OUR ASTRONOMICAL COLUMN.

ASTRONOMICAL OCCURRENCES IN JUNE:—

June 6. 5h. 37m. to 9h. 20m. Transit of Jupiter's Sat. III. (Ganymede).

7. 4h. 24m. Conjunction of Mercury and Mars. Mercury 0° 19′ N.

" 13h. 0m. Mercury at greatest elongation, 23° 58′ E.

13. 9h. 57m. to 13h. 39m. Transit of Jupiter's Sat. III. (Ganymede).

14. 10h. 13m. to 11h. 24m. Moon occults 4 Sagittarii (mag. 4·6).

19. 11h. 10m. Minimum of Algol (β Persei).

21. 8h. 19m. Sun enters Cancer and Summer commences.

22. 8h. 32m. Venus in conjunction with Mars, Venus 2° 4′ S.

28. Eclipse of the Sun partially visible at Greenwich. Begins 5h. 14m.; Middle 5h. 38m.; Ends 6h. 2m. Magnitude (Sun's diameter = 1) 0·065. At the time of greatest obscuration nearly one-fifteenth of the Sun's southern limb will be occulted.

THE RETURN OF ENCKE'S COMET.—A telegram from the Kiel Centralstelle announces that Encke's comet was found by Mr. Woodgate, of the Cape Observatory, on May 27. Its position at 17h. 49m. (Cape M.T.) on that date was R.A. = 2h. 59·3m., dec. = 7° 29′ S. This is situated about half a degree north of ρ Eridani, and is, at present, unobservable in these latitudes.

THE RADIAL VELOCITY OF ALGOL.—No. 22, vol. ii., of the *Mitteilungen der Nikolai-Hauptsternwarte zu Pulkowo* contains a very full discussion by Prof. Belopolsky of the radial-velocity observations of Algol made at the Pulkowa Observatory during the years 1905–7. The results obtained from each line on each spectrogram are discussed in detail, and the following elements are finally derived:—ω 42°·5 ± 1°·35, e = 0·0476 ± 0·0037, T = 2·509 ± 0·00019 days, a = 1,693,523 ± 106 km., and i = 90°.

THE RADIAL VELOCITY OF ϵ URSÆ MAJORIS.—From two spectrograms obtained at Potsdam in 1889, Profs. Vogel and Scheiner found the radial velocity of ϵ Ursæ Majoris to be −30·4 km., the measurements being made on the Hγ line. But from nine very consistent plates, secured with the Bruce spectrograph in 1902–3, Prof. Adams derived the value −9·4 km., and in 1903 this was confirmed by measurements of seven plates obtained at Potsdam, the mean value being −9 km. Vogel and Eberhard then re-measured the original plates, and confirmed the first value. The comparison of these results suggested that, possibly, the radial velocity of ϵ Ursæ Majoris is variable. That the star is of peculiar interest is shown by the fact that its spectrum is given as type I. *a* 2 in Vogel's classification, as VIII. P. in the Harvard classification, and that Sir Norman Lockyer, whilst classing it as "Sirian," has pointed out that it has several well-marked peculiarities.

For these reasons Messrs. Baker and Schlesinger, of Allegheny Observatory, obtained—during March and April, 1907—and the former measured, seven spectrograms taken with the Mellon spectrograph, which gives a measurable spectrum of 21 mm. in length between λ 3925 and λ 4750. The resulting mean value was −7·1 km. ± 0·46 km., and as this agrees so closely with that obtained by Prof. Adams and with the later value of Prof. Vogel, the matter must still be considered as requiring further investigation (Publications of the Allegheny Observatory, vol. i., No. 4, p. 23).

OBSERVATIONS OF JUPITER'S SATELLITES.—Some interesting observations of eclipses and occultations of Jupiter's satellites are recorded by M. S. Kostinsky in No. 4249 of the *Astronomische Nachrichten* (p. 14, May 20). On April 3 photographic and visual observations of a partial eclipse of J. ii. by the shadow of J. i. were secured; the brightness of J. ii. was diminished about 0·3–0·4 magnitude according to the eye observations, and the minimum brightness occurred at 11h. 52·3m. (Pulkowa M.T.). On February 24 an occultation of the second satellite by the first was observed at 10h. 45·5m., and on March 27 and 30 two series of photographs of the second and third satellites were secured during their eclipse by the planet's shadow.

