March 24, 1887.

Professor STOKES, D.C.L., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

Major A. W. Baird, R.E. (elected June 4, 1885), was admitted into the Society.

The following Papers were read :—

I. "Preliminary Note on the 'Radio-micrometer,' a New Instrument for Measuring the Most Feeble Radiation." By C. V. BOYS, Demonstrator of Physics at the Science Schools, South Kensington. Communicated by Professor A. W. RÜCKER, F.R.S. Received February 24, 1887.

Till lately the thermopile and galvanometer have afforded the most delicate means of detecting and measuring radiant energy. This combination has been surpassed by Professor Langley, who has made use of the increased resistance of metallic wires or the diminished resistance of a carbon filament when warmed.

It seems difficult to believe, in consequence of the very small change of resistance which even iron undergoes when slightly warmed, that this is the best principle to make use of in designing the most sensitive possible instrument. I felt that if an instrument depending on thermo-electric force could be made as beautifully as Professor Langley's bolometer, a better result ought to be obtained. The one point in which the bolometer has a great advantage is the small mass of the part to be heated, whereas a thermopile, delicate as the bars may be, has a mass so enormous that both the rate of heating and the ultimate rise of temperature must be small in comparison.

A thermopile with bars as thin as the wires of the bolometer cannot be made with antimony and bismuth, and yet such a construction would be required before the thermo-electric force could be utilised to the same extent that the change of resistance is in the bolometer.

If the conducting wires had no resistance, no advantage would be gained by having more than one junction, provided that the galvanometer were properly proportioned. If it were not for the resistance and torsion of the stretched wires, the moving coil galvanometer of

Deprez (on the principle of Sir W. Thomson's siphon recorder) would have many advantages. It occurred to me that if an active bar were made with two pieces of metal, antimony and bismuth, as thin as possible, soldered edge to edge, and if the outer edges were joined by an arch of copper, and if this were hung in a strong magnetic field, all the advantages of an ideal thermopile and of the Deprez galvanometer would be gained, while the impossibility of the former, and the resistance and tension of the stretched wires of the latter, and the resistance of the wires connecting the thermopile with the galvanometer would be abolished. I anticipated that a greater delicacy would be obtained than has been considered possible, that the instrument would be convenient in that it would be of necessity dead beat, that its indications would be proportional to the received radiations, that it would have the constant and definite zero which mechanical control such as torsion gives, that it would not be affected by the magnetism of objects near it, and that as the circuit could be suspended in a hole in a mass of metal with one window for the radiation to enter, the instrument should be very insensitive to temperature changes other than those in the line of action. It has the further advantage that for spectroscopic work the radiation may be limited by a narrow slit without much reducing its sensibility.* It is, however, a fixed instrument that cannot be handled and pointed like the thermopile or the bolometer.

I have made some preliminary experiments to test these conclusions. One instrument, made by my friend Mr. Cunynghame very roughly with a torsion wire support only a few inches long, is fairly sensitive.

One which I made with the active bar about $6 \times 8 \times \frac{1}{6}$ mm., and with a circuit 1 cm. square, of one turn of which the three sides are made of copper wire about $\frac{1}{3}$ mm. in diameter, and in which the motion of the circuit is resisted by a torsion fibre of the finest spun glass about 10 cm. long, gives when placed on the poles of a permanent magnet results so good that I have ventured to submit the instrument for inspection to the Royal Society. This particular instrument is capable of showing the heat which would be cast by a candle flame on a halfpenny at a distance of 200 yards.† As I have not yet employed what I know to be the best proportions, it is evident that very great sensibility is possible.

* I should have mentioned that much larger angles could be measured if the fibre were suspended by a torsion head and the light brought to a definite position for every observation.—[*March* 2, 1887.]

† This same instrument with a 38 cm. fibre in a field of about 100 units only, gave a deflection of 4·5 cm. when the heat cast by a candle flame 12 feet off fell on the active bar which was exposed over a surface of 4 × 6 mm., therefore a candle $254\frac{1}{2}$ feet distant would produce a visible effect, or the heat which would fall on a halfpenny 1168 feet from a candle flame would be sufficient to be observable if it were directed on to the active bar.—[*March* 2, 1887.]

It is easy to calculate exactly what deflection will be caused by a given rise of temperature in any instrument. Taking quantities, all of which can be easily obtained, namely, antimony and bismuth, each $5 \times 5 \times 0{\cdot}25$ mm., one arch of copper wire one-eighth of a square mm. in section, completing a circuit of one square cm., suspended in a field of 10,000 units by a thread of such a torsion as would give an undamped period of oscillation of 20 seconds, the least movement that could be detected would be produced by a rise of temperature of about one ninety-four millionth of a degree centigrade. It seems to be capable of attaining about 100 times the sensitiveness of the bolometer. Further, the electromotive force acting at this temperature would be only about one million millionth of a volt, which is probably smaller than any that can be detected by other means.

I am now engaged in working out such details as the various maxima. Thus for a certain shape of circuit and number of turns a certain thickness of copper gives the best result; of various shapes the rectangle only is practically convenient, but taking the best thickness of wire for each successive length, a certain length is better than any other; with a particular shape and the best thickness, two turns are better than one or three, but it does not follow that this will be so for all shapes; no advantage is gained by employing more than one junction. An increased sensibility may be produced by either using a longer torsion thread or a stronger field, a certain relation between these and the resistance will give a maximum quickness.

