larger surfaces from which to manœuvre, and consequently can have a higher minimum speed.

This increase of top speed, coupled with the extension of speed range, has brought many minor troubles that have called for special scientific investigations. The difference between minimum 'take-off' speed and normal 'cruising' speed is now so marked that a variable pitch propeller is necessary if maximum efficiency is demanded under all conditions. This has proved to be practicable in metal, but up to now is about three times the weight of a fixed pitch wooden airscrew. Servo-assisted controls are often necessary on both large and fast machines, and the correct relationship between aerodynamic balance, servo-action and manual operation of the various control surfaces, and their correlation with each other, is not easy to establish.

Considering the future, there are three main lines of progress: further reduction of drag, reduction of structure weight and improvement in engine performance. The margin between the present attained minimum drag and pure skin friction is small, and no great improvement in this is likely unless some revolutionary discovery points to a means of compelling the boundary layer flow to remain laminar over a much greater portion of a surface. Also as the speed of a body approaches the speed of sound in air the effect of compressibility causes a rapid rise in drag. The world's speed record is already six-tenths of the speed of sound. The problem of cooling will also be complicated by the natural rise in temperature of a body moving rapidly through air. Reduction of structure weight of a large order does not seem probable, unless research in atomic physics brings the production of synthetic materials with properties vastly superior to those in use at present. Improvements in engine performance will only be of a detailed order, unless something revolutionary in the manner of converting the latent energy in fuel into power is discovered.

Light and Temperature and the Reproduction of Plants*

By Prof. V. H. Blackman, F.R.S.

THE path of the plant physiologist who sets out to make accurate measurements of the effect of light and temperature on the growth and multiplication of the plant is beset with many hindrances. In the first place, the plant, the system which he investigates, is never completely reproducible. No two living things are exactly alike, and the variability of the biologist's material is an ever-present threat to the accuracy of his work. Something can be done to reduce the variability by selecting the progeny of a single individual, using clonal or pure-line plants. After the most careful selection, however, some variability inevitably remains; this must be evaluated by statistical methods.

EFFECT OF LIGHT

With the study of the influence of such an external condition as light, other difficulties arise. Sunlight, as we receive it, is inconstant in quantity and variable in quality. In exact studies of the action of light which are to last for more than the briefest period, one must inevitably resort to artificial sources of illumination, since they alone can be held constant for long periods. Unfortunately, electric light sources, though wanting nothing in steadiness, are very different from sunlight. No illumination engineer has yet achieved the 100 per cent efficiency of the 'cold' light of the glow-worm which includes no heat rays. Caution must therefore be exercised in applying to plants grown under natural conditions the physiological results obtained with artificial light sources.

Although in experimental work the constancy of the illuminant can be assured by the selection of artificial light, the uniformity of illumination of the whole plant surface is much more difficult of accomplishment. If the light source is removed so far from the plant that its upgrowth results in no marked difference of intensity between the upper and lower portions, then the illumination received is generally of too low intensity. When considering this difficulty some ten years ago, it was evident that the need was for a plant which had no upward growth but spread only horizontally. It was then realised that, in the ordinary duckweed (*Lemna minor*) of our ponds, Nature has provided such a plant. From that time onward, the physiological behaviour of this plant has been intensively studied in the laboratories of the Imperial College of Science.

By placing the plant under carefully controlled conditions, a regular, continuous growth can be

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* Substance of the Friday Evening Discourse delivered at the Royal Institution on February 21.

ensured, and the effect of light and temperature upon it can be followed very simply. One has only to start a culture with a certain number of fronds, the frond being the unit of growth, and count every day the number of fronds present and so find how favourable or unfavourable are different temperatures and different light intensities for its multiplication.

The question arises as to the measure of the rate of multiplication to be employed. It is evident that as all fronds are multiplying, the more fronds there are at any given moment the more will be produced—in other words, the number produced in the culture during any given period is dependent upon the number existing in the culture at the beginning of that period. The multiplication of duckweed thus obeys the 'compound interest law', and can be expressed in a simple mathematical way. With money at compound interest the interest is added periodically, usually at annual periods. Nature, however, does not usually work spasmodically, so we find that as duckweed grows steadily in continuous light the new material which results is added continuously.

