EXPERIENTIA

Vol. XV - Fasc. 1 | Pag. 1–40 | 15. I. 1959

The Factor Time in the Growth of Living Substances

By F. GUMMERT*

In 1860, at a meeting of natural scientists in what was then St. Petersburg, the embryologist v. BAER[1] expounded an 'experiment in thinking' which, condensed to a few lines, may be described as follows:

Suppose that a man of 90 years were to live 1 million times as long, that is to 90 million years of age, and another were to live one-millionth of 90 years, that is 47 minutes only; and suppose that both these theoretical homunculi were to have the same number of sensory perceptions, thoughts, heart beats, etc., as a normal man has in 90 years. Now, could the 90 million year old man distinguish night from day? No, for him they would alternate so rapidly that he would live in a perpetual twilight composed of light and dark combined. Would the 47 minute old man see a horse galopping? No, for him it would appear as stationary as for us an oak tree growing.

Had v. BAER known of cinematography, he would perhaps have given the following explanation: the 90 year old man has experienced in his life-time (90×360) 32,850 days and nights, while the 90 million year old man would experience 32,850,000,000. This would mean that he would have about the same impression of gray which a normal man has from a film showing alternate black and white images in very rapid succession. On the other hand, our normal perception of 1 minute's view of a galopping horse would 'last' for the 47 minute old man $^1/_{47}$th of his whole lifespan, which corresponds to nearly 2 years for normal man. He would therefore be unable to perceive any movement.

NIETZSCHE[2] considered this 'experiment in thinking' so important that he commented upon it in his inaugural lecture in Basle. In this present age of space travel, it may be noted that any living creatures that might exist on other planets are in no way sure to receive our Morse messages, since we may be sending them far too quickly or far too slowly, by several tenths of degrees.

There are a few more reflections on the factor of time to be found in the biological literature which may be briefly described.

LECOMTE DE NOUY[3], who used the rate of healing of wounds to deduce the 'true physiological age' of a patient, and who evolved the concept of 'biological time', pictures in his book *Human Destiny* a microbe living in one of the cracks of an elephant's skin, the equivalent to us of a canyon six or seven thousand feet high. The 24 h of the microbe's day represent 4 generations or 100 years of human life. Even if the ancestors of this microbe had built up and transmitted to him a science, as ours have done in less than 10 generations, it is conceivable that he would not have a very clear idea of the laws governing his universe: the elephant. When the elephant scratches himself, or takes a bath, the microscopic dweller of the valley can be excused if he attributes these unpredictable cataclysms to an entirely different cause.

JULIAN HUXLEY had heard of the observations of an astronomer on Mount Wilson who, in his spare time, measured the varying speeds of ants. He found that the speed with which they covered a certain distance was so exactly dependent on temperature that he could measure differences of 1°C. HUXLEY, in a chapter of his *Biological Essays* entitled *The Philosophical Ants*, imagines how extremely difficult it would be for a philosopher-ant to find a plausible explanation for the fact that in summer the ants in the cool of their ant-heap can only recite their ant national anthem 1500 times a day, yet outside in the heat they can repeat it 2000 times running. This particular problem

* Kohlenbiologische Forschungsstation e. V., Essen.

[1] K. E. v. BAER, *Welche Auffassung der lebenden Natur ist wichtig? und wie ist diese Auffassung auf die Entomologie anzuwenden?* Reden, gehalten auf wissenschaftlichenVeranstaltungen, und kleinere Aufsätze, vermischten Inhaltes. (I. Teil Reden, St. Petersburg 1864.)

[2] F. NIETZSCHE, *Gesammelte Werke*, 4. Band: Vorträge, Schriften und Vorlesungen 1871 bis 1876 (München 1921), p. 298.

[3] LECOMTE DE NOUY, *Human Destiny* (Longmans, Green & Co., New York-London-Toronto 1947), p. 45.

is not amongst our human worries, for without our ancestors doing anything towards it, we have developed in the process of time into warm-blooded animals with a speed of movement (i.e. the number of movements in a given unit of time) which is independent of outer temperature. HUXLEY believes, however, that we humans are faced with somewhat comparable problems. He mentions the theory of relativity in physics, and he thinks that the question of time-relativity in biology has as yet been far too little taken into account.

That the relationship to time of different sorts of animal varies within the animal kingdom was shown by v. UEXKUELL[4]. For instance, an aggressive fighting-fish sees no movement when a film of an opponent fish is shown at the speed at which we humans normally see a film, but it attacks the supposed enemy if the images appear at shorter intervals.

MOLTKE, in reply to Bismarck's question what, after all the events of the founding of the Deutsches Reich, seemed to him still worth experiencing, is said to have answered: to see a tree grow.

In this connection, the famous saying, attributed to Frederick the Great: *he who can make 2 stalks of corn grow where one grew before is more worth to me than a general who wins battles*, can be interpreted also in the temporal sense of producing 2 harvests in the same time-span in which formerly only one harvest was reaped.

