The Journal
of the
Astronomical Society of South Africa.

Vol. 2. OCTOBER, 1928. No. 3.

VARIABLE STARS.

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(*Presidential Address, Session* 1927-8.)

Introduction.

Like most sciences, the study of astronomy has experienced various vicissitudes of fortune, definite stagnatures and impulses.

In prehistoric times any astronomy that then existed must have been simply a means to the ascertainment of seasons and festivals. Rude men only wanted to know when to plough and when to sow, when to sacrifice, and when to abstain from doing so; when the new moon would appear as a ribbon of light in the western sky, and when the principal stars rose and set. Astronomy in these far-off days was a handmaiden to natural religion.

Then later in this dim dawn of history men read myths in the heavens, saw figures and fancies among the stars, witnessed their glorious sun turn into blackness even at noon, and watched the silvery light of the moon change into blood in their midnight sky. And wonder and alarm held them.

But two thousand years ago, in the golden age of Greece, this wonder and alarm gave place to ordered enquiry. It was the birth-time of the true scientific spirit. The philosophers of that marvellous age of intellectual achievement sought to discover, if possible, the reasons for, or causes of, the various phenomena they witnessed. This they did not succeed in doing, but they were the pioneers of all the searchers after truth who would follow. They reared the scaffolding by which other men would build, and how majestic is the edifice that has been erected on the lines clearly laid down by the great Greek philosophers of Plato's day!

But this time of intellectual achievement gave place to more than a millennium of decline. Astronomy became shadowed over by the esoteric mysteries of astrology, and, except in strange places in still stranger lands, the thought of the world stood still for nigh fifteen hundred years.

The second quickening came in the spacious days of Galileo, Kepler, Halley and Newton, when progress was along the avenue of geometric analysis, and the exposition of the laws which govern motion and mass.

Then again this definite period gave place to that of the Herschels, when descriptive science, the topography of the heavens, the physical features of the planets, star gauging, occupied the thoughts of astronomers.

Once more this epoch moved into a day known to us older men, a day when refined and exact measurement was brought to a height of accuracy by such as Struve and Gill that has not yet been surpassed. To aid such observers the comprehensive mathematical genius of Bessel was made captive.

In the present day a galaxy of younger men, among others Jeans and Eddington in England, Shapley and Russel in America, Hertzsprung and Schwarzchild on the Continent, and Spencer Jones in South Africa, have taken the whole universe itself as their province, its dimensions, its constitution, its vast movements, and they have pushed their area of enquiry out into the very hinterland of space, out into the remote regions where majestic spiral nebulæ and great globular clusters swirl and sweep and surge in the profound silence and the unrelieved darkness of the vague recesses of space. In this great enterprise they have obtained no small assistance from discoveries dealing with variable stars.

History of Variable Star Research.

The branch of astronomy which has been most affected by this ebb and flow of interest and of importance is the study of stellar variation, that section of astronomical research which deals with the more or less regular changes in brightness of which so many stars give evidence. In a striking way this phenomenon of stellar variation heralded the dawn of exact astronomy. In the second century before Christ the attention of Hipparchus was drawn to the possibility of stellar variation by the sudden appearance of a bright star in the heavens, a *nova* we would call it now. An enquiry as to whether this particular star had ever been seen before produced only crude and valueless answers. Determined that future generations should be better able to deal with such occurrences than he was, this father of exact and systematic astronomy set about the construction of a catalogue of the brighter stars, no mean task in these days, for he was the first to see the need for such an undertaking.

Hipparchus gave in his catalogue not only the latitude and longitude of each star, using for the first time the terms with which we are now so familiar, but he classified them with magnitudes, six divisions from the brightest to the faintest that he could see at Alexandria. Later on we will consider the light value of a single magnitude as thus determined by the great Greek, but at this stage we would simply say that his standard of measurement was at once so simple and so scientific that this mode of division remains until the present day. And if we, to-day, produce maps far more detailed, far more accurate, than those produced by his survey, this must be said, that we still adhere to the fundamental principles he laid down.

But 16 centuries were to pass, barren centuries, before a single variable star was discovered. Three or four *novæ* were seen—they could not well be unnoticed—but such a phenomenon as a variable star was unthought of. For to the astronomers of even three centuries ago the stars were inviolate, immutable, golden nails in the dome of heaven which that greedy destroyer time could neither tarnish nor loosen.

In August, 1596, however, David Fabricius saw in the constellation of the Whale a bright star which by the end of the year had disappeared. He considered it one of those new stars that from time to time flamed out in the heavens, presaging the birth of kings or the advent of great men.

Seven years later Bayer recorded the star in his well-known catalogue, thus giving it a local habitation and a name. In 1638 Holwarda watched the star through a complete cycle; but it was not till 1667, seventy years after its discovery, that Boulliand detected its period.

Thus the first definite variable became known to astronomers. They called it *Myra*, the wonderful, for so it seemed to them—a star waxing and waning like the inconstant moon was indeed a wonderful phenomenon.

In 1669 Montanari rediscovered the variation of *Beta Persei*. We say rediscovered, for its ancient name, *Algol, El Ghoul*, the demon, bears testimony to the fact that Arab astronomers must have witnessed something strange and threatening in its appearance. Even to-day there is something sombre and threatening about its winking light.

The complete determination and explanation of Algol's variation was given by Goodricke in 1782, more than a century after its discovery. And yet another century intervened between Goodricke's theory of Algol's light changes and the confirmation of his brilliant conjecture by Vogel with the Potsdam spectrotelescope.

A few more variable stars were discovered before the 18th century passed to its close. Goodricke, whose name will ever be revered in this branch of astronomy, discovered two short-period stars, one being the famous *Delta Cephei,* a star which has given its name to all other variables of this now important class.

When the nineteenth century dawned nine variable stars of more or less regularity were known to astronomers, and, what is of more importance, the classes into which variable stars to-day are subdivided were not unknown to men of far vision.

(1) There were the *Novæ,* those stars which for a brief space had their day and then ceased to be, shining for a time so brightly that all men wondered, then slowly and intermittently moving on to extinction. "Stellar Guests" the Chinese called them.

(2) The long period stars, those whose period usually approached a year, stars that glowed with a ruddy light, and whose punctuality was not always to be relied upon. And surely this is not to be wondered at, for in the case of some long period stars the range of brightness is through a thousand grades, that is, the star at a maximum is a thousand times brighter than it is at a minimum.

(3) The short period stars, those orbs whose cycle of variation is completed in a few days, and whose amplitude of variation is rarely over two magnitudes. As we have already indicated, these stars are called Cepheids, after the first star of this class discovered by Goodricke.

(4) The Algol variables, that remarkable class whose light changes are due to partial or total eclipse. They are, as we know now, close binary stars revolving in a plane either in or not much removed from the line of sight. When we enter upon the 19th century we witness a new development in variable star research. Hitherto with the exception of one or two, chiefly John Goodricke, the work done was irregular and pointless. It was difficult to believe that the phenomenon of stellar variation was anything but a rare circumstance. In a volume on astronomy, written in the last decade of the 18th century, which I possess, and at times read, just to cheer my soul with a vision of the road along which we have travelled, there is a single paragraph devoted to the six variable stars then known. The writer evidently regarded them as strange and exceptional occurrences.

Even Herschel, in his well-known "Outlines of Astronomy," gave scant place to variable star research.

But the thought of the world was rapidly changing in this respect. We have already referred to the wonderful achievements of John Goodricke, whose death at 22 years of age robbed astronomy of one of its most promising votaries. He was succeeded, both in spirit and in enterprise, by the two Baxendells, Knott, Pogson and Hind. On the Continent Heis, Schmidt, Argelander and Schonfield reduced the study to a science. Argelander's *Uranometria Nova,* published in 1843, as well as his many articles on stellar variation, are to this day models of intense labour and clear thought.

And so the discovery and observation of variable stars grew steadily. By the year 1850 thirty-eight stars of this class were known to astronomers.

Almost all these, however, were in the Northern Hemisphere, for as yet no distinctly photometric survey of the southern sky had been taken. There were catalogues of position, but the magnitudes of the stars catalogued did not rest on any scientific basis.

In 1870 Gould, a pupil of Argelander, and therefore one sharing the same spirit, established an observatory at Cordova under the authority of the Argentine Government. In 1880 his *Uranometria Argentina* was published, giving the brightness of every star visible to the naked eye in the southern sky. In the course of this work fourteen variable stars were discovered, the first sheaves of a big harvest, for now in this year of grace 1928 nearly 2,000 southern variable stars are known.

Gould's work opened up a very great field. My own thoughts, since early youth, had turned to astronomy, and so in 1888, and after considerable correspondence with Gould and Pickering and consultation with Gill, my lifelong friend, I determined to erect a small observatory at Lovedale for the single purpose of observing southern variable stars and other allied phenomena. I spent two years in getting my hand into the work, becoming skilful in determining differences of magnitude, acquainting myself with the labours of other observers. I also, after repeated preliminary trials, adopted a method of observing and recording from which I never departed.

These two years of preparation were well-spent years, and I would urge the same course upon all young people who wish to take up a definite line in astronomy. Chart your path clearly before you begin!

In 1890 I entered upon the work that I carried on, unbrokenly, for thirty years—thirty happy years.

Meantime the Harvard Observatory had established at Arequipa in 1892 an astronomical station for a photographic survey of the southern sky. In 1893 the Cape Observatory had, under Gill, embarked upon a similar Durchmusterung. This photographic method soon resulted in the discovery of hundreds of variable stars, and the list of such objects for both hemispheres rapidly rose to over a thousand. Not only did the examination of photographs yield variable stars and *novæ,* but the close connection between spectra and light changes led to the discovery of many variables from an examination of stellar spectra.

The science was enriched by the labours of Innes round about the nineties of last century. His observations and results are recorded in Vol. IX of the Cape Annals.

The 20th century saw the foundation of a number of associations for the study of variable stars. In our own southern land this Society, over which I have the honour to be President, has put variable star work in the forefront of its endeavours, and as an Association we may point with no mean gratification to the achievements of Watson, Long, Cousins, Houghton, Skjellerup, Smith, Ensor, and others who in this wonderful sun-drenched, starlit land of ours have found success and happiness in their scientific pursuits.

The last fifteen years has witnessed a very great expansion in the area of variable star research. It has become linked up to stellar chemistry and stellar thermodynamics. It has extended its borders until it has become a powerful agent in the determination of stellar distances, thus giving substantial support and confirmation to other modes and results of stellar surveying.

And thus the science which a hundred years ago did not seem to lead anywhere, except in the inspired visions of a few devoted men who did not live to see the rearing of the building whose foundations they laid, is now intimately bound up with the size, constitution and evolution of the stellar universe.

It is fitting now, having too briefly and too imperfectly traced the history of variable star research, to enquire into the interpretation of the results achieved by the various observers. I shall only deal with such interpretations as I think are beyond dispute. Naturally there must be a vast amount of theory which is as yet unproven and often unwarrantable. This we may leave to another age to accept or reject. We all know these children of ours who never come to maturity. How often do we hastily turn over the leaves of some magazine lest we see their dead faces on the printed page.

Interpretation of Results.

I think it will be more helpful if we consider the results obtained and the interpretation of them in connection with the four classes of variable stars. For although all stars that vary in brightness are variable stars, the causes of this variation are fundamentally different. An Algol variable has nothing in common with a Cepheid variable except its variation. The variation of the one is due to eclipse, the variation of the other is due to pulsation. Then again the conditions which produce a nova are not those which produce either an Algol star or a Cepheid variable, so it is necessary to consider each class separately. Of the four well-known classes of variable stars, that which is surrounded with least doubt is the Algol class, the class whose variation is due to the eclipse of one star by another.

More than a century ago John Goodricke gave this explanation of the variation of Algol, the one eclipse variable then known. The explanation is contained in the *Philosophical Transactions* under the date 27 June, 1785, and anyone who reads the calm, sure, prophetic words of this young man, only barely 22, must rise from his task with profound admiration for this sorely afflicted genius. He was a deaf-mute.

But it seemed such a strange thing to astronomers of Goodricke's day, and even to many after his time, that stars should revolve round one another almost in contact. To ordinary men the conditions seemed impossible. But Argelander accepted and elaborated the theory, giving the relative size and brightness of the twin stars, their orbit, and the inclination of that orbit to the line of sight.

This relative relation was changed into actual distances when Vogel, with the Potsdam spectrographs, certified to the accuracy of Goodricke's explanation.

Since then there has been no doubt regarding the cause of Algol variation.

Substantial contribution to the theory of Algol variation was made some fifteen years ago at Lovedale when, from a consideration of the elements of southern variable stars, I was able to prove that the density of this class of star is from one-tenth to one-hundredth that of water; that is, the great majority of Algol variables are gaseous.

The form which two stars would take revolving in near or actual contact had already been the subject of profound study by Poincaré in France and Darwin in England. The address of the latter to the British Association at their South African meeting on this very matter will be in the memory of some of the audience.

Meantime a very careful study of the close binary stars RR Centauri, X Carinæ and V Puppis had been entered upon at Lovedale. A special form of telescope with rotating prism in front of the object glass was constructed for the two former stars, and a system of revolving mirrors for the last star. I was able definitely, after many years of work, to prove that at least RR Centauri and V Puppis very closely approximated to the form Poincaré and Darwin said theory demanded. I may say here that some of my deductions made at Lovedale rested on estimates of brightness less than five-hundredths of a magnitude, but as my margin of error with the specially constructed instruments was two-hundredths of a magnitude, I felt confidence in my conclusions. Two-hundredths of a magnitude may have little meaning to some. One might say two-thousandths of a magnitude and not create wonder. But two-hundredths of a magnitude means the difference in brightness between the light of a candle at 100 yards and of the same candle at 101 yards.

