part of the rays which go to form the compound white, was plainly of a different grain from the small particles commonly present in the sky, for these arrest the blue rays and scatter them, allowing the rays towards the red end of the spectrum a freer passage, so as to impress the eye with the predominant red colour of luminous objects seen through a long stretch of atmosphere. Since the declining sun in India turned strongly green, the particles competent to arrest the red rays must have exceeded, in the path of the rays, the ordinary blue-arresting particles in quantity or power. But as the sun approached close to the horizon, the lower atmosphere, by cutting off the more refrangible rays, reduced the green, and sometimes caused the red to predominate in the setting sun. The particles of a common blue haze cause the sun to set deep red. The volcanic dust particles may have exceeded in magnitude the particles which cause haze, and possibly the stratum may have contained particles which might be visible under the microscope. That this dust stratum was still present in the higher atmosphere in January was indicated by the greenish tinge of moon and stars. It was largely composed of particles of sufficient magnitude to reflect white light, for a little before sunrise the sky seemed clouded over with something resembling white cirrus haze; but like a film of dust on a mirror, or the floating dust in a room, it was not visible except at certain angles. Condensed vapour, or ice particles in a very fine state of division, would account for the persistent halo or corona of varying radius, but so also would particles of transparent pumice. Assuming the red-arresting stratum to have remained during the autumn and winter months at altitudes from forty to twenty miles, descending say 1000 feet per day during 100 days, the effects observed after sunset and before sunrise were only what might be expected to follow by reflection from the minute surfaces. In the case of ordinary cirrus, the tints up to half an hour after sunset are as follows: white, pale yellow, yellow, orange, pink, red, deep red; or the red only may be visible if the texture be thin and the early twilight strong. With a continuous red-arresting stratum, however, we must consider what influence its horizontal breadth, through which the sun's rays must pass when near setting, would have upon the light reflected from the western sky. At a height of thirty miles the sun would be shining through a great length of the stratum, as viewed from the elevated point, when it had already set on the earth immediately below. At this point, thirty miles above the earth's surface, supposing that to be the height of the stratum, the vapour of the lower air would not yet be strongly exerting its influence in arresting the blue rays, but the sheet of dust would exert its maximum power of stopping the red rays, and the light which survived best, and which from the earth's surface we should see reflected soon after sunset from above the western horizon, would be green. The stratum being so composed as to be capable of reflecting all kinds of light, but by its own action through a great breadth filtering out some of the less refrangible rays, as it did more powerfully in India when less attenuated, the reflected light of the sun above the western horizon, and indeed towards north and south as well, could not fail to be affected with an excess of green. As the sun sank still lower, viewed from the height of thirty miles, it would begin to be largely robbed of the blue and green rays by the ordinary lower atmosphere, and the next colour in the western sky would consequently be yellow, which would equally be reflected by the matter composing the stratum. The yellow would be the result of a competition between the red-arresting upper dust and the blue-arresting lower air. As the sun descended still lower, the power of the ordinary vapour-charged strata would assert itself, and the yellow would pass to orange, pink, and crimson, just as the colour of the sun seen from any eminence commonly changes in setting. The upper haze would merely reflect these naturally changing colours, but the later tints would be more striking as darkness increased. All the changes observed in the first afterglow are thus fully accounted for by larger than ordinary sky particles arresting red waves and the general mass of the stratum reflecting all rays falling upon it. The secondary after-glow would show similar gradations if the first were strong enough to emit much light, but the red in it would be most conspicuous, for the action of the lower air in eliminating blue would be more powerful than the thin veil of dust in eliminating red. There was, however, a distinct greening of the eastern sky on several occasions, signifying the approach of the secondary afterglow. The increase of apparent brilliancy of both glows as they sank westwards would of course be due to perspective.

THE FIXED STARS[1]

II.

I HAVE said that the angle between the stars is measured in terms of the scale, but the scale-value, in seconds of arc, may change by the effects of temperature and from other causes.

