Appleton, Wis.

Hartman, Rudolph, B. S. C. E., '01. Instr. in Engineering, University of Wisconsin.

Hart, Chas. W., B. S. M. E., '96. Hart, Parr & Co., Charles City, Ia. Home address, 609 Iowa St.

Hartwell, Frank I., B. S. M. E., '95. Died 1897.

Harvey, John L., B. S. M. E., '00. Prescott Pump Works, Milwaukee.

Haskin, Edwin E., B. S. M. E., '01. Norberg Engine Co., 3125 Wells St., Milwaukee, Wis.

Hawn, Russell J., B. S. C. E., '01. Portland Cement Works, Craigsville, Va.

Hayden, Chas. B., B. S. E. E., '96. Sun Prairie, Wis.

*Heald, Eugene H., B. S. C. E., '00. Oak Park, Ill.

Hegg, John R., B. S. C. E., '00. Killed on the Island of Luzon, Jan. 25, 1902.

Hedke, Chas. R., B. S. C. E., '00. Kilby Mfg. Co., Easton, Weld Co., Col.

Heine, R. E., B. S. E. E., '98. Ass't Prof. of Elec. Eng. University of Washington.

Hile, Chas. H., M. E., '94. Boston Elevated Ry., 552 Harrison Ave., Boston, Mass.

Hinrichs, Christian, B. S. M. E., '90. Cramp & Son's Ship Yards, 3295 Park Ave., Philadelphia, Pa.

Hippenmeyer, Irving R., B. S. M. E., '02. Vilter Mfg. Co., Milwaukee, Wis.

Hirschberg, Walter P., B. S. C. E., '00. Cambria Steel Co., 340 Locust St., Johnstown, Pa.

Hirshheimer, H. J., B. S. M. E., '91. La Crosse Plow works, 218 N. 8th St., La Crosse, Wis.

Hobart, F. G., B. S. M. E., '86; M. E., '90. 724 Prairie Ave., Beloit, Wis.

Hogan, J. J., B. S. E. E., '99. Western Electric Co., Chicago, Ill.

Holt, F. W., B. S. C. E., M. L., '88; LL. B., '89. U. S. Patent Office, Washington, D. C.

Hoskins, L. M., B. S., '83; M. S. 85; C. E., '87. Prof. of Mechanics, Stanford University, Cal.

Hoyt, Warren A., B. S. C. E., '00. Altoona, Pa.

Humphrey, C. W., B. S. E. E., '00. Madison Gas & Elec. Co., Madison, Wis.

*Hunner, Earl E., B. S. C. E., '00. Tom Thumb Mine Republic, Washington, D. C.

Hurd, John T., B. S. C. E., '01. Provincial Supervisor at Iligan, Isabella Prov., Philippine, Is.

Hurd, Nathanial L., B. S. M. E., '01. Amer. McKenna Process Co., Joliet, Ill.

Icke, John F., B S. C. E., '00. City Engineer, Madison, Wis.

James, Ben W., B. S. M. E., '97. Illinois Steel Co., 401 Herkimer, Joliet, Ill.

*James, Oscar B., B. S. M. E., '91. Richland Center, Wis.

Jenne, R. L., B. S. E. E., '98. Dead.

Jones, Geo H., B. S. E. E., '97. Chicago Edison Co. Chicago, Ill.

Johnson, Carl A., B. S. M. E., '91. Gisholt Machine Co., Madison, Wis.

*Joyce, Pat. F., B. S. C. E., '93. Engr. with Wisconsin Central, Abbottsford, Wis.

Keller, C. A., B. S. E. E., '99. J. G. White & Co., Little Rock, Ark.

Kelley, Patrick J., B. S. E. E., '02. Care of J. G. White, Montgomery, Ala.

Kiehn, Wallace P., B. S. E. E., '97. Engr. on Wall St., New York City.

King, Arthur C., B. S. M. E., '01. Northern Electric Co., Madison, Wis.

Kirchoffer, Wm. G., B. S. C. E., '97. City Engineer, Baraboo, Wis.

Klug, L. J., B. S. C. E., '98. American Bridge Works, Chicago.

Knowles, J. H., B. S. C. E., '99. Oregon Short Line Ry., Salt Lake City, Utah.

Kohl, Oliver B., B. S. E. E., '02. Madison Gas & Elec. Co., Madison, Wis.

Kremers, John G., B. S. E. E., '98. 554 4th St., Milwaukee, Wis.