Yet even this refinement of measurement has been surpassed. Stebbins, Director of the Illinois Observatory, used in his classic investigation of the light curve of Algol a selenium cell the responsiveness of which was six-thousandths of a magnitude. Because of this extraordinary accuracy he was able to detect a secondary minimum in the light curve of Algol, thus proving that the companion of Algol is not wholly dark. But whether another observer with the same apparatus would reach the height of accuracy attained by Stebbins is to be doubted. I have in my own experience two instances of the intimate connection between the instrument and the observer. I was anxious to establish a relation between my magnitudes and those adopted in England and in America as the result of surveys by the Harvard photometer in the one country and the Oxford wedge photometer in the other. The Directors of these two great observatories sent me their photometers. Astronomers are ever the most generous of men, both with regard to their observations and their instruments.

But I could make nothing of either instrument; somehow I felt that they rebelled against being used by me. I was not their creator, and there was a feeling of antagonism between us. Pritchard they knew, and Pickering they knew, but Roberts they did not know.

And so when a young observer comes to me and says, "What instrument shall I use?" I say, "Use the one you like best," for the astronomer and his instruments must be one in spirit, in design, and in friendship.

It was said of Gill that he could make his famous heliometer do everything but speak; at any rate, he could measure the diameter of a sixpence at the distance of a mile. I shall not repeat the story. But other observers have found the heliometer anything but a satisfactory instrument. So my urgent advice to all observers is to adopt their own system of observing, construct their own instruments, and stick to them.

But I am away from my present subject, which is the meaning of the results obtained in variable star work.

Long period variation is still a mystery. We know that the variation is not due to eclipse. We know that the stars slightly change in colour as the variation progresses: a similar change takes place also in the spectrum of the star.

One is inclined to regard the changes in brightness as due to surface change of some sort, probably closely allied to the sun-spot variation on the sun's surface. The red colour of all these stars, the fact that their period of variation is in the neighbourhood of one year, and the yet more important fact that their period is subject both to secular and circular change, are facts that must help towards a solution of the problem of long period variation.

I have during the past thirty years kept nearly a hundred long period stars under almost constant observation, and now that time is mine in which to reduce and compare these observations, I find that in the case of over seventy of these stars there is the clearest evidence of a period-variation usually from twenty to thirty times the length of the mean period. Whether this cyclical variation in period is connected with long period line of sight variation detected at various observatories, and especially at the Cape Observatory, I cannot say. It is so easy to come to conclusions. What we will require to do is to determine more and yet more the cyclical variation in period of those stars.

Whatever explanation is urged in explanation of this class of variable must meet the apparent great difficulty of the amplitude of variation that these stars undergo. Consider the well-known southern star R Carinæ, discovered by Gould in 1872, and of which we have regular observations down to the present day. At times this star reaches the fourth magnitude, and falls to about the twelfth. That is R Carinæ at its maximum brightness is twelve hundred times brighter than it is at a minimum. Now since eclipse is excluded, and we have no evidence as yet of vast pulsations, we must conclude that the change is in the star itself, perhaps periodic conflagrations of a stupendous nature. Spectroscopic observations favour this conclusion.

This class of variable is by far the most numerous. From the day when the first of its class was discovered to the present time four long period stars are detected for one of the other classes.

To-day nearly five thousand variable stars are known—enough to occupy a whole army of observers—and of these at least four thousand are long period stars. Gould held that nearly every star in the sky varied slightly; anyone who has had extensive experience in observing will agree with this opinion. It is possible, therefore, that long period stars are only the more outstanding exhibitions of a variation to which the whole universe is subject. It is in the region which includes short period variation, with its numerous subdivisions, that the greatest adventure has taken place during recent years.

The form of the light curve of these stars bears some very outstanding characteristics. The ascent to maximum is very rapid, amounting, as in the case of U Carinæ, to one-sixth of the whole period. This ascent also is very regular, while frequently the descent to minimum is in the form of a sinuous line.

That variation of this type might in some way be connected with binary movement was early suggested. Actual eclipse was out of the question, but it was possible that a binary system with a very eccentric orbit might experience tides due to the approach of the members of the system. Also the rotation of a star with unequally bright hemispheres was proposed. But there was always and ever in the minds of astronomers the fact that these theories were gravely lacking. Some twenty years ago spectroscopic investigation indicated motion backwards and forwards in the line of sight. And again the binary theory was raised from its sick bed, only to meet certain death when the spectroscopic results were fully examined. For a comparison of the light curve and the orbital curve proved that the minimum of brightness occurs in all stars, when such comparison was possible, when the star is receding most rapidly. Further, the slowness of the orbital movement of the fainter star showed that it moved inside the circumference of the larger companion. These two objections were sufficient to set aside the idea of orbital movement as explanatory of short period variation.

Jeans suggested that the variation of this class of star might be due to pulsation, that every short period variable was a gigantic gaseous mass expanding and contracting in rhythmic mode synchronous with the period of the star. Shapley and Russel in America, Eddington in England, pursued this line of thought, bringing to bear upon it all the forces of argument that thermodynamics and the laws of energy and motion could supply.

There are still difficulties to be overcome. For example, it is found that the maximum of brightness occurs when the star is contracting most rapidly. But this and similar difficulties are outbalanced by the fact that the spectrum of the star varies from Fo at maximum to G2 at minimum, by the additional fact that the velocity of approach and recession is too small to admit of orbital movement—Delta Cephei, for instance, is 80 million miles in diameter, but the maximum movement indicated by the spectroscope is only 2½ million miles.

The pulsation theory accordingly holds the field. The throbbing star gives rise to periodic heating and cooling; that is, the alternate compression and expansion changes the rate of radiation, and thus the light of the star ebbs and flows.

A still further relation was urged by Shapley, viz., that the period of any short period variable is inversely proportional to the square root of its density. The longer the period the less the density of the star, and thus we have a distinct relationship operating right through space. If, therefore, we know the period of a star we may safely assume its density, and, knowing the distance, its brightness. We shall indicate later on the great importance of this law as a means of determining stellar distances.

But a striking proof of the reality of this law $\left(P = \frac{\kappa}{\sqrt{d}}\right)$ has a personal and an unpleasant character. There is a star in the southern sky, just visible to the naked eye, called R Muscæ. Both Gould and myself considered its period to be nine hours; the upholders of the relationship between density and period deemed this period to be too small, since the star was so bright. Hertzsprung, from his own observations and others supplied to him, proved that the period of R Muscæ was not nine hours but nine days, thus bringing its variation into conformity with the law of brightness.

An important sub-group of Cepheid variable are those that vary in a few hours. One star pulsates in a little over three hours: the majority vary around ten hours. The best example of this sub-class is the southern variable S Aræ. S Aræ completes its light changes in less than 11 hours. Its rise to maximum is very rapid, occupying about 40 minutes only; indeed, so rapid is it at certain stages of its ascent that the star is seen to increase in brightness during the two or three minutes that the observer takes to make his observation. S Aræ is the typical star of the group called cluster variables, because they are mostly found in globular clusters. In the cluster Messier 3 there are at least 200 such rapid variables; in Omega Centauri there are about 100, and since 70 globular clusters are known, we may, without undue arithmetical strain, approximate to the possible number of this curious class of variable.

Shapley of Harvard has made an intensive study of these stars, and he finds that they are suitable standards for determining stellar distances.

Globular clusters are so far distant from us that we may regard all the stars in any one cluster as equally distant from us. But the law of such stars is that their intrinsic brightness is a measure of their period. All stars of the same period will be of the same brightness.

Now if the stars of a definite period in one cluster are fainter than the stars of the same period in another cluster, this means that the former is further away, and the difference in brightness is a measure of the distance. To put the matter more concretely: The mean magnitude of 110 Cepheid stars in the cluster Messier 3 is 15.5, while the mean magnitude of 76 stars in Omega Centauri is 13.6; the mean magnitude of Cepheid stars in our stellar system is 10.0. Now if we regard these stars as of the same brightness as our sun, this would give for our stars a mean distance of 900 light years, for Omega Centauri 6,000 light years, for Messier 3 15,000 light years. The most remote cluster as yet that has been measured in this way is 200,000 light years away from us.

Beyond these lie the spiral nebulæ, separated from us by an abyss of at least one million light years. Such distances are utterly beyond our comprehension. I leave it to psychologists to consider how it is that we can with assurance deal with such distances, understanding quite clearly the mode and method of our approach, and yet when we arrive at a solution we have not even the most shadowy conception of what our result means. But, apart from this burst of pessimism, I think it is matter of great gladness to workers in the region of stellar variation that the portion of astronomy which fifty years ago ranked low in the science should to-day be the most powerful engine in arriving at a conception of the dimensions of the universe.

Relation to Cosmic Investigation.

We have not dwelt upon the important relation that Cepheids of the same period have the same brightness in that particular cluster, or at a definite distance, so that a Cepheid variable with a definite period will have a definite absolute brightness; it will be a standard, as we have seen, with which to measure distance.

But the relationship between density and period goes further than this. The theory indicates that if the period of a Cepheid variable changes, then the density must change also. If the period slowly lengthens, as the periods of some stars do, then the destiny must grow less, and since the mass remains the same, then the star must expand in bulk; if, on the other hand, the period shortens, then the star is contracting, and a very simple calculation will reveal the amount of contraction.

We are thus face to face with one of the most important issues in astronomy, the evolution of the stars. Whence came they and whither? So grave and great a question we cannot answer, but we can say this with certainty, that if the period of a Cepheid variable is diminishing slowly year by year, century by century, then its density is increasing. Its bulk is growing less; the pulsations, while more frequent, are growing feebler, till at last period and pulsation ceases and the star is a rigid solid body, palpitating with fierce heat no more. This has no doubt been the history of many a decadent sun whose heart is so cold and dead that it beats no more.

Many stars, Cepheid stars, give evidence of this secular decrease. I had many on my list in Lovedale. In some instances the decrease was slight, two or three seconds in a century, but the decrease was there unmistakably.

But there are as many increasing periods as decreasing, for Nature is not moving to its doom. There is a spring as well as a winter in its year, and a constant process of regeneration and restoration moves on. Giant stars become dwarf stars, and dwarf stars giant stars in an eternal round.

If there is anything which modern astronomy teaches more than another it is the eternity and infinity of matter, and the unceasing modes of its multitudinous manifestations.

Probable Future of Variable Star Research.

The future of variable star research must be pre-eminently statistical. The thousands of stars must be carefully catalogued, their periods accurately known, their cyclical and secular variations determined. All this must be allied to spectrographic analysis. The position in space of each must be defined. Where there are streams of variables these must be located, and their chief characteristics set forth. In this there is room for, as I have said, an army of observers.

Forty years ago, when I began variable star work, the issue was uncertain, the future line of march very uncertain. We had simply to go on.

Now the way is blazed and the aims very clearly defined. In this land, where our winters are so clear and our summers are so serene, there is an opportunity for progress that no other land can offer. It is for our young observers to take up the task and —go on.

I thank you again for the honour you have done me in making me your President. I am quite sure it is rather an honour to the section of astronomy that I represent, and concerning which I feel glad that I have been able in a small way and imperfect to further its progress and to enlarge its domain.

LUNAR CRATERS AND THE VOLCANIC THEORY.

By H. C. Mason.

It is something of a paradox that although the moon's physical features have been so long studied, and so carefully mapped, there is no accepted theory of their origin; for although her surface is diversified like the earth's with mountains, plains and valleys, the resemblance seems to end there. Excepting a few volcanoes, confined to particular regions, the earth has nothing to compare with the extraordinary abundance of ring-shaped, crater-like formations which dominate the lunar landscape, presenting every gradation in size from the limits of visibility to mountain-encircled plains a couple of hundred kilometres in diameter. When seen in a small telescope, these formations at once suggest a volcanic origin, and the volcanic explanation was naturally the first in the field. But later and more painstaking observers found great difficulty in sustaining this theory, at any rate as regards the larger formations. For a saucer differs scarcely more in size and shape from a thimble than does a typical lunar crater-formation, such as Clavius or Ptolemæus, from a typical volcano like Etna or Vesuvius. While the more cautious have refused to theorize on the subject at all, others have had recourse to surmises, such as the impact of enormous meteorites, or the glaciation hypothesis of Peal and Philip Fauth. Even the staunchest defenders of the eruptive explanation have tended to deprecate any close comparison with terrestrial volcanism, and to postulate some remote period of far more intense and widespread igneous activity than anything recorded in the history of the earth.

It may seem presumptuous for one who can put forward no claim to original research to attempt a contribution to so controversial a subject. But the case of the moon appears to the writer to illustrate the disadvantages of specialization. The true explanation of these remarkable features of our satellite doubtless involves more sciences than one, and the lunar observer can seldom claim to be a specialist in all. The mathematical astronomers have turned their attention elsewhere.

At the risk of being thought old-fashioned, if not ignorant, I propose to show that some of the principal objections raised against the volcanic explanation of these strange formations are invalid in the light of recent physical and geological theory, that others do not fully take into account the far-reaching consequences of the difference between lunar and terrestrial gravity, and that, apart from these inevitable consequences, no material difference in structure, composition, or the forces at work beneath the crust need be assumed in order to account for the contrast between the moon and the earth in respect to these features.