Bessel, in his researches on the parallax of 61 Cygni, determined by independent means the effect of temperature on his scale-value, and applied corresponding corrections to his observations. But he also took the precaution to employ two stars of comparison situated at right angles to each other with respect to the principal star, so that the effect of parallax would be at a maximum for one comparison star at the season of the year when it was at zero for the other, and *vice versâ*.

But in the course of previous researches I found that there were sources of error other than mere change of the temperature of the air, viz. differences of temperature in different parts of the instrument, and changes in the normal focus of the observer's eye, which exercised a very sensible influence on the results. It was necessary to devise some method by which these should also be eliminated.

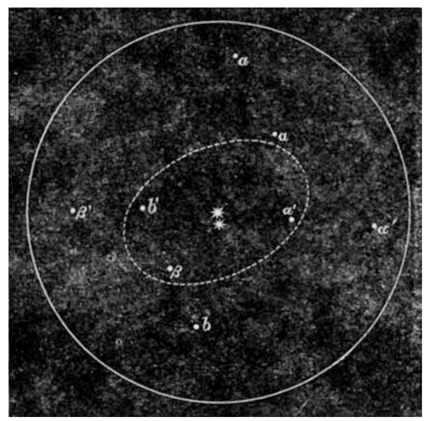

DIAGRAM II.—Showing comparison stars employed in determining the parallax of α Centauri.

There is a very simple means of doing this. Instead of taking two comparison stars at right angles, take two comparison stars situated nearly symmetrically on opposite sides of the star whose parallax is to be determined—such, for example, as the stars α and β in Diagram II. Now observe these distances in the order α, β, β, α, on each night of observation; so that on each night the observations of both distances are practically made at the same instant. Then, whatever causes have combined to create a systematic error in the measurement of one of these distances, precisely the same causes must create precisely similar systematic error in the measurement of the other distance. Thus if, by the regular or irregular effects of temperature or by changes in the normal condition of the observer's eye, we measure the distance α too great, so for the simultaneous observations of the distance β we shall from precisely the same causes measure that distance too great also.

But the *difference* of the distances will be entirely free from all errors of the kind; and, if the distances are not quite equal, it is very easy to apply a correction on the assumption that the sum of the distances is a constant.

In Diagram II. the circle represents a radius of 2° surrounding the star α Centauri. The distance of the component stars α_1 and α_2 Centauri in the diagram is enormously exaggerated for the sake of clearness. Guided by the principles just explained, search was made for comparison stars in pairs symmetrically situated with respect to α Centauri, and otherwise favourably situated for measurement of parallax.

You will remember that from the effects of parallax all stars appear to describe small ellipses about a mean position; stars near the pole of the ecliptic describing nearly circles, and those

[1] Lecture on Friday evening, May 23, at the Royal Institution, "On Recent Researches on the Distances of the Fixed Stars, and on some Future Problems in Sidereal Astronomy," by David Gill, LL.D., F.R.S., Her Majesty's Astronomer at the Cape of Good Hope. Continued from p. 137.

near the ecliptic very elongated ellipses. Obviously, then, those pairs of stars are most favourable—other conditions being equal—which lie near the major axis of the parallactic ellipse. The dotted ellipse in Diagram II. represents the form of the parallactic ellipse; that is to say, the form of the apparent path which α Centauri must describe if it is affected by parallax. Of course the size of the ellipse is exaggerated—in fact in the diagram nearly 5000 times—therefore remember that the diagram represents only that which we can compute before we have observed, viz. the *shape* of the ellipse, or the relations of the lengths of the two axes; the *absolute* size has to be determined from the observations.

The most favourable couple of comparison stars in our drawing is that marked α and β—they are nearest to the major axis of the parallactic ellipse, and they are very symmetrically situated with respect to α Centauri.