Kratsch, Wm. H., B. S. M. E., '97. Geo. Challoners Sons Co.. Oshkosh, Wis.

Kurtz, Chas. M., B. S. C. E., '97. "The Reed", Ogden, Utah.

Kurtz, Ed. B., B. S. M. E., '94. Laclede Power Co., St. Louis, Mo.

Lademan, Otto T., B. S. E. E., '97. St. Louis Elec. Construction Co., St. Louis. Mo.

Lacey, Frank H., B. S. E. E., '01. 518 Columbus Ave., Boston, Mass.

Landgraf, F. K., B. S. M. E., '98. Draftsman, Wm. E. Hill & Co., Kalamazoo, Mich.

Lapham, Chas., B. S. C. E., '81. 3118 Mt. Vernon Ave., Milwaukee, Wis.

Lardner, Henry A., B. S. E. E., '93; E. E., '95. N. J. White & Co., 29 Broadway, New York City.

Lathrop, Wm. F., B. S. E. E., '02. Sullivan, Mach. Co., Denver, Col.

Lawton, E. W., B. S. M. E., '89. DePere, Wis.

Lea, John M., B. S. E. E., '02. Western Elec. Co., Chicago, Iil.

Legg, Ernest F., B. S. E. E., '01. General Electric Co., Schenectady, N. Y.

Leich, Oscar M., B. S. E. E., '98. 610 Wilson Ave., Ravenswood Sta., Chicago, Ill.

Lemon, Luther E., B. S. E. E., '96. Vindex Elec. Co., 158 Iowa Ave., Aurora, Ill.

Lennon, Hawley D., B. S. G. E., '02. Grad. Student U. W., Madison, Wis.

Leuth, Emil S., B. S. M. E., '97. Designer, Brown Corliss engine, 213 14th St., Milwaukee.

Leuth, P. F., B. S. M. E., '98. Designer Milwaukee Elec. Co., Milwaukee.

Lindem, Olaf J., B. S. C. E., '00. Died at San Antonia, Texas.

Lindeman, A., B. S. M. E., '85; M. E., '87. J. P. Lindeman & Son, Milwaukee, Wis.

Lloyd, Conrad C., B. S. C. E., '96. C. M. & St. P. Ry., 860 Cass St., Milwaukee, Wis.

Logemann, R. T., B. S. C. E., '99. Monadnock Bldg., Chicago, Ill.

Mabbett, Walter F., B. S. C. E., '02. Eng. Dep't., C. M. & St. P. Ry., Chicago, Ill.

MacGregor, W. F., B. S. M. E., '97. Supt. J. I. Case T. M. Co., Racine, Wis.

*McKee, Louis A., B. S. E. E., '02. Gen'l Elec. Co., Pittsburg, Pa.

McEvoy, George E., B. S. M. E., '02. Illinois Steel Co., S. Milwaukee, Wis.

Maldauer, Arthur, B. S. C. E., '96. Civ. Engr. (R. Modjeski) 1742 Monadnock, Bldg., Chicago, Ill.

Malec, Anton, B. S. M. E., '98. Madison, Wis.

Maurer, Ed. R., B. S. C. E., '90. Prof. of Mechanics, University of Wisconsin.

*Mayer, August, B. S. C. E., '83. Shreveport, La.

Marvin, Arba B., B. S. E. E., '00. Patent office, Washington, D. C.

Mason, C. T., B. S. M. E., '99. Illinois Steel Co., 1109 Cass St., Joliet, Ill.

McCulloch, A. L., B. S. C. E., '95. Died.

McArthur, A. R., B. S. M. E., '00. American Tin Plate Co., 1529 S. J. St., Elwood, Ind.

*McDonald, Clinton, B. S. C. E., '97.

*McKim, Jas. A., B. S. C. E., '91. Haught-Noelke Iron Works, Indianapolis, Ind.

Mead, Geo. A., B. S. E. E., '95. Ohio Brass Works, Mansfield, Ohio.

*Mead, O. A., B. S. C. E., '92. R. McMillan & Co., Appleton, Wis.

*Melville, Jas., B. S. C. E., '75; C. E., '78. Sun Prairie, Wis.

*Merriam, H. N., B. S. C. E., '98. Canadian Pacific Ry., Brooklyn, N. Y.

Merrick, E. G., B. S. E. E., '00. Stanley Elec. Mfg Co., Pittsfield, Mass.