Since the author of this paper comes from the Ruhr district, he may add the following observation: for us human it is of paramount importance in the utilization of wood and coal that the combustion is neither very rapid, as in an explosion, nor very slow, as in the process of rotting, but proceeds at such a speed that man can use it for heating, cooking, and smelting.

It is just this temporally slow progression of the chain of reactions of the carbon compounds which makes carbon the most suitable of all the 92 elements to be, firstly, the chief structural material of all living organisms, and, secondly, the energy-spender for the vast majority of them (with the exception of sulphur and iron bacteria). About 50% of all organic dry substance consists of carbon. The transition towards molecular configurations which contain progressively less energy, up to the final point of CO_2 which is energy-neutral, proceeds smoothly in the smallest possible stages.

HUXLEY is right: problems of time are dealt with much less, both generally and in biology, than problems of space and form. Amongst the time-problems in biology, such as the time taken to produce a stimulus, the day-rhythms, etc., there is one special question which has been particularly neglected and that is the question of the time-factor in the growth of living substance. It is not easy to gather material on the subject. Observations such as that some sorts of bamboo plant grow 20 feet in 3 days are too uncertain. But there are some data in the literature which can be used, as for instance: that young silkworms reach within 35 days 8000 times their weight at hatching; or that the octopus is one of the most rapidly growing animals. A specimen caught on August 8 weighed 65 g; on being fed well, it had increased to 600 g by October 10, to 1,300 g by January and 2,400 g by April 27.

There seems to be hardly any work on the comparison of the growth of substance in different organisms. The only investigation of this kind of which I know is that of MYERS[5] entitled significantly *The Physiology of the Algae*. In my own case, also, the impulse to study this question arose from the mass culture of algae at the Kohlenstoffbiologische Forschungs-Station which I founded in Essen. It seemed stimulating to follow up the question of what minimum period of time is necessary in order to double the initial amount of organic substance under observation. In MYERS' publication there is a short section in which the 'growth rates' of different algae are compared with those of bacteria, with one species of yeast, and with a protozoon.

It has been my aim to collect from the biological literature, data on the increase in weight in animals and plants, both unicellular and multicellular, and in populations, to which I can add the records of the Kohlenstoffbiologische Forschungs-Station in Essen.

As an index number which is more or less suitable for purposes of comparison, I have used the 'doubling step' (Verdoppelungsschritt), as may be explained by an example: BRODY[6], in his compendium *Biogenergetics and Growth with Special Reference to the Efficiency Complex in Domesict Animals*, gives the following weights for Holstein cattle:

Months	Weight/lbs	Increase/lbs	DS (doubling step) calculated from BRODY's figures
0	94	—	—
1	125	31	0·35
2	164	39	0·35
3	214	50	0·45
		120	1·15
13	796	55	0·13
14	870	74	0·11
15	978	108	0·19
		237	0·43

The absolute increase of 237 lbs in the first quarter of the second year is almost double as great as the

[4] J. VON UEXKÜLL, *Streifzüge durch die Umwelten von Tieren und Menschen*, Nachdruck in Rowohlts Deutsche Enzyklopädie (Das Wissen des 20. Jahrhunderts im Taschenbuch mit enzyklopädischem Stichwort), Bd. 13 (Hamburg 1956).

[5] J. MYERS, Ann. Rev. Microbiol. *5*, 157 (1951).

[6] S. BRODY, *Biogenergetics and Growth with Special Reference to the Efficiency Complex in Domestic Animals* (New York 1945).

120 lbs of the first quarter year, but, taking the initial weights of 94 lbs and 796 lbs respectively, the *relative* increase in the first 3 months is much greater. It is the value which is of interest to us here. In the cases quoted, the comparative figures are 1·15 DS in the first 3 months of life and 0·43 DS in the 13th to 15th months.

Let us take the human case. From the infant weight of 3 kg and a weight of 65 kg at 19 years of age, the DS is 4·3, that is doubling the weight from 3 to 6 kg, from 6 to 12, 12 to 24, and 24 to 48 kg and somewhat more in 19 years. The first DS is in the first year, the next in the third, and the next normally in the 8th or 9th year, while the fourth occurs in the 15th or 16th year of life. I cannot here enter into the very interesting question of sex differences.

Let us look at the monthly weights in the first year of life: the increase is greater in the first month than in the second, and in the second month than in the third, and so on. The first DS of 3 to 6 kg is already attained in the fifth month of life.

Even more intensive is the increase of living substance in the growth of the human embryo, although the question of what should be regarded as a normal fetus is difficult to answer, and here we may speak rather of the transformation as much as of the formation of living substance.

