following elements. It appears that this division is less well marked, and makes itself less noticeable chemically than the close of the sub-groups already considered. If we take first the division between n_{43} and n_{44} (for $n=4$) in table I., we find that this occurs in the rare earths; and corresponding to it is the difference between cerium earths and ytterbium earths, which is especially noticeable magnetically. The curve for the paramagnetism of the ions rises, according to Cabrera and Stefan Meyer, to a maximum, then falls off almost to zero at the end of the cerium earths, reaches a higher maximum with the ytterbium earths, didymium, and holmium, and falls finally to zero at cassiopeium ($Z=71$).

The close of the sub-group n_{32} appears, as we have already said, not to be noticeable spectroscopically; in contrast to this we have found that the close of n_{21} is marked by $\bar{j}=0$ in tin and lead, and probably also in carbon and silicon. But how about the chemical effects of the close? Are there compounds which are aiming at the four-shell as there are for the eight-, two-, and eighteen-shells? The answer will be of great interest for the understanding of chemical compounds, and towards it I can make the following contribution, based on an observation of H. G. Grimm relating to the crystal structure of certain diamond-like compounds. The subject is treated in a paper by Grimm and myself in the *Zeitschrift für Physik* (1926), where also the above remarks about copper, silver, and gold may be found.

The characteristic structure of diamond is known from the work of Sir William Bragg. Diamond is built up simply of tetrahedra in such a way that every carbon atom is surrounded by a tetrahedron of other carbon atoms. Zinc sulphide crystallises in the same arrangement, as zincblende, with each zinc atom surrounded by a tetrahedron of sulphur atoms and vice versa, but it also crystallises in another way, as 'wurtzite'; in this, while we still have interpenetrating tetrahedral systems, the structure is not cubical but hexagonal; the tetrahedra are merely disposed in a different way, in relation to one another, from that which occurs in the diamond. We will classify both together as tetrahedral structures. The crystal carborundum (CSi), so important technically, is likewise tetrahedral, with different modifications, which are distinguished by the way in which diamond- and wurtzite-structures alternate with one another in the hexagonal c -axis. As a result of this alternation the repetition-distance is here extraordinarily large—almost 40 Å.U., indeed, in one of the modifications.

Now, however, we have this to consider: this tetrahedral structure occurs not only in the fourth column of the periodic table (e.g. in carbon, silicon, carborundum, germanium, tin), but also in compounds of neighbouring elements, those neighbours being equally

distant on opposite sides from the fourth column. We may in fact state as a definite theorem that tetrahedral symmetry occurs *only* in such binary compounds as have both components at most three places from a four-shell, and both equally distant.

I.	II.	III.	IV.	V.	VI.	VII.
	Be	Al	C	N	O	
Ag	Zn		Si		S	I

It is very natural to assume that in all these compounds the mechanism of the bonds is the same as in the diamond. This is quite obviously a non-polar bond, since it unites two similar atoms, and we conclude that in zinc sulphide it is also non-polar; i.e. the compound is not $Zn^{++}S^{--}$. This is confirmed by X-ray intensity measurements, which, according to H. Ott, certainly do not correspond to Zn^{++} and S^{--} , but probably to neutral Zn and S. The idea of a four-shell would have suggested even the reverse picture, Zn^{--} and S^{++} , since the sulphur atom must give up two electrons if it is to be reduced to the four-shell of silicon, and zinc must acquire two to reach that of germanium; however, the intensity relations seem rather to indicate neutral Zn and S. Similarly, beryllium oxide, in contrast to magnesium oxide and calcium oxide, is at least not the polar salt $Be^{++}O^{--}$. In calcium oxide and calcium carbonate tetrahedral structure is not observed, nor is it to be expected theoretically, since calcium is not two places before a four-shell.

I prefer not to go further at present into the mechanism of the reciprocal binding of such four-shells; even in the simplest case of the diamond we know nothing certain about it. It is most probable that the binding is performed by pairs of electrons, each of which goes round two carbon atoms, as in G. N. Lewis's theory of the sharing of electron pairs.

In conclusion, then, we have found that the theory of the Periodic System shows at what elements we are to expect completed sub-groups. In addition to the inert-gas eight-shell, the shell of eighteen, and even more that of two electrons, is a goal at which the elements in a stable compound are aiming. The four-shell, on the other hand, is evidenced by a tetrahedral crystal structure, which points to the same kind of binding together of the atoms as we have in the diamond; this binding is not performed by the electrostatic attractions of polar ions of the usual sign, but is probably a matter of neutral atoms. It seems reasonable to hope that the great chemical problem of the non-polar bond will be brought nearer its solution by a close study of tetrahedral crystal structures.

The Shipworm.¹

By Dr. W. T. CALMAN, F.R.S.

ALTHOUGH nowadays iron ships no longer fear the *calamitas navium*, as Linnæus called it, the shipworm still remains a constant source of anxiety to harbour engineers in many parts of the world. For

example, the damage caused by it to wharves and jetties on the shores of San Francisco Bay, during the years 1919 and 1920, was estimated at no less than 15,000,000 dollars.