Meyers, Alvin V., B. S. E. E., '01. Telluride Power Transmission Co., Provo, Utah.

*Myer, Ed. W., B. S. M. E., '95. Nordberg Mfg Co., Milwaukee, Wis.

Minch, H. J., B. S. M. E., '92. 222 W. Gorham St., Madison, Wis.

Minch, Oscar J., B. S. M. E., '93. Paoli, Wis.

Minch, Walter B., B. S. M. E., '00. Western Elec. Co., Chicago, Ill.

Monahan, J. J., B. S. C. E., '95. Filer & Stowell Co., Milwaukee, Wis.

Moore, Lewis E., B. S. M. E., '00. American Tin Plate Co., Elwood, Ind.

Moore Sherman, B. S. C. E., '02. Care of U. S. Lake Survey, 33 Campau Bldg., Detroit.

Morrow, Homer, B. S. M. E., '01. Nordberg Engine Co., Milwaukee, Wis.

*Morrow, Frank E., B. S. C. E., '92. Address unknown.

Mors, Geo. C., B. S. M. E., '92. American Tin Plate Co., Carnegie Bldg., Box 965, Pittsburg, Pa.

Munger, Ed. T., B. S. M. E., '92. Green Bay, Wis.

*Munroe, Wm., Ph. B., C. E., '73. Box 230, Great Falls, Montana.

Murphy, M. N., B. S. E. E., '01. Care of Geo. A. Fuller Co., 68 William St., New York.

Nes, T. G., B. S. E. E., '99. Chicago Telephone Co., Chicago, Ill.

*Nelson, C. L., B. S. C. E., '00. 127 Turk St., San Francisco, Cal.

Nelson, F. W., B. S. M. E., '97. Died at West Jordan, Utah in August, 1902.

*Nethercut, E. S., B. S. C. E., '89. Paige Iron Works, Chicago, Ill.

Newman, Fred. J., B. S. E. E., '98. Westinghouse Elec. & Mfg. Co., Pittsburg, Pa.

Nicholas, A. A., B. S. E. E., '01. Gen. Elec. Co., Schenectady, N. Y.

Nommensen, R. A., B. S. C. E., '99. Died July 12, 1902.

Oschsner, R. J., B. S. E. E., '94. Brown Hoisting Co., Cleveland, Ohio.

*Older, Clifford. B. S. C. E., '00. Pittsburg, Carnegie & Western R. R., Pittsburg, Pa.

Olson, Arthur C., B. S. C. E., '02. Eng. Dept C., M. & St. P. Ry., Milwaukee, Wis.

Olson, L. W., B. S. E. E., '99. Green Bay, Wis.

Olson, M. C., B. S. E. E., '99. Gen. Elec. Co., Schenectady, N. Y.

Olson, Sidney, B. S. C. E., '02. Deceased.

*O'Neill, Wm. R., B. S. M. E., '87. Pacific Vinegar Co., Portland, Ore.

*Ostenfelt, C. L., B. S. C. E., '85. 1117 Schiller Bldg., Chicago, Ill.

Owens, L., B. S. E. E., '97. People's Gas & Elec. Co., Peoria, Ill.

*Paine, Jas. P., B. S. C. E., '77. 223 Pleasant St., Milwaukee, Wis.

Palmer, A. H., B. S. E. E., '96. Died July, 1901.

Palmer, R. B., B. S. E. E., '01. 23A. College Hill, Cannon St., London, Eng., Care J. G. White Co., Limited.

Parmon, A. L., B. S. C. E., '85; C. E., '89. Died Oct. 3, 1899, at Spokane, Wash.

*Parmley, W. C., B. S. Met. E., '87; M. S., '93. 19 Burt St., Cleveland, Ohio.

*Parsons, W. J., B. S. C. E., '00. Erec. Dept Am. Bridge Co., Pittsburg, Pa.

reston, W., B. S. E. E., '02. Designing Dep't Chicago-Edison Co., Chicago, Ill.

*Pennock, Wm. H., B. S. M. E., '83. 606 N. Y. Life Bldg., Omaha, Neb.

Perkins, J. H., B. S. E. E., '96. Youngstown Elec. Co., 670 Bryson St., Youngstown, Ohio.

Phillips, J., B. S. C. E., '87. Died 1893.

*Phillips, N. F., B. S. C. E., '77. Monitor Mfg. Co., 423 W. 26th St., Minneapolis, Minn.

