the sun are readily transmitted, but those of lower order returned by the boiler, are arrested and thus retained inside of the bell.

Returning to the subject, it appears now that the thickness and condition of the atmosphere govern in a great measure the temperature of the earth, and a number of inferences can be based on that theory.

Carbonic acid being a better absorber of heat, by many times, than either oxygen or nitrogen, the small percentage of this gas in the atmosphere may have a great deal to do with our temperature. At a past period the percentage of this gas may have been less than at present. This might explain the glacial period. Before the immense fields of coal were deposited under ground, the air must have been richer in carbonic acid, and hence a better protector of heat. This may account for the luxury and abundance of vegetable growth of that period.

Thus my studies were carried farther than I originally intended, but it is almost impossible to investigate any subject without being led on other topics. The laws of nature are so closely related to each other, that no line of division can be drawn, and one discovery suggests another.

A STANDARD GAUGE SYSTEM.*

By GEORGE M. BOND, Hartford, Conn.

In a paper presented at the May meeting of the Society last year, a statement, or "report of progress" was submitted, showing the method adopted by the Pratt & Whitney Company, of Hartford, Conn., by which the question of practically establishing a standard for size gauges was to be scientifically determined, accurately subdividing the Imperial yard into feet and inches and fractional parts of an inch, and describing briefly the extent to which was carried the scientific research found absolutely necessary for such an undertaking; it remains now to present to the consideration of those who may be interested, a statement of the results proceeding from the practical application of all the thorough, conscientious investigation of Professor Rogers, of Harvard College Observatory, whose invaluable experience and professional services, in obtaining for the company the transfer and subsequent subdivision of the British yard, gave the foundation for

*From advance sheets of the transactions of the American Society of Mechanical Engineers.

what has been accomplished, enabling the company to feel warranted in earnestly inviting an inspection of the means now available for the production of standard sizes, and asking for it the endorsement of the engineering profession, should it be found worthy of such necessary support.

The comparator referred to in the previous paper, has been placed in position upon brick piers in a room outside the main building, erected especially for it, and is comparatively free from the jar and tremor of the machinery, even unaffected by the jar of passing trains (the tracks of the New York, New Haven and Hartford, and of the New York and New England Railroads being quite near), the rigidity of the instrument and the excellent workmanship in its construction preventing any perceptible vibration during an observation, even when the high power microscopes, magnifying 150 diameters, are used.

The illumination required in using these microscopes is perfectly attained by reflection, using a plate-glass mirror placed outside of the window of the comparing room, at an inclination of 45 degrees, giving clear diffused light, cloudy weather even improving the general effect, as the light is then whiter than that reflected from a clear blue sky, and the lines on the standard bar, as seen through the medium of the Tolles' illuminating prisms with which the objectives are fitted, are clearly and sharply defined at any time during daylight, and in any position of the microscope plate; by thus avoiding the use of artificial light and consequent effect of a variable temperature, far more satisfactory results are obtained.

The investigation for the determination of the necessary corrections for errors due to horizontal or vertical curvature of the path of the microscope plate, has shown conclusively the unexcelled workmanship in the construction of the comparator; as an instance of how slight these errors really are, it was found after repeated observations, the means being carefully collected, that the horizontal curvature, *i. e.*, the bending sidewise of the cylindrical guides or ways upon which the microscope plate slides, at the part investigated, was that having a radius of *eleven miles*, and a consequent correction to be applied of about one ten-thousandth of an inch in 18 inches, the latter distance referring to the position of the measured standard when placed either side of the line of motion of the centre of the microscope plate, moving between fixed stops, and which is the constant quantity to which is referred the subdivisions of the standard bar; as the microscope is usually within