One effect of the low value of gravity upon the moon is undisputed—the absence of an appreciable atmosphere or visible expanses of surface water. Hence one of the two principal agents which have combined to mould the earth's surface, erosion, is removed, and has probably been absent during the greater part of the moon's existence. Although terrestrial mountains have been raised by compressive and uplifting forces, the forms they now wear are principally the effect of erosion; we cannot, therefore, expect the lunar mountains to resemble them closely in appearance, any more than the blocks from the quarry can be expected to rival the work of the sculptor. The poet could not have sung of the mountains of the moon:—

> "The hills are shadows and they flow
> From form to form, and nothing stands:
> They melt like mist, the solid lands,
> Like clouds they shape themselves and go."

On the contrary, nothing but fresh outbreaks from below could be expected to obliterate the lunar features, whereas terrestrial volcanoes are (geologically speaking) an ephemeral phenomenon: in the next geological period their lofty cones will be worn down again to the barest stumps, or levelled with the plain. If the earth's atmosphere and oceans had never existed, and all the products of eruptive activity throughout its past history were still visible except such as had been buried by later eruptions, its superficial appearance would undoubtedly present a striking resemblance to that of the moon, except in the size (and in some respects, shape) of these eruptive formations. All men would be pock-marked if every boil and pimple left its scar.

Before proceeding further it is desirable to refer to the change in the geological outlook brought about by the discovery of radio-activity in the rocks. A source of supply of the earth's internal heat has been discovered which is continually renewed, and there is no reason to doubt its existence in the lunar rocks also. The assumption that lunar volcanism must necessarily be extinct has little support in present-day theory.

The notion that the presence of surface water is essential to volcanic activity is so doubtful and disputed that it cannot weigh in the balance against any positive evidence of such activity upon the moon. Meteorites contain explosive gases, and molten rock or lava is charged with a mixture of gases and vapours, which render it ebullient like champagne or soda-water as soon as the superincumbent pressure is removed. It is possible, however, that periodically active volcanoes owe their irritability to the intrusion of water percolating from the surface, whereas lunar volcanism might be expected to be of the dormant and occasional type, more violent, but less frequent. Craters of explosion would thus be typical upon the moon, rather than lofty cones built up from the accumulated outpourings of long-continued activity. If the absence of the grander eruptive phenomena at the present time is due to something more than a mere phase of quiescence, it may be explained by the exhaustion in the lunar rocks of the elastic vapours to which the past eruptions were due.

Omitting those points of contrast which may reasonably be attributed to the absence of erosion on the moon, there are two outstanding differences between the grand lunar craters and terrestrial volcanoes which demand an explanation: the immense width of the gigantic walled plains of the moon in proportion to the height of the encompassing wall, and the enormous volume of material nevertheless contained in that wall—features that seem to place these wonderful formations beyond the possibility of comparison with ordinary volcanoes. A ring-wall, for instance, with a diameter of 250 kilometres, a mean height above the internal plain of about four kilometres, and a slope of 22°, might contain, say, forty thousand cubic kilometres of rocky material, whereas a terrestrial volcano containing one thousand cubic kilometres of material would rank among the giants.

But the great width of the lunar craters in proportion to their height is adequately explained (supposing them to have been formed out of erupted volcanic material) by the low value of lunar gravity and the absence of air-resistance to the motion of projectiles. Moreover, the immense volume of such ejected material contained in the encompassing wall can also be explained by the low value of gravity, and the greater depth from which it is possible, in consequence, for the eruptive forces to find a vent. The comparatively level region between the centre and the outer wall records the clearance effected by the first lateral explosion of the escaped gases, which, compared with similar forces on the earth's surface, would meet from solid obstacles with only one-sixth of the resistance to a pushing or rolling movement*—for, owing to the low value of lunar gravity, the mountains of the moon weigh as mere walls of straw, or, to do them justice, of rather light wood. The circular plain thus formed would provide an ample basin for the outflow of erupted lava, and the central mountain, or boss, is accounted for by the falling back upon the vent of the central portions of the ejected core.

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*On the theory here suggested the overturning moment of this explosion-wind would be again augmented in proportion to the height above the moon's surface through which its force was exerted.

These aspects of the lunar problem I propose to enlarge upon further, as they lie at the root of the whole question, although other characteristic features of lunar topography need to be explained before the volcanic theory can be called complete.

It has often been pointed out that owing to the diminished power of lunar gravity, ejected materials would travel six times as far on the moon before falling to the ground compared with similar materials ejected with like force from a terrestrial volcano. Hence a lunar crater-cone formed of such materials might be expected to have a correspondingly larger diameter, even though the orifice of ejection, or vent, was of the same size. As regards the lighter fragments, ashes and dust, this difference in the range of ejection would be enormously increased by the absence on the moon of atmospheric resistance to the motion of a projectile, for the earth's atmosphere imposes a limit to the size of a fragment which can be projected to any great distance, whereas on the moon the lighter the missile the further it would travel when expelled by a gaseous explosion. But these considerations taken alone have been thought insufficient to account in full for the extraordinary difference in magnitude between the largest terrestrial volcanoes and the great lunar craters; for whereas the diameter of terrestrial volcanic craters rarely exceeds five or six kilometres, the corresponding maximum on the moon is two to three hundred kilometres. The above considerations would readily be allowed to explain a ratio of eight or ten times, but scarcely a ratio of forty or fifty times, as between the two maxima. Will the fact that the force of gravity on the moon's surface is only one-sixth of terrestrial gravity suffice to explain so great a difference as this?

The answer is, "Yes, if the gravity ratio can be shown to act in more than one way, so that the different effects reinforce one another, and the ratio between the respective crater-diameters, and likewise between the volumes of ejected material, depends on a higher power of the gravity ratio, as, for instance, the square."

It is strange that so ordinary a possibility appears to have escaped the notice of selenologists, who seem to have hitherto accepted the linear ratio of six times between the respective forces of gravity on the two planets as ending the matter, without attempting any mathematical investigation of the various ways in which that ratio would affect the problem in hand. Yet the well-known formula for obtaining the range of a projectile in the void shows that, even if there were no air-resistance in the case of the earth, a lunar cannon discharged with the same angle of elevation, and but two and a half times the muzzle velocity, would carry thirty-seven times as far as a similar weapon fired on the earth's surface.

I do not know whether actual experiments have ever been made on the results of explosions in the void, for comparison with those of explosions resisted by an atmosphere. But the theory of ballistics shows that some of those results would be curious, not to say startling. For instance, the wad of a blank cartridge would be as dangerous as a bullet.

Imagine the thickness of such a wad to be one-tenth of the length of the bullet, and its density one-twentieth of that of the bullet. Its mass, therefore, would be a two-hundredth of the bullet's mass. But we are informed in text-books that the muzzle-velocity of a bullet (other factors remaining the same) is inversely proportional to the square root of its mass. In the case supposed, therefore, our imaginary wad leaves the muzzle with more than fourteen times the velocity of the bullet.* To such velocities on the part of light bodies our atmosphere opposes an impenetrable resistance, and the terrible missile is brought to a stop in a few yards.

Now the muzzle velocity imparted to the bullet by modern service rifles usually exceeds 800 metres per second. This velocity multiplied by 14 is equal to 11,200 metres per second. In the absence of air a projectile launched vertically upwards from the surface of the earth at a velocity of 11,180 metres per second would never return. About one-fifth of that velocity would suffice for the same result in the case of the moon.

It will be seen, therefore, that known and familiar forces may sufficiently account for the spraying of fine or vaporous material, ejected into the void from a lunar vent, over an immense radius from the orifice of eruption. An impression as of frozen streaks of spray is what first leaps to the eye on viewing the white rays of Tycho through a small telescope; and I believe this to be a case in which first impressions are best.

The bulk of the solid material ejected from the vent would settle at a less distance, depending on the size of the fragments, but it would nevertheless be dispersed over a far wider radius than in the case of the earth. For on an airless planet, neither a low density nor a jagged and irregular shape would be any drawback to the propulsion of an ejected fragment; indeed, the light, flat, wad-like piece would present the broadest surface to the propelling force in proportion to its own mass, and so receive the most powerful initial impulse.

Notwithstanding the resistance of the atmosphere and the greater force of terrestrial gravity, modern artillery can fire up to ranges exceeding fifty kilometres. Without bringing terrestrial air-resistance into the comparison, this range would be equivalent to three hundred kilometres on the moon; in other words, a modern army entrenched on the crater-wall of one of the largest ringed plains on the moon could easily bombard its enemies on the opposite side. But what is the power of modern artillery compared with the forces released in the eruption of Krakatoa in 1883, the sound of which was heard 3,000 miles away?

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* This illustration is not intended as a contribution to ballistics, the formula referred to being obviously of limited application.

In the further development of this argument it will be assumed that the maximum intensity of volcanic eruptive force, presumed to be due to superheated vapours at equivalent pressures and temperatures, is the same on planet and satellite. Now, it is a matter of common observation that elastic vapours, in forcing a way of escape when under pressure, do not form a larger orifice than is necessary to relieve that pressure. The bubbles on a plate of hot porridge, a cooling surface of furnace slag, the fumaroles thrown up by a layer of outpoured and cooling lava, the parasitic cones on the flanks of a volcano, form a series of miniature volcanoes with increasing diameters of orifice which depend on the forces at work and the resistances to be overcome. If the resistances are too great, there will be no eruption; if an opening is forced by the imprisoned vapours, it will, in accordance with the principle of least work accepted by nature and man alike, be no wider than circumstances require. It is these circumstances that set a limit to the maximum size of terrestrial volcanic vents, and another limit to the maximum size of lunar volcanic vents, owing to the difference in the force of gravity on the two planets.

The resistance which a solid body offers to a force tending to punch or tear a hole through it is called its resistance to shear, and is due to the cohesion and friction between its parts. Both sources of resistance are proportional to the area of the surfaces which are tending to slide past one another, and the force of friction is also proportional to the pressures normal to those surfaces. Now the actual horizontal pressures which prevail at different levels beneath the earth's crust are unknown, but they are presumed to be a function of the weight of the overlying strata. It is not necessary to the present argument to know this function, provided it can be assumed that the crust of the moon is composed of similar materials to that of the earth, and that at whatever depth in either body the vertical pressures are the same, there the horizontal pressure, co-efficient of friction, and forces of cohesion are the same also. If this is hypothesis, it is at any rate the least hypothetical assumption that can be made. It will be assumed further that the depths we are concerned with are small compared with the moon's radius, and still smaller compared with that of the earth. As a matter of convenience, both bodies will sometimes be referred to as planets.

Then if the force of terrestrial gravity be taken as six times that of lunar gravity, a sectional sketch,* representing diagrammatically the shearing resistances at different levels beneath the earth's surface, will be similar to one drawn for the moon, if the terrestrial depths are represented as one-sixth compared with corresponding lunar depths. Alternatively, the lunar diagram will serve equally well for the earth, allowance being made for the difference in vertical scale. The diagrams will show, therefore,

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* See Fig. 1. The author's thanks are due to Mr. R. Stoddart and Mr. F. H. Caine for assistance in the preparation of the drawings.

that over any vertical section the total resistance to shear above levels of equal vertical pressure on the moon should be six times as great as upon the earth. Hence the total resistance to an upward thrust, arising in strata of equal pressure, and acting over the same base, will be six times as great in the lunar case. If, therefore, the layer or stratum which is tending to lift be one below which the weight of the superincumbent strata is more than counterbalanced by an expansive force due to the efforts of compressed vapours to make their escape, these vapours will meet with a sixfold greater opposition in the lunar case. Let two localities selected for comparison be regions showing a weakness in the crust of either planet which is relatively uniform over a certain area, and let the vapours break through in the case of the earth, forming a vent of the maximum size for that planet. Then if the similar area of weakness on the moon be sufficiently large, a similar vent will be formed on the moon also, but of six times the depth and six times the diameter compared with the terrestrial case, this being the maximum size of volcanic vent for the moon. At greater depths than these the imprisoned vapours, by hypothesis, cannot escape, though earthquakes may arise from their efforts to break through.

The lifting force in the supposed lunar maximum case acts over a base of thirty-six times the area, and the pressure is proportionately greater. On the other hand, the resistances to shear are increased only sixfold by this extension of the area of the base, being proportional to the area of the encompassing wall of the cylinder of material which rests upon the base. Hence the lifting force and the resistance to that force are both thirty-six times greater than in the parallel terrestrial case, and therefore bear the same proportion to one another. If, therefore, an explosion takes place in the case of the earth, forming a vent of the largest diameter possible upon that planet, a similar explosion may be expected in the parallel case on the moon; but the orifice will be six times as deep and six times as wide, and the volume of ejected material will be 216 times as great. Nevertheless the intensities of the forces at work are equal in both cases, and the lunar forces, like the terrestrial, have performed the least amount of work necessary to effect their escape See Fig. 2.*

As soon as movement begins the pressure will be relieved, and the orifice already formed will suffice for the escape of the whole of the imprisoned vapour. In the further development of the argument, it will be assumed that even in the case of the much larger lunar orifice the store of imprisoned vapour will be large enough to maintain a relatively undiminished flow of gas for some little time—enough to allow of the scattering of the

* The argument ignores the possibility of a rupture due to the upward bending of the crust; but analogous reasoning leads in that case to a like conclusion, the forces and resistances being multiplied for the moon by 6^3 instead of 6^2.

ejected materials without an appreciably greater loss of pressure than takes place in the course of a maximum eruption on the earth.