Taking the weight of the human egg-cell as 0·004 mg, and the weight of the child at birth as 3 kg, the DS would be 29·5 in 9 months, without taking account of the cells which have died. This would give an average of 1 DS about every 10 days. In reality, about 18 DS are attained in the first 8 weeks, i.e. on the average 1 DS in 3 days, although probably at the very beginning of development 1 DS occurs in less than 24 h. Thus there is at first a turbulent and then a smoother rate of growth, which is however still more intensive than in later life.

In comparison with animals, the special position of man, with his very long period of youth, must be noted. The time taken to reach adult size is about

20 years for man,
2 years for the cow and horse,
1 year for the sheep and pig,
$^1/_2$ a year for the rat, mouse, and hen.

In cattle, 3 DS are attained in the first year, in comparison with about 1·5 DS in man, while sheep reach 3 DS in about half the time taken by cattle. Newborn lambs weigh about double as much as newborn infants, but they attain more than the weight of a 19 year old youth in 12 months. One may say that sheep increase in 1 month as much as humans in 2 years.

With pigs, 3 DS are attained at the end of the second month, and 6 DS in 9 months, that is an increase from a birth weight of 1·5 kg to about 100 kg. Similarly to the pig, very rapid growth is seen in rats and mice, and in addition to this, these species have bigger litters than cattle and sheep.

Naturally the differences in mammals are largely due to differences in the stage of development at birth; in other words, the pre-birth age is different. Lambs are born 'later' than humans, mice 'earlier' in a state of helplessness. The weight of the newborn young in proportion to the weight of the mother varies very greatly: in the bear, it is 1 to 600, in man 1 to 22, in the guinea pig 1 to 7.

Geese, hens, ducks, and pigeons show no very great difference from the freshly hatched chick to the fully grown bird compared with pigs and mice. The same is true for fish and insects, as for the above mentioned silkworm and octopus.

The development of the chick embryo in the hen's egg is of a similar order to that of mammals. In the first 7 days, the substance of the chick embryo is more than doubled each day.

The greatest increase in substance in animals is seen in the young bee larva, where the nature of the nutrition with particularly high-grade food certainly plays a part: in $4^1/_2$ to 5 days the weight increase is from 0·1 to 157·6 mg, i.e. 10·67 DS in this short period of time.

For comparison it may be mentioned that the famous piece of hen's heart which has been cultured *in vitro* since 1912, only attains 1 DS every 2 days. Naturally, the substance which grows on to it must be removed from time to time, otherwise there would be abnormal masses of tissue from the heart.

In multicellular animals, therefore, we get in the best case 1 DS in about $^1/_2$ day.

What of heterotrophic unicellar animals? Apart from the technical difficulties, it is hardly worth observing an unicellar as an individual with regard to its temporal process of growth. Up to the moment of division, there *must* be an increase of substance to the size of the mother cell, otherwise there would be a dwarfing of the species in a few generations.

The capacity of unicellular organisms to absorb food is especially great, since their surface is relatively much larger than that of multicellular animals. A sphere with a diameter of 1 m has a surface of about 6 sq.m., whereas the total surfaces of microorganisms which can fit into 1 cm^3, also have a total surface of 6 sq.m. I believe that the law of surface tension is just as important for microorganisms, if not more so, than the force of gravity for human beings.

I do not wish to go into details as regards either the methods of measuring (counting, determination of carbon dioxide liberated, or of lactic acid produced, etc.) or such things as the peculiar fissure divisions[7],

[7] M. HARTMANN, *Allgemeine Biologie*, 3. Aufl. (Jena 1947). – E. KÜSTER, *Die Pflanzenzelle* (Jena 1935).

formation of spores, sprouting, etc. I shall simplify the question by considering only the splitting into 2 parts.

Where the culture is made on agar, or, for instance, in Erlenmeyer flasks, as soon as an optimal number of cells is reached in the culture, the process of division, and thus the growth, is slowed down. Here, too, there is first a turbulent growth in youth and then a slowing off which is comparable to the ageing of multicellular animals.

In bacteria, moulds and yeasts, there is a wide range of variations similar to that of multicellular animals, but on the whole, much shorter periods for attaining 1 DS.

In the production of nutrient yeast, the doubling of living substance is reckoned to occur in about 3 h in practice, according to information sent me by the Zellstoffwerke Waldhof. From the literature, the optimal increase for beer yeast is about 1 DS in 1 h. In a whole series of bacteria, the DS is shorter, with the record in coli bacterium with 1 DS in 16·4 min!

In order to realise what that increase really means, the following experiment in thinking may be made: If we assume that the coli bacteria had sufficient food and space at their disposal, we may reckon with 4 DS/h, which is 96 DS/day. This would mean that after 24 h there would be a number of coli bacteria of the order of 30 noughts. This means a mass of nearly 1 km^3. After 220 DS, that is in about $2^1/_4$ days, there would be a mass of 1 cubic light-year! This is naturally a play with figures which is merely intended to show what may happen with such short DS. With an 8-h culture of *Escherichia coli*, 13·49 DS have in fact been obtained.