A partial eclipse of the second by the third satellite was observed by Herr Fauth at the Landstuhl Observatory at 8h. 17m. 55s. (M.E.T.) on February 20.

THE ORBIT OF α ANDROMEDÆ.—The following elements for the orbit of α Andromedæ are published by Mr. Baker in vol. i., No. 3, of the Publications of the Allegheny Observatory (pp. 17–22):—P = 96·67 days, e = 0·525, T = 1907 November 2·40, ω = 76°·21, K = 30·75 km., γ = −11·55 km., A = 34·60 km., B = 26·90 km., and $a \sin i$ = 34,790,000 km. The discussion of the orbit was based on the measures of eleven lines between λ 3933·789 and λ 4481·437 on ninety-four plates obtained with the Mellon (single-prism) spectrograph, and the results are compared with those previously obtained at the Lowell, Lick, and Potsdam observatories.

THE UNITED STATES NAVAL OBSERVATORY.—The annual report of the United States Naval Observatory for the fiscal year ending June 30, 1907, gives the usual data regarding the time-service, publications, &c., and a brief summary of the observations made with each set of instruments. The observation of each star in Sir David Gill's Zodiacal Catalogue of 2798 stars was nearly complete, but a few more observations remained to be made in the autumn of 1907. More than 3000 observations were made by different observers with the new self-registering transit micrometer installed in October, 1906, and the results again prove the efficiency of this instrument. Bad weather limited the number of photoheliograms obtained, records being secured on only 150 days; spots were shown on the negatives on 148 days. There are now 1455 solar negatives in hand, and in order to minimise the labour of reducing these it is proposed that a heliomicrometer, as devised by Prof. Hale, be installed.

ON THE SHAPES OF EGGS, AND THE CAUSES WHICH DETERMINE THEM.[1]

THE eggs of birds and all other hard-shelled eggs, such as those of the tortoise and the crocodile, are normally simple solids of revolution, but they differ greatly in form according to the configuration of the plane curve by the revolution of which the egg is, in a mathematical sense, generated. Some few eggs, such as those of the owl or of the tortoise, are spherical or very nearly so; a few, such as the grebe's or the cormorant's, are approximately elliptical, with symmetrical or nearly symmetrical ends; the great majority, like the hen's egg, are ovoid, a little blunter at one end than the other; and some, by an exaggeration of this lack of antero-posterior symmetry, are blunt at one end but characteristically pointed at the other, as is the case in the egg of the guillemot and puffin, the sandpiper, plover, and curlew.

Various theories, based upon the principles of natural selection, are current and are very generally accepted to account for these diversities of form. The pointed, conical egg of the guillemot is generally supposed to be an adaptation advantageous to the species in the circumstances under which the egg is laid; the pointed egg is less apt than a spherical one to roll off the narrow ledge of rock on which this bird lays its solitary egg, and the more pointed the egg so much the fitter and likelier is it to survive. The fact that the plover or the sandpiper, breeding in very different situations, lays eggs that are also conical elicits another explanation, to the effect that the conical form permits the many large eggs to be packed closely under the mother-bird. The round egg of the tortoise and the elongated egg of the crocodile have been supposed to be developed in conformity with the shape of the creature that has afterwards to be hatched therein. Whatever truth there be in these apparent adaptations to existing circumstances, it is only by a very hasty logic that we can accept them as a *vera causa* or adequate explanation of the facts; and it is obvious to my mind that, in attempting to deal with the forms assumed by matter, whether in the organic or the inorganic world, we ought first to attempt to deal on simple physical lines with the forces to which it has been subjected, that is to say, the intrinsic forces of growth

[1] A paper read before the Zoological Society of London on April 28 by Prof. D'Arcy Wentworth Thompson, C.B.

acting from within and the forces of tension and pressure that may have acted from without.

Certain elementary points in regard to the formation of the egg must be borne in mind :—

(1) The "egg," as it enters the oviduct, consists of the yolk only, enclosed in its vitelline membrane. As it passes down the first portion of the oviduct, the white is gradually superadded, and becomes in turn surrounded by the "shell-membrane." About this latter the shell is secreted, rapidly and at a late period.

(2) Both the yolk and the entire egg tend to fill completely their respective membranes, and, whether this be due to growth or imbibition on the part of the contents or to contraction on the part of the surrounding membranes, the resulting tendency is for both yolk and egg to be, in the first instance, spherical, unless otherwise distorted by external pressure.