The conductivity of aluminium compared to its mass is, as is well known, more than that of any other material, so it would be preferable to copper if it were not for the difficulty of soldering it.

The instrument may be made with a second active bar, forming the other end of the rectangle, with its own window, and can thus be used differentially, one bar being exposed to the radiation to be measured and the other to any compensator.

It is interesting to note that the damping action is slightly reduced by the Peltier effect.

I anticipate some difficulty in using the field produced by an electromagnet; for even if the effect of the heating of the coils by the current can be avoided, as I think it may by the use of long iron connecting-rods passing through water, any variation of current will give rise to motions of the suspended circuit, the nature of which I described in the 'Phil. Mag.,' September, 1884. But after these difficulties are removed, there will remain the diamagnetism of the three metals and the great damping action. With fields of reasonable strength, the diamagnetism may be set against the torsion of the thread, so that but feeble controlling force may be obtained by a thread of moderate length, but for electromagnetic fields I propose to

paint the circuit with a solution of a salt of iron until it is magnetically neutral.

Mr. Cunynghame suggested to me, when I explained to him my views, that a rotating instrument might possibly be made like Crookes' radiometer. After some trouble I have devised and made a most simple rotating pile. It consists of a cross with bismuth arms and an antimony centre. To the end of each arm is soldered a piece of copper wire, the four wires being parallel to one another, and at right angles to the plane of the cross. The four free ends of the wires are soldered to a ring of copper wire parallel to the cross. If this is balanced on a point between the poles of a permanent magnet, and if radiant heat is allowed to fall on the right hand side of the cross, looking from the north to the south pole, the cross will at once begin to oscillate, making larger and larger oscillations until it rotates, which it will do indifferently in either direction. If the heat falls upon the left hand side, any motion that it may have is at once arrested. It follows that if the source of heat is removed and the cross is turned mechanically, the right hand side will be cooled and the left warmed.

If the cross is made with antimony arms and a bismuth centre, then what was true of the right hand side is now true of the left, and *vice versâ*.

Instead of a cross and four wires, I think an antimony disk, with many pieces of bismuth and many wires or with a ring of bismuth, and many wires forming a sort of drum armature, would give a better result; but the one described with four arms rotates rapidly when the spark at the end of a blown-out match is held near it.

We have in this rotating pile, which might be called an electric radiometer, an electromagnetic motor, which is almost an exception to the axiom that such an engine cannot be made without sliding or liquid contacts.

I am now working out fully the conditions of maximum sensibility, and hope to communicate shortly a paper to the Royal Society, in which they are discussed, and at the same time to show an instrument of the best construction and some results obtained with it.

Note added March 23, 1887.

I have found, both by calculation and experiment, that the movement of the circuit becomes perfectly dead beat with a field of a little over 1000 units; therefore advantage is gained by using more than one junction, as a stronger field can then be used before the motion becomes dead beat.

I have spoken of a fine glass fibre as a torsion support. Since this

was written I have discovered a method of making fibres with a perfect elasticity, and so have avoided the inconvenience of the shifting zero of the glass fibre, and with a torsion, if required, ten million times less than that of spun glass. This will be described at the next meeting of the Physical Society.

II. "Note to a Memoir on the Theory of Mathematical Form ('Phil. Trans.' 1886 (vol. 177), p. 1)." By A. B. Kempe, M.A., F.R.S. Received February 26, 1887.

An interesting letter of criticism from Professor C. S. Peirce on my recently published Memoir on the Theory of Mathematical Form has led me to reconsider certain paragraphs therein, relating to the definition of what I have termed "aspects," and I am anxious to make the following amendments.

For Section 5 substitute—

5. In like manner some *pairs* of units are distinguished from each other, while others are not. Pairs may in some cases be distinguished even though the units composing them are not. Thus the angular points of a square are undistinguishable from each other, and a pair of such points lying at the extremities of a side are undistinguished from the three other like pairs, but are distinguished from each of the two pairs arrived at by taking the angular points at the extremities of the diagonals, which pairs again are undistinguishable from each other. Further, though two units a and b are undistinguishable from each other, an absence of symmetry may cause ab to be distinguished from ba. Thus, if we put aside differences arising from their positions on the paper, and the use of reference letters (Secs. 41 and 42), the three black spots, a, b, c, shown in fig. 1, are undistinguished from each other; but ab is distinguished from ba, for when we take the spots a, b, in the order ab an arrow proceeds *from* the first spot *to* the second, but when we take them in the order ba an arrow proceeds *to* the first spot *from* the second.

For Section 7 substitute—

7. Again, there are distinguished and undistinguished triads, tetrads, ... m-ads, ... n-ads, ... ; every m-ad being of course distinguished from every n-ad. Just as we may have ab distinguished from ba, though a is undistinguished from b, so we may have $pqrst$ . . . . uv distinguished from $qusvt$ . . . . rp, though the units p, q, r, s, t, ... u, v, are all undistinguished from each other, and further, though their pairs are also undistinguished, as likewise their triads, &c. Here $pqrst$ . . . . uv and $qusvt$ . . . . rp will be termed, as in the case of pairs, different *aspects* of the collection p, q, r, s, t, ... u, v. An aspect will be fully defined and con-