With the new material added continuously, the relation between the number of fronds at the beginning and end of any given period can be expressed by the equation $N_t = N_0 e^{rt}$ where N_t is the number given at the end of the period t, N_0 the initial number, r is the rate of compound interest and e the base of natural logarithms.

TABLE I

Day.	Frond numbers.	
	Observed.	Calculated.
0	100	86
1	127	122
2	171	173
3	233	245
4	323	368
5	452	493
6	654	699
7	918	990
8	1406	1404
9	2150	2137
10	2800	2822
11	4140	4001
12	5760	5672
13	8250	8042

Table I from the work of Ashby and Oxley in the Imperial College laboratories shows the rates of multiplication observed and those to be expected if the rates are perfectly regular; the temperature was 24° C. and the illumination 500 foot-candles. The discrepancies between expectation and performance are only slight.

Using the formula applying to the increase in frond number or the relative multiplication rate we find in another experiment, one by H. L. White, that $N_t = N_0 e^{0.349t}$ where t is measured in days. The rate of interest was 34·9 per cent per day; this implies a speed of duplication of almost exactly two days, actually 1·99 days. Starting with a hundred, one would at this rate achieve a million in a little more than twenty-six days. For a flowering plant this rate is sufficiently remarkable; it is, however, nothing to that of bacteria, which may double their number every half-hour and so increase from a hundred to a million in about seven hours. If not the actual numbers but the logarithms of the frond numbers are plotted against time, then with a perfectly regular multiplication rate, all the points should fall on a straight line. In Fig. 1, from Ashby and Oxley's results, it is seen how closely the points correspond with a straight line. It is a curve such as one would expect in a purely physical or chemical experiment; it shows how by using the greatest care biological material may be made to yield data of very high accuracy.

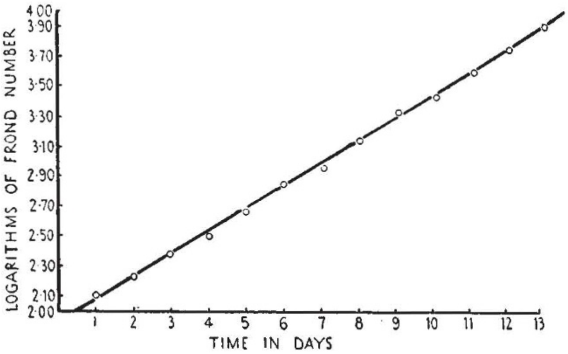

FIG. 1. Logarithms of frond number of *Lemna minor* plotted against time in days. The figures are taken from an experiment at 24° C. and 500 foot-candles. The straight line drawn through the points corresponds to the equation $y = 0{\cdot}152x + 1{\cdot}935$. (From Ashby and Oxley.)

One of the most surprising products of the work on duckweed is the discovery of the very low light intensity to which it is attuned. When one considers that the duckweed floating on the surface of the water is often exposed to direct sunlight with a brightness of many thousand foot-candles, it is unexpected to find that *above* 750 *foot-candles increase of intensity has no value*. At 1,400 foot-candles, far below direct sunlight, there is even an injurious effect.

A marked difficulty of research in plant physiology which is not met with in physical and chemical work is the change in the plant as we subject it to different conditions; the system we are studying is altered by the experimental conditions to which we expose it. With high light intensities we get thick fronds and with low light intensities thin ones, just as with sun and shade leaves in our gardens.

Another interesting phenomenon has come to light. As is well known, the green plant is dependent on light for the manufacture of its food materials, which are produced from water and the carbon dioxide of the air by the process of photosynthesis. Since multiplication of the plant requires a supply of new raw material, it might be expected that the rate of multiplication would be dependent on the rate of photosynthesis. One finds, however, that there is no close relationship between the two. For example, they respond very differently to the effect of light intensity; rate of photosynthesis is still rising at a brightness of 1,600 foot-candles while the multiplication rate ceases to increase above 750 foot-candles. Light therefore affects the multiplication rate not only through food supply but also directly.