one inch, rarely over two and a half, from the centre line of the stops or caliper jaws between which the end measure pieces or the cylindrical gauges are placed, this correction evidently becomes too small to be applied practically, within the limit of a six-inch gauge; for a foot or a yard it would become necessary, as the variation of the chords of the subtended arcs then becomes quite perceptible. The errors due to inequality of temperature in the standard steel bar and the hardened steel end-measure gauges must be carefully guarded against, the latter effect being far more important, practically, and often very misleading. In the case of a four-inch hardened steel end-measure gauge experimented upon, the coefficient of expansion being nearly one one-hundred thousandth of its length, one degree of change of temperature from that maintained in the reference bar, introduces an error of nearly one twenty-five thousandth of an inch in the total length, and hence, as a change or inequality of five or even ten degrees might be easily overlooked, the four-inch gauge would be found to be from one-five thousandth ($\frac{1}{5000}$) to one twenty-five hundredth ($\frac{1}{2500}$) of an inch too short, when equality of temperature is restored; when it is asserted that an actual variation of so minute a quantity as *one thirty-thousandth* of an inch, and even less, can be readily detected by any tool-maker familiar with the use of an ordinary micrometer or a close gauge, the importance of keeping *within* this limit is apparent,—of course, this shortening effect is not so marked in smaller sizes, still the ratio is the same, and this error must be carefully avoided.

The subdivisions upon the six-inch hardened steel standard bar have been carefully investigated upon the new comparator, to determine how nearly these inch spaces equal each other, the total length of the four inches which are ruled upon this six-inch bar being *exactly standard* at 62 degrees Fahrenheit, according to the official report of Professor Rogers, received December 1st, 1881, and in this report, the results obtained by him, determining this relation of the inch spaces to each other, was found to agree closely with the results obtained by me, as the following comparison will show, these minute corrections being necessary in accurately determining the subdivisions of the Imperial yard, which they represent :

Corrections.	Prof. Roger's Report.	Results obtained.
Total 1 inch, <i>add</i> ,	0.000008	0.000008 ($\frac{1}{30}$ yard.)
Total 2 inches, <i>subtract</i> ,	0.000026	0.000027 ($\frac{1}{36}$ ")
Total 3 inches, <i>subtract</i> ,	0.000005	0.000006 ($\frac{1}{12}$ ")
Total 4 inches,	correct	correct ($\frac{1}{3}$ ")

The results given in the last column are the *means* of a number of observations, taken at different times and under various conditions of temperature, etc., and cover a period of about four weeks, the final results having been obtained December 31st.

The value of the divisions of the micrometer employed was carefully determined in order to reduce them to the same unit used by Professor Rogers, and was found, using the microscope marked "B," to equal $\frac{1}{88500}$ of an inch (0.000016, nearly).

When it is considered that the two results were obtained under different conditions, and using different microscopes, and with comparators differing in construction, the correctness of the *principle* upon which the comparison is founded, certainly needs no other proof.

The method of obtaining this relation of the separate inches upon the six-inch standard, was referred to in the former paper, and is that of comparing each inch with a constant distance moved over by the microscope plate between fixed stops, a constant pressure of contact being obtained by the use of electro-magnets, the separate inch spaces being thus referred to an *invariable* quantity or distance, and their relation to each other consequently determined.

To explain more fully this operation, the method adopted is as follows: A series of readings is taken at the zero or initial line of the first inch space, using the micrometer referred to, the microscope plate being held firmly against the fixed stop by the electro-magnet; the microscope then moves with the sliding plate until the latter is in contact with the other fixed stop, and held by the electro-magnet, the plate having moved as nearly an inch as it may conveniently be done,—generally a little more than an inch, in order to have the *sign* of the reading always the same,—from three to five readings of the micrometer are then taken at each position of the microscope, and the order reversed, to eliminate possible error; the first inch is thus compared with a fixed quantity, and the same operation repeated for the remaining inch spaces.

The difference between the distance moved by the microscope plate and the distance between the defining lines representing inches, is found by subtracting the *means* of the readings obtained, and thus eliminating the possible error of any single observation.