With superincumbent strata of greater thickness than the presumed limit for either planet, no eruption will take place, because the forces of expansion are less than the combined forces of weight and resistance to shear. At higher levels, on the other hand, a smaller expansive force will produce eruption, the diameter of the core blown out being also proportionately smaller. Thus craters of all intermediate sizes below the respective maximum limits (including those extinct volcanoes of the earth of which only traces remain) will be found on either planet, those approaching the maximum limit being naturally fewest in number.

The pipe or tube blown out by a lunar maximum eruption will be like the barrel of a field gun as compared with that of a fowling-piece for the terrestrial eruption, and out of this bore of six times the length and calibre the ejected materials will be fired; the effects might be expected to resemble the discharge of grape or canister, compared with a charge of small shot, both weapons using the same powder. Again comparing the two imaginary cylinders of rocky material at the commencement of the eruption, the weight resting on unit area of the base is the same, but the volume and mass to be set in motion is six times greater (per unit area of base) in the case of the moon: hence the rate of acceleration given to the superincumbent mass is only one-sixth in the lunar case. But the lifting pressure acts through six times the distance, and as by hypothesis the pressures remain equal (or vary *pari passu*) in the two cases,* it follows from the laws of dynamics that the velocity of ejection of the materials is likewise the same. The analogy of gunnery may again serve as an illustration, pieces of ordnance of the most varied calibres often producing very nearly the same velocity at the muzzle of the gun. When the surface is reached the shearing resistances disappear and the lifting force reaches its maximum, to diminish rapidly again with the expansion of the gases. If it is assumed that the work done against gravity by the gases above the surface, in further accelerating the vertical velocity, maintains the same equivalence per unit of mass, it will follow by dynamical law (ignoring air resistance in the case of the earth) that the ejected materials will rise on the average to six times the height compared with the terrestrial eruption, but will take six times as long in doing so.

Before the main body of rising gas escapes from the orifice, it must have extruded the solid core of that orifice in the form of a swiftly rising mountain of immense altitude, the sides of which, by their weight, would doubtless tend to break inwards the

* While the pressure would tend to fall more rapidly in the large orifice, much less energy would be expended in fluid friction and collisions between the ejected masses and the walls of the orifice.

edges of the vent, and so widen the orifice and increase the quantity of ejected material. Being still resisted in a vertical direction by the central mass of extruded material, the released gases will at first explode sideways with great violence, driving everything before them and forming the first cast, as it were, of a crater of explosion. It has already been pointed out that owing to the lightness of solid objects resting on the moon's surface, and their greatly reduced power of resisting a shove or overturn, this lateral expansion of gas will be correspondingly effective in sweeping the surrounding country like a gigantic besom. (See Figs. 3 and 4.)

A natural operation of this kind would usually take place in a succession of pulsations or explosions, the marks of which are apparently visible in the concentric vertical stratification of many of the lunar craters. But for the purposes of argument it will be simpler to imagine the course of events as one continuous eruption. Before the lateral expansion of the outpoured gas has spent its force, fresh reinforcements from below have continued to lift the central core of fragmentary or pulverized materials in a huge column or cloud, rising like an inverted cone, from which ejected fragments of all sizes are shot umbrella-wise in all directions at various velocities.

If the average vertical and horizontal velocities of the ejected fragments could be assumed to be equal for the two contrasted cases, their average range before falling to the ground would be six times as great on the moon as on the earth. But at the height of the explosion, which in the lunar case has at least six times as long an interval for projecting the materials, a correspondingly greater volume of gas is poured out, with relatively increasing velocity, through a thirty-six times greater orifice. However long the stream of gas may continue to flow, no further work can be done by the terrestrial volcano upon materials which have already fallen upon the crater-cone, whereas on the moon the work of increasing the horizontal velocity of the ejected fragments continues throughout an interval which is at least six times as long, and which is further lengthened in proportion to any increase in the vertical velocity.

In the concluding phase of the eruption, with the gases freely intermingled with the solid fragments and pressing them outward in all directions, we are no longer concerned with a core of material filling the future vent with its unbroken mass like a cork. Each separate fragment may now be followed along its individual course, and under these conditions the lunar volcano will be found to be a far more efficient machine for distributing its ejected materials than its terrestrial rival—always assuming, however, that even in the lunar case the internal gaseous reservoir pours forth its contents with relatively undiminished energy, like a tank with a very large open tap, which nevertheless maintains a steady stream owing to the great head of water above it.

In the case of water flowing through long pipes under a constant head of pressure, fully three times the velocity will be developed in a pipe having six times the diameter as compared with its fellow pipe. It is therefore fair to assume that the relative vertical velocity of the issuing gases in the lunar case goes on increasing in the course of the eruption, even though initially equal to that of the gases in the terrestrial case. Some fraction of this increased vertical velocity will be imparted to all solid materials involved in the stream of gas, and will increase in a like proportion their time of suspension and flight, and consequently their range of projection beyond the orifice. But the work done by the rapidly expanding gases in giving horizontal velocity to the ejected fragments will tend to be proportional to the time of flight, while the horizontal velocity itself will be proportional to the square root of the work done in imparting it—approximately proportional, therefore, to the square root of the time of flight.

Hence the time of flight of an average projectile in the lunar case will be of the order of six times that in the terrestrial case, multiplied by a factor for the increased vertical velocity of the issuing gases, a factor that may be assumed to be greater than one and less than three; and the average range of the ejected lunar fragments will be increased compared with that of the corresponding terrestrial fragments in proportion to this time of flight, multiplied again by a factor representing the increase in the horizontal velocity, and approximately equal to the square root of the relative time of flight.

Assume, for example, that the mean vertical velocity of a lunar fragment becomes 1.69 times as great as that of its corresponding terrestrial fragment. Its relative time of flight will therefore be 6×1.69, and its relative range of projection will be:

$$(6 \times 1.69) \sqrt{(6 \times 1.69)}$$

$= 32.3$ times the range of the terrestrial fragment.

When the powerful factor of air-resistance which handicaps the terrestrial missile is also taken into account, it is no longer a matter of surprise that the average diameter of the largest lunar craters should exceed that of the largest terrestrial volcanoes some forty or fifty times.

The most effective angle of elevation for projecting a missile in the void is $45°$; but there is a zone nearly as effective on either side of this. Separated by this zone from the projected fragments of lower trajectory, the central core of ejected material, thrown highest above the lunar surface and longest in returning, will tend to fall back into and around the vent after the first lateral expansion of the erupted gases has ceased or greatly diminished. Unless the outpoured lava following the first eruption is able to melt and assimilate the whole of this central core, it will remain as a central mountain or boss—one of the typical features of the lunar landscape. On the other hand, the fragments of much lower trajectory than $45°$, which under other circumstances must soon have come to rest comparatively near to the orifice of eruption, will have been caught in the blast of the lateral explosion and swept or rolled towards the encompassing wall where the rain of falling missiles was gathering strength for resistance. (Figs. 4 and 5.)

In a paper of the necessary limits of length it is not possible to apply the theory here put forward to explain the minuter details of lunar topography. Nor is it possible to do more than hint at the wider questions suggested by it, such as the limits of planetary stability and the origin of meteorites. For the theory at once suggests that no planet with a surface containing radio-active minerals, and large enough to store up the heat supplied by them, can be stable if much smaller than our moon.

Note on Figure 2.

At the bottom of each of these imaginary tubes, ready to be formed by a volcanic explosion, is a layer of superheated vapours, which exerts an intense lifting force, the pressure and temperature being assumed equal in both cases. This may be attributed to the existence of an underground lake of lava, or molten "batholite."

The same conditions of equilibrium exist at the moment before eruption in Cases (A) and (B), the total lifting pressure on the one hand, and the total weight and resistances to shear on the other, being each multiplied, in Case (B), by 36, which is the square of the ratio between the forces of gravity on the surfaces of the earth and moon.

On the moon the greater relative depth and mass of material can receive only one-sixth of the acceleration, but as the lifting force acts through six times the distance, the velocity of ejection at the surface is presumed to be the same.

This will suffice for the ejection of the materials to at least six times the distance on the moon, but concurrent dynamical relations tend to multiply this effect very greatly.

Notes on Figures 3 and 4.

Phase (1) shows the opening stage of the eruption at the surface, after the contents of the volcanic pipe have been expelled; phase (2) the stage at which the escaping gases, in taking the line of least resistance, are rushing out laterally to form a ring-wall of the ejected materials; phase (3) a still more advanced stage in which further materials are added to the ring-wall; phase (4) a section of the resulting crater, central boss, and circular rampart.

After the cessation of the eruption, the partial or total collapse of the shaft is liable to cause subsidence and fissuring of the crater-floor.

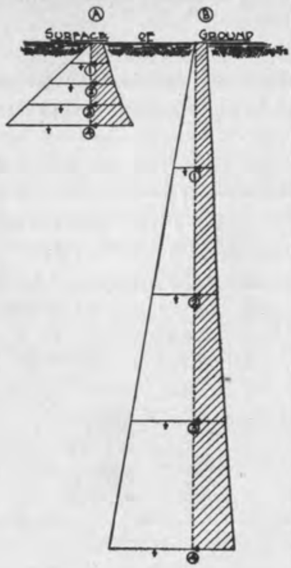


FIGURE. 1.

SECTIONAL SKETCH REPRESENTING

VERTICAL PRESSURES shown thus —↓— and RESISTANCES TO SHEAR ←—— at depths ①, ②, ③, ④ below the earth's surface, fig. Ⓐ, and below the moon's surface, fig. Ⓑ, drawn to six times the vertical scale of Ⓐ.

The area of each diagram to the right of the vertical line ① ④ represents the total resistance to shearing forces, being six times greater for the moon at levels of corresponding vertical pressures ①, ②, ③, ④

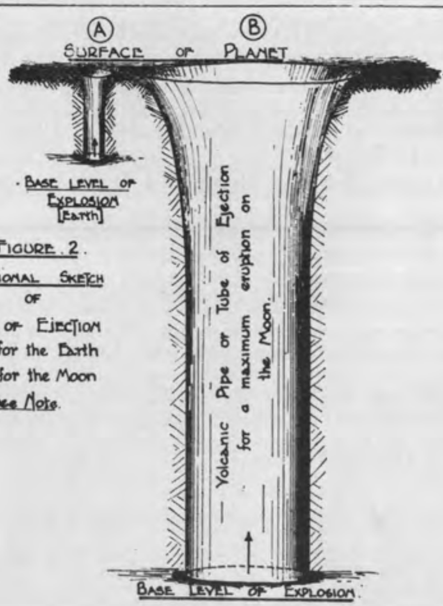
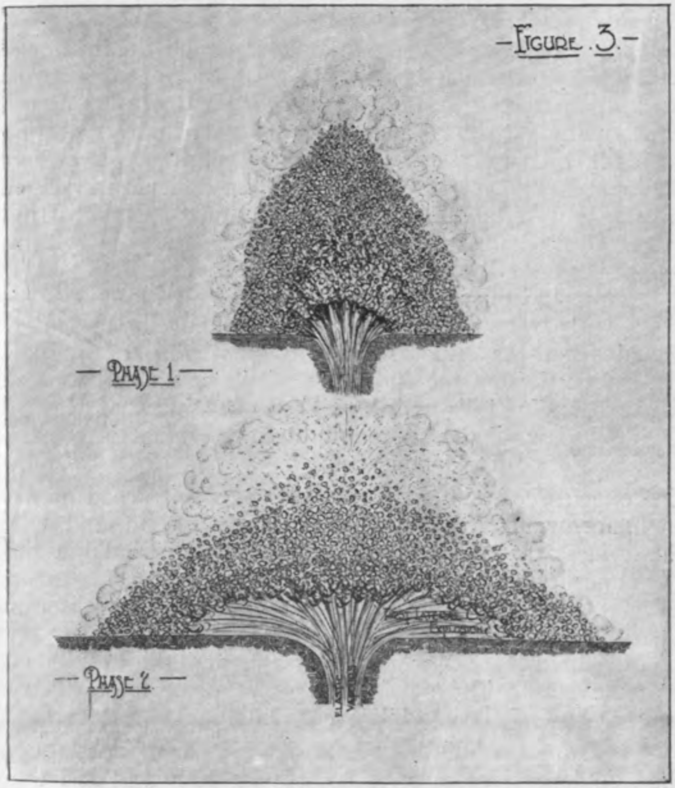