So regular is the growth of the plants under carefully controlled conditions that one can use the compound interest principle in the study of a *deleterious* factor. In some experiments, also by H. L. White, in which the plants were starved of potassium, an element essential for their growth, it was found that the growth-rate fell off at a constant rate as starvation set in. Thus with full nutrition the rate of compound interest was 33 per cent per day, while under potassium starvation this rate fell off at a rate of 15 per cent compound *decrement* per day.

PHOTO-PERIODISM

If we turn our attention to plants which reproduce themselves not by budding, as in duckweed—a process of vegetative reproduction—but by sexual reproduction, that is, by the function of flowers and fruits, we find again that light and temperature have profound effects.

Light is, of course, necessary for the unfolding of the flower buds, and often for their growth, but of recent years a much less obvious relationship has been established between light and the flowering of plants. It is, of course, well known that we have spring-flowering plants like *Viola*, *Anemone* and *Hepatica*, autumn-flowering forms like *Chrysanthemum*, *Nicotiana* and *Dahlia*, and numerous plants which flower in the summer. It used to be assumed that the time of flowering was determined by the temperature or by the relationship between temperature and intensity of light. The actual controlling factor was determined only in 1918 in the United States. A certain giant variety of tobacco, grown in Maryland, known as Maryland Mammoth, generally failed to flower or was cut down by frost before it had seeded. It could not therefore be multiplied by seed. In 1918 a potted plant of this variety happened to be brought into the greenhouse in the autumn. Protected thus from the frost, it flowered in November and later set seed. Experiments were then made with seedlings, and it was found that if seeds were sown in the autumn in the greenhouse they flowered very early, but if sown in the spring the plant grew vegetatively throughout the summer, only flowering in the autumn. Close investigation showed that the effect was due neither to temperature nor to light intensity, but the flowering was a response to the brevity of the autumn day. The plant is a *short-day* plant, that is, it will only flower if exposed to days of not more than 12 hours. Such plants when grown in temperate conditions flower only in the autumn or spring. To this class belong *Nicotiana*, *Cosmos*, *Poinsettia*, some species of *Ipomœa*, *Bougainvillea*, and the sub-tropical cereals such as maize, sorghum and other millets. With some varieties of soybean such as Biloxi the time to flower can be shortened from the 120 days required under normal conditions of summer illumination to 28 days when the period of daylight illumination is artificially shortened to 12 hours.

Sharply contrasted with these are the *long-day* plants which require for flowering a period of 14–15 hours, and thus bloom normally in the long summer days. To this group belong the spring varieties of the temperate cereals, runner beans, red clover, garden pea, lettuce, potato, the evening primrose, *Cassia*, *Sedum*, *Rudbeckia*, etc. Garner and Allard, who were the first to discover this response of flowering to length of day, have termed it *photo-periodism*.

Valid generalisations in biology are notoriously difficult of attainment, so that one is not surprised to find that there are many other plants which are so moderate in their demands that they may be described as indeterminate; they flower in both long and short days. To this class belong many widely distributed weeds, such as dandelion, chickweed and groundsel. In the tropics only short days are available, whereas in high latitudes short days are only available at times at which the temperature is liable to be too low for flowering. A plant to be useful both in the tropics and under outdoor conditions in high latitudes must be indeterminate in its light needs, that is, show no photo-periodic response. Plants like *Poinsettia* and *Bougainvillea*, which come from Central America, if they are to flower can tolerate no more than 12 hours of light. In our latitudes therefore they have no horticultural value except under warm greenhouse conditions, since they flower in the autumn and winter.