Now turn to Diagram III. Here is exhibited the results of my measures on a very large scale—in a manner similar to that in which the height of the barometer for different hours of the day, or the comparative price of wheat at different seasons of the year or in different years, is now exhibited in the daily papers. Imagine the star α about a mile immediately below any point of that curve, and the star β rather over three-quarters of of a mile immediately above the same point, and you would then have a diagram to scale.[1] The middle horizontal line represents the mean difference of these two distances, and each dot or

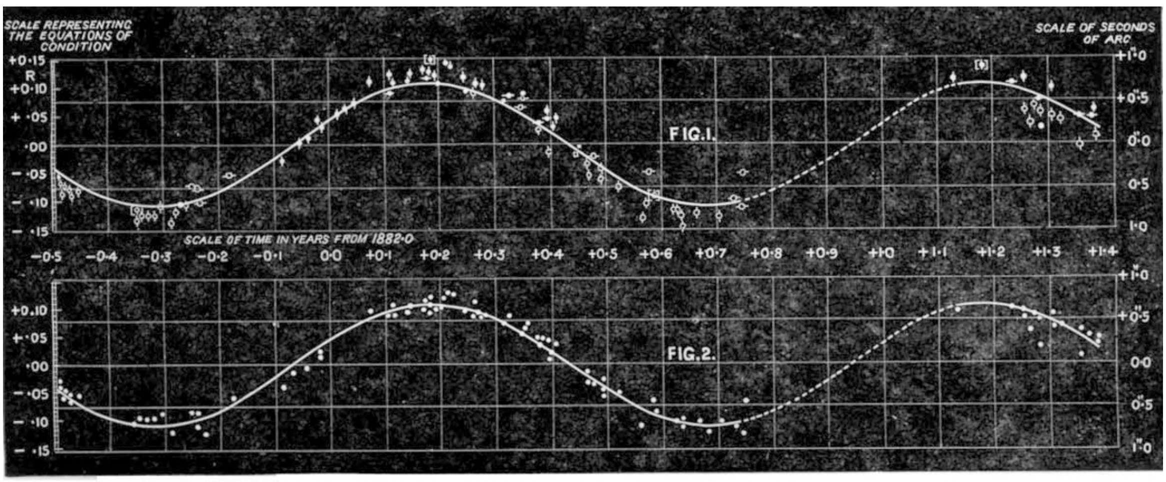

Diagram III.—Curves showing the results of the observations of α Centauri relative to the comparison stars α and β.

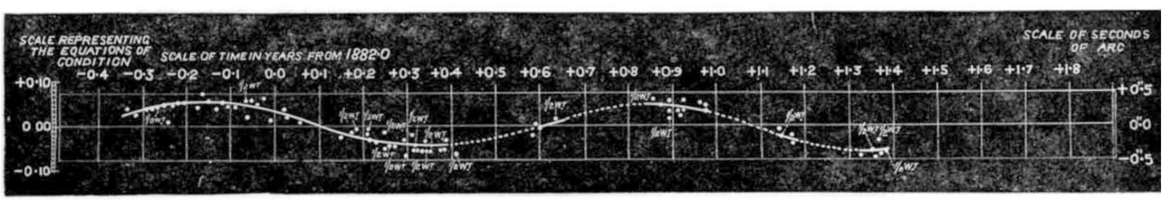

Diagram IV.—Curve showing results of observations of Sirius for parallax.

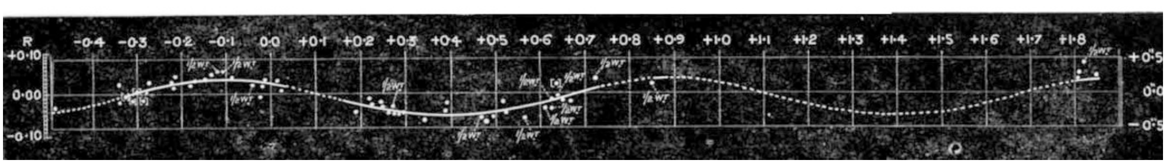

Diagram V.—Curve showing results of observations of Indi for parallax.

mark on Fig. 1 of the diagram represents the variation of that distance according to each successive observation. The different kinds of dot represent measures made at different hour angles, or when the relation of the direction of measurement to the line joining the observer's eye is different. These different kinds of personal errors were separately investigated, and they were then allowed for and the observations were corrected accordingly.

