has been shown to prove that no higher degree of tractive force is to be expected from the double-pole method of determining the magnetisation limit of magnetic substances than has been obtained by the single-pole method.

May 20, 1897.

The LORD LISTER, F.R.C.S., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The Bakerian Lecture was delivered as follows:—

BAKERIAN LECTURE.—"On the Mechanical Equivalent of Heat." By OSBORNE REYNOLDS, M.A., F.R.S., Professor of Engineering, Owens College, and W. H. MOORBY. Received March 10, 1897.

(Abstract.)

The purpose of this research differs essentially from that of any previous research on the mechanical equivalent of heat. In order to diminish the loss of heat by radiation, as well as to obtain the equivalent for water in the neighbourhood of ordinary temperatures, the ranges of temperature over which the previous dynamical measurements have been made are greatly less than the standard interval between the physically fixed points of temperature to which all thermal measures are referred, and so have of necessity involved the use of scales, the intervals of which depend on the constancy of the relative expansions of such substances as glass, mercury, and air. On the other hand, in this research the object has been to determine the mechanical equivalent of the total heat necessary to raise the temperature of water over the standard interval of temperature, and thus to obtain directly the equivalent of the mean specific heat between the freezing and boiling points.

This undertaking is the result of the occurrence of circumstances which afforded an opportunity such as might not again occur. This consisted in the facilities offered by the appliances which formed the original equipment of the Whitworth Engineering Laboratory, in 1888, the more essential of these being an engine of 100 H.P., working one of Professor Reynolds' hydraulic brakes. This brake maintains any constant moment of resistance on the engine shaft, independent of the speed, all the work done being converted into heat, which appears in the rise of temperature of a steady stream of

water flowing through the brake, the magnitude of which stream is independent of the load on the brake or the speed of the engine, and is under independent control.

The existence of the Manchester town water, of a purity expressed by 3 grains of salts to the gallon, conveniently distributed in the laboratory, as well as auxiliary power, both steam and water.

Although unconsciously, the research was really commenced in 1890, when, without any intention of making a determination of the heat equivalent of the work done on the brake, but solely for the purpose of verifying the mechanical balance of the brake, provision for thermal measurements was added, and a system of trial instituted, in which the object sought was only that of obtaining consistent results over definite portions of the scales of uncorrected thermometers, eliminating the errors resulting from radiation by taking the differences of two trials. In these trials the temperature ranged from 40° to 50° F., and their development was continued over two years. Then it occurred to Professor Reynolds that by the same method the great facility which this brake was then seen to afford would be available for the independent determination of the mechanical equivalent, if it could be arranged that water should enter the brake at the temperature of melting ice, and leave it at that of water boiling under the standard pressure. Since then all that would be required of the thermometers would be the identification of these temperatures, and with a range of 180°, small errors would be comparatively of small importance. At first the difficulties seemed formidable; but on trying by gradually diminishing the supply of water to the brake when it was absorbing 60 H.P., and finding that it ran steadily under control of its automatic gear till the temperature was within three or four degrees of boiling, he further considered the matter, and during the next two years convinced himself of the practicability of the necessary additional appliances by preliminary designs. These consisted in—

1. An artificial atmosphere or means of maintaining a steady air pressure of 4/3 atmosphere in the air passages of the brake.

2. A circulating pump and water cooler, by which the entering water, some 30 lbs. a minute, could be forced through the cooler into the brake at a temperature of 32°, having been cooled by ice from the temperature of the town main.

3. A condenser by which the water leaving the brake at 212° might be cooled down to atmospheric temperature before being discharged into the atmosphere and weighed.

4. Such alteration in the manner of supporting the brake on the shaft as would prevent excess of leakage from the bushes in consequence of the greater pressure of air in the brake, since not only would the leaks be increased but when the rise of temperature was

increased to 180° the quantity for any power would be diminished to one-sixth of that for a rise of 30°, so that any leakage would become six times the relative importance.