Within the last few years a good deal of attention has been paid to the shipworms by investigators in

¹ Substance of two lectures delivered at the Royal Institution on April 17 and 24.

Great Britain and, more especially, in America, and noteworthy additions have been made to our knowledge. Only a few of the more striking results can be touched on here.

The question of how the shipworm excavates the wood to form its burrow has been much discussed. The earlier observers had no doubt that the valves of the shell—which they called the teeth—were the instruments of excavation, but some later writers have supposed that the wood was acted on by a solvent secretion and then rubbed away by the fleshy foot. Lately Mr. R. C. Miller, in America, has been able to watch the animal at work, by laying bare the inner end of the burrow and cementing a cover-glass over the opening. He found that the sucker-like foot adheres now to one part and now to another of the inside of the burrow, and the animal is wedged firmly in position by the swelling up of a fleshy lobe lying over the back of the shell. A rocking movement of the valves produced by alternate contractions of the two adductor muscles causes the rows of minute teeth on the surface of the valves to rasp away the wood, and, as the foot shifts its position after each stroke, the boring proceeds evenly and the circular form of the burrow is preserved. In hard and fine-grained wood, microscopic parallel scratches can be observed which are the tool-marks of the excavator.

Most bivalved molluscs feed on minute living organisms and organic particles suspended in the water, and the food-collecting function of the so-called gills is at least as important as their respiratory function. It is possible that the shipworm obtains a part of its food in this way, but it also swallows the fine sawdust produced by the rasping movements of its valves, and the stomach and intestine are found on dissection to be crammed with wood-pulp. This does not prove that the wood is actually a source of food, for some related molluscs (*Pholadidæ*) that bore into rock, similarly swallow the innutritious mud produced by their boring operations. As compared with the *Pholadidæ*, which burrow only to get shelter, the elongated worm-like shape of the shipworms (some of which are six feet long) suggests the need for continued boring to obtain food while keeping in touch with the surrounding water at the mouth of the burrow. Recent work, however, shows that the wood is actually digested. Potts has observed phagocytic ingestion of wood-particles in the 'liver,' while Harrington found that an extract from the same gland acted on sawdust to produce glucose. Dore and Miller, in America, have analysed the borings after passing through the alimentary canal of the shipworms and compared the composition with that of the wood itself. They found that while the amount of lignin remained unchanged, the cellulose was reduced by 80 per cent. and the hemicelluloses by 15.56 per cent.

This, however, is not the whole story. It seems to be well attested that, in certain circumstances, the shipworm ceases to bore and shuts itself completely off from the wood by continuing the shelly lining over the end of its burrow. Where this has been done, the only source of food-supply will be the suspended particles drawn in by the respiratory current. The same is probably true of the somewhat mysterious giant shipworm, *Kuphus arenarius*, which does not bore into

wood but lives vertically embedded in the mud of mangrove swamps with only its siphons projecting from the surface.

The practical man, when confronted with problems such as those presented by the shipworm, is sometimes apt to pay too little heed to the history of the subject and to waste time in finding out for himself facts that were discovered and recorded long ago. The learned Sellius, two hundred years ago, was at pains to confute the suggestion that the shipworm could emerge from its burrow and swim away to bore into a fresh piece of timber. Such a supposition was natural enough when nothing was known of the microscopic free-swimming larvæ, but it is surprising to find it revived in an official report issued only three years ago by the Department of Scientific and Industrial Research.

It is characteristic of the shipworm that it may appear suddenly in places that have previously been free from its depredations. Thus we find records of great outbreaks of shipworm in Holland in 1730, 1770, 1825 and 1858, at San Francisco in 1917, and so on. In most of these cases the damage is severe for two or three years, then the attack dies away and little or nothing is heard of the pest in the intervening periods. When one of these outbreaks occurs, the practical men generally begin by attributing it to importation of infection from abroad. In Drake's time the shipworm was commonly regarded as having been brought from the New World. In the eighteenth century the East Indies were supposed to be its place of origin. Linnæus concisely says of it, "ex Indiis in Europam propagata." In the recent San Francisco outbreak something was said of importation from Europe.

It is possible that some truth may underlie these beliefs. The commonest species of shipworm in northern Europe, *Teredo navalis*, has been found in places so widely separated as the Cape of Good Hope, Australia and San Francisco, and there is every probability that this wide range, unusual in a marine invertebrate, is due to the species having been carried to these distant parts in the timbers of ships. But it is unlikely that the individual outbreaks can often be due to this cause. It is certain that in most cases the shipworms have lurked unnoticed in odd corners until rapid multiplication owing to favourable conditions has directed attention to them. It becomes of importance, therefore, to determine what these favourable conditions are.

Individual outbreaks have sometimes followed years of deficient rainfall, leading to increased salinity in the waters of bays and harbours, and attempts have been made to find out the degree of salinity which is most favourable. It was found at San Francisco that *Teredo navalis* was active and apparently thriving at a salinity of 15 per thousand, that is to say, in water containing rather less than half the amount of salt usually found in ocean water. As the water was diluted the animals became less active until at 4 per thousand they withdrew into their burrows. While enclosed in the wood, however, they remained alive, though inactive, for three weeks in fresh water, ready to resume operations when replaced in saltier water. It would be interesting to know how the free-swimming

larvæ are affected by changes of salinity, but there appear to be no detailed observations on this point.