The observations so corrected are represented in Fig. 2, where each black dot expresses the result of the observations of a single night, and the curve is the computed curve resulting from a mathematical discussion of the observations.

You must be careful to understand that this is not simply the kind of curve which best represents the observations. The curve is limited by purely geometrical conditions to have its maximum on March 7 and its minimum on September 10, and to follow a precise form of curve according to a simple law. The observations only determine the range from maximum to minimum, and yet you see how perfectly the maximum of the observations agrees with the maximum of the curve, and the minimum of the observations with the minimum of the curve, and how closely the law is followed throughout.

The result was that from these observations the parallax of α Centauri was 0″·747, or practically three-quarters of a second of arc.

But I was not content with this result alone. I wished further confirmation, and selected another pair of stars, α′ and β′, shown in Diagram II.

[1] In the wall diagram one second of arc was represented by about 15 inches.

From similar observations with these comparison stars I obtained for the parallax of α Centauri 0″·760, a result which is identical with the last within the limits of the probable error of either.

My friend Dr. Elkin selected the stars *a b* and *a′ b′* as his comparison stars, and in a precisely similar way he obtained as the mean of his results a parallax of 0″·752, a result identical with my own, so that we may conclude as one of the most certainly established facts of astronomy that the parallax of α Centauri relative to an average star of the seventh or eighth magnitude is three-quarters of a second of arc.

It is therefore beyond all doubt that Henderson's discovery was a real one. Herschel's verdict must therefore be confirmed, and the palm for first breaking down the barriers that separated us from any knowledge of the distances of the fixed stars be accorded to the memory of the Cape Astronomer Henderson.

So far as all existing researches go, α Centauri is the nearest of the fixed stars. Regarding the faint comparison stars as practically infinitely distant, let us try to realise how near or how far distant α Centauri really is.

There are, of course, an infinite number of illustrations which one might employ to convey some idea of such a distance. I shall content myself with one of them—something akin to which has already been used by Dr. Ball within these walls.

We are a commercial people, we like to make our estimates in pounds sterling. We shall suppose that some wealthy directors have failed in getting Parliamentary sanction to cut a sub-Atlantic tunnel to America, and so for want of some other outlet for their energy and capital they construct a railway to α Centauri. We shall neglect for the present the engineering difficulties—a mere detail—and suppose them overcome and the railway open for traffic.

We shall go further, and suppose that the directors have found the construction of such a railway to have been peculiarly easy, and that the proprietors of interstellar space had not been exorbitant in their terms for right of way. Therefore, with a view to encourage traffic, the directors had made the fares exceedingly moderate, viz. first class at one penny per 100 miles.

Desiring to take advantage of these facilities, an American gentleman, by way of providing himself with small change for the journey, buys up the National Debt of England and of a few other countries, and, presenting himself at the booking-office, demands a first-class single to α Centauri. For this he tenders in payment the scrip of the National Debt of England, which just covers the cost of his ticket; but I should explain that at this time the National Debt, from little wars coupled with some unremunerative Government investments in landed property, had run up the National Debt from 700 millions to 1100 millions sterling. Having taken his seat, it occurs to him to ask—

At what rate do you travel?

Sixty miles an hour, sir, including stoppages, is the answer.

Then when shall we reach α Centauri?

In forty-eight million six hundred and sixty-three thousand years, sir.

Humph, rather a long journey.

But enough of joking. If we wish to deal with distances so immense, we must adopt a more convenient unit of measure.