The following is a series of micrometer readings, and comprises the means of all the observations by which the corrections of the separate inches were obtained, illustrating the system adopted, and which has

been used invariably by Professor Rogers in his investigations of the subdivisions of the yard and meter bars, now in the possession of the Pratt and Whitney Company.

COMPARISON OF INCHES.

	L.	R.	L.	R.	
1st inch.....	58.1	65.8	58.0	65.5	} Reverse order.
	58.6	66.0	58.1	65.8	
	58.5	65.4	58.0	65.8	
	<u>58.4</u>	<u>65.7</u>	<u>58.0</u>	<u>65.7</u>	
Mean.....	58.0	65.7			
Mean.....	58.2	65.7			

$$R - L = + 7.5 \text{ divisions of micrometer.}$$

	L.	R.	L.	R.	
2d inch.....	56.2	65.8	55.4	65.4	} Reverse order.
	55.6	65.8	56.0	65.4	
	56.2	66.0	55.4	66.0	
	<u>56.0</u>	<u>65.8</u>	<u>55.6</u>	<u>65.6</u>	
Mean.....	55.6	65.6			
Mean.....	55.8	65.7			

$$R - L = + 9.9.$$

	L.	R.	L.	R.
3d inch.....	55.0	63.0	57.0	63.0
	55.8	63.0	57.0	63.5
	55.7	63.6	57.0	62.8
	<u>55.5</u>	<u>63.2</u>	<u>57.0</u>	<u>63.1</u>
Mean.....	57.0	63.1		
Mean.....	56.3	63.1		

$$R - L = + 6.8$$

	L.	R.	L.	R.
4th inch.....	57.4	64.3	56.0	64.2
	57.8	64.8	56.1	64.5
	57.8	64.8	56.8	64.5
	<u>57.6</u>	<u>64.6</u>	<u>56.3</u>	<u>64.4</u>
Mean.....	56.3	64.4		
Mean.....	56.9	64.5		

$$L - L = + 7.6$$

CORRECTION Σ

+ 7.5 + 0.45 + 0.45 = correction for first inch.

+ 9.9 - 1.95 - 1.50 = correction for total 2 inches.

+ 6.8 + 1.15 - 0.35 = correction for total 3 inches.

+ 7.6 + 0.35 + 0.00 = correction for total 4 inches.

Mean + 7.95

The differences of the observed inch spaces with respect to the constant quantity obtained by the motion of the microscope plate, are added and their mean taken, from which the corrections are determined with the proper signs; in order to check the accuracy of the latter work, these corrections are added, the final result being evidently zero, the column under " Σ " showing this algebraic sum.

It may be appropriate here to state that the six-inch bar upon which these four-inch spaces are traced, is a standard which is, without doubt, the only hardened steel *line-measure* bar in existence, which is exactly one-ninth part of the Imperial yard at 62° Fahrenheit, and Professor Rogers considers it as such in his report, before referred to.

In order to apply these subdivisions, which include all sizes, from one-sixteenth of an inch to four inches, varying by sixteenths, to a practical form, fixtures have been provided and are in constant use, for reducing to *end* measure the distances thus accurately spaced, and a caliper attachment has lately been added from plans proposed by Professor Rogers, by which the diameter of existing cylindrical gauges, as well as the length of end-measure pieces from one-sixteenth of an inch to six inches may be tested with the same precision that characterizes the investigation of the linear spacing of the standard bar, also providing means for a rigid inspection of finished gauges before they leave the works, thereby insuring uniformity.

To illustrate how nearly alike two pieces may be made, two standard inch end-measure gauges were worked down under the microscope, independently of each other, using the lines upon the ruled standard reference bar and the fixture referred to, which, when compared with each other by the most careful tests, using close or "snap" gauges, and tested thus by tool-makers experienced in work requiring the utmost practical precision, neither piece could be singled out as the larger, the effect of unequal expansion caused by temperature being avoided during the test. Under the microscope, both pieces were found to be exactly alike by a *single* observation, while the comparison, by a series of readings showed a mean difference between the two pieces of one-tenth of a division of the micrometer, and when it is remembered that one division has a value of only $\frac{1}{88000}$ th of an inch, the duplication, it may be assured, is certainly satisfactory, and is clearly within a practical, if not a theoretical limit of accuracy.

