Whilst the photographs furnish abundant material for the further study and consideration of the normal movements of a variety of animals and of man, there are some in the series which are especially suggestive of new lines of research. Amongst these are the series illustrating locomotion in man in diseased conditions, such as locomotor ataxia, and lateral sclerosis. A distinct line of scientific inquiry is suggested by those photographs which represent men, women, or children, in the course of movement which is associated with emotion. A new chapter in Mr. Darwin's "Expression of the Emotions" could be written by the aid of some of these series, and a most interesting line of investigation, to be followed up by new photographic analysis, is indicated. Not only is the play of facial muscles connected with the series of emotions of the base-ball player recorded in half a dozen pictures taken between the moment of raising the bat and striking the ball, but in other photographs we have unconscious expression of mental condition exhibited by rapidly transient movements of the whole body. These are especially noticeable in the series of a naked child approaching a stranger in order to offer to her a bunch of flowers, and in the three or four phases of movement of the young woman springing from her bath after she has been unexpectedly "douched" from head to foot with a bucket of ice-cold water.

It is clear enough that the correlation of movements of facial and limb muscles in the expression of emotion can be best studied by such instantaneous photographic series as the Muybridge publication contains; and, as Darwin, with his marvellous insight, showed, such study of emotional states furnishes some of the most important evidence with regard to the relationship of man and animals.

It is no doubt true that the immediate result of Mr. Muybridge's work, from the scientific point of view, is the desire which they evoke to apply this method systematically and experimentally to a variety of subjects of investigation. The present pictures have great value, and many of them great—indeed astonishing—beauty (*e.g.* the wrestling boys). They should be purchased by those who can afford them for the purpose of bearing a share in the expense of so important an experiment as that set agoing by the University of Philadelphia. But we should like to see the batteries turned on again, and a number of new subjects investigated. Terrestrial locomotion has been gradually developed through an amphibious transition from aquatic locomotion. The movements of fishes, of tadpoles, salamanders, turtles, and crocodiles should be included in the scope of any study of vertebrate limb-play. But even more necessary is it that in future the scientific method, of theory, test hypothesis, and experiment, should be followed in the application of the photographic batteries, so that each set of photographs may definitely prove some particular point or points in the orderly development of a general doctrine.

For my own part, I should greatly like to apply Mr. Muybridge's cameras, or a similar set of batteries, to the investigation of a phenomenon more puzzling even than that of "the galloping horse." I allude to the problem of "the running centipede." I have a series of drawings made from large West Indian specimens which I kept alive for some time in my laboratory at University College. At the same time I made drawings and recorded as well as I could the movements of the legs of *Peripatus capensis*, which was also (through Mr. Sedgwick's kindness) living in my laboratory. I am anxious to compare with these movements the rapid rhythmical actions of the parapodia of such Chætopods as Phyllodoce and Nephthys on the one hand, and the curious "gait" of the Hexapod insects, of which Prof. Lloyd Morgan has already written a few words in NATURE. Passing on to scorpions and spiders, and then to shrimps, lobsters, and crabs, we should eventually possess the outlines of an investigation of Arthropod locomotion. There is no doubt that the Muybridge battery would be the one effective means of study in the case of the centipede and marine worms, although in some cases a good deal may be done by intent observation and hand-drawn records. The difficulty of this investigation, and the disastrous results in the way of perplexity which follow from too close an application to it *without* the aid of Mr. Muybridge, is set forth in certain lines, the authorship of which is unknown to me or to the friend who kindly sent them to me on hearing that I was studying the limb-play of centipedes. May I be pardoned for quoting them, and associating in this way fancy with fact, whilst expressing the hope that Mr. Muybridge will take steps to prevent any such catastrophe in the future as these lines record!

A centipede was happy—quite!
Until a toad in fun
Said, "Pray which leg moves after which?"
This raised her doubts to such a pitch,
She fell exhausted in the ditch,
Not knowing how to run.

E. RAY LANKESTER.

ON THE DETERMINATION OF MASSES IN ASTRONOMY.