(3) The egg is subject to pressure within the oviduct, which is an elastic, muscular tube, along the walls of which pass peristaltic waves of contraction. These muscular contractions may be described as the contraction of successive annuli of muscle, giving annular (or radial) pressure to successive portions of the egg; they drive the egg forward against the frictional resistance of the tube, while tending at the same time to distort its form. While nothing is known, so far as I am aware, of the muscular physiology of the oviduct, it is well known in the case of the intestine that the presence of an obstruction leads to the development of violent contractions in its rear, which waves of contraction die away, and are scarcely if at all propagated in advance of the obstruction.

(4) It is known by observation that a hen's egg is always laid blunt end foremost.

(5) It can be shown, at least as a very common rule, that those eggs which are most unsymmetrical, or most tapered off posteriorly, are also eggs of a large size relatively to the parent bird. We may accordingly presume that the more pointed eggs are those that are large relatively to the tube or oviduct through which they have to pass, or, in other words, are those which are subject to the greatest pressure while being formed or shaped. So general is this relation that we may go still further, and presume with great plausibility in the few exceptional cases (of which the apteryx is the most conspicuous) where the egg is relatively large though not markedly unsymmetrical, that in these cases the oviduct itself is in all probability large (or perhaps weak) in proportion to the size of the bird. In the case of the common fowl we can trace a direct relation between the size and shape of the egg, for the first eggs laid by a young pullet are smaller, and at the same time are much more nearly spherical than the later ones; and, moreover, some breeds of fowls lay proportionately smaller eggs than others, and on the whole the former eggs tend to be rounder than the latter.

We may now proceed to inquire more particularly how the form of the egg is controlled by the pressures to which it is subjected.

The egg, just prior to the formation of the shell, is, as we have seen, a fluid body, tending to a spherical shape and *enclosed with a membrane*.

Our problem, then, is: Given a practically incompressible fluid, contained in a deformable capsule, which is either (*a*) entirely inextensible, or (*b*) slightly extensible, and placed in a long elastic tube the walls of which are radially contractile, to determine the shape under pressure.

(1) If the capsule be spherical, inextensible, and completely filled with the fluid, absolutely no deformation can take place. The few eggs that are actually or approximately spherical, such as those of the tortoise or the owl, may thus be alternatively explained as cases where little or no deforming pressure has been applied prior to the solidification of the shell, or else as cases where the capsule was so little capable of extension and so completely filled as to preclude the possibility of deformation.

(2) If the capsule be not spherical, but be inextensible, then deformation can take place under the external radial compression, only provided that the pressure tends to make the shape more nearly spherical, and then only on the further supposition that the capsule is also not entirely filled as the deformation proceeds.

In other words, an incompressible fluid contained in an inextensible envelope cannot be deformed without puckering of the envelope taking place.

Let us next assume, as the conditions by which this result may be avoided, (*a*) that the envelope is to some extent extensible, or (*b*) that the whole structure grows under relatively fixed conditions. The two suppositions are practically identical with one another in effect.

(3) It is obvious that, on the presumption that the envelope is only moderately extensible, the whole structure can only be distorted to a moderate degree away from the spherical or spheroidal form.

(4) At all points the shape is determined by the law of the distribution of *radial pressure within the given region of the tube*, surface friction helping to maintain the egg in position.

(5) If the egg be under pressure from the oviduct, but without any marked component either in a forward or backward direction, the egg will be compressed in the middle, and will tend more or less to the form of a cylinder with spherical ends. The eggs of the grebe, cormorant, or crocodile may be supposed to receive their shape in such circumstances.

(6) When the egg is subject to the peristaltic contraction of the oviduct during its formation, then from the nature and direction of motion of the peristaltic wave the pressure will be greatest somewhere behind the middle of the egg; in other words, the tube is converted for the time being into a more conical form, and the simple result follows that the anterior end of the egg becomes the broader and the posterior end the narrower.