Plumb, H. T., B. S. E. E., '01. Instructor of Applied Electricity, Pratt Inst., Brooklyn, N. Y.

Polley, George A., B. S. C. E., '02. Eng. Dept. C. & N. W. Ry., Winona, Minn.

*Pope, Geo. W., B. S. C. E., '98. Wisconsin Bridge Co., N. Milwaukee, Wis.

*Potter, Wm. G., B. S. C. E., '90; C. E. '94. Alvord & Shields, 127 Hartford Bldg., Chicago, Ill.

Powell, A. O., B. S. C. E., '80; C. E., '90. U. S. Engrs Office, 3d fl. Bank of Minn. Bldg., St. Paul, Minn.

Powell, E. H., B. S. M. E., '91. 1609 Vermont St., Lawrence, Kan.

Powrie, Wm. R., B. S. M.E., '96. Powrie & Sons, Waukesha, Wis.

Prael, Fred W., B. S. M. E., '91. American Can Co., Fairhaven, Wash.

Purdy, C. T., B. S. C. E., '85; C. E., '86. Geo. A. Fuller Co., 137 Broadway, New York.

*Quirk, Jos., B. S. C. E., '73. Jos. Quirk Milling Co., Waterville, Minn.

Radke, Albert A., B. S. E. E., '00. Chicago-Edison Co., 139 Adams St., Chicago, Ill.

*Ramien, C. H., B. S. M. E., '96. Filer & Stowell Co., 560 4th St., Milwaukee, Wis.

Ransom, Geo. B., B. S. C. E., '91. Engr. U. S. N. Sta., Portsmouth, N. H.

Reedal, P. E., B. S. E. E., '96. Christensen Eng. Co., 687 Prospect Ave., Milwaukee, Wis.

Reilly, H. W., B. S. E. E., '97. J. G. White & Co., Monroe, Mich.

*Rendtorff, E. J., B. S. E. E., '95. Address not known.

Reynolds, W. E., B. S. E. E., '99. Chicago Telephone Co., Chicago, Ill.

Rhine, Chas. A., B. S. E. E., '00. 715 Clybourn St., Milwaukee, Wis.

Richards, J. F., B. S. C. E., '98. Totenville, S. I., N. Y.

Richards, W. A., B. S. M. E., '99. Instr. East Side High School, Milwaukee, Wis.

Richards, W. J., B. S. E. E., '93. Christensen Eng. Co., Milwaukee, Wis.

Richter, A. W., B. S. M. E., '39; M. E., '91. Asst. Prof. in Engineering, University of Wisconsin.

Robinson, Geo. P., B. S. E. E., '96. Wis. Telephone Co., Milwaukee, Wis.

Rogers, Walter A., B. S. C. E., '88; C. E., '97. Vice-Pres. Bates & Rogers Co., 1205 Manhattan Bldg., Chicago, Ill.

Rollmann, A. C., B. S. E. R., '01. Arnold Magnetic Clutch Co., Milwaukee, Wis.

Rosenstengel, R., B. S. C. E., '94. Christensen Eng. Co., Milwaukee, Wis.

*Rosenstengel, Wm. R , B. S. M. E., '87. 442 Northampton St., Buffalo. N. Y.

Ross, H. H., B. S. E. E., '96. 34 Congress St., Detroit, Mich.

Rowell, L. D., B. S. E. E.,'01. Arnold Magnetic Clutch Co., Milwaukee.

Ruka, Fred W., B. S. E. E., '96. Boscobel, Wis.

*Rumsey, S. S., B. S. C. E,, '97. Allis-Chalmers Co., Milwaukee, Wis.

Salsich, Le Roy, B. S. C. E., '01. Hibbing, Minn., care of Minn. Iron Co.

*Sanborn, J. N., B. S. M. E., '81; C. E.,'84. B. & N. M. R. R., Brainard, Minn.

Sanborn, Roy A., B. S. E. E., '01. Weston Bros.' Consulting and Contracting Engineers, Chicago, Ill.

Sands, E. E., B. S. C. E., '00. Care of U. S. Geol. Surv. Grand Jct,, Col.

Saunders, Albert B., B. S. M. E., '02. C. & N. W. Ry., West Chi. Shops, Chicago, Ill.

Sawyer, A. R., E. E., '96. Prof. of Elec. Eng., Kentucky State College, Lexington, Ky.