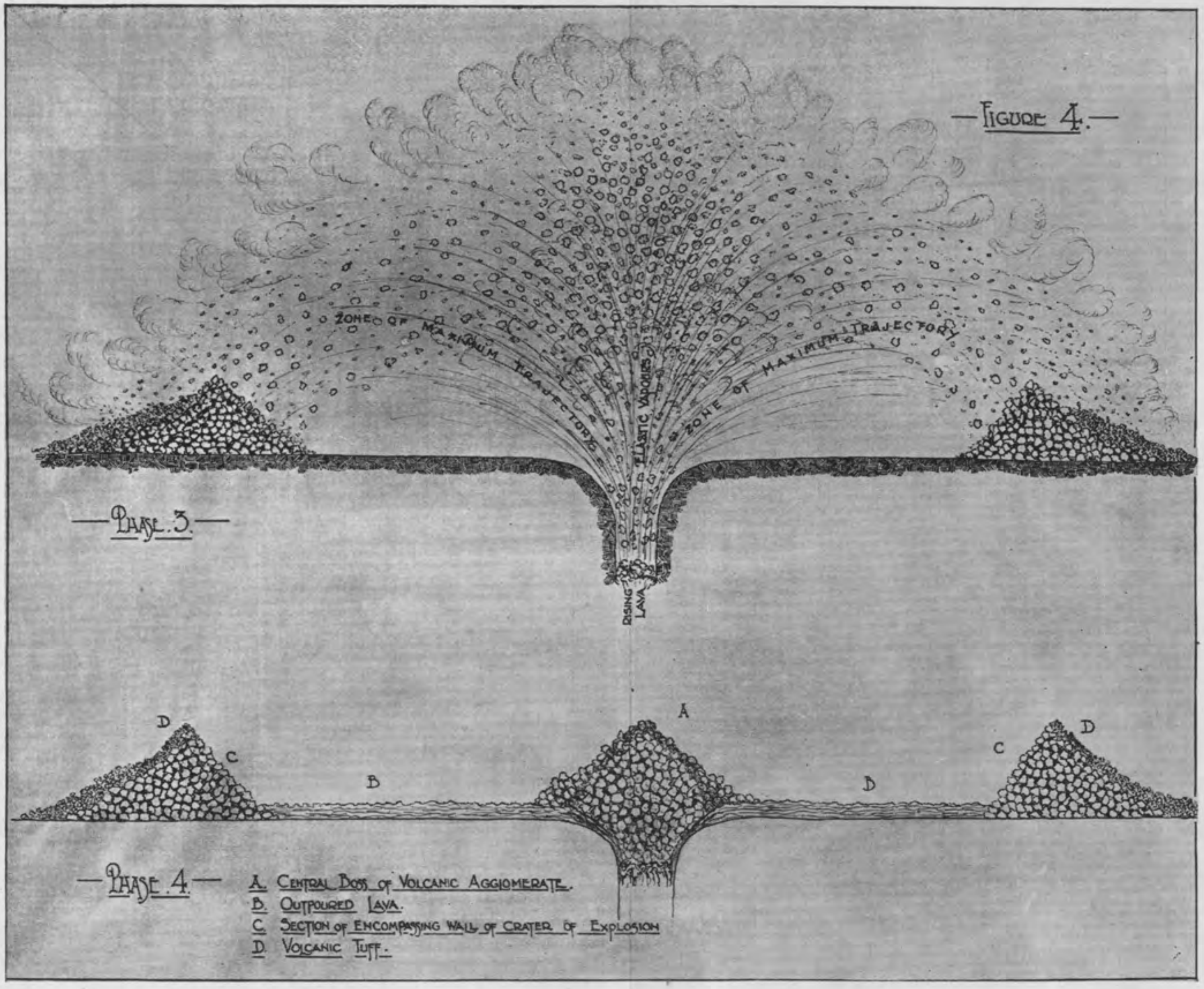
FIGURE. 2.

SECTIONAL SKETCH OF

TUBE OF EJECTION
Ⓐ for the Earth
Ⓑ for the Moon
See Note.



— Figure 3. —


—Figure 4.—
Zone of Maximum Trajectory
Zone of Maximum Trajectory
Elastic Vapours
Rising Lava
—Phase. 3.—
D
C
B
A
D
C
D
—Phase. 4.—
A. Central Boss of Volcanic Agglomerate.
B. Outpoured Lava.
C. Section of Encompassing Wall of Crater of Explosion
D. Volcanic Tuff.

LAMONT-HUSSEY OBSERVATORY OF THE UNIVERSITY OF MICHIGAN, BLOEMFONTEIN, SOUTH AFRICA.

The Lamont-Hussey Observatory of the University of Michigan, which is located on Naval Hill, Bloemfontein, is now actively engaged in searching for and measuring double stars. It may be of interest to the astronomical public of South Africa to sketch in brief the main facts relating to its establishment, equipment, and programme of work.

In early December, 1926, the telescope and the first observer arrived in Bloemfontein. The vicinity of Bloemfontein had been decided upon as the locality for the observatory by Professor W. J. Hussey in 1924. He favoured particularly locating on Naval Hill, or on a kopje eight miles south of Bloemfontein, called Leuuwberg. Leuuwberg proved too difficult and expensive of access, and ultimately the north section of Naval Hill was chosen. Thus the Lamont-Hussey Observatory is within the corporate limits of Bloemfontein, easily accessible by a good road, cut off almost completely from direct view of any city lights, supplied with water and electricity from the city systems, well protected from the usual surface dust stirred up by variable winds, screened from the full force of the south and west winds by the surrounding hills and the higher south brow of Naval Hill, and with a view of the surrounding country that is remarkably fine for a Free State landscape.

The expense of site and site improvement, road and road maintenance, water line, power line, sewage system, and architectural services was to be borne by the municipality, but that of building the building, the dome, and the telescope was to be met by Mr. R. P. Lamont, of Chicago, Illinois. The observatory, as its name indicates, is in part a memorial to Professor Hussey by his friend and former college mate, and the results of the programme here will be published as a memorial to Professor Hussey as one of the world's great double star observers.

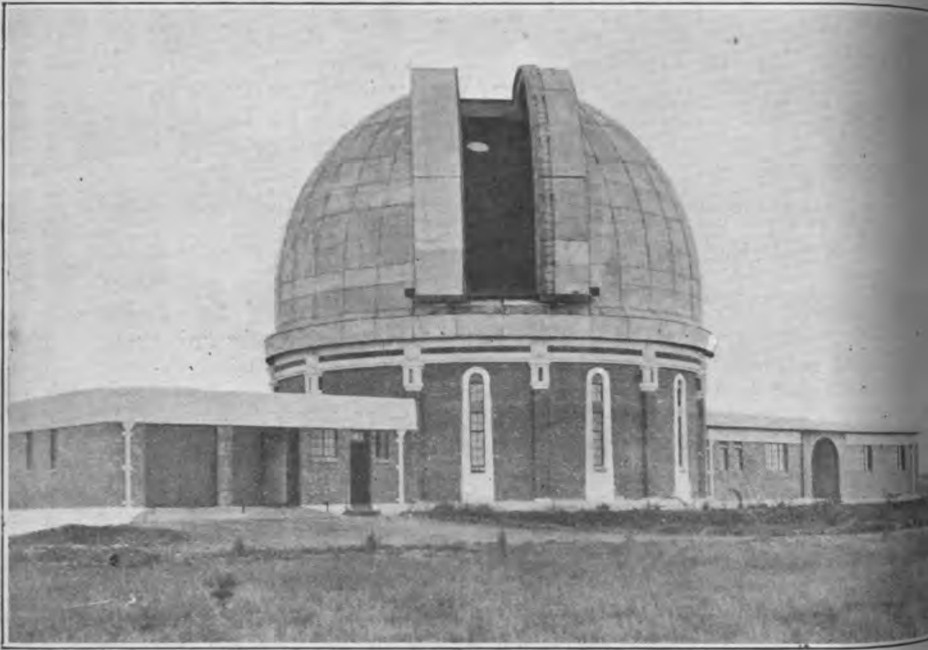
Ground for the building was broken in early June, 1927, and by the middle of December, 1927, the circular wall and the two wings were practically completed. Meantime the other two observers and the dome had reached Bloemfontein in November. In December the erection of the dome was begun, and by March, 1928, was finished. While the sheeting was being fixed on the dome the telescope erection was started by the three observers. Its erection was finished by the middle of April, 1928. Some mechanical difficulties were met which hindered the successful operation of the telescope, so that it was not put into regular use until about the middle of May, since when it has been used every clear night on which the seeing has been at all suitable.

The Lamont-Hussey Observatory was officially opened by the Mayor of Bloemfontein on April 28, 1928. The function was made exclusively a municipal one, in token of the interest exhibited and the help furnished by the municipality in the establishment of the observatory. The astronomical public of South Africa will be welcomed at any time they see fit to visit us, and must consider their first visit as their share in the dedication of the institution. While the observatory may not be considered a permanent part of South Africa, it hopes to be a credit to South Africa by producing noteworthy work during the years it remains in Bloemfontein.

The Director of the Lamont-Hussey Observatory is Professor R. H. Curtiss, of the University of Michigan, where he is also Director of the Detroit Observatory. The three resident observers in Bloemfontein are Associate Professor R. A. Rossiter, of the University of Michigan, Mr. M. K. Jessup and Mr. H. F. Donner, both formerly of the Astronomical Department of the University of Michigan. Dr. Rossiter is here for the full term of the special double star program, eight years or more, while Mr. Jessup and Mr. Donner are here for three years.

During the next six or eight years the particular program of the Lamont-Hussey Observatory will be that of searching for and measuring double stars. For the whole tenure of the observatory in Bloemfontein very little will be done outside of double star work. Since the large refractor of the Union Observatory was put into operation on a double star survey of the southern sky several years before the Lamont telescope was installed in Bloemfontein, in actual practice the Lamont-Hussey Observatory is co-operating with the Union Observatory in finishing the double star survey started by them. Each observatory has its own special areas to work over, and results are frequently exchanged, so that each group of observers may keep the Southern Double Star Catalogue roughly up to date. The Union Observatory is acting as the central office or clearing house for double stars in the southern hemisphere. and as such the Lamont-Hussey Observatory reports to them weekly both newly found double stars and a list of the known doubles remeasured during the week. The Union and Lamont-Hussey Observatories are making a special point of close co-operation, so that the work may be carried on both thoroughly and systematically. By so doing, not only will the maximum number of new double stars be found, but also all the known doubles that need attention will be remeasured.

For carrying out this program of double star searching and measuring, the Lamont-Hussey Observatory is equipped with a single large visual telescope with a 27-inch objective and a focal length of forty feet six inches. The Lamont telescope is by a very narrow margin the largest refractor in the Southern Hemisphere. Actually the Lamont and Union telescopes are almost of equal size and resolving power. What is possible with one is possible with the other, and both are of excellent quality. Telescopes of this size have a normal resolving power of about one-fifth to one-sixth of a second of arc. Double stars should be detected, then, under best conditions, when no wider separated than one-tenth of a second of arc. This must undoubtedly mean not only a great increase in the actual number of doubles found, but also in the accuracy with which the measures can be made as compared to what could be obtained with comparatively small instruments in the past. And to get best results the instrument must be in the hands of a highly skilled observer. A fifteen-inch telescope in the hands of a highly skilled double star



LAMONT-HUSSEY OBSERVATORY, BLOEMFONTEIN.

observer would make an amateur on the Lamont or Union telescope strain to equal his results.

The accompanying photograph shows where the Lamont telescope is housed. The Lamont-Hussey Observatory is a structure of brick and concrete, consisting of a circular wall and two wings, one for library and offices, the other for workshop and garage. The circular wall is surmounted by a structural steel dome, of which the outside diameter at the skirt is nearly fifty-eight feet, and the weight is just over fifty tons. The dome slit consists of two sliding doors that open from the middle of the slit by rolling back on straight track. The opening mechanism is such that both open at the same time, and a heavy wind cannot blow the doors open, but tends to blow them shut and keep them shut. The two wings are as low as feasible, and with flat concrete roofs. Radiation from the roofs does not bother the seeing, and the offices are unusually cool in summer. Heating of the offices in winter is entirely electrical, so as to eliminate the smoke nuisance. The height of the hill itself prevents the smoke of the town from being a nuisance.

This brief sketch may be of some slight interest to our astronomical friends, but they had best come and see for themselves how delightfully we are located, and what we are doing and what we do it with.

ASTRONOMICAL SOCIETY OF SOUTH AFRICA.

SESSION 1927-28.

Annual Report of the Council.

In presenting their report for the session 1927-28, the Council are again able to record a successful year in the history of the Society.

The membership at the 30th June stands at 109 members and 7 associates.

The retiring President, Senator the Hon. A. W. Roberts, D.Sc., will deliver his Presidential address on "Variable Stars" at the present meeting. The Society is grateful to Dr. Roberts for the services he has rendered in the very limited time at his disposal after fulfilling his many political duties.

During the year under review the Council has met four times, those members residing away from Cape Town being represented by their alternates.

One number of the Journal (Vol. 2, No. 2) was issued during the present session. While the Council still look forward to the time when funds will permit of a more frequent publication of the Journal, they consider that the interests of the Society are best served by continuing the plan of issuing one Journal per annum containing the Presidential Address, reports of the Society's work, etc. They feel that the publication in permanent form of a record of the Society's activities is in present circumstances the most suitable arrangement; the issue of printed circulars and supplementary reports can only be undertaken when increased funds are available. The Journal is circulated to Societies and institutions in many parts of the world, and enables the results of our work to reach the experts in the various branches of astronomy. The books reviewed in the Journal, and publications received from other Societies, etc., are placed in the

VARIABLE STAR SECTION.

I have again the pleasure to report steady and satisfactory progress in the Variable Star Section. In spite of the fact that the bad weather in Cape Town during last June made a difference of at least two hundred observations in the totals for that month of the Cape Town observers, the total for the year ending June 30 is only five below that of the year before. We have added a considerable number of fresh fields to our list, and the two new members referred to below will, we hope, help us to increase our output materially.

We are very sorry that Mr. Long has been unable to make any observations during the year. A large number of variables observed by him alone have in consequence received no attention.

The total for the year ending June 30 is 3,395 observations of 74 variables, against 3,400 observations of 71 variables for the year before. The observations were divided among the members as follows:—

H. E. Houghton: 1,067 observations of 42 stars.

W. H. Smith, 1,080 observations of 66 stars.

G. E. Ensor, 1,248 observations of 71 stars.

New Members.—Mr. A. H. Wood, of Grahamstown, has joined the Section, and we hope to receive regular contributions from him during the year. Mr. Harry Hayman, a student at the Transvaal University College, Pretoria, intends to join the Society and also the Section.

Your Director's thanks are again due to the Union Observatory and to Harvard College Observatory for current literature and star maps.