Having thus the means for closely reproducing established sizes, and no possible wear occurring to the bar from which these sizes are taken, the accurate duplication becomes a comparatively simple operation.

In order to produce standard work within the limit of a yard, or a meter, there has been furnished by Professor Rogers, two steel yard and meter bars, referred to in the previous paper, one of these bars tempered, the other being left soft, but having hardened steel plugs, which are adjustable, for the purpose of bringing the surfaces into focus under the microscope; upon these hardened plugs the lines are ruled, both bars having line and end-measure, thus providing means for testing the accuracy of the pitch of screw threads of any desired length, and for standard length gauges up to thirty-six inches, or to a meter.

The coefficient of expansion has been determined for each by Professor Rogers with the most scrupulous exactness as stated in his report, and also the relation, at 62°F. , between these steel bars and the two bronze standards, both of which are line measure, (the latter are described in the paper previously referred to) so that gauges of any size may be made almost independently of temperature, other than the care required in keeping this condition as nearly uniform as possible for both the reference and the measured bar during the time of the transfer, or the determination after having been transferred.

The subject of accurately producing standard leading screws is receiving its share of attention, and those who use micrometers will readily understand its bearing upon the precision with which they may be made, and how unsatisfactory because of the necessary corrections to be applied in many instances, even when standard at some one part of the divided head—a uniform lead or pitch of the screw, however much may be the total error (within a reasonable limit), making a great improvement in their construction.

Besides a complete set of end-measure gauges, varying by sixteenths from one-quarter to four inches, there is now ready for inspection a complete plant, consisting of tools and fixtures for producing the standard United States or Franklin Institute thread gauges, every detail having been carefully considered, and every difficulty overcome in the operation for perfecting, not only these standard gauges as to size, but the pitch of the thread, the correct angle, and the width of flat at the top and bottom of the thread. The accuracy of this work is now open to the inspection of all who may be interested, and rapid duplication by *machined* work is now an assured success.

It is the conviction that the "bottom" has finally been reached, that warrants the Pratt and Whitney Company in thus inviting a

thorough inspection of the means available, and the methods employed, for producing standard gauges, and earnestly desiring an impartial verdict as to its accuracy and practicability, whether or not, the system as adopted and carried out, has any real merit upon which the confidence of those using gauges for interchangeable work may be safely based.

DISCUSSION.

PROFESSOR ROBINSON: This paper is of the highest merit and of the greatest possible interest to members of the Society, and it is a matter of great satisfaction to the mechanical engineers of this country that there is some one who is able to take hold of this question and treat it so ably as it has been treated; and inasmuch as the methods and results, as stated by the reader, are laid open for inspection by others, I think it is due, in consideration of the amount of effort and expense which has been given to this matter, that the Society, as a matter of duty, should appoint a committee to avail itself of the privileges offered of investigating this, and of making such a statement regarding it as will be found advisable; and undoubtedly this is a thing which the Society will be willing and anxious to endorse in every particular as a standard of the country. For one, I should be glad to see a committee appointed to give this matter the attention it deserves.

PROFESSOR EGLESTON: I notice that there is no reference in this paper to any instrument in the shape of a caliper of any kind used as a gauge. I do not know whether the members of the Society are familiar with the fact that in 1875 the Institute of Mining Engineers appointed a committee on standard gauge, and that committee came to just exactly the conclusion which is expressed here, that diameters or linear measures ranging in fractions of a millimeter or an inch were the only gauges which were standard or could be standard. It is a peculiar gratification, as a large part of the work fell to my hands, to see that idea so fully sustained. It is a matter of a great deal more importance than perhaps would appear just now. I believe the English engineers are again agitating the question of standards, and are going back to the old caliper idea. So I have heard recently. So I think it is really a retrograde movement. Most of you may know the fact, but we discovered in the course of our investigations

that if you take a dozen standard gauges, so-called, out of any package, you will find no two of them alike.