The most convenient unit for our purpose is the number of years that light would take to reach us. Light takes almost exactly 500 seconds of time to come from the sun; this is a figure easy to remember, and is probably exact to a single unit. The sun is ninety-three millions of miles distant, and this figure I believe to be exact within 200,000 miles.

Quite recently the accuracy of these figures has been confirmed in a very remarkable way by different kinds of investigations by different observers; otherwise I should not have quoted them with so much confidence.

The parallax of α Centauri is three-quarters of a second of arc; therefore its distance is 275,000 times the distance of the earth from the sun, and therefore light, which travels to the earth from the sun in 500 seconds (*i.e.* in $8\frac{1}{3}$ minutes) would take 4·36, or a little more than $4\frac{1}{3}$ years to come from α Centauri.

You will find in the accompanying table a specific account of the other results which were arrived at by Dr. Elkin and myself by precisely similar means, and you will find on the wall diagrams representing my own detailed observations in the case of Sirius and ε Indi.

TABLE II.—*Results of Recent Researches on the Parallax of Stars in the Southern Hemisphere*

Name of Star	Observer	Star's magnitude	Annual proper motion in arc	Parallax	Star's distance in light units, or number of years in which light from star would reach the earth	Velocity of star's motion in miles per second at right angles to line of sight
			″	″		
α Centauri ...	G. & E.	1	3·67	0·75	4·36	14·4
Sirius	G. & E.	1	1·24	0·38	8·6	9·6
Lacaille 9352	G.	$7\frac{1}{2}$	6·95	0·28	11·6	73
ε Indi... ...	G. & E.	$5\frac{1}{4}$	4·68	0·22	15	63
o_2 Eridani ...	G.	$4\frac{1}{2}$	4·10	0·17	19	69
e Eridani ...	E.	$4\frac{1}{2}$	3·03	0·14	23	64
ζ Tucanæ ...	E.	—	2·05	0·06	54	101
Canopus ...	E.	1	0·00	Insensible	—	—
β Centauri ...	G.	1	—	Insensible	—	—

Time does not permit me to go into more detail as to each of these separate results, full of interest though they are, and each of them representing months of labour.

My object now is to generalise, to point out the conclusions that must be drawn from these two tables of parallax (Tables I. and II.), and to see what are the broad lessons that they teach us.

A glance is sufficient to show that neither apparent magnitude nor apparent proper motion can afford a definitive criterion of the distance of any fixed star—that different stars really differ greatly in absolute brightness and in absolute motion.

And now, what is the work before us in the future?

The great cosmical problem that we have to solve is not so much what is the parallax of this or that particular star, but we have to solve the much broader questions—

1. What are the average parallaxes of stars of the *first*, *second*, *third*, and *fourth* magnitudes, compared with those of fainter magnitude?

2. What connection does there subsist between the parallax of a star and the amount and direction of its proper motion, or can it be proved that there is no such relation or connection?

With any approximate answer to these questions we should probably be able to determine the law of absorption of starlight in space, and be provided with the data at present wanting for determining with more precision the constant of precession and the amount and direction of the solar motion in space. And who can predict what hitherto unknown cosmical laws might reveal themselves in the course of such an investigation?

It is important to consider whether such a scheme of research is one that can be realised in the immediate future, or one that can only be carried to completion by the accumulated labours of successive astronomers.

I have very carefully considered this question from a practical point of view, and I have prepared a scheme, founded on the results of my past experience. I have submitted that scheme for the opinion of the most competent judges, and in their opinion, as well as my own, the work can be done, with honest hard work for one hemisphere, within ten years. I have offered to do that work for the southern hemisphere with my own hands, and a proposal for the necessary instruments and appliances is now under the consideration of my Lords Commissioners of the Admiralty. I need hardly add that in this matter I look confidently for that complete consideration and that efficient support which I have never failed to receive at their hands since I have had the honour to serve them.