The life of man, animal, and bacteria is dependent on the products of autotrophic plants. Naturally heterotrophic beings cannot build up more substance than is assimilated by autotrophic plants in the dispersed energy of the sun's light.

In a very rough and simplified way, it may be said that man needs about 20 years till he is fully grown, but if a stalk of oats or a cabbage needed so long to get ripe, it would be impossible for such a large mass of humans to live on the earth.

Apart from the entirely different way in which plants are built up, and the provision of energy for the plant organism through solar radiation – in contrast to the chemical energy required by the heterotrophic organisms – there are also other differences which I shall briefly mention: smaller respiratory losses than in animals, dependence on the site at which the seed strikes its roots (particularly the moisture), much greater range of structure, great differences in the weight of seeds – for instance those of the coconut palm and those of the tobacco plant. One advantage is that the dry substance of plants can be more easily measured – for the sake of convenience, the water content was ignored in the weight of heterotrophic organisms. In the following examples, the roots are also calculated, and average values from a large number of cases are taken, since the range of structure of individual plants is so great.

The following figures represent the DS per week: for red clover from the fourth week – 1·0, 1·3, 1·6, 1·3, 0·7, and then rapidly decreasing.

For the sunflower, the following figures show the effect of sun and rain: second week – 1·7, 2·0, 1·5, 1·8, 1·5, 1·0, 0·5 until the sixteenth week when it reached zero, with a total of 12·5 DS.

For tobacco during the same period, we find 18·6 DS, for sugar beet 15·3 DS, while hot-house cucumbers attained 10·1 DS 10 weeks after bedding out. The values for maize, lucerne, hemp, peas, cotton, cauliflower, kale, lettuce, and grape-vine are lower.

The maximum increase in weight has been recorded in the sugar beet, with a rise from 0·06 to 0·64 g dry weight, or 3·4 DS in 1 week.

This is less than the 10·67 DS in 4·5 days recorded for the bee larva, less than embryonal development, and very much less than the maximum in bacteria; but, on the whole, it can be said that multicellular plants outdo animals in the increase of organic substance in the total of DS, which is up to 18·6 in one summer. In making comparisons, it should be noted that 1 DS increase is already a doubling of weight, and a difference of 3 DS is an 8-times increase in substance.

For plants which live several years, an indication, instead of a series of figures, may be sufficient: in prewar Germany, the straw of the German corn crop in t was almost equal to the yield of timber, reckoned in m^3. From this, it can be concluded that the yield of the forests in an equivalent area does not equal that of the one-year plants.

In the autotrophic unicellular organisms also, I will consider for the sake of simplicity only the division into two. If the algae *Eudorina elegans*, cultivated by Hartmann[8] over a long period, divides into 32 daughter cells every fifth night, this produces the same result as if 1 division occurred every 24 h: on the first, second, third, fourth, and fifth day, 2, 4, 8, 16, 32 cells respectively.

In marine diatoms, 2·1 DS in 1 day have been observed, and in 1 week 9 DS. The publications of Winokur[9], of the Institute for Plant Physiology, Columbia University, New York, have proved particularly illuminating. In several cultures of 8 different sorts of *Chlorella* at 4 different light intensities, he obtained in the first 9 days over 8 DS in one case, over 7 DS in 6 cases, over 6 DS in 8 cases, over 5 DS in 13 cases, over 4 DS in 17 cases and in about 100 cases lower DS. His bestgrowing chlorella culture had the

[8] M. Hartmann, *Die dauernd agame Zucht von Eudorina elegans* (Archiv für Protistenkunde 1921–1943).

[9] M. Winokur, Amer. J. Bot. *35*, 118 (1948); *36*, 287 (1949).

following DS each day: 0·01, 1·27, 2·17, 2·13, 1·32, 0·57, 0·16, etc. From the second to the fifth day, practically 7 DS were attained and then the rate decreased with variations to 0 on the 24th day. On the first day, a so-called 'lag-phase' was seen, then a steep rise to an optimum, then a gradual decrease with slight fluctuations. At the Kohlenstoffbiologische Forschungs-Station, we obtained the best results at the most intense illumination and simultaneous bubbling in of CO_2 in our algae cultures. The results from cultures in small flasks were worse than those in vertical glass tubes. Cultures in open ditches outside the glass house attained about 5 DS in 10 days, while the best tube cultures in artificial light showed 10 DS in 10 days. In the beginning, the cultures used regularly to produce 1 DS in 1 to 2 days.

If one considers the increase of populations, for instance of *Drosophila*, in a limited living space, in the same way as algae or bacteria cultures, one finds a similar development as in multicellular organisms, namely strong growth in youth, slowing down on ageing of the culture, and finally cessation of growth.