Schafer, Otto, B. S. C. E., '98. C., M. & St. P. R. R. Depot, Minneapolis, Minn.

Schapper, Kurt, B. S. M. E., '02. Chicago Telephone Co., Chicago, Ill.

Scheiber, A. V., B. S. E. E., '99. Chicago Telephone Co., Chicago, Ill.

Schildauer, Edw., B. S, E. E., '97. Chicago-Edison Co., Chicago, Ill.

Schmidt, C. J., B. S. E. E., '97. T. M.. E., R. & L. Co., Milwaukee, Wis.

Schmidt, F. E., B. S. C. E., '00 Engineering News, 220 Broadway, New York City.

Schroeder, F. A., B. S. E. E., 99. Johnston, Pa.

Schuchardt, R. F., B. S. E. E., '97. Chicago-Edison Co., Chicago, Ill.

*Schulz, A. G., B. S. C. E. '75. Porterville, Cal.

Schuster, J. W., B. S. E. E., '99. Inst. Elec. Eng., University of Wisconsin.

Schumann, Theo., B. S. E. E., '95. Died March 26, 1896.

Schneider, H. C., B. S. M. E., '98. Supt. Baker Mfg. Co., Evansville, Wis.

Schroeder, John T., B. S. C. E., '02. Asst. Res. Engr. Oliver Springs, Tenn.

Scott, Geo. A.. B. S. E. E., '02. Inst. Elect. Eng. Dept., Univ. of Wis., Madison, Wis.

Scott, H. H., B. S. E. E., '96. Lincoln Elec. Light Co., Lincoln, Neb.

Seaman, Harold, B. S. E. E., '00. Elec. Storage Battery Co., New England Bldg., Cleveland, Ohio.

Severson, Harry, B. S. C. E., '01. Barber & Coleman, Rockford, Ill.

Seymour, M. E., B. S. E. E., '98. Gen. Elec. Co.. New York City.

Sheldon, S. R., B. S. E. E., '94. West. Elec. Mfg. Co., Chicago, Ill.

Shelton, A. W., B. S. C. E., '83; LL. B., '85. Rhinelander, Wis.

*Short, F. J., B. S. M. E., '97. Fairbanks. Morse & Co., Beloit, Wis.

*Short, Jas. M., B. S. C. E., '89. Haught-Noelke Iron Works, Indianapolis, Ind.
Silber, Fred. D., B. S. E. E., '94. Lawyer. Atwood Bldg., Chicago, Ill.
Smith, Allard, B. S. E. E., '98. Chicago Telephone Co., Chicago, Ill.
Smith, Alson I., B. S. E. E., '93. Smith Bros., Wauwatosa, Wis.
*Smith, F. H., B. S. C. E., '91. 117 Hinsdel Pl., Elgin, Ill.
Smith, Harry A., B. S. E. E., '98. General Elec. Co., Cincinnati, Ohio.
*Smith, H. B., B. S. Met. E., '85. First Nat. Bank, Colton, Cal.
Smith, James E., B. S. C. E., '02. Burlington R. R., Benton City, Mo.
Smith, L. S., B. S. C. E., '90; C. E., '95. Prof. in Engineering, University of Wisconsin,
Smith, P. S., B. S. E. E., '98. Kellogg Switch Board & Supply Co., Chicago, Ill.
Smith, Robert T., Jr., B. S. C. E., '02. Baltimore, Md.
*Smith, S. T., B. S. C. E., '00. Sturgeon Bay, Wis.
Spence, Harry, B. S. E. E., '98. Principal 5th Dist. School, La Crosse, Wis.
*Spencer, R. C., Jr., B. S. M. E., '86. 1505 Schiller Bldg., Chicago, Ill.
*Spindler, Max, B. S. C. E., '98. With Osborn Eng. Co., Cleveland, O. Resides 1012 Superior St., Toledo, O.
Stanchfield, Bartley, B. S. M. E., '94. Fond du Lac, Wis.
Stanchfield, Geo. H., B. S. C. E., '92. Watertown, Wis.
Starks, Sanford P., B. S. M. E., '02. Grad. Stu Cornell Univ., Ithaca N. Y.
Stevens, Chester H., B. S. C. E., '02. Engr. Dep't Chi. & Alton Ry., Chicago, Ill.
Stevens, John, Jr., B. S. M. E., '89. Appleton, Wis.
Stewart, R. W., B. S. C. E., '99. C. & A. R. R., Chicago, Ill.
Stieler, Frederic C., B. S. E. E., '02. T. M. E. R. & L., 451 Broadway, Milwaukee, Wis.
Stockman, Louis R., B. S. C. E.,' 02. Care of L. S. Smith, Madison, Wis.
Stone, Melvin B., B. S. C. E., '00. N. P. R. R., St. Paul, Minn.
*Sturtevant, H. B., B. S. C. E., '80; C. E., 88. Pioneer Iron Co., Ely, Minn.
Swaty, David Y., B. S. C. E., '98. Penn. Lines Engineering Dept., Pittsburg, Pa.
Sunderland, Ira C., B. S. C. E., '02. Care of U. S. Lake Survey, 33 Campau Bldg., Detroit, Mich.
Swenson, Magnus, B. S. Met. E., '80; M. S., '83. 944 Monadnock Blk., Chicago, Ill.
Swenson, Bernard V., E. E., '01. Prof. of Elec. Eng., University of Wisconsin.
Sweet, John F., B. S. M. E., '93. Browning Mfg. Co., Milwaukee, Wis.
*Swinborne, E. D., B. S. M. E., '88. G. A. Harter & Co., 1116 Lake St., Chicago, Ill.
Taylor, J. C., B. S. E. E., '01. Sullivan Machine Co., Claremont, N. H.
Terven, Lewis A., B. S. E. E., '02. Nernst Lamp Co., Pittsburg, Pa.