5. Some means by which assurance of the elimination of the radiation and conduction could be obtained, as with a temperature of 140 F. above the laboratory these would probably amount to 2 or 3 per cent. of the total heat.

6. Scales for greater facility and accuracy in weighing the water with a switch actuated by the counter.

7. A pressure gauge or barometer by which the standard for the boiling points might be readily determined at 3° or 4° F. above and below the boiling point, so as to admit of ready and frequent correction of the thermometers used for identifying the temperature of the effluent water.

8. Some means of determining the terminal differences of temperature and quantities of water in the brake, which would be relatively six times as large as with 30° rise.

These preliminary designs apparently demonstrated the practicability of the appliances, and also the possibility of their inclusion in the already much occupied space adjacent to the brake. But there remained still much to be done in the way of experimental investigation in order to obtain the data for proportioning the appliances.

In July, 1894, Mr. Moorby having undertaken to devote himself to the research, the experiments necessary for the appliances were at once commenced, and these, together with the construction of the appliances and then standardising, and preliminary experiments while this was in progress, occupied till February, 1896, when Mr. Moorby commenced the main experiments which were continued into July, 1896.

In these experiments the time of running was 62 minutes; the speed 300 revolutions a minute, on the speed gauges. Observation of speeds, of the temperature of the in-flowing and effluent water, and of the temperature of the air were made every two minutes. Observations of the slope of the temperature of the shaft were made every eight minutes.

The temperature of the inflowing water varied from 32·5° to 34°, and that of the effluent from 210° to 214° F. The effluent water was cooled to 8·5° before entering the tank on the scales, in which it was weighed, weighings being taken before and after each trial.

The temperature of the metal surface of the brake was sensibly the same as that of the effluent water (212°), and, by taking the difference in the work absorbed in two trials and the differences in the heats developed, the errors of radiation and balance in the brake were approximately eliminated; and in order to complete the elimination the coefficient of radiation was approximately determined, so that a

correction might be applied for any residual differences of temperature as observed, and in the same way with the slope of temperatures. Further assurance was also obtained by making some trials with the brake naked and others with it covered, so as to reduce the loss of heat to one-fifth; and, in the same way, with every circumstance which could affect the result trials, means were taken to vary the circumstances in different series of trials, so as to obtain an estimate of the limits of error. All the appliances were most carefully standardised; and taking all the limits of error into account the limit of the sum was less than 0·0003.

In all 52 trials were included in the final result. Of these—

25 with loads on the brake of			1200 ft.-lbs. at		70 H.P.
21	,,	,,	600	,,	35
6	,,	,,	400	,,	23

From these, twenty-five separate determinations were made of the equivalent, subject to certain general corrections given below, which gave a mean value 777·91. From this none of the separate determinations differed by as much as 0·2 per cent., and when arranged in eight groups, according to the circumstances under which they were made, the greatest divergence from the mean was 0·036 per cent.

It was found impracticable to eliminate entirely from each determination the losses of heat due to radiation, conduction, leakage of water, &c., and so it was found advisable to determine what these losses were. This information was given by the trials themselves, and the necessary corrections were applied to each separate determination. As illustrating the extent to which the method adopted did eliminate these errors, it is interesting to remark that on the mean value of the equivalent determined, without taking these errors into account, the error was only 0·0192 per cent.

Certain final corrections, which had the same values for all trials, were made to the mean value of J, given above. These were introduced on the following various counts :—

I. Length of the brake lever (0·00042).
II. Salts dissolved in Manchester water (0·00003).
III. Air dissolved in water used in the trials (—0·00021).
IV. Reduction of weighings to vacuo (—0·00120).
V. Varying specific heat of water (—0·00006).
VI. Pressure on thermometer bulbs (—0·00037).
VII. Work done against gravity (0·00007).
VIII. Engagement of counter (0·00001).

Their total effect was to introduce a correction factor of (1 — 0·00125).

The mean corrected value of the specific heat of water between freezing and boiling points, as measured in mechanical units at Manchester, is found to be 776·94.