A list of the maxima and minima of the stars observed by the Section is attached. As is usual, many maxima and minima have been missed owing to proximity of these variables to the sun.

Notes.

063462 Nova Pictoris.

The discovery made by Mr. Finsen, of the Union Observatory, that Nova Pictoris had become a double star was an event of outstanding interest and importance. Such an occurrence has never been noted before in the history of astronomy, and on account of its great rarity may possibly never be seen again.

Nova Pictoris was discovered by our fellow member, Mr. R. Watson, of Beaufort West, on the 25th of May, 1925. From the first its behaviour was unusual. At the time of discovery its magnitude was 2.4. It rose gradually to a maximum of magnitude 1.5 on June 8, and faded to magnitude 3.5 at the end of June. At the end of July there was a second rise in brightness to magnitude 2.0, followed by another drop to magnitude 3.7 at the beginning of August.

Finally, there was a third rise to magnitude 1.9 on the 10th August, 1925, and since that date a steady decline, with a few slight fluctuations to the present value of magnitude 7.2.

The distinguishing characteristic of Nova Pictoris in contrast with other novæ, such as Nova Aquilæ 1918 and Nova Cygni 1920, has been the slowness with which it rose to a maximum and then faded. Most novæ reach maximum in about 24 hours after discovery and fade rapidly. Nova Pictoris, on the other hand, took a fortnight after its discovery to reach its maximum, and has faded very slowly.

Also, the new star spectrum characteristic of all novæ was abnormally slow in making its appearance. Novæ observed before reaching their maximum show an ordinary star spectrum while their brightness is increasing, and at the time of greatest brilliancy the spectrum changes entirely to the new star type. In the case of Nova Pictoris there was no trace of the new star spectrum on the 9th June; on the 10th June the spectrum had changed entirely to the new star type.

The new star spectrum was first observed in 1891 in the case of Nova Aurigæ; it is one in which the hydrogen lines appear doubled, both a dark and a bright line due to hydrogen appearing with the dark line on the side towards the blue end of the spectrum. ("Canopus" in the *Australasian.*)

The most interesting developments in connection with Nova Pictoris have occurred within the last few months. Harvard Announcement Card No. 55 of February 7, 1928, reported a cablegram from Prof. Hartmann, of La Plata. ("Nova Pictoris diameter one second.")

Dr. J. S. Paraskevopoulos, in Harvard Bulletin 856, March 1, 1928, states: "Photographs of Nova Pictoris made at the Boyden Station of the Harvard Observatory, at Bloemfontein, O.F.S., South Africa, with the 10-in. Metcalf telescope, on various nights, show clearly that the nova is surrounded by a narrow and well-defined ring of not very high density and of small diameter. A careful comparison of the image of the nova with the images of other stars of the same brightness, and close to the nova on the plate, precludes the assumption that the effect may be due to halation or to any other optical cause."

Nova Pictoris was photographed on many occasions at the Union Observatory, and the rings were plainly seen.

Dr. van den Bos informed your Director that he had tried the effect of various diaphragms, both square and hexagonal, in front of the object glass of the 26½ in. telescope, with the result that the rings appeared to have been modified by the shape of the diaphragm, thus confirming to some extent the opinion of the Greenwich authorities, *i.e.,* that the rings were *not* objective.

The latest expert opinion certainly supports this view. Dr. Spencer Jones, of the Royal Observatory, Cape Town, in an address before the Royal Astronomical Society, states: "The rings, 3″ in diameter, are *not* objective, but are optical phenomena due to the star's light having a different mean wave-length from an average star. Hence no weight can be given to values of the star's parallax deduced from them." (Report in *Nature*.)

The latter part of Dr. Spencer Jones' remarks refers to the modification in the estimates of the star's parallax from about 4,500 light years to the much smaller figure of 40 light years, based on the diameter of the rings. It was held that if the ring system was an objective phenomenon the parallax could hardly exceed 40 light years, since with one of 4,500 light years even the greatest stellar velocities observed could not produce a disc of sufficient diameter to be perceptible in the comparatively short period of three years.

The chief interest in Nova Pictoris lies, however, in the remarkable splitting of the star. When this was first detected by Mr. Finsen there were apparently only two nuclei visible. There are at the present time four seen, surrounded by a gaseous envelope.

Dr. Spencer Jones, in the address before the R.A.S. referred to above, said: "The star shows an oval nebulosity, the major axis of which, lying approximately E. and W., is about 1½″ in length. Within this are four nuclei, the relative positions of which may be understood if a triangle is drawn with the base upwards.

"The nuclei are (1) at the centre of gravity, the brightest; (2) at the lower angular point, the faintest; (3) and (4) slightly below the lower angular points."

Dr. van den Bos, in a recent letter to your Director, gives the position-angles and distances of the nuclei as follows: "The brightest in the centre, a fainter one at about 240°, 0.″4, a similar one at about 100°, 0.″4, and a much fainter difficult one about 0°, 0.″3."

In the same letter Dr. van den Bos writes: "I think that it is generally held by those who have observed the nova both spectroscopically (Lunt, Hartmann) and visually (Dawson, Finsen, and myself), and also Mr. Wood, that the nova presents strong evidence in favour of *internal* causes of the nova phenomenon, and against *external* causes (collision between two stars, star and meteoric shower, or swarm of small planets, star and nebula)."

Finally, a remark by "Canopus" in the *Australasian* is of interest: "We do not know yet what causes the explosion of a star. Nor do we know, what I think is extremely important, what kind of star is likely to explode. The fact is very striking that almost all new stars have been very faint before their outburst. It is remarkable, too, that the three or four stars whose spectra have been examined before they reached their greatest brightness have been stars of a type that is hotter than the sun."

In the preparation of the above note on Nova Pictoris I have made free use of the following publications, viz.: Articles in the *Australasian* by "Canopus"; in *Nature*, and in the Harvard Bulletins, dealing with the nova. I have also been greatly helped by Dr. van den Bos, of the Union Observatory, to whom I am indebted for the latest information relating to the nova.

145971 S Apodis.

This irregular variable, which has remained at about magnitude 10.0 for the past three years, has now dropped to less than 13.2. The decline apparently began in November, 1927. Unfortunately the variable was too faint for our observers from the middle of November, 1927, till February, 1928, but was followed during that interval by Baldwin, of Melbourne.

When our Section picked it up again on February 10th, 1928, it was 11.2 magnitude. At the end of February it was 12.0 magnitude, and on the 19th March 13.2. It is now less than 13.2.

S Apodis is one of the rare Coronæ Borealis type, and, as *Popular Astronomy* remarks: "If the Association of Variable Star Observers attempted no other work than that of observing irregular variables of this type, its existence would be fully justified."

The preceding minimum of S Apodis began in March, 1924, and lasted about five months; it reached 13.0 magnitude in June, 1924.

G. E. Ensor,
Director.

Maxima and Minima for Year ending June 30, 1928.

Designation.	Star.		Magn.	Date.
001032	S Sculptoris	M	7.5	1927 Nov. 3. Flat.
001862	S Tucanæ	M	9.0	1928 Feb. 19.
005475	U Tucanæ	M	8.2	1927 Sept. 2.
025050	R Horologii	M	4.6	1928 Jan. 20. Flat.
043623	R Reticuli	M	7.2	1928 Jan. 20.
044349	R Pictoris	M	6.5	1928 Feb. 14.
051533	T Columbæ	m	12.1	1927 Sept. 3.
	do.	M	6.9	1927 Dec. 21.
	do.	m	12.4	1928 April 13.
054331	S Columbæ	M	9.7	1927 Dec. 19. Flat.
054629	R Columbæ	M	8.4	1928 Jan. 27.
055686	R Octantis	M	7.0	1928 April 21.
073173	S Volantis	M	8.9	1928 April 21. Flat.

Designation.	Star.		Magn.	Date.
074241	W Puppis	M	7.6	1927 Nov. 24.
	do.	M	9.4	1928 March 20.
	do.	m	12.6	1928 May 19.
082476	R Chamæleontis	M	8.4	1928 March 20. Flat.
091868	RW Carinæ	M	8.6	1927 Dec. 10.
092551	Y Velorum	M	9.2	1928 Feb. 11.
092962	R Carinæ	m	9.5	1927 Nov. 19.
	do.	M	4.4	1928 April 16.
100661	S Carinæ	M	5.0	1927 July 11. Flat.
	do.	M	5.5	1927 Dec. 1.
	do.	m	9.5	1927 Feb. 8.
	do.	M	5.5	1928 April 28.
101058	Z Carinæ	M	11.1	1927 Nov. 17.
101153	W Velorum	M	9.3	1928 Jan. 11.
111661	RS Centauri	M	8.0	1928 April 20.
115058	W Centauri	M	8.2	1928 Jan. 12.
131283	U Octantis	M	7.4	1927 Nov. 24.
132422	R Hydræ	M	4.0	1927 August 31. Flat.
	do.	m	9.3	1928 March 19.
133633	T Centauri	m	8.2	1927 August 6.
	do.	M	5.9	1927 Sept. 24.
	do.	M	5.9	1928 March 10.
	do.	m	8.8	1928 May 8.
134236	RT Centauri	m	12.6	1927 July 18.
	do.	m	12.4	1928 March 20.
134677	T Apodis	M	8.8	1927 Oct. 16.
140959	R Centauri	M	5.5	1927 Oct. 24.
	do.	m	9.1	1928 Jan. 27.
	do.	M	5.5	1928 April 25.
145254	Y Lupi	M	10.3	1927 August 6.
151822	RS Libræ	m	11.5	1927 June 17.
	do.	M	7.5	1927 Oct. 3.
	do.	M	7.7	1928 May 8.
152849	R Normæ	m	12.8	1927 July 31.
	do.	M	7.2	1928 May 17.
155823	RZ Scorpii	m	12.2	1927 Sept. 1.
	do.	M	9.0	1928 April 28.
160021	Z Scorpii	M	9.3	1927 Sept. 30. Flat.
161122b	S Scorpii	M	10.5	1927 July 15.
164319	RR Ophiuchi	M	8.3	1927 June 17.

Designation.	Star.		Magn.	Date.
165030	RR Scorpii	M	5.4	1928 March 20.
172486	S Octantis	M	9.6	1927 Nov. 27.
174162	W Pavonis	M	9.0	1927 July 28.
174161	U Aræ	M	8.0	1927 Nov. 20.
	do.	M	8.0	1928 June 15.
180363	R Pavonis	M	7.8	1927 Dec. 1.
193972	T Pavonis	M	8.2	1928 Jan. 13.
195142	RU Sagittarii	M	7.0	1927 August 21.
	do.	M	7.0	1928 April 21.
212030	S Microscopii	M	8.9	1927 Nov. 25.
221938	T Gruis	m	11.6	1927 July 29.
	do.	M	8,2	1927 Sept. 23.
	do.	m	11.3	1927 Dec. 1.
	do.	M	8.7	1928 Jan. 19.
223462	T Tucanæ	M	8.0	1927 Oct. 1.
232746	V Phœnicis	M	9.0	1927 Sept. 16.
233815	R Aquarii	n	10.4	1927 Dec. 26.
235265	R Tucanæ	M	8.8	1927 Sept. 23.

CAPE CENTRE.

Annual Report, 1927-8.

Your Committee, in presenting this the fourteenth annual report, have to record the continued progress of the centre during the year now closed.

Membership.

Twelve additions have been made to the roll of membership, and ten names have been struck off owing to resignations and other causes. There are now seventy-seven members and eight associates—a total of eighty-five, as compared with eighty-three at the beginning of the session.

It is with sincere regret that your Committee have to record the death of Mr. William Reid, a foundation member of the Society, and for many years the honoured and distinguished director of the Comet Section of the Society. It is satisfactory to know that his work is held in high esteem throughout the astronomical world, and that early in the present year he was honoured by the Royal Astronomical Society by being awarded the Jackson-Gwilt Medal and gift.

Meetings.

During the period under review there have been nine ordinary meetings of the Centre, and your Committee have met seven times.

In February an Observational Meeting was held at the Royal Observatory. The thanks of the Centre is due to His Majesty's Astronomer for this privilege. The following addresses and papers were presented and discussed at the ordinary meetings:—

"The Theory of the Atom," Mr. H. C. Mason.
"The Elementary Mathematics of Astronomy," Mr. S. Skewes.
"Obscuring Clouds," Mr. H. E. Houghton.
"The Starry Heavens" (Popular Lecture), Mr. D. G. McIntyre.
"The Total Eclipse of the Sun of June 29, 1927," Capt. D. Cameron-Swan, F.R.P.S., etc.
"The Nebulæ," Mr. A. W. Long, F.R.A.S.
"Time-Difficulties of Observation," Mr. H. Horrocks, B.A.
"Some Experiences in an Observatory," Mr. H. C. Mason.
"The Habitability of Planets," Capt. D. Cameron-Swan, F.R.P.S., etc.
"Energy of the Stars," Mr. D. C. Burrell.

Finance.

The finances of the Centre continue to be satisfactory, as the financial statement will show.

Articles in the Press.

Monthly notes with charts of the sky have been published in the *Cape Times* as in previous years, and articles on astronomical phenomena continue to be published in *Die Burger*, both series of articles being contributed by members of the Centre.

Financial Statement for the Year ended 30th June, 1928.