The like work will be undertaken for the northern hemisphere by my friend Dr. Elkin, who is now in charge of the heliometer at Yale College in America. It is at present the finest instrument of the kind in the world, and a photograph of it you have already seen upon the screen.

I most earnestly trust that we may be granted health and strength for this work, and that no unforeseen circumstances will prevent its complete accomplishment.

Before closing this lecture I wish briefly to allude to another engine of research in sidereal astronomy which quite recently has received an enormous development, and whose application appears to offer a rich harvest of results. I refer to the application of photography to astronomical observation.

Your respected member, Mr. De la Rue, is the father of this method. Time does not permit me to dwell on his early endeavours and his successful results, but they are well known to you all. He opened up the field, and he cleared the way for his successors.

The recent strides in the chemistry of photography and the production of dry plates of extreme sensibility have permitted the application of the method to objects that formerly could not be photographed. Here, on the screen, are the spectra of stars photographed directly from the stars by Dr. Huggins, the lines which tell of the chemical constitution and temperature of the star's atmosphere being sharply defined.

Here are photographs of the great comet of 1882, which, with the cooperation of Mr. Allis of Mowbray, I obtained at the Cape, by attaching his ordinary camera to an equatorially mounted telescope, and with its aid following the comet exactly for more than two hours. Each one of the thousands of points of light that you see is the picture of a fixed star. The photograph suggests the desirability of producing star maps by direct photography from the sky.

Here on the screen is a photograph of the great nebula of Orion, or rather a series of photographs of it made by Mr. Common of Ealing. You will note the gradual development of detail by increase of exposure, and the wonderful amount of detail at last arrived at. Here are photographs from drawings of the same, and you will note the discrepancies between them. And here is a photograph of a star cluster also by Mr. Common.

No hand of man has tampered with these pictures. They have a value on this account which gives them a distinct and separate claim to confidence above any work in which the hand of fallible man has had a part.

The standpoint of science is so different from that of art. A picture which is a mere copy of nature, in which we do not recognise somewhat of the soul of the artist, is nothing in an artistic point of view; but in a scientific point of view the more absolutely that the individuality of the artist is suppressed, and the more absolutely a rigid representation of nature is obtained, the better.

Here is a volume compiled by one of the most energetic and able of American astronomers—Prof. Holden. It contains faithful reproductions of all the available drawings that have been made by astronomers of this wonderful nebula of Orion from the year 1656 to recent times.

If now we were to suppose one hundred years to elapse, and no further observation of the nebula of Orion to be made in the interval; if in some extraordinary way all previous observations were lost, but that astronomers were offered the choice of recovering this photograph of Mr. Common's, or of losing it and preserving all the previous observations of the nebula recorded in Prof. Holden's book—how would the choice lie? I venture to say that the decision would be—Give us Mr. Common's photograph.

Is it not therefore now our duty to commence a systematic photographic record of the present aspect of the heavens? Will not coming generations expect this of us? Does not photography offer the only means by which, so far as we know, man will be able to trace out and follow some of the more slowly developing phenomena of sidereal astronomy?

Huggins has shown how the stars may be made to trace in the significant cipher of their spectra the secrets of their constitution and the story of their history. Common has shown us how the nebulæ and clusters may be separately photographed, and it is not difficult to see how that process may be applied, not only to special objects, but piece by piece to the whole sky, till we possess a photographic library of each square half-degree of the heavens. But such a work can only be accomplished by consummate instruments, and with a persistent systematic continuity which the unaided amateur is unable to procure and to employ. It is a work that must be taken up and dealt with on a national scale, on lines which Huggins and Common have so well indicated, and which has already been put in a practical form by a proposal of Norman Lockyer's at a recent meeting of the Royal Astronomical Society.

I would that I had the power to urge with due force our duty as a nation in this matter, but my powers are inadequate to the task.