IN the *Annuaire du Bureau des Longitudes* for 1889 occurs an interesting article by M. Tisserand on the methods employed in the measurement of the masses of the heavenly bodies. The writer begins with an explanation of the elementary principles leading to the law of Newton that *all bodies attract one another with a force which is proportional to their masses and inversely as the square of the distance between them.* He proves, in a popular manner, that this force is equal to the product of mass into acceleration; and therefore, speaking theoretically, to compare the masses of two bodies it is only necessary to apply directly to each of them the same force and to measure the acceleration produced; or, if a body be placed in succession at the same distance from the sun and the earth it will be attracted towards each with a force which is proportional to their masses. Hence, since the space traversed by a body is directly proportional to the acceleration, if during the first second the body fell 330 metres towards the sun, and 1 millimetre towards the earth, it would be obvious that the sun had a mass 330,000 times greater than the earth. Similarly, by applying the law of inverse squares, the relative masses of the sun and earth might be found when the distance of the body from each was not the same. We find that the earth falls towards the sun 10·60 metres in a minute, and that our moon falls towards the earth 4·90 metres in the same time. But the earth is 386 times nearer the moon than it is to the sun, so correcting for difference of distance we get $\frac{4\cdot 9}{(386)^2} =$ 0·0000328 metre as the fall of the moon towards the earth in a minute. Therefore the sun's mass is to the earth's mass as 10·6 is to 0·0000328—that is, 1/323,000. This method is, however, dependent on our knowledge of the distance of the sun and moon. The same calculation may be employed, without modification, to find the mass of a planet having a satellite. Kepler's third law is used for expressing the mass m of a planet in terms of the sun's mass M. The formula being:—

$$\frac{m}{M} = \left(\frac{a'}{a}\right)^3 \left(\frac{T}{T'}\right)^2,$$

where a is the semi-major axis of the planet's orbit and T the time of revolution round the sun; a' and T' representing similar terms for the satellite.

In the case of Jupiter, observations of the four satellites may be made and the mean result taken. A recent determination by M. Schur gives the value 1/1047·232 as compared with the sun.

Saturn's mass has been obtained from observations of its two largest satellites, Titan and Japetus. Bessel's researches made it 1/3502, whilst Struve found a value 1/3498. This gives roughly the fraction 1/3500 as the planet's mass.

Newcomb deduced, from observations of the four satellites of Uranus, a mass 1/22,600, and by observations of Neptune's one satellite found a value 1/19,380 as the planet's mass.

Before the discovery of the Martian satellites by Hall, the mass of the planet was a matter of great uncertainty. The discoverer's observations of the satellites led him to assign 1/3,100,000 as the mass of Mars, a result probably not far from the truth.

The Masses of Planets without Satellites.

For the determination of the masses of Mercury and Venus a different and much less exact method of procedure is used. If the masses of Venus and the earth were known, the perturbations they would give to the motion of Mercury could be easily calculated. Let the orbit be calculated which Mercury would have if it existed alone with the sun, and then let its true path be found. By comparing the two paths the disturbing effect of Venus and the earth may be also found. In a similar manner the calculated and true paths of Venus may be compared; the disturbing masses being Mercury and the earth. In this way a series of equations is obtained from which the masses of Mercury and Venus may be isolated. The result in the case of Mercury is 1/5,000,000.

The Mass of Jupiter.

M. Tisserand gives a full discussion of the methods of determining Jupiter's mass, which, being so considerable, shows itself in its effects upon many bodies of our system.

Beginning with comets, he quotes the comet of Lexell as a typical case. In 1769 this comet approached very near to Jupiter, and by the planet's action was brought within our range of vision and given a period of $5\frac{2}{3}$ years. Its return in 1776 could not be observed, and before another revolution could be completed, viz. in 1779, the comet was shown by Lexell to have again approached very near to Jupiter, nearer than the fourth satellite. The probable result was that the elliptic orbit was transformed into a parabolic one by the predominance of the planet's attraction over that of the sun, and the comet left our system, never to return.

From observations of the perturbations of Winnecke's comet, M. de Haertl found Jupiter's mass to be 1/1047·175, whilst Faye's comet gave the value 1/1047·788.

Some of the asteroids approach very near to Jupiter, amongst these are (24) Themis, (49) Pales, and (153) Hilda, and from observations of the motion of Themis the planet's mass has been found 1/1047·538. Estimations have also been made by observations of the perturbations of Saturn, but, since the necessary series should cover a cycle of 900 years, and only 120 years are available, the method is not yet very exact. This accounts for the anomalous result 1/1070·5 found by Bouvard in 1821.

It is also mentioned that Airy, from 1832 to 1836, observed the motion of the fourth satellite and found for Jupiter a mass 1/1047·64, whilst Bessel in 1841 found 1/1047·905.

The following are the masses of the planets given by M. Tisserand, with the earth as unit:—

Mercury	$\frac{1}{16}$	Jupiter	310
Venus	$\frac{4}{5}$	Saturn	93
The Earth ...	1	Uranus	14
Mars	$\frac{1}{10}$	Neptune	17

Cavendish's method for determining the mean density of the earth is next explained, and it is shown that, knowing the relative masses of the planets as given in the above table, we may express their weights in pounds.