Viewed from the angle of the horticulturist, photo-periodism is of great interest, for it places in his hands a new power of control. By the use of artificial light for lengthening the period of illumination in spring and autumn, 'long-days' can be provided for flowering out of season. Similarly, by reducing the day to one of ten hours by the protection of the plants from light during a portion of the day, autumn blooming can be induced in summer. In the case of Maryland Mammoth tobacco, once the secret of its sterility had been penetrated the economic problem was easily solved. Seed production is achieved in Florida where there are short days without the rigours of an autumn climate.

To the plant physiologist, on the other hand, photo-periodism presents a most baffling problem. When considering a reaction in the plant induced by light, he attempts at first to interpret it in terms of chemistry and therefore expects the 'product law' to hold. The effect should depend on the quantity of light energy received, and so should depend both on the time of exposure and the intensity of light. With the photo-periodic reaction we find no such relationship. It might be thought at first sight that the long-day plants require a greater light-supply for their flower formation than do the short-day ones. But this cannot be the explanation, for with long-day plants an exposure to a 10-hour day can be continued for a period which will give a total light supply much higher than is given by an exposure to a 14-hour day; yet flowering will result in the second case and not in the first. *Duration of illumination* rather than quantity of light is the important thing, and this is exceedingly difficult to interpret in terms of physiology. In the case of short-day plants there is some reason for believing that it is the corollary of the period of illumination, namely, the *period of darkness*, to which attention should be directed.

(*To be continued.*)

André Marie Ampere, 1775–1836

By Dr. D. McKie, University College, London

ANDRÉ MARIE AMPÈRE was born in Lyons on January 20, 1775, and died at Marseilles on June 7, 1836. His early childhood was spent in the country near his birthplace and his first studies were directed by his parents. A childish pastime of carrying out complicated arithmetical calculations with little pebbles was prophetic of his future devotion to mathematical studies, a devotion that was evidenced again when his father, a retired merchant, began to teach him Latin; for the young Ampère quickly showed his great preference for mathematics, whereupon his father wisely allowed natural inclination to take its own course, providing the necessary introductory works from his own small library. But when these had been mastered, more advanced reading was necessary; and it is recorded that, at twelve years of age, Ampère, accompanied by his father, went to ask in his piping boyish voice for the loan of the works of Euler and Bernoulli from the College Library at Lyons. He appears to have mastered these classics also; and he read widely in the literary, historical, scientific and philosophical authors of his country. In fact, like a recent Lord Chancellor of England, he turned to the current encyclopædia, in his case that of Diderot and d'Alembert, to equip himself with the accumulated knowledge of the ages; and a half-century later he was able to recite from memory whole passages from the famous "Encyclopédie" that expressed the genius of eighteenth century France.

Ampère's extraordinarily rapid intellectual development was, however, interrupted by the tragic death of his father, executed in 1793 as a victim of the Revolution. The shock of this event left Ampère bereft of all his faculties for a whole year, in which he is said to have done nothing but play childishly with heaps of sand and gaze vacantly at the sky, until by a fortunate chance he picked up Rousseau's "Lettres sur la botanique", the reading of which revived his interest and carried him back to his scientific studies. He now began to teach mathematics; and shortly afterwards, in 1801, he was appointed to the École centrale at Bourg. In 1803 he became professor of mathematics at the Lycée in Lyons. But in 1805 his increasing reputation carried him to an appointment at the École polytechnique in Paris, where he was appointed professor in 1809. He was elected to the Academy in 1814, and in 1824 he became professor of physics at the Collège de France.

In August 1799 Ampère contracted a happy but short-lived marriage with Mlle. Julie Carron, the daughter of a devout neighbouring family. The family were not over-blessed with this world's goods, but in their company Ampère appears to have found his spiritual ease, possibly through their reflection of his own natural piety, his religion throughout his life being something totally apart from his scientific interests and speculations. The only child of the marriage, a son, Jean Jacques, was born in 1800 and became a professor at the Collège de France and a member of the Academy. Mme. Ampère died after prolonged illness in 1803, some short time after Ampère had returned home from a separation enforced by his teaching duties elsewhere; and it is fortunate, having regard to the