(7) With a given shape and size of body, equilibrium in the tube may be maintained under greater radial pressure towards one end than towards the other. For example, a cylinder having conical ends, of semi-angles θ and θ' respectively, remains in equilibrium, apart from friction, if $p\cos^2\theta = p'\cos^2\theta'$, so that at the more tapered end where θ is small p is large. Therefore the whole structure might assume such a configuration, or grow under such conditions, finally becoming rigid by solidification of the envelope. According to the preceding paragraph, we must assume some initial distribution of pressure, some squeeze applied to the posterior part of the egg, in order to give it its tapering from. But, that form once acquired, the egg may remain in equilibrium both as regards form and position within the tube, even after that excess of pressure on the posterior part is relieved. Moreover, the above equation shows that a normal pressure no greater and (within certain limits) actually less acting upon the posterior part than on the anterior part of the egg after the shell is formed will be sufficient to communicate to it a forward motion. This is an important consideration, for it shows that the ordinary form of an egg, and even the conical form of an extreme case such as the guillemot's, is directly favourable to the movement of the egg within the oviduct, blunt end foremost.

(8)[1] The mathematical statement of the whole case is as follows:—In our egg, consisting of an extensible membrane filled with an incompressible fluid and under external pressure, the equation of the envelope is $p_n + T\left(\frac{1}{r} + \frac{1}{r'}\right) = P$, where p_n is the normal component of external pressure at a point where r and r' are the radii of curvature, T is the tension of the envelope, and P the internal fluid pressure. This is simply the equation of an elastic surface where T represents the coefficient of elasticity; in other words, a flexible elastic shell has the same mathematical properties as our fluid, membrane-covered egg.

The above equation is the *equation of equilibrium*, so that it must be assumed either that the whole body is at rest or that its motion while under pressure is not such as to affect the result. Tangential forces, which have been neglected, could modify the form by alteration of T. In our case we must, and may very reasonably, assume that any movement of the egg down the oviduct during the period when its form is being impressed upon it is very slow, being possibly balanced by the advance of the peristaltic wave which causes the movement, as well as by friction.

The quantity T is the tension of the enclosing capsule—

[1] The mathematical statement is not my own; I am indebted for it and for other help in the editing of this paper to my colleague, Prof. W. Peddie.

the surrounding membrane. If T be constant or symmetrical about the axis of the body, the body is symmetrical. But the abnormal eggs that a hen sometimes lays, cylindrical, annulated, or quite irregular, are due to local weakening of the membrane, in other words, to asymmetry of T. Not only asymmetry of T, but also asymmetry of p_n, will render the body subject to deformation, and this factor, the unknown but regularly varying, largely radial, pressure applied by successive annuli of the oviduct, is the essential cause of the form, and variations of form, of the egg. In fact, in so far as the postulates correspond near enough to actualities, the above equation is the equation of *all eggs* in the universe. At least this is so if we generalise it in the form $p_n+\frac{T}{r}+\frac{T'}{P'}=P$ in recognition of a possible difference between the principal tensions.

(9) In the case of the spherical egg it is obvious that p_n is everywhere equal. The simplest case is where $p_n=0$, in other words, where the egg is so small as practically to escape deforming pressure from the tube. But we may also conceive the tube to be so thin-walled and extensible as to press with practically equal force upon all parts of the contained sphere.

(10) If while our egg be in process of conformation the envelope be free at any part from external pressure (that is to say, if $p_n=0$), then it is obvious that that part (if of circular section) will be a portion of a sphere. This is not unlikely to be the case actually or approximately at one or both poles of the egg, and is evidently the case over a considerable portion of the anterior end of the plover's egg.

(11) In the case of the conical egg with spherical ends, as is more or less the case in the plover's and the guillemot's, then at either end of the egg r and r' are identical, and they are greater at the blunt anterior end than at the other. If we may assume that p_n vanishes at the poles of the egg, then it is plain that T varies in the neighbourhood of these poles, and, further, that the tension T is greatest at and near the small end of the egg. It is here, in short, that the egg is most likely to be irregularly distorted or even to burst, and it is here that we most commonly find irregularities of shape in abnormal eggs.

(12) If one portion of the envelope were to become practically stiff before p ceases to vary, that would be tantamount to a sudden variation of T, and would introduce asymmetry by the imposition of a boundary condition in addition to the above equation.