Determination of the Masses of Asteroids.

Some pages are devoted to a discussion of these small bodies. It has been found that the effect of each asteroid is to give a motion to the line of apsides of Mars's orbit. The sum of these effects is the same as would be produced by taking a mean orbit of all the asteroids and distributing them uniformly in it. Leverrier made a calculation on the assumption that the total mass of the asteroids was equal to that of the earth, and he found that, if they had a mass only equal to one-fourth that of the earth, Mars would be disturbed by an amount clearly perceptible to us. M. Swedstrup has found the assumption too high, and has calculated that the sum of all the asteroids known up to August 1880 is only about 1/4000 of the earth's mass, or about 1/50 that of the moon. Three comparatively large asteroids have had their diameters measured. Sir W. Herschel found the apparent diameter of Ceres and Pallas to be 0″·35 and 0″·24 respectively; the equivalent in kilometres being 250 and 170. For Vesta, Mädler found an apparent diameter 0″·65, or 470 kilometres. If these bodies be supposed to have the same density as the earth, their proportional masses will be found—Ceres, 1/130,000; Pallas, 1/420,000; Vesta, 1/20,000. By photometric means, the diameters of these asteroids have been determined by Prof. Pickering, and also of some much smaller, such as Eve, with a diameter of 23 kilometres, and Menippe, whose diameter is only 20 kilometres, being no larger than the meteorites met by the earth daily.

Determination of the Masses of Satellites.

The method of determining the mass of our satellite based upon the fact that it is the common centre of gravity of the earth and moon, and not the earth itself, which moves in an elliptic orbit round the sun, is fully explained by the writer. By means of it, the mass of the moon has been found 1/81 that of the earth. Observations of the proportion of lunar to solar precession, as well as lunar and solar tides, also furnish a means of determining the moon's mass.

Masses of Jupiter's Satellites.

These bodies, so proportionally small, the greatest being only 1/10,000 of the planet's mass, cannot have their masses accurately determined by the measurement of the angle subtended by the line joining the planet to the common centre of gravity; for, since the line joining the planet to its satellite is divided into parts inversely proportional to their masses in order to find this point, the line in question is very small. Hence the best method of determining the measures of the satellites in this case is, according to M. Tisserand, by measurement of the disturbances upon each other. This method was propounded and worked out by Laplace with the following results, in terms of Jupiter's mass:—

1st satellite ...	1/59,000	3rd satellite ...	1/11,000
2nd ,, ...	1/43,000	4th ,, ...	1/23,000

This proportion would give the third satellite a mass about double that of our moon.

The Satellites of Saturn.

Titan, as its name suggests, is the largest of the family, and consequently exercises a considerable influence over the others. Prof. Hall found that under its action the major axis of Hyperion's orbit made a complete revolution in about eighteen years. Newcomb, Tisserand, Stone, and Hill have each investigated the matter, but it is mainly due to the two latter observers that Titan's mass has been found 1/4700 that of Saturn. Prof Pickering has compared the diameters of the other satellites with that of Titan by photometric means, and, if they all have the same density, the following numbers represent their masses, Saturn's mass being unity :—

Mimas ...	... 1/500,000	Rhea ...	... 1/32,000
Enceladus	... 1/270,000	Hyperion	... 1/1,800,000
Tethys ...	... 1/75,000	Japetus	... 1/110,000
Dione ...	... 1/85,000		

The mass of Saturn's rings has been found 1/620 that of the planet by observations of the rotational movement which it imparts to the major axes or line of apsides of the satellites.

The masses of the satellites of Uranus and Neptune are not known to any degree of accuracy. The two satellites of Mars have had their masses deduced from photometric measures, but they are so small—about 10 kilometres in diameter, being no larger than the smallest known asteroids—that the numbers found cannot be very exact.

Masses of some Stars.

M. Tisserand rightly gives a dissertation, full and clear withal, of this subject. Sir William Herschel was the discoverer of the relative motions of binary stars in 1802. The obvious conclusion from such a discovery was that the laws of gravitation were universal. Truly, it was not logical to make such an assumption, and some objections have been raised, but the *onus probandi* rests with those who doubt it. In considering the motions of the components of a binary star system, it must be remembered that they revolve round a common centre of gravity. It is usual, however, to consider the principal stars as fixed, but augmented by the mass of its satellite, the latter having an orbit which is the mean of the two. Knowing the fall of the satellite to its primary in one second, we may calculate what it would be if at the same distance from it that the earth is from the sun. But we know by how much the satellite would fall towards the sun, since it would fall as the earth. Hence the consideration of the two falls will give the sum of the masses of the stars in terms of the sun's mass.