Tessier, L. G., B. S. M. E., '93. De Pere Terra Cotta Co., De Pere, Wis.

Thompson, Jas. R., B. S. Met. E., '87; B. S., '88; M. S., '92. Newport Mining Co., Ironwood, Mich.

Thorkelson, H. J. B., B. S. M. E., '98. M. E. Instructor in Steam Eng., U. W., 915 University Ave., Madison, Wis.

Thorkelson, Wm. L., B. S. M. E., '02. 1812 Washington Ave., Racine Junction, Wis.

Thorp, Geo. G., B. S. M. E., '92. St. Clair Steel Co., Empire Bldg., Pittsburg, Pa.

*Thygeson, N. M., B. S. Met. E.. '85; LL. B., '87. Attorney, St. Paul, Minn.

*Thuringer, Chas., B. S. C. E., '93. U. S. Engineer's Office, Milwaukee, Wis.

Tibbitts, H. L., B. S. C. E., '94. Lumber M'f'r Hazelhurst, Wis.

Townsend, H. I., B. S. E. E., '01. Chicago Telephone Co., Hampton, Iowa.

*Trautman, G. H., B. S. M. E., '97. Fairbanks, Morse & Co., Beloit, Wis.

*Trippe, H. M., B. S. C. E., '96. C. & N. W. Ry., Baraboo, Wis.

*Trowbridge, J. B., B. S. C. E., '76; M. D. Rush, '82. Hayward, Wis.

True, E. B., B. S. E. E., '96. Chicago Edison Co., Chicago, Ill.

*Turner, Jos. M., B. S. C. E., '77. Supt. Public Schools, Burlington, Wis.

Uehling, O. C., B. S. C. E., '90. 330 Grove St., Milwaukee, Wis.

*Updegraff, Milton, B. S., B. M. E., '84; M. S. '86. Naval Observatory, Washington, D. C.

Van Ness, L. G., B. S. E. E., '96. Lincoln Gas & Elec. Co., Lincoln, Neb.

Van Ornum, J. L., B. S. C. E., '88; C. E., '91. Prof. of Engineering, Washington University, St. Louis, Mo.

Vaughn, F. A., B. S. E. E., '95. 271 31st St., T., M., E. R. & L. Co., Milwaukee, Wis.

Vea, F. J., B. S. M. E., '01. Supt. of Stoughton Wagon Works, Stoughton, Wis.

Viebahn, G. O., B. S. C. E., '93. Died Feb. 2, 1897, Watertown. Wis.

*Wade, C. G., B. S. C. E., '84. C. G. Wade & Co.. 228 La Salle St., Chicago, Ill.

Waldo, Geo. E., B. S. M. E., '85; LL. B., '88. 1223 Monadnock Bldg., Chicago, Ill.

Waldo, M. A., B. S. M. E., '84. Mo. Valley Bridge & Iron Works, Leavenworth, Kan.

