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LIX. *On Sensitive Galvanometers.* By R. THRELFALL, M.A.,
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To the Editors of the Philosophical Magazine and Journal.

GENTLEMEN,

THOUGH I expect the matter will have been almost forgotten when this reaches England, I still desire, if possible, to meet some of the criticisms which have been levelled at me by Professor Gray in the *Philosophical Magazine* for February 1890, and by Professor Ayrton at the Physical Society on January 17th. Of Professor Ayrton's criticisms I have only as yet seen a report in 'Nature' for January 30, but since they appear in the main to coincide with Professor Gray's as nearly as I can judge, I will endeavour to reply to both at once.

In the first place, then, I must of course plead guilty to having made a mistake in arithmetic (to my shame be it said), and must express my thanks to Professors Ayrton and Gray for pointing it out. It now appears that instead of my success with the Gray galvanometer being a thousand times less than Professor Gray's, it is only about a hundred times less as compared with the performance in 1884, and three times less as compared with his results in 1889. As the matter is one which purely depends on instrument-making and experimenting, I can only say that I am very glad to find myself approach so nearly to Professor Gray. With respect to the much graver and more important charge that I have overestimated the performance of another type of galvanometer, I can only say that the mistake rests entirely with my critics, though very likely through my own fault in endeavouring to achieve conciseness of statement. That the galvanometer described did actually attain the sensitiveness quoted, viz. 5 divisions to 10^{-11} ampere of current, a fresh reference to my notebook amply proves. Neither in my paper on "The Measurement of High Specific Resistances," nor in the following one on the Specific Resistance of an Impure sample of Sulphur, have I given any data from which this value was computed. How, then, can Professors Ayrton and Gray have concluded that I was in error? Professor Ayrton, as I imagine, and certainly Professor Gray, have obtained their data from the resistance-measurements quoted; but it is purely gratuitous on their part to assume that these were the data used by me, and as a matter of fact they were not. In writing the paper, which pretended to be an account of an absolute measurement, I gave the maximum sensitiveness reached by the galvanometer in order to show that I had a good margin in the actual experiments, and was

not using the galvanometer at its limit of sensitiveness. Surely it is not necessary to remind such well-known experimentalists as my critics that an absolute measurement depending on the indications of an instrument at its extreme sensitiveness are always liable to objection. I find in fact from my notebook that the sensitiveness mentioned having been obtained, it was reduced (by lowering the control magnets) to meet the requirements of the work in hand. The resistance of the sulphur turned out to be much less than I had anticipated, for I had got three hundred and sixty small storage-batteries ready for the work, as well as some forty Clark-cells; so I reduced the number of cells and the sensitiveness of the galvanometer in what appeared to me at the time as the most advantageous manner. On reading the paper, however, I see that I was not so explicit (for the sake of brevity) as I might have been. I welcome a discussion on sensitive galvanometers, however, though it has been raised somewhat at my own expense, because I believe that the galvanometer-method has several advantages over the electrometer-method in high-resistance measurements. To this, however, I will not now refer, but will instead make some further remarks anent sensitive galvanometers.

My friend Mr. Boys, at the Physical Society some time ago, said that my quartz fibres were too long and thick. Well, that is a matter of opinion. I used the finest fibres that I could manipulate; and as I saw that I could handle a yard of them almost as well as an inch, I did not see why I should not reap the advantage of length. I saw Mr. Boys's fibres, and I do not think that he mounts much finer ones than I do, though as it is purely a matter of manipulatory skill I daresay Mr. Boys *can* mount finer fibres than I can. If I can persuade Mr. Gray to use quartz instead of silk as a means of suspension, I am sure he will live to bless me. While I am on this subject I will add, that if Professor Gray will reread my paper he will find he has been unjust to me in stating that I must have used the galvanometer near the limit of sensitiveness as the zero was "always on the move." He will find that the whole sentence runs thus:—"It is practically impossible to get a galvanometer of this degree of sensitiveness to work with a silk fibre, the zero being always on the move." Since I gave this as one reason for having adopted quartz, Professor Gray will, I think, see that his argument, in so far as it depends on the galvanometer being at its limit of sensitiveness, is baseless, and that his stricture is unmerited.

With respect to quartz fibres, I may say that I am forwarding a paper on this subject to you; but meanwhile I desire to

state here that I have gone back to Mr. Boys's method of preparing the quartz, which (as might have been expected) is much better than mine. I wonder how many people have any real idea of what a sensitiveness of "five divisions to 10^{-11} ampere" really means. From the glibness with which we talk of sensitiveness, I fancy the conception has not generally been really grasped. Let me give an illustration. We all look on the eye as perhaps our most sensitive organ. In the *Philosophical Magazine* for January 1889 is a paper by Professor Langley, in which an estimate is made of the minimum rate of expenditure of energy (by radiation) which can affect the eye. The estimates are of course rough and not very concordant, and there is some obscurity arising from the hoary-headed difficulty of distinguishing between work and rate of working. However, it follows from the data given, that an expenditure of work at the rate of 2.6×10^{-6} C.G.S. per second will affect the eye so as to produce vision when the light has a wavelength nearly that of the line A; while an expenditure at the rate of 2.6×10^{-11} (or 5.7×10^{-12} from another part of the paper) will produce the same effect if the light is green. Now the galvanometer I described had a resistance of nearly 16,000 ohms; and since 10^{-11} ampere produced a deflexion of five divisions, we may say that we could detect a current of 10^{-12} ampere (giving a deflexion of half a division). In this case a simple calculation (without arithmetical error) shows that the galvanometer absorbed work at a rate of about 1.6×10^{-9} ergs per second. Consequently the sensitiveness of the galvanometer may be said to stand half way between that of the eye for crimson and green light respectively.

I never intended to institute a comparison between Prof. Gray's form of galvanometer and the Thomson form: what I wanted was to get a workable instrument as easily as possible, and I found the Thomson form most easily manageable. Though the Gray form may be workable at the hands of such exceptionally skilful manipulators as its inventors, I do not think that for the ordinary run of experimentalists it is to be compared with the older form, and I certainly do not pin any faith to silk fibres a few inches long. Though, as Professor Gray remarks, his form of galvanometer possesses "solid advantages," as it certainly does, still it possesses also solid disadvantages, and these will, I think, in the long run be found to predominate.

I am, Gentlemen,

Yours obediently,

University of Sydney, N.S.W.,
March 7, 1890.

RICHARD THRELFALL.