It might be expected that the life of such a culture would run through quicker the greater the number of descendants, that, for instance, populations of animals with a larger egg number would sooner fill their living space than those animals with a lower egg number. However, this may prove to be a false conclusion, as the following example shows: let us assume that there were enough space in the oceans and that no marine forms of life were to die, and that a female herring lays 1 million eggs a year (in actual fact it is less). If, now, we were to put a herring-pair and a single unicellular alga into the sea, the alga *must* already after 20 divisions reach 1,000,000, and after 30 divisions 1,000,000,000. Even if the alga were to divide only once a week, it would still reach greater masses sooner than the herrings.

According to the data given by PEARL[10], a *drosophila* female lays, for at least 10 days, from 25 to 40 or 50 eggs, and the tiny larvae hatch after 24 to 48 h, eat banana pulp for 3 to 4 days and then change into chrysalis. From these, the fully developed flies crawl after a further 4 or 5 days, to start immediately to breed and to begin laying eggs after 12 to 24 h. From one generation to the next, it only takes 9 to 12 days under favorable conditions of temperature and food. (It is just this short duration of a generation, the factor of time in the forming of living substance, which makes *drosophila* a favorite species for research in genetics.) One is tempted to think that those strains would show the greatest increase which have the largest number of eggs. But it is the duration of each generation which is the more important factor. If one reckons out, from the data of PEARL, the possible increase in living substance, beginning in the first case with the longest duration of 12 days and the highest egg number of 50, and in the second case with the shortest duration of 9 days and the lowest egg number of 25, one obtains in the first case in 36 days from 50 eggs 3 generations and about 125,000, and in the second case from only 25 eggs, 4 generations and about 390,000 descendants.

For problems of human populations also, the span of time between 2 generations is of at least similar importance as the number of children, that is to say, an early age of marriage can offset a low number of children.

It may be briefly noted that in egg and milk production there is no great divergence from the DS values seen in animals, if we equate the eggs and milk with the living substance. The annual yield of eggs corresponds to about twenty times the caloric-content of the best laying hen, which would represent in our scheme somewhat more than 4 DS per year. In spite of the seemingly high egg number, there is no great divergance from the DS seen in several of the multicellular animals observed. The same is true for milk.

A word in passing on the curious fact that there are so-called 'omnivorous' animals and others again which are most particular specialists, such as for instance the aphids which live on oats or barley plants in summer and on bird cherries in winter.

The present article is consciously limited to the determination of the differences in the time intervals in the increase of living substance in different sorts of organism. A treatment of the much more interesting problem of the reason for these differences would extend beyond the scope of this paper. Just one typical example of the influence of exterior factors may be given, for which I have to thank Prof. BRAUN of Bonn. The duration of the whole development takes 113 days in the corn beetle if the temperature in the granary is kept at 15°C and only 29 days at 27°C.

It has been shown that there are great differences in the time-span in the increase of living substance. The times taken to attain a doubling fluctuate in different organisms between a few minutes and several years: they vary between about 1 and 100,000. Thus the differences in the time factor in propagation are of the order of the differences in size and weight between a whale and a mite, or a *sequoia* and a *chlorella*.

To these results collected from a large number of observations, there are still a few points which may be briefly touched upon.

If the absolute weights of organisms are plotted in a graph an S-shaped curve is often obtained, that is the optical picture is of a slow acceleration followed by a sharp rise and then a slowing again. With end weights of many kilograms, the initial stages of de-

[10] R. PEARL, *The Biology of Population Growth* (New York 1925); Quart. Rev. Biol. *2*, 538 (1927).

velopment which lie in the region of milligrams and grams are not sufficiently revealed by such a curve. The criterion which I have used of the DS shows, often after a shorter or longer 'lag-phase', the greatest increase to occur just at these early stages, since here it is *relatively* greater, taken from the initial weight. Only absolute weights, as shown on an S-shaped curve, represent for the problem of my theme a certain optical delusion.

On the other hand, it must be pointed out that the period of greatest DS in youth, for an organism or a culture, is usually not the period of optimal yield. *The Optimum Catch* is the title of a paper by HJORT, JAHN, and OTTESTAD[11], in which it is shown that the catching of whales within the limits of their yearly increase is not dangerous for the stock of whales and may even be advantageous from the point of view of the greatest possible catch, but that if these limits are exceeded, then there will be a very rapid decrease in the number of whales to hunt. The theory of the best gain depends on the fact that there is in every population an optimal density to maintain the maximal number of descendants. If this density is exceeded, the population-number receeds, and if it is allowed to become too reduced, then the 'parent stock' is not large enough to produce the greatest possible number of descendants, although the rate of growth may be higher than at the optimal density. If the maximal permanent yield is considered, then the factor of space must be added to the factor of time, in the sense of the extent of the natural or artificial living space.