(13) Within the egg lies the yolk, and the egg is invariably spherical or very nearly so, whatever be the form of the entire egg. The reason is simple, and lies in the fact that the yolk is itself enclosed in another membrane, between which and the outer membrane lies a fluid the presence of which makes p_n for the inner membrane practically constant. The smallness of friction is indicated by the well-known fact that the "germinal spot" on the surface of the yolk is always found uppermost, however we may place and wherever we may open the egg; that is to say, the yolk easily rotates within the egg, bringing its lighter pole uppermost. So, owing to this lack of friction in the outer fluid, or white, whatever shear is produced within the egg will not be easily transmitted to the yolk, and, moreover, owing to the same fluidity, the egg will easily recover its normal sphericity after the egg-shell is formed and the unequal pressure relieved.

GEODETIC INVESTIGATIONS IN THE UNITED STATES.[1]

THE report of the U.S. Coast and Geodetic Survey for 1907 has just been received. For the details of the extensive cartographic work of the bureau in the United States proper, Alaska, Porto Rico, and the Philippines, as well as for the account of the progress of the primary triangulation and levelling of precision, the report itself must be consulted. Certain important work of the survey receives bare mention, as, for instance, the results of the investigation of the earth's figure, based on geodetic operations in the United States. This is owing to the fact that these results were communicated to the International Geodetic Association in a preliminary report which has been published.

Soon after the California earthquake of April 18, 1906, it became evident that the permanent horizontal displacements of large areas covered by triangulation in California had so changed the lengths and directions of the lines joining the triangulation stations as greatly to diminish the value of the triangulation for its primary purpose as a framework for future surveys. During the year, therefore, new triangulation extending from Point Arena to stations south of Monterey Bay was done, which serves to restore the value of the old triangulation by determining the new positions of sixty-one of the old triangulation stations. The triangulation included the Farallon Lighthouse, twenty-two miles to the westward of the great fault accompanying the earthquake, and the stations Mocho and Mount Diablo, thirty-three miles to the eastward of the fault. The new triangulation serves to trace the permanent distortions and displacements of the earth's crust for many miles back from the fault in each direction, and to show that they follow certain regular laws. This is the most extensive and accurate determination by triangulation of the effects of an earthquake which has yet been made anywhere in the world. Appendix 3 of the report gives a full report of this investigation.

A report on the measurement of six primary bases with steel and invar tapes in 1906 is printed as Appendix 4. The invar (nickel steel) tapes have a coefficient of expansion about 1/28th that of steel tapes, hence it is much less difficult to keep the temperature errors within the required limit with invar tapes than with steel tapes. Invar tapes had not been used in the United States until 1906 in primary base measurements. The thorough tests of these tapes, made by using them on six bases in conjunction with the steel tapes formerly used, showed that measurements may be made more conveniently, accurately, and at smaller cost per mile than with the steel tapes, and that the invar tapes are sufficiently durable and stable for safe field use. This demonstration is believed to be a distinct step in advance in base measurement.

The steady progress in the magnetic survey of the United States, and accumulation of magnetic observational data, as mentioned in Appendix 5 of the report, should be of special interest to the surveyor and the navigator, as well as to those pursuing the study of the science of terrestrial magnetism. Throughout the year the measurements of the earth's magnetism were made at places distributed over a majority of the States and territories of the United States, and at numerous places at sea along the Atlantic and Pacific coasts of North and South America, and in Porto Rico and the Philippines. Important information was secured in the equatorial regions. Numerous "repeat" observations were made throughout the country in order to follow as closely as possible the secular change in the magnetic elements. Five magnetic observatories were maintained in continuous operation, and important seismological data were also obtained. The facilities of the observatories were afforded to all investigators who desired to make standardisation comparisons of their instruments, and in response to numerous requests information or observational data was furnished for practical application or for use in special investigations of terrestrial magnetism and allied phenomena.

Appendix No. 6, constituting the concluding portion of a manual of tides, treats of the flow of water, of river tides, tidal currents, permanent currents, annual inequality, lake tides, seiches, and miscellaneous tidal matters. Charts of co-current lines are given for the principal marginal waters along the Atlantic coast of the United States. The numbers upon these lines show the times of the maximum flood current. The dependence of the permanent ocean currents and the annual height inequality upon the prevailing winds is briefly pointed out. Seiches are shown to exist in harbours and other tongues of water, as well as in lakes, but their character is fundamentally different in some respects. The analyses of observations upon the tides of Lake Superior show that they follow closely the equilibrium theory, although the

[1] "Report of the Superintendent of the Coast and Geodetic Survey showing the Progress of the Work from July 1, 1906, to June 30, 1907." (Washington: Government Printing Office, 1907.)