Wales, C. M., B. S. M. E., '85. Cleveland Forge & Iron Works, 11 Broadway, New York City.

Warner, H. R., B. S. M. E., '98. American Cotton Co., Waco, Tex.

Warner, F. D., B. S. M. E., '96. 242 Stark St., Portland, Ore.

Warner, M. F., B. S. E. E., '95. H. W. Johns Co., New York City.

Washburn, F. E., B. S. C. E., '01. Thebes, Ill.

Wassmansdorf, O. F., B. S. C. E. '00. Address not known.

Wasweyler, H. W., B. S. M. E., '85. Milwaukee Brass Mfg. Co., 311 9th St., Milwaukee, Wis.

Watson C. H., B. S. M. E., '01. Pueblo, Col.

Watson, James W., B. S. E. E., '02. Grad. Scholar in E. E. in U. W., Madison, Wis.

Webb, H. S., E. E., '98. Prof. Elec. Eng., University of Maine, Orino, Maine.

Weed, L. B., B. S. C. E., '00. Minnesota Iron Co., Mc Kinley, Minn.

West, A. J., B. S. M. E., '87. Allis-Chalmers Co., Milwaukee, Wis.

*Wheelan, Jas., B. S. C. E. '77. Address not known.

White, F. B., B. S. M. E., '86. Died, June 27, 1886, Madison, Wis.

*Whomes, H. R., B. S. M. E., '00. C. & N. W. R. R., Chicago, Ill.

*Wiley, R. R., E. E., '99. Address not known.

Williams, C. H., B. S. M. E., '96. Four Lakes Light & Power Co., Madison, Wis.

Williams, Lynn A., B. S. M. E., '00. Patent Attorney, Chicago, Ill., 1450 Monadnock Bldg.

Williams, Wm. H., B. E. E., '96. Prof. in Montana State College, Bozeman, Mont.

Williams, L. D., B. S. C. E., '01. Penn. R. R. Co., Pittsburg, Pa.

*Williamson, E. L., B. S. C. E., '00. Address not known.

*Wilson, E. F., B. S. M. E., '84. North Tonawanda, N. Y.

*Wipfler, R. E., B. S. C. E., '00. U. S. Geol. Survey, Kelleyton, Ala.

Wise, P. L., B. S. C. E., '88. Terre Haute & S. W. R. R.. Marion, Ind.

Wolter, B. C., B. S. C. E., '75. Appleton, Wis.

Wood, H. H., B. S. M. E., '01. Stoughton Wagon Works, Stoughton, Wis.

*Wood, W. W., B. S. C. E., '76. Rushville. Neb.

Woodward, Wm. L., B. S. M. E., '94. 420 Main St. LaCrosse, Wis.

Worden, B. L., B. S. C. E., '93. Wis. Bridge & Iron Co., Milwaukee, Wis.

Worden, E. P., B. M. E., '92. Prescott Steam Pump Co., Milwaukee, Wis.

Wray, Jas. G., B. S. E. E., '93. Chicago Telephone Co., Chicago, Ill.

Young, Henry W., B. S. E. E., '02. Western Elec. Co., Chicago, Ill.

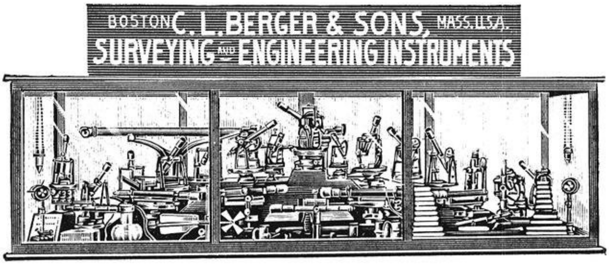
Young, Jas. R., B. S. M. E., '93. Died July 6, 1895.

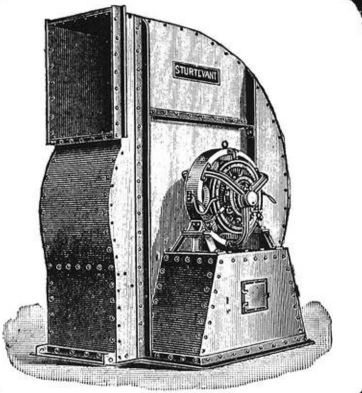
Zabel, M. B., B. S. E. E., '98. 78 5th Ave.. Chicago, Ill.