THE PRESIDENT: I suppose the members would be interested if Mr. Pratt would tell us how they went to work in this undertaking. Mr. Pratt told us the story at Hartford, but many gentlemen are here to-day who were not with us then, and I presume it would be very interesting to all to know how Messrs. Pratt and Whitney were led into this prolonged, expensive, and nice investigation.

MR. PRATT: I will relate the story in the briefest possible way. We were called upon to furnish a set of standard thread gauges, and of course the first thing to do was to get the sizes, and upon examining the different makes of gauges we found no two sets alike, and we were forced to commence, as we thought, at the bottom, and at that time, in sending about a foot-piece that we had obtained, we found that those investigating it did not agree upon its value. Among others Professor Rogers was applied to, to investigate the foot-piece, and he had quite a struggle over it with some of our prominent manufacturers of gauges. They could not agree, and Professor Rogers took it upon himself, at his own expense, to go to Europe, and go to the bottom of the thing. He visited the best authorities in Europe, and spent four months there in investigation. After we had obtained the services of one of the graduates of the Stevens Institute, and in connection with Professor Rogers, we constructed two comparators, one of which Professor Rogers has himself, and one of which we have; they being exactly alike. After Professor Rogers returned he investigated the foot-piece, and found it to be about what he had found it to be before, and then, after the new comparator was finished, he found his statement verified. Previous to this time, fortunately, Professor Rogers had been for several years constructing a ruling machine, and he had it completed about this time. We have gone very carefully into this thing. I do not feel egotistic about it at all. What we want is that every one who is interested in the matter, every society that takes any interest in it, should come and examine our methods and our measurements. If they are good, let us have a standard. If they are not, let us throw them away. It has cost us probably twenty thousand dollars to-day, and I am willing to throw it away if anybody can show us better. We want a standard, and I will not stand in the way of any one else.

who has a better machine. I feel very much interested in the subject, myself; and I think we shall succeed in what we have undertaken.

Supply of Air to Houses.—MM. Autier and Mongey have devised plans for the distribution of cool, fresh air to houses. The former proposed to employ a feeble pressure, while the latter recommends a pressure of five or six atmospheres, together with special refrigeration, in order to obtain increased cold by expansion, on the plan of the frigorific engines of Windhauser, P. Gifford, etc. The Holley system, as employed by the Steam Supply Company in Lockport, is quoted as an evidence of the economy of large public provisions for the distribution of such means of family comfort as heat, gas, fresh air, and relief from the oppressive heats of summer. The distribution of such air would not only contribute to bodily comfort and public health, but it would also retard the fermentations and decompositions of animal and vegetable substances, and it might, at the same time, be employed to furnish motive power.—*Chron. Industr.* C.

AN EXTENSION OF THE THEOREM OF THE VIRIAL AND ITS APPLICATION TO THE KINETIC THEORY OF GASES.*

By H. T. EDDY, C. E., PH. D., University of Cincinnati.

1. INTRODUCTORY.

Clausius published, in 1870, a paper upon a *New Mechanical Theorem Applicable to Heat*,† which he designated as the *Theorem of the Virial*, and which he applied to the stationary *progressive* motion of the molecules of gases.

The object of this paper is to demonstrate an analogous theorem applicable to the stationary *rotary* motion of the molecules of gases, and by the aid of these two theorems to improve, to some extent, the kinetic theory of gases, especially in removing an heretofore inexplic-

* From the Scientific Proceedings of the Ohio Mechanics' Institute, for March, 1883.

† Berichte der niederrhein. Gesellsch. für Natur u. Heilkunde, Juni, 1883. Phil. Mag., Series 4, vol. 40, 1870, p. 122.

Pogg. Ann., vol. 141, p. 124.