As early as 1938, KETCHUM and REDFIELD[12] had worked out a method of maintaining a continuous yield from cultures of marine diatoms. The numerous papers on the mass culturing of algae in recent years, especially in Japan and U.S.A., are, however, all finally based on the publication of HARDER and v.WITSCH[13]. The statement is made in this paper that if 1·2 g of algae in a glass tube of 5 cm diameter and 80 cm length, with ordinary air passing through, are placed in a north-aspect green-house in 6–10,000 Lux day light, then in 10 days there is a net yield of 9 g fresh weight... while a surface of 500 m^3 would give a net yield of 100 kg of fat in 6 summer months.

In experiments made at the Kohlenstoffbiologische Forschungs-Station in Essen, in contrast to those of the pioneers of Göttingen, a green alga was used and CO_2 was passed through. An attempt was made to find out at what timeintervals one *half* of the cultures must be removed to get the maximum yield. After taking away one half of the alga substance, the culture tubes were naturally replenished with water and 'fertiliser'.

A good alga culture gave the following values:

Days	Dry weight g/l	Increase g/l	DS
0	0·0029	—	—
4	0·09	0·051	in 4 days 4·80
7	0·56	0·48	in 3 days 2·82
10	1·48	0·92	in 3 days 1·39
14	2·37	0·89	in 4 days 0·71
17	2·54	0·17	in 3 days 0·10
21	3·81	1·27	in 4 days 0·57
24	3·80	—	—

From the figures it is clear that the removal of the half of the culture between the tenth and the forteenth days, and the repeating of the halving every 3 to 4 days, has led to a better total result than starting afresh every 2 to 3 weeks.

It seems to be not impossible to obtain a yield from *green algae* of about 30,000 Kcal/qm/year.

For comparison, the following figures:

Insolation of solar energy on horizontal		900,000 Kcal/qm/year
of which photosynthetically active about		450,000 Kcal/qm/year
yield in Kcal –	sugar beets	3,500 Kcal/qm/year
	potatoes	1,240 Kcal/qm/year
	wheat	780 Kcal/qm/year
	beef	150 Kcal/qm/year
	milk	170 Kcal/qm/year

Mass cultivation of algae, as worked out in numerous valuable papers in U.S.A., and now particularly by TAMIJA[14] in Japan, seems to offer good prospects for the future.

After rat feeding experiments made by FINK[15], chicks were successfully reared on algae instead of fish protein, and at present tests are being made by KRAUT[16] and WITT[17], in feeding swine with algae cultures from the Kohlenstoffbiologische Forschungs-Station in Essen.

The question is still to be mentioned of what happens to an increase of the *total sum* of living substance on the earth. Can tendencies be detected of a stronger increase in either of the two chief groups, the autotrophic or the heterotrophic organisms? In spite of the

[11] J. HJORT, G. JAHN, and P. OTTESTAD, Hvalrådets Skrifter *7*, 92 (1933).

[12] B. H. KETCHUM and A. C. REDFIELD, Biol. Bull. *75*, 165 (1938).

[13] R. HARDER and H. v. WITSCH, Ber. deutsch. bot. Ges. *60*, 146 (1942). – *Bericht über Versuche zur Fettsynthese mittels autotropher Mikroorganismen* (Report on trials with autotrophic microorganisms for the synthesis of fats), Forschungsdienst 1942.

[14] H. TAMIJA, *Growing Chlorella for Food and Feed*, Proc. World Symposium Appl. Solar Energy, Phoenix, Arizona 1955, p. 231; Ann. Rev. Plant Physiology *8*, 309 (1957).

[15] H. FINK and E. HEROLD, Hoppe-Seyler's Z. *305*, 182 (1956); *307*, 202 (1957).

[16] Prof. Dr. H. KRAUT, Direktor des Max-Planck-Institutes für Ernährungsphysiologie, Dortmund.

[17] Prof. Dr. M. WITT, Direktor des Max-Planck-Instituts für Tierzucht und Tierernährung, Mariensee Krs. Neustadt a. Rübenberge und Trenthorst über Bad Oldesloe.

maximal utilization of sun's rays by the arrangement of leaves of plants per unit of space, it seems, on the basis of theoretical calculation, that *per unit of surface* the autotrophic organisms need more time for the formation of substance than do the heterotrophic, as, for instance, when lactic acid bacteria in 1 cm^3 of milk are compared with algae in 1 cm^3 of water. The formation of molecular configurations with higher caloric value, performed by means of the sun's energy as in photosynthesis, appears to need more time than does the chemical conversion of the molecules formed by photosynthesis into other molecules inside the heterotrophic organism. This is also the reason why heterotrophic organisms, being less bound to one place owing to their capacity to make movements, are better suited to gather their food over a larger area than are plants.