Receipts.	£	s.	d.		£	s.	d.	*Payments.*	£	s.	d.
Balance in hand the 30th June, 1927					10	1	3	Contributions under Article IX of Constitution	29	1	7
Subscriptions—								Rent of Meeting Room ..	10	0	0
	£	s.	d.					Rent of P.O. Box	1	5	0
Arrears ...	6	5	0					Typewriting and Stationery	3	11	6
Current Year	47	19	6					*Cape Times* and postage to country members ..	5	2	10
In advance ..	3	18	9		58	3	3	Advertising meeting	0	15	0
Subscriptions to *Cape Times*					0	9	6	Secretary's Expenses ..	2	8	5
Commissions on cheques					0	6	3	Treasurer's Expenses ..	0	0	4
								Bank Charges	1	0	6
								By Balance	15	6	1
					£69	0	3		£69	0	3

JOHANNESBURG CENTRE.

ANNUAL REPORT, 1927-28.

The year just ended has been less eventful than usual for the Johannesburg Centre of the Association. One member has resigned during the year, and the Society has received with great regret the news of the death of Mr. F. J. Nance, a very active member. Four new members have been added during the year.

The visits to the Union Observatory, held on 25th August, 1927, and 25th May, 1928, were well attended, although the evening on the former occasion was overcast and the telescopes were not visited, but a pleasant and instructive time was spent on the photographs of celestial objects of interest, and an informal discussion and question night, in which those present took part, and the Observatory staff were in their customary position of mentors. The latter evening was cloudy, but fortunately situated clear patches of sky allowed the seeing of a number of interesting objects, Saturn and Nova Pictoris amongst the number.

When a visit was arranged to the residence of Mr. Forrest, the evening was unfortunately rainy, and the use of a telescope impossible.

On 22nd September a visit was paid to the Yale University observatory at Milner Park, by courtesy of Dr. Alden. About ten of the members attended, who were greatly interested in the equipment of the observatory and the photographic results exhibited. Dr. and Mrs. Alden entertained those present to tea at the conclusion of the evening.

On 13th October Mr. H. E. Wood and Dr. J. Moir had arranged to give an account of their experiences in England at the total eclipse of 29th June. Mr. Wood was unable to attend, so Dr. J. Moir gave his account, which was followed with close attention. He exhibited a number of photographs and other illustrations, which greatly assisted the appreciation of his address.

A number of other papers, which the Committee had provisionally arranged for, failed to eventuate, owing mainly to the members who had been expected to contribute them being so much away from Johannesburg that they were unable to fit into our programme.

The cordial thanks of the Centre are tendered to the Union Astronomer and the staff of the Union Observatory, to Dr. and Mrs. Alden, to Dr. J. Moir and Mr. A. Forrest, for their courtesy and hospitality to the members of this Centre during the year, and to Mr. Geddes for the continued use of his Post Office box.

Adopted at general meeting, 22nd June, 1928.

STATEMENT OF INCOME AND EXPENDITURE FOR YEAR ENDED 30TH JUNE, 1928.

Income.	£	s.	d.	*Expenditure.*	£	s.	d.
To balance on hand, 30th June, 1927	22	18	5	By Periodicals..	4	2	0
„ Subscriptions	20	13	6	„ Secretary's Membership to British Astronomical Association..	1	1	0
„ Donation	0	10	6	„ British Astronomical Memoirs	1	1	0
„ Periodicals sold	0	6	0	„ Bank Expenses	0	12	6
„ Exchange on cheques	0	1	6	„ Postages and stationery	0	8	6
				„ Petty Cash	2	0	0
				„ Transferred to Headquarters..	10	18	0
					20	3	0
				„ Balance on hand	24	6	11
	£44	9	11		£44	9	11

Astronomical Society of South Africa.

STATEMENT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED 30TH JUNE, 1928.

Income.	£	s.	d.	*Expenditure.*	£	s.	d.
Balance brought forward, 30th June, 1927	22	19	8	Printing Journal (Vol. 2, No. 2)	43	19	6
50 per cent. Subscriptions (Cape Centre)	28	16	4	Printing and Stationery	3	2	6
50 per cent. Subscriptions (Johannesburg Centre)	10	18	0	Postages	2	9	9
Sale of Journals	1	1	0	Rent and Electric Light	2	6	0
Sale of "Sundial" (50 per cent.)	0	13	1	Bank Charges	0	12	3
Donation (Natal A.A.)	5	0	0	Balance carried forward	20	3	4
Donation (Dr. Moir)	1	4	9				
Donation (Capt. Cameron-Swan) ..	2	0	0				
Commission on Cheque	0	0	6				
	£72	13	4		£72	13	4

Audited and found correct.
E. J. STEER.
June, 30, 1928.

W. H. SMITH,
Hon. Treasurer.

Obituary.

WILLIAM REID.
1861—1928.

The news of Mr. Reid's death will have brought with it a sense of personal loss to all members of the Society. Even to those who never knew him, his writings in the JOURNAL will have conveyed something of that atmosphere of enthusiasm and helpfulness which were always his leading traits. They will also have conveyed some idea of the astonishing application which lifted him into the front rank of comet discoverers.

William Reid was born at Pitcaple, Aberdeenshire, on August 23, 1861. He early showed an interest in things scientific, and was loaned a reflecting telescope, with which he made his earliest astronomical observations. But it was not as an astronomer that Mr. Reid first entered the scientific world. He first attracted notice as an entomologist. For his labours in this field he was made a Fellow of the Entomological Society; and a rare Scots moth bears his name to this day. His name may also be found upon the title-page of a rare little book which describes the butterflies and moths of Aberdeenshire.

But just when he had gained no little eminence as a Scots entomologist, Mr. Reid was forced, for health reasons, to leave Scotland. South Africa was his chosen land of immigration. Here he joined his brother-in-law, Mr. James Chalmers, with whose commercial ventures he was actively associated to within a few months of his death.

In South Africa astronomy was the science which claimed him. At first his observations were of a miscellaneous nature. But when the old Cape Astronomical Association (the parent of our Society) formed its Comet Section, Mr. Reid was asked to become Director. Why he should have been selected, he often remarked, was a puzzle to him; but it was a happy choice. For he fostered comet-sweeping in South Africa. And his selfless devotion to his task brought him, in the end, an international reputation.

Besides having been a Fellow of the Entomological Society, Mr. Reid was a member of the British Astronomical Association. He was a foundation member of the old Cape Association; and he served almost continuously on the Council, and, subsequently, on the Council of our Society. Of our Society, too, he was the first amateur astronomer to be elected President. And his presidential address is surely the most human document which has ever appeared in the Society's JOURNAL.

Mr. Reid discovered six comets, besides rediscovering d'Arrest's comet after all hope of its rediscovery had been abandoned. There is also to his credit the independent discovery of a Skjellerup comet, which he did not claim, but for which he received the O'Donohoe Medal, making in all seven awards of that medal to him. Early in the present year he was honoured by the Royal Astronomical Society, which awarded him the Jackson-Gwilt medal and gift.

Mr. Reid died at Rondebosch on 8th June, 1928, after a lingering illness, bravely borne. And at his passing the words

JACKSON-GWILT MEDAL OF THE ROYAL ASTRONOMICAL SOCIETY, PRESENTED TO MR. W. REID, 1928.

of that rapt mystic, Francis Thompson, commemorating a Dead Astronomer, were doubtless in the minds of many of us:

"Starry amorist, starward gone,
Thou art—what thou didst gaze upon."

And there we may well leave our old and unforgotten friend, William Reid.

M.

Reviews.

"Stars and Atoms." By A. S. Eddington, M.A., D.Sc., LL.D., F.R.S. [Pp. 127, with 11 illustrations.] (Oxford: At the Clarendon Press, 1927. Price 7s. 6d. net.)

"Stars and Atoms" was the title of an evening discourse given at the meeting of the British Association at Oxford in August, 1926. The volume under review is an expansion on this lecture. It deals in a popular manner with some of the recent developments of astronomy which have followed upon the rapid growth in our knowledge of the structure of the atom and the properties of the electron; it illustrates also the manner in which the astronomer, who studies matter in the stars and in the nebulæ which is under conditions that the physicist is not able to reproduce in the laboratory, has contributed to the progress of atomic physics. These advances in physics and in astronomy react upon one another to their mutual advantage.

The volume is divided into three lectures. The first is entitled "The Interior of a Star," and gives an account of what has been learnt of late years—largely through the investigations of Professor Eddington himself—about the interior of a star and the processes which result in stellar radiation. The second lecture, "Some Recent Investigations," deals, as the title implies, with several by-products of the main investigation of the constitution of the stars. It includes, amongst others, sections on the story of Algol, the story of the companion of Sirius, the story of Betelgeuse and the cloud in space. The third lecture, "The Age of the Stars," deals with the problems of stellar evolution and the maintenance of stellar radiation.

The volume is delightfully written, and, in spite of the fact that some mental concentration is now and again demanded of the reader, it is a book for the armchair. For it is romance—and romance of a high order. It illustrates to the full Professor Eddington's gift of popular exposition—his ability to present an abstruse subject in simple language, his keen imagination, his love of paradox, and, above all, his physical intuition. We cannot refrain, even at the expense of making this review unduly long, from quoting a few paragraphs which give a picture of what is happening inside a star. The reader will be able to judge from these of the style in which the volume is written:—

"We can now form some kind of a picture of the inside of a star—a hurly-burly of atoms, electrons, and ether-waves. Dishevelled atoms tear along at 100 miles a second, their normal array of electrons being torn from them in the scrimmage. The lost electrons are speeding 100 times faster to find a new resting-place. Let us follow the progress of one of them. There is almost a collision as the electron approaches an atomic nucleus, but, putting on speed, it sweeps round in a sharp curve. Sometimes there is a side-slip at the curve, but the electron goes on with increased or reduced energy. After a thousand narrow shaves, all happening within a thousand millionth of a second, the hectic career is ended by a worse side-slip than usual. The electron is fairly caught, and attached to an atom. But scarcely has it taken up its place when an X-ray bursts into the atom. Sucking up the energy of the ray, the electron darts off again on its next adventure.

"I am afraid the knockabout comedy of modern atomic physics is not very tender towards our æsthetic ideals. The stately drama of stellar evolution turns out to be more like the hair-breadth escapades on the films. The music of the spheres has almost a suggestion of—jazz.

"And what is the result of all this bustle? Very little. The atoms and the electrons, for all their hurry, never get anywhere; they only change places. The ether-waves are the only part of the population which accomplishes anything permanent. Although apparently darting in all directions indiscriminately, they do on the average make a slow progress outwards. There is no outward progress of the atoms and electrons; gravitation sees to that. But slowly the encaged ether-waves leak outwards as through a sieve. An ether-wave hurries from one atom to another, forwards, backwards, now absorbed, now flung out again in a new direction, losing its identity, but living again in its successor. With any luck it will in no unduly long time (ten thousand to ten million years, according to the mass of the star) find itself near the boundary. It changes at the lower temperature from X-rays to light rays, being altered at each rebirth. At last it is so near the boundary that it can dart outside and travel forward in peace for a few hundred years. Perhaps it may in the end reach some distant world where an astronomer lies in wait to trap it in his telescope and extort from it the secrets of its birth-place.

"It is the leakage that we particularly want to determine, and that is why we have to study patiently what is going on in that turbulent crowd. To put the problem in another form: the waves are urged to flow out by the temperature gradient in the star, but are hindered and turned back by their adventures with the atoms and the electrons. It is the task of mathematics, aided by the laws and theories developed from a study of these same processes in the laboratory, to calculate the two factors—the factor urging and the factor hindering the outward flow—and hence to find the leakage. This calculated leakage should, of course, agree with astronomical measurements of the energy of heat and light pouring out of the star. And so finally we arrive at an observational test of the theories."

"Modern Astronomy: Its Rise and Progress." By Hector Macpherson, M.A., Ph.D., F.R.S.E., F.R.A.S. [Pp. ix + 196, with 25 illustrations.] (London: Oxford University Press, 1926. Price 6s. net.)

The title of this volume is somewhat misleading. "Modern" is a relative term, and there are many who would define modern astronomy as dating from the first application of the spectroscope and of photographic methods to the study of the skies. But Dr. Macpherson considers the birth of modern astronomy to be due to Copernicus, and gives the date of its nativity as the 23rd of May, 1543, "when Copernicus received on his death-bed an advance copy of his *magnum opus*—the volume which was to revolutionize human thought—*De Revolutionibus Orbium Cœlestium.*" There is much justification for this view, for from this time astronomy began to awaken from a long period of stagnation. Shortly afterwards came the invention of the telescope and the discoveries of Galileo.

The volume is based on a course of ten lectures which the author delivered at the Aberdeen United Free Church College in 1926. After an introductory historical chapter, five chapters are devoted to the solar system and the study of surface markings and physical conditions of the various members. The remaining four chapters deal with the stars and the stellar universe, with modern views as to the structure of the universe, and with various theories of cosmogony. The volume is well written and up-to-date, though, as a broad review of modern astronomy in the stricter sense referred to above, it is somewhat unbalanced. As an illustration of this, we may recall the great work of Sir David Gill and the pre-eminent position which he held amongst astronomers for many years; we look for an account of his work and find not a single reference to his name in the index!

"Astronomy." A revision of Young's "Manual of Astronomy." In two volumes. I. The Solar System. II. Astrophysics and Stellar Astronomy. By H. N. Russell, Ph.D., D.Sc., R. S. Dugan, Ph.D., and J. Q. Stewart, Ph.D. [Vol. I, pp. xi + 470 + xxi, with 183 figures; Vol. II, pp. xii + 471 to 932 + xxx, with 124 figures.] (Boston: Ginn and Co., 1927. Price (two volumes) 21s. net.)