The following is the formula employed :—

$$\frac{m + m'}{M} = \left(\frac{a}{p}\right)^3 : T^2 ;$$

m and m' are the masses of the two stars ; M that of the sun ; a is the angle, expressed in seconds, which is subtended at the earth by the semi-major axis of the satellites orbit ; p is the "annual parallax" of the binary group expressed in seconds ; whilst T is the time in years of one revolution of the satellite. These are the numbers that have been obtained for four groups, the distances of which from the earth are known :—

Star.	Parallax.	Magnitude.	Sum of Masses.
α Centauri	... 0″·80	... 1	... 1·8
η Cassiopeiæ	... 0″·15	... 4	... 8·3
70 p Ophiuchi	... 0″·17	... 4·5	... 2·5
o^2 Eradini	... 0″·22	... 4·5	... 1·0

Sirius and its Companion.

The article concludes with a complete history of the work which suggested the existence of a companion to Sirius. Bessel had determined the proper motion of thirty-six stars by observations of their right ascensions and comparing with Bradley's, but he found that in the case of Sirius the hypothesis of a uniform variation was irreconcilable with them, and suggested that the irregularities might be produced by the action of some obscure body. As a proof that obscure bodies exist in the heavens, the case of Tycho Brahé's Nova is quoted, this being a star which suddenly appeared in Cassiopeia in 1572, and then gradually disappeared without change of place. After Bessel's death Peters found that it was possible to account for the irregularities by the supposition that Sirius described an orbit in fifty years whose eccentricity was about 0·8. Safford, in 1861, from a discussion of the declinations of Sirius, came to the same conclusion as Peters ; whilst Auwers, in 1862, after investigating about 7000 right ascensions and 4000 declinations, found the time of revolution to be forty-nine years, and the eccentricity 0·601. At the same time as Auwers was engaged with his calculations, Alvan Clark discovered a small star only about 10″ from Sirius, which appeared to be the companion. Future considerations supported the surmise, and proved that this body was precisely what was required to account for the orbit of Sirius round the common centre of gravity.

If Gill's measure of the parallax of Sirius be taken as correct, viz. 0″·38, the sum of the masses of the two stars is equal to 4·4 that of the sun. Sirius has about twice the mass of its companion, and they are separated by a distance a little more than twice the distance of Uranus from the sun.

From a discussion of similar little irregularities in the proper motion of η Cassiopeiæ, Struve found its mass to be 6·6 compared with the sun, whilst its companion was 1·7 times as great.

A reflection on the inability of astronomers before Copernicus to make such measurements as those preceding, concludes this retrospect.

R. A. GREGORY.

A NEW FORM OF REGENERATIVE GAS-LAMP.

FROM the time when Mr. Frederick Siemens first introduced regenerative gas-burners, now ten years ago, down to the present day, this method of burning gas for illuminating purposes has been adopted all over the world, and has come to the assistance of the gas companies by illustrating the fact that, with proper appliances, gas can produce the same brilliant effects as are ordinarily produced by means of electricity, at much less expense both as regards first cost and working. We would explain that in regenerative lamps the heat which is usually wasted in ordinary burners is to a great extent returned to the flame. The manner in which this result is brought about is by intercepting, by means of a regenerator, the heat passing away with the products of combustion, and applying the heat thus saved to raise the temperature of the air which feeds the flame, thus increasing the temperature of the latter, and its illuminating power ; for it may be admitted that the higher the temperature of a body rendered incandescent by heat, the greater is the proportion of light rays emitted out of the total amount of energy radiated. This being the case, the amount of heat carried from such a source of illumination to the surrounding atmosphere by conduction and convection must be less than in the case of a burner consuming the same quantity of gas burning at a lower temperature, which circumstance, combined with the well-known economy resulting from the use of these burners, accounts to a great extent for the popularity which regenerative lamps have attained.

Mr. Frederick Siemens has lately introduced a new form of regenerative gas-lamp, which we understand is highly efficient, and is in consequence being largely adopted ; its construction is shown in the accompanying diagram. It is known as the Siemens inverted type, and is produced in various ornamental designs, which have been much admired. After passing through the governor A, and the tap b, the gas enters an annular casing ; in the lower portion of this, a number of small tubes are fixed, forming the burner, from which tubes the gas passes out in separate streams. By this means, combustion of a very perfect character takes place, as the air is directed round each separate stream of gas, and thus enabled to combine most intimately with it. Within the circle of small tubes is a trumpet-shaped porcelain tube, d, and around the outside and inside of this the gas burns downwards and slightly upwards, as indicated by arrows,