The total amount of the substance of all heterotrophic organisms can of course never exceed that of the autotrophic form of life. In actual fact, the total mass of substance of the autotrophic organisms on the earth is much greater than that of the heterotrophic ones. In pre-war Germany, which represented $^1/_{1000}$th of the total surface of the earth, I once calculated the following figures, starting from carbon content:

C in million tons:	atmosphere	800
	forests (wood)	750
	other green plants (summer)	100
	man and animals . . .	5
	microorganisms in soil	2·5

From these figures, one sees not only the relatively small mass of the heterotrophic beings, but also that the total living substance has about the same C content as the atmosphere above it.

The words of LIEBIG[18] are appropriate here: ' ... es handelt sich also in der Agrikultur hauptsächlich darum, die besten und zweckmässigsten Mittel anzuwenden, um den Kohlenstoff der Atmosphäre, nämlich die Kohlensäure, in die Pflanzen unserer Felder übergehen zu machen.' (In agriculture it is mainly a question of using the best and most practical means to mass the carbon of the atmosphere, that is the carbon dioxide, in to the plants of our fields.)

If, by afforestration of the deserts, a further 10% of the C of CO_2 of the atmosphere were built into living organisms, then the 0·03 volume % content of the atmosphere of CO_2 would be decreased to 0·027 volume %. We can hardly assume that this would occur without some slowing of photosynthesis, since we know that fertilising with CO_2 in a glass-house increases the yield and shortens the vegetation time.

[18] J. LIEBIG, *Chemische Briefe*, zweiter Abdruck, Akademische Verlagshandlung von C. F. Winter (Heidelberg 1845), Sechsundzwanzigster Brief, p. 320.

It follows from this that periodic DS in greater or less intervals – in fact the actual topic of this paper – would necessarily be bound to changes within the total mass of living substance.

The question further arises whether the total living substance on the earth shows any tendency to increase in proportion to the inorganic material? Over the whole history of the earth, there has certainly been no such tendency to be seen since the period in which the plant and animal worlds, both unicellular and multicellular, have spread over the water and land surfaces of the earth. The statement can be made on the basis of compound interest calculation for such long eras of time. If we assume that such an increase had been 1% per year, this, based on compound interest, would give 1 DS in 69 years, after 100 years 2·7 times and after 1000 years almost 21,000 times more. It is therefore clear that the increase of living substance in the history of the earth and of life *must* be well below 1% per year. It is, however, a different matter when certain periods of time in the history of life on the earth are considered. The two following figures are entirely accepted in science:

C in the present atmosphere at 0·03 vol.% –
about 600,000,000,000 t;

C in fossil coal and oil layers –
about 5,000,000,000,000 t.

There hardly remains any other conclusion than that *before* the time of the carboniferous forests, the content of CO_2 in the atmosphere *must* have been greater than after the period of coal and oil formation. If mankind continues to 'un-coal' these reserves to the same extent and at the same speed as in the last decades, then every ton of coal which is burnt, and every barrel of oil poured into motors, must increase the CO_2 content of the atmosphere. This rise in the CO_2 content of our atmosphere leads to higher temperatures (greater 'hothouse effect' the higher the proportion of CO_2 in the air-mass) and to the possibility of forming greater organic masses, so that in the end the earth's crust would be similar to what it was at the beginning of the age of the coal forests. It is curious to think how little attention has been paid to this problem of change in the world environment by science, even when it is a question spread over tens and hundreds of years.

To conclude this paper, one more DS may be mentioned which is of the greatest importance for the development of mankind:

According to the last census made by the UNO, the population of the world was

in 1951, 2,519,000,000,
and in 1955, 2,691,000,000.

This means a yearly increase of 1·7%, or 1 DS in 41 years!

Zusammenfassung

Zu dem wichtigsten Arbeitsgebiet der Kohlenstoffbiologischen Forschungsstation e.V., Essen, gehört die Massenzucht von Algen. Von ausschlaggebender Bedeutung ist dabei die in bestimmten Zeitabschnitten, zum Beispiel Tagen oder Wochen, zu erreichende Zunahme an organischer Trockensubstanz. In Verbindung mit diesen Arbeiten erschien es reizvoll, der Frage nachzugehen, wie es sich mit der Zunahme organischer Substanz je Zeiteinheit bei den verschiedenen Lebewesen – einerseits Tieren und Pflanzen, andererseits Vielzellern und Mikroorganismen – verhalte, insbesondere, welche minimale Zeitspanne in der Praxis nötig ist, um eine Verdopplung der zu Beginn der Beobachtungen vorhandenen organischen Substanz zu erhalten.

Als Messzahlen werden Verdopplungsschritte (DS) = doubling step angewandt. Für kurze Zeitspannen wurden folgende «Spitzenleistungen» (aus der Literatur) ermittelt:

Bienen-Maden von 0,1 auf 157,6 mg = 10,67 DS in 4½–5 Tagen;
Bacterium coli 1 DS in 16,4 min.;
Zuckerrüben 3,4 DS in 1 Woche.