Young's "Manual of Astronomy" has long been out of print. The volumes under review, though a revision of Young's book, form to all intents and purposes a new work. Astronomy has made great advances in all directions during the past decade, and these developments have naturally called for adequate treatment. The revision has consequently increased the length considerably.

No astronomer—amateur or professional—can afford to be without these volumes, which, considering the amount of material contained in them, are priced at a moderate figure. The detailed indices and the numerous tables of data make the work a valuable one for reference purposes. The knowledge of mathematics demanded of the reader is very slight, the calculus being completely avoided.

The first volume deals with the fundamental conceptions, astronomical instruments, and problems of practical astronomy, followed by a detailed study of the solar system, including related subjects such as the motion of the earth, the aberration of light, precession and nutation, celestial mechanics, and the origin of the solar system. It is in the second volume that the greater interest lies, as most of the recent developments are dealt with in this volume. These developments have almost all followed from the application of the spectroscope to astronomy, and the volume begins appropriately with a chapter on the analysis of light. Two chapters are then devoted to the application of these methods to the sun and to the study of its spectrum and its radiation.

Physical principles are necessarily closely bound up with the modern study of the atmospheres and interiors of stars. These principles are explained in a chapter on atomic theory and astrophysics. Five chapters are devoted to the stars, their number, brightness, distribution, motion, luminosities, temperatures and diameters, and to double stars (including visual and spectroscopic binaries) and variable stars. The next two chapters deal with star clusters, the Milky Way and nebulæ. The last two chapters are devoted to the constitution and evolution of the stars.

It is not possible in the brief space of a review to give an adequate idea of the comprehensiveness of the volumes, though the wide range of the contents may be gathered from the brief description just given. Particular care has been taken to ensure accuracy throughout. We can without hesitation recommend every reader of these pages to purchase the volumes, to study them, and then to place them on his bookshelves in a place handy for reference, for he will find himself continually referring to them.

"An Outline of Stellar Astronomy." By Peter Doig, F.R.A.S. [Pp. viii + 183, with 24 figures.] (London: Draughtsmen Publishing Co., 96, St. George's Square, S.W.1, 1927. Price 7s. 6d. net.)

The volume under review is, in the words of the author, "an attempt to give an outline of the main features of the present state of knowledge of the constitution, dimensions, motions and distribution in space of the stars and nebulæ. . . . An attempt has been made throughout to give concisely, by tabular presentation wherever this is practicable, modern data from which the theories of astrophysics have been constructed."

The volume is not suitable for the reader who has no knowledge of the subject, but those who are generally familiar with the results of modern research will find the volume useful for reference purposes; of special value are the tabulated data.

It must be emphasized that the volume is "an outline"; it consists practically of a series of notes dealing with various points, the related matter being grouped together. The first part deals with observational data—the dimensions, luminosities, and masses of the stars; their movements, number and distribution; binary stars, variable stars and novæ. The second part deals with the nature of a star, based upon observation and the application of physical principles; the surface of the star, as revealed by the spectroscope, is discussed first, and then the interior, as revealed by modern investigations, is described. Two chapters are devoted to theories as to the evolution of the stars and as to the nature of stellar variability. The third part deals with the stellar universe; first our galactic system is discussed, and then external systems are dealt with.

A number of appendices give useful information on various points of interest.

Original references are given at the end of each chapter, which increases the value of the volume for the working astronomer. A more detailed index would prove of value; in particular, references to individual stars should be given. The volume is obviously of such great value for reference purposes that it is to be regretted that this aid to finding information quickly on any particular point is somewhat inadequate.

The volume is well printed and illustrated, some of the diagrams being particularly good.

"The Universe of Stars: Radio Talks from Harvard Observatory." Edited by Harlow Shapley and Cecilia H. Payne. [Pp. ix + 205, with numerous plates.] (Published by the Observatory, Cambridge, Massachusetts, 1926. Price not stated.)

This volume is a unique scientific enterprise. Nine members of the staff of the Harvard Observatory co-operated in broadcasting an extensive series of astronomical talks, with the aim of presenting to the large unseen audience an account of some of the results of research in pure science. The talks have been published in book form and so made available to an even wider public by the Harvard Observatory as a further experiment.

The experiment is one which deserves success. Broadcasting can become an important factor in public education, and those members of the public who listened to the whole of this series have acquired a fairly broad knowledge of astronomy.

The volume contains 22 talks, grouped under the four headings—(i) the material and methods of astronomy; (ii) the solar system; (iii) the stars; (iv) the stellar universe. A wide range of subjects is covered: we may instance, for example, talks on "The Amateur's Work in Astronomy"; "Telescopes and their Uses"; "Astronomical Tests of Relativity"; "The Age of the Earth"; "The Stuff Stars are Made of"; "Beyond the Milky Way"; "Life in Other Worlds?"

Each talk is complete in itself. A certain amount of overlapping is therefore inevitable, but there is the gain that the volume can be opened anywhere and one of the talks read without the necessity of reading all those which precede it in order to understand it properly. It hardly need be mentioned that the facts are up to date and accurate.

The volume is well illustrated with plates, reproduced, for the most part, from Harvard photographs. It can be recommended to anyone, knowing little or nothing of astronomy, who is anxious to gain some understanding of the universe in which he lives.

"Leitfaden der astronomische Beobachtung." Von Ob.-Ing. H. T. Gramatzki. [Pp. vi + 111, with 35 figures.] (Berlin: Ferd. Dümmlers Verlag, 1928. Price: paper covers, M. 3.50; bound, M. 4.50.)

The proud owner of a first small telescope, seeking guidance as to how best to use it, will find this small volume a considerable help. It is surprising what useful work can be done with a four-inch or even with a two-inch telescope. A section is devoted to a brief description of the refracting and the reflecting telescope, and the defects to which each is liable are explained. The methods of adjusting for latitude and azimuth are described. The meaning of resolving power is discussed and formulæ given for the limits of separation of double stars with components of unequal magnitude for any aperture. The study of planets and planetary markings, photometry, and the observation of variable stars, and the measurement of star colours with a small telescope are then discussed. A micrometer and a photometer of simple type are discussed.

One section is devoted to observations which can be made without any optical aid at all, including the observation of meteors.

When one reflects that very little is really known about the changes in brightness and colour of a bright star like Betelgeuse, it is obvious that the owner of a small telescope need not fear that he can do no work of real value with his modest equipment. The reading of a simple handbook, such as the one under review, will show him that he can choose between several fields of useful endeavour.

"Astronomy and Cosmogony." By Sir J. H. Jeans, M.A., D.Sc., LL.D., F.R.S. [Pp. x + 420 + 16 plates.] (Cambridge University Press, 1928.) 31s. 6d. net.

At a time when, in the rapid progress of a comparatively recent advance in scientific knowledge, speculations and conflicting theories are constantly undergoing revision, the appearance of a book from the pen of a master, bringing under review the present position in a considerable portion of the field of investigation, is most welcome. Thus Sir J. H. Jeans' latest book comes as an opportune addition to the literature relating to modern theories of the physical state of stars.

The treatment of the main subject matter, which centres round Jeans' own views, is preceded by an outline of the observational data. Such physical principles as are of constant use, and are not best introduced in the discussion of particular developments of the theory, are collected in a second chapter.

Jeans holds that, to meet the requirements of stability, stars must be largely liquid. It is thus that his theory is brought into close relation with his earlier work on rotating fluids. On these principles a scheme of cosmogony is built to explain the various structures, from binary stars to the galactic system, known to observational astronomy. The treatment of this wide field of inquiry occupies the second half of the volume.

Though a considerable amount of mathematical development is inevitable in such a treatise, the results are explained in non-technical terms. Much of the discussion is completely freed from technical expression, and the result is a volume in which the non-mathematical reader also can follow with interest the views on stellar physics advocated by its author.

The Editor acknowledges the receipt of publications, etc., from the following:—Antwerp Astronomical Society; British Astronomical Association (New South Wales Branch); East Bay Amateur Astronomical Association, California; Engelhardt Observatory, Kasan; Harvard College Observatory; Lick Observatory; New Zealand Astronomical Society; Prague National Observatory; Tartu (Dorpat) Observatory; Vereinigung von Freunden der Astronomie und kosmischen Physik, Berlin; Yale University Observatory.

NATAL ASTRONOMICAL ASSOCIATION.

EXTRACTS FROM ANNUAL REPORT OF THE HON. SECRETARY, SIXTH SESSION, 1927-28.

The Association has maintained its activity, and the following lectures and papers were delivered during the year:—

August: "Satellites and their Movements," Mr. A. I. F. Forbes (of Cape Town).
September: "The Wonders of the Universe," Mr. D. L. Forbes, F.R.A.S.
October: "Comets," Mr. H. J. S. Bell.
November: "The Elements of Lunar Eclipses," Mr. C. F. Wickes.
February: "The Celestial Sphere," Mr. H. Roadknight.
March: "Bradley and his Times," Mr. J. D. Mumford.
April: "Astronomy and the Poets," Mr. W. H. Potts; "The Elements of Solar Eclipses," Mr. C. F. Wickes.
May: "Nova Pictoris," Mr. W. Smart.

During the year our membership decreased by 8, and now stands at 54, of whom 46 are town and 8 country members.

It is with great regret that we have to record the death of one of our foundation members, Mr. Thomas Ellis, who took a keen interest in the work and welfare of the Association, and was an invaluable member of the Committee.

The popularity of the Observatory steadily increases. We continue to receive numerous applications for visits, which we appreciate, and endeavour to fill to the best of our ability. We have had no less than 150 visitors there this year. They became more acquainted with some of the wonders of astronomy and the appearance of the heavenly bodies by means of the equatorial telescope, under the able demonstration of Messrs. Forbes, Roadknight and Fox.

In the early evening of December 8th a total eclipse of the moon occurred. Preparations were made to observe and photograph the eclipse, but the phenomenon was obscured by a severe thunderstorm.

On the afternoon of May 19th there was a total eclipse of the sun, but visible to us in South Africa only as a partial eclipse. To encourage members to observe it they were supplied with a diagram showing the times and phases of the phenomenon. A party of members and friends, under the direction of Mr. D. L. Forbes, F.R.A.S., observed it from the Observatory under ideal weather conditions, which made it a glorious spectacle to behold. Photographs were taken of it before the sun had set.

Our cordial relations have been maintained with the Astronomical Society of South Africa. In November we received 36 copies of the 2nd No. of Vol. 2 of the Journal of the Society, and these were immediately distributed to our members.

Astronomical Society of South Africa.

OFFICERS AND COUNCIL, 1928-9.

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Mars: J. Moir, M.A., D.Sc., F.C.S., 66, Ditton Avenue, Auckland Park, Johannesburg.

Meteor: T. Mackenzie, 46, Market Street, Grahamstown.

Variable Stars: G. E. Ensor, Pretoria Hospital, P.O. Box 201, Pretoria.

Editor of Journal: H. Spencer Jones, M.A., Sc.D., B.Sc., F.R.A.S.

Librarian: A. F. I. Forbes, "Craigie Brae," Liesbeek Road, Rosebank, C.P.

Secretary of Computing Section: T. Mackenzie, 46, Market Street, Grahamstown.

COMMITTEE OF CAPE CENTRE, SESSION 1928-9.

Chairman: Capt. D. Cameron-Swan, F.R.P.S., etc.

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Hon. Secretary: H. W. Schonegevel.

Hon. Treasurer: A. F. I. Forbes.

Committee: Messrs. D. C. Burrell, B. Jearey, F.R.A.S., A. W. Long, F.R.A.S., D. G. McIntyre, W. H. Smith.

The following appointments were also made: Hon. Auditor, E. J. Steer: Hon. Librarian, S. Skewes.

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Treasurer: W. Geddes.
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Committee: Miss H. L. Troughton, W. M. Worssell, W. B. Jackson, J. D. Stevens.

THE ASTRONOMICAL SOCIETY OF SOUTH AFRICA.

NEW MEMBERS.

Collins, G. C., Acutt's Arcade, Durban.
Gohl, J. C., Culemborg, Palmyra Road, Newlands.
Grix, Mrs. J., 141, Musgrave Road, Durban.
Horrocks, H., B.A., F.R.A.S., Royal Observatory, Cape Town.
Nathanson, H. H., 4, Avoca Villas, Mill Street, Cape Town.
Oliver, Miss A., Park Street, Brakpan.
Oliver, Miss M., 127, Northdene Avenue, Brakpan.
Pratt, R. R., B.Sc., A.M.I.C.E., P.O. Box 1358, Cape Town.
Roadknight, H., 232, Stamford Hill Road, Durban.
Schlesinger, Professor F., Yale University Observatory, New Haven, Conn., U.S. America.
Simenhoff, J., Jean Lodge, St. James' Road, Sea Point.
Wickes, C. F., 113, Ninth Avenue, Durban.
Wood, A. H., Rhodes University College, Grahamstown.
Paraskevopoulos, Dr. J. S., Boyden Station, Harvard Observatory, Bloemfontein.

The addresses of the following members are now as stated below:—

Beusch, A., P.O. Box 240, Windhoek, S.W. Africa.
Davis, J. B., 13, Albany Street, East London.
Forrest, A., 44*a*, Garden Road, Orchards, Johannesburg.
Jearey, B. F., F.R.A.S., Villa Carina, Alexander Road, Muizenberg.
Innes, R. T. A., D.Sc., F.R.S.E., F.R.A.S., F.R.Met.S., 26, Pope Street, Johannesburg.

Any changes of address should be notified to the Secretary of the Centre to which the member or associate belongs.