All these observations, however, have been made on a single species, *Teredo navalis*. There are many other kinds of shipworms and, although we know little of their habits, we do know that they differ greatly in the degree to which they can adapt themselves to water of reduced salinity. *Teredo navalis*, which can flourish in water only half as salt as that of the oceans, probably owes its evil reputation to the fact that its tolerance for brackish water enables it to invade estuaries and harbours where the water is commonly less salt than that of the sea outside. It is the common species in the North Sea and comes up the Thames as far as Greenwich. At Plymouth, another species, *Teredo norvegica*, appears to be the commonest, and it will probably be found to prefer salter water. On the other hand, various tropical species ascend rivers, such as the Ganges and the Zambezi, to places where the water is quite fresh. There is even a report that a shipworm occurs in Lake Tanganyika, although no specimens have yet been seen by naturalists.

It should be clear, then, that an accurate determination of the existing species of shipworms and of their conditions of life is of great importance from a strictly practical point of view. How far we are from having this knowledge is perhaps only realised by those who have tried to determine collections of shipworms from

different parts of the world. But that is no reason why such knowledge as we have should be neglected. In some recent investigations on the efficiency of certain poisons when used to protect wood against attack by shipworms, the authors do not even trouble to tell us what species of shipworm was used in their experiments.

A study of the shipworm suggests some considerations bearing on current biological theories. For example, like all highly specialised organisms living under peculiar conditions, the shipworms raise in the most striking way the problem of adaptation. The form of the body, the shape of the shell-valves with their file-like rows of teeth and the pivots on which they rock, the disposition of the muscles, the sucker-like foot, the alimentary canal—all these and many other details of structure co-operate to form a mechanism which is unintelligible except as a device for boring into and feeding on wood. The mutation theory of evolution teaches that organisms have evolved by sudden changes of structure which had no relation to the needs of the organism and only an accidental fitness for its mode of life. It is scarcely exaggeration to say that according to this school the shipworm bores into wood and feeds on it because it happens to find itself provided with suitable implements for doing so. If that were all the help to be got from the theory of evolution, it would be better to go back to the doctrine of special creation.

Obituary.

DR. H. B. GUPPY, F.R.S.

HENRY BROUGHAM GUPPY, who died at Martinique on April 23 on the voyage home from Tahiti, began work at a time when a medical training was the usual method of approach to a scientific career. Like other eminent naturalists, he started that career as a surgeon in Her Majesty's Navy. But the inspiration of the islands of the great oceans remained throughout his life as the directing force of his painstaking investigations of the problems relating especially to geographical distribution which they suggested.

In 1878 Dr. Guppy visited the China Seas; but his great opportunity came in 1881, when he was appointed surgeon to H.M.S. *Lark*, which was commissioned for survey work in the western Pacific. Two volumes on the Solomon Islands, published in 1887, contain the results of three years' study on the ethnology, natural history, and geology of this somewhat difficult group, where it was necessary to 'dare a little' in order to learn. The problem of coral-reef formation especially attracted him, and in 1888 he was able to continue his study of the problem on the Keeling-Cocos Islands, a classic locality, as the subsidence-theory held by Darwin was the result of a brief visit to the Islands during the voyage of the *Beagle*. Guppy, who examined all the islands and islets, more than twenty in number, concluded that these small atolls and horse-shoe islands only assume their characteristic form after the island has been thrown up by the waves (see NATURE, 39, 236, 1889). Later, in his physical and geological monograph of Vanua Levu, Fiji (1903), he describes

as "one long story of emergence" the building up of the island by reef-formation on a submarine basaltic plateau.

The problem of the stocking of coral islands had interested Dr. Guppy from the first, and between 1890 and 1896 he made a careful study of British plants from the point of view of dispersal by water—a paper on "The River Thames as an Agent in Plant Dispersal" was read at the Linnean Society in 1892. This prepared him for three years' intensive work in Fiji and Hawaii (1896–99), and later on the west coast of South America (1903–4). The fruit of these observations was "Plant Dispersal" ("Observations of a Naturalist in the Pacific," vol. 2, 1906), an eminently suggestive work and a mine of information on the floras, especially littoral, of the islands and eastern shores of the Pacific, and the means of dispersal which have been effective in their formation. General problems are also discussed; and the hypothesis of a great Pacific land-area is dismissed: "We have much to learn before it would be safe to look to hypothetical changes of sea and land to explain difficulties in distribution." The problem of fruit and seed became the *motif* of his work, and his "Studies in Seeds and Fruits; an Investigation with the Balance" (1912) is a study of mechanical and physiological problems bearing on means of dispersal. These were preparatory to his second book on this subject, "Plants, Seeds, and Currents in the West Indies and the Azores" (1917), a record of his personal observations during visits to the Islands, and a valuable contribution to the study of Island floras. The award of the Linnean Medal of the Linnean Society in the same year, and his