In dem Aufsatz werden weitere, sich bei dem Thema aufdrängende Probleme behandelt, so die Zunahme von Populationen im begrenzten Lebensraum, zum Beispiel bei *Drosphila*, die Frage, ob etwa die gesamte lebende Substanz auf Erden gegenüber der anorganischen Materie eine zunehmende Tendenz zeige und weitere Zusammenhänge.

Brèves communications - Kurze Mitteilungen
Brevi comunicazioni - Brief Reports

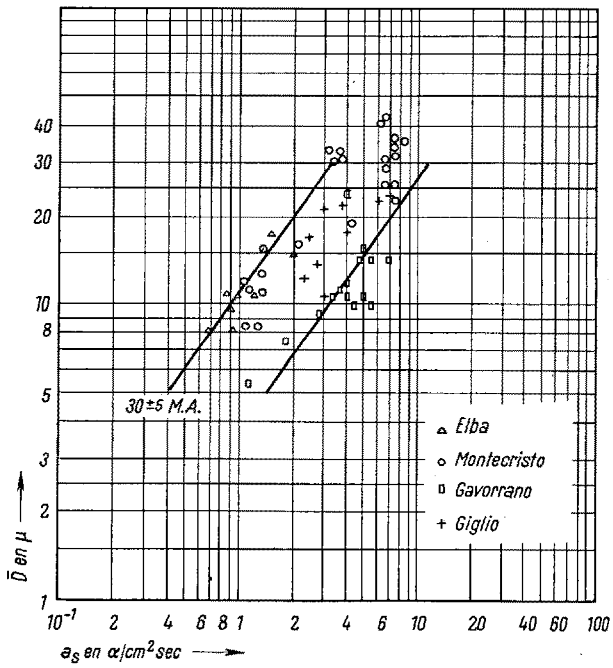
Les auteurs sont seuls responsables des opinions exprimées dans ces communications. – Für die kurzen Mitteilungen ist ausschliesslich der Autor verantwortlich. – Per le brevi comunicazioni è responsabile solo l'autore. – The editors do not hold themselves responsible for the opinions expressed by their correspondents.

Age des halos pléochroïques de quelques granites tertiaires de la Toscane

L'étude quantitative des halos pléochroïques dans les roches d'âge connu a montré que ceux-ci peuvent être utilisés pour la datation des roches. La méthode utilisée[1] permet de déterminer le rapport entre l'âge inconnu d'une roche et celui connu d'une roche étalon si leur biotite présente la même sensibilité à la coloration artificielle. Il s'ensuit qu'elle devrait s'appliquer spécialement à la comparaison des âges des roches jeunes (tertiaires) car dans ce cas des différences d'âges relativement faibles (quelques dizaines de millions d'années) pourraient être mises en évidence, le rapport des âges des roches considérées étant suffisamment grand.

Nous donnons ici une telle application de cette méthode. Nous avons étudié les halos de deux granites de l'archipel toscan Montecristo et Giglio et ceux du granite continental de Gavorrano. Ces granites sont liés aux plissements des Apennins. D'après ce qui est admis des âges de ces plissements, Giglio et Gavorrano devraient être plus jeunes que l'Elbe, alors que Montecristo serait d'un âge très voisin. Le granite de l'île d'Elbe (Monte Capanne) déjà étudié a été pris comme roche étalon. Il est au plus Miocène-Oligocène[2] ce qui correspond à 30 ± 5 MA d'après l'échelle B de Holmès. La biotite de Gavorrano présente la même sensibilité à l'irradiation expérimentale que la biotite de l'Elbe, alors que celle de Montecristo est légèrement plus faible et celle de Giglio plus forte.

Les résultats des mesures du paramètre $\bar{D}$ de la densité optique des halos et de l'activité alpha spécifique *as* des inclusions correspondantes sont représentés dans la Figure. La meilleure droite passant par les points expérimentaux des halos de Gavorrano y est tracée.



L'ensemble des points de $\bar{D} < 30\ \mu$ correspondant aux halos de Montecristo est situé légèrement à droite de l'isochrone de l'Elbe. Compte tenu de la sensibilité plus faible de cette biotite par rapport à celle de l'Elbe, l'âge des halos de Montecristo est semblable à celui des halos de l'Elbe.

La position de la meilleure droite correspondant aux mesures des halos de Gavorrano, relativement à celle de l'isochrone de l'Elbe, montre que le rapport des activités

[1] S. DEUTSCH, D. HIRSCHBERG et E. PICCIOTTO, Bull. Soc. belge Géol. *65*, 267 (1956). – S. DEUTSCH, P. KIPFER et E. PICCIOTTO, Nuovo Cim. *6*, 796 (1957).

[2] L. TREVISAN, Boll. Soc. geol. ital. *70*, 435 (1951). – P. FALLOT, Cours du Collège de France (1956–1957).