I employ rather the words of Sir John Herschel, because no words of mine can equal those of him who was the prose-poet of our science, whose glowing language was always as just as it was beautiful, and whose judgment in such matters has never been excelled. They were spoken in the early days of exact sidereal astronomy, when the strongholds of space were but beginning to yield the secret of their dimensions to the untiring labour and skill of Bessel, of Struve, and of Henderson. Think what they would have been *now* when they might have told how Huggins' spectroscope had determined the kinship of the stars with our sun, how it had so far solved the mysteries of the constitution of the nebulæ, and pointed out the means of determining the absolute velocity of the celestial motions in the line of sight. Think what Herschel would have said of those photographs by Common that we have seen to-night of that nebula that Herschel himself had so laboriously studied, and whose mysterious convolutions he had in vain endeavoured adequately to portray; and think of the lessons of opportunity and of duty that he would have drawn from such discoveries, as you listen to his words spoken forty-two years ago:—

"Such results are among the fairest flowers of civilisation. They justify the vast expenditure of time and talent which have led up to them; they justify the language which men of science hold, or ought to hold, when they appeal to the Governments of their respective countries for the liberal devotion of the national means in furtherance of the great objects they propose to accomplish. They enable them not only to hold out but to redeem their promises, when they profess themselves productive labourers in a higher and richer field than that of mere material and physical advantages.

"It is then, when they become (if I may venture on such a figure without irreverence) the messengers from heaven to earth of such stupendous announcements as must strike every one who hears them with almost awful admiration, that they may claim to be listened to when they repeat in every variety of urgent instance that these are not the last of such announcements which they shall have to communicate, that there are yet behind, to search out and to declare, not only secrets of nature which shall increase the wealth or power of man, but TRUTHS which shall ennoble the age and country in which they are divulged, and, by dilating the intellect, react on the moral character of mankind. Such truths are things quite as worthy of struggles and sacrifices as many of the objects for which nations contend, and exhaust their physical and moral energies and resources. They are gems of real and durable glory in the diadems of princes, and conquests which, while they leave no tears behind them, continue for ever unalienable."

UNIVERSITY AND EDUCATIONAL INTELLIGENCE

CAMBRIDGE.—The following are among the Readers and University Lecturers just now appointed:—Readers—Comparative Philology, Dr. Peill; Botany, Dr. Vines. University Lecturers—Comparative Philology, Mr. E. S. Roberts; Sanskrit, Mr. Neil; Mathematics, for Part 3 of the Tripos, Division A, Mr. Forsyth; Division B, Mr. Hobson; Division C, Mr. Glazebrook; Division D, Mr. J. J. Thomson; Applied Mechanics, Mr. Macaulay; Botany, Mr. F. Darwin; Animal Morphology, Mr. A. Sedgwick; Advanced Physiology, Dr. Gaskell and Mr. Lea; Histology, Mr. Langley; Geology, Mr. D. Roberts; Moral Science, Mr. Keynes.

Prof. Colvin has presented to the Fitzwilliam Museum between eight and nine hundred books on Classical Archæology, on behalf of certain members of the University, to be deposited in the library of the Museum of Classical Archæology.

A warm discussion arose on the 30th ult. in the Arts School, on the Report recommending the erection of new lecture-rooms and work-rooms for Biology and Physiology. Mr. Huddleston said the estimate of 3000*l*. a year ago had grown to 10,000*l*. now. He had hoped that finality was reached last year. Mr. Oscar Browning objected to the proposals that they were reckless and extravagant. Why not ventilate the present lecture-rooms, if they were so much used as was described? The proposal to buy 150 microscopes for 1000*l*. was one of the most ridiculous he ever heard of. Why should not each student bring his own? A science man's library was exceedingly small and inexpensive. Mr. Mayo thought sufficient accommodation might be provided by using the Museum of Zoology as a lecture-room for large classes. Mr. Sedgwick described the inconveniences felt in the late course of Elementary Biology, when 206 men had to pack