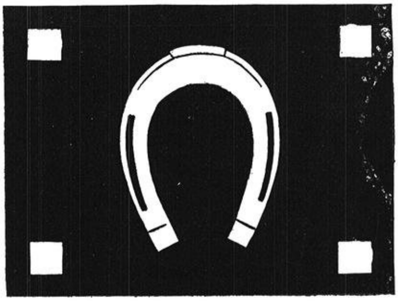
Zimmerman, O. B., B. S. M. E., 96; M. E., '00. Ass't Prof. of Mach. Des. U. of W.

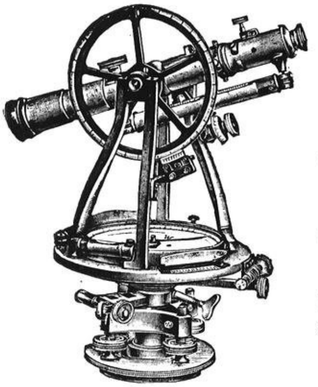
Zinn, W. B., B. S. M. E., '98. Ill. Steel Co., 2908 Highland Bldg., Milwaukee.

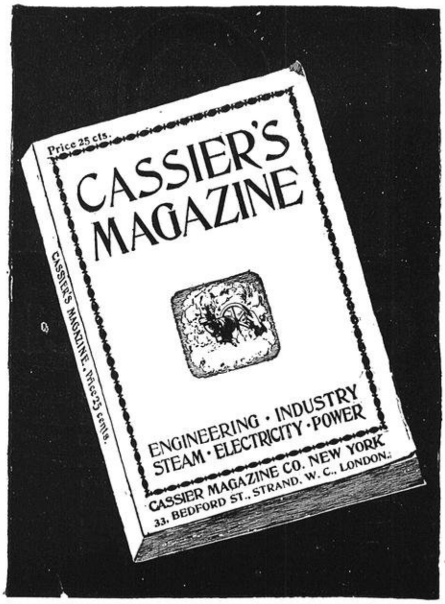
Zweitusch, E. O., B. S. M. E., '86; M. E. 88. Engelufer 1, Berlin, S. O., Germany.


BOSTON C. L. BERGER & SONS, MASS. U.S.A.
SURVEYING AND ENGINEERING INSTRUMENTS

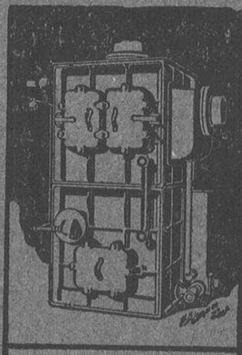

STURTEVANT






Price 25 cts.
CASSIER'S MAGAZINE
CASSIER'S MAGAZINE. Price 25 cents.
ENGINEERING · INDUSTRY
STEAM · ELECTRICITY · POWER
CASSIER MAGAZINE CO. NEW YORK
33, BEDFORD ST., STRAND, W. C., LONDON.

COCHRANE HEATERS



COCHRANE HEATERS

COCHRANE HEATER

COCHRANE HEATERS

COCHRANE HEATERS

Cochrane Feed Water Heaters

Will Make 4 Tons of Coal Do the Work of 5 Tons

In many cases the installation of a Cochrane Feed Water Heater, without any change in your boilers, engines, or other equipment, will enable you to do with four tons of coal what formerly required five tons—simply because you save the heat value of your exhaust steam and utilize it to better advantage.

Even in a plant run all condensing, a Cochrane Heater will make nine tons do the work of nearly ten.

From 5 to 20 per cent is the saving in fuel you can count on if you install a Cochrane Heater, the exact percentage depending on the conditions, and in some cases where "Cochranes" have been used the saving has exceeded 20 per cent.

But that isn't all. A Cochrane Heater will materially purify your feed water, it will enable you to make steam faster and in greater quantities, and it will lessen the strain on your boilers and increase their life.

The design, the construction, and the service these Cochrane Heaters perform, are solid arguments why you ought to have one. Why not start the ball by asking for our **Catalogue 44-H** and the price of the size of Heater suitable for your plant.

COCHRANE HEATERS

COCHRANE HEATERS

HARRISON SAFETY BOILER WORKS,

3176 N. 17th St., Philadelphia, Pa.

Manufacturers of the Sorge-Cochrane System and of the Cochrane Steam and Oil Separators.

COCHRANE HEATERS

COCHRANE HEATERS

COCHRANE HEATERS