

close by, similar swarms were to be seen. Even these, however, were inaccessible; but I caught some of an apparently similar swarm drifting over the ground between the bushes, and inclose some of the specimens herewith. To me they look just like the insects which ordinarily strew one's table under the lamp at night (I notice, by the way, that to-night there are none, though the window is open as usual), and therefore I am led to suppose that the special character of the swarms noticed to-day appertains to some condition of the atmosphere, and not to the species of insect; but perhaps some of your contributors can throw light on this point. It would also be very interesting to know whether similar swarms were noticed elsewhere to-day, and whether they showed the same slant as was noticed here.

R. E. FROUDE.

Admiralty Expt. Works, Haslar, Gosport, May 27.

P.S.—The swarms of flies disappeared about 1 p.m., as the thunder clouds cleared away.

Popular Botany.

WE do not expect accurate scientific information from journalists; but so much confusion and error are seldom compressed into a small space as are to be found in a paragraph of which I send you extracts, cut from a London daily:—"A sad case of accidental poisoning by wild hemlock is reported from Tyne Dock. A little band of school children playing on some waste ground had gathered a quantity of a common variety of this dangerous plant, known to country folk as 'fool's parsley.' According to the evidence of one of the party, a little girl aged eight named Pringle, her sister 'said it was cabbage, and she should eat some.' Another boy and girl, named Shafter, who were still younger, followed her example. All three were soon afterwards taken ill. One 'complained of her legs as if they were tired'—a common symptom of hemlock poisoning—and 'her head afterwards got bad.' Pringle ultimately recovered under treatment, but the two Shafter on reaching home gradually became unconscious, and died the same afternoon within twenty minutes of each other. This species of hemlock, known to science as the *Conium maculatum*, is said to be much more poisonous in May than in any other month." It would be interesting to know what the plant really was. It can hardly have been the true hemlock, *Conium maculatum*, and instances of fatal poisoning by fool's parsley, *Aethusa cynapium*, are so rare that an authentic record would be valuable. It is difficult to imagine either of these plants being mistaken for cabbage. Can it have been *Cicuta virosa* or *Oenanthe crocata*? It would be interesting if any reader of NATURE could throw light on the subject.

The following delightful paragraph is cut from the same paper a few days later:—

"Can plants see? Darwin gave it as his opinion that some of them can [one would like to know where], and an Indian botanist relates some curious incidents which tend to verify the belief. Observing one morning that the tendrils of a convolvulus on his verandah had decidedly leaned over towards his leg as he lay in an attitude of repose, he tried a series of experiments with a long pole, placing it in such a position that the leaves would have to turn away from the light in order to reach it. In every case he found that the tendrils set themselves visibly towards the pole, and in a few hours had twined themselves closely round it."

ALFRED W. BENNETT.

Gaseous Diffusion.

IN your Notes of last week there is a description of an experiment for showing gaseous diffusion, devised by Prof. v. Dvorák, which, however, does not seem so striking as one that was shown at the Royal Institution more than twenty years ago by, I think, Dr. Odling.

A cylindrical porous battery cell was closed by a cork through which passed a vertical glass tube of about half an inch in diameter. The lower end of the tube was bent upwards into the form of a delivery tube, and was placed in a pneumatic trough, with a cylinder filled with water inverted over the end of the tube. On placing an inverted bell-jar of hydrogen over the porous cell, gas was rapidly collected in the cylinder, and this contained sufficient hydrogen to explode on the application of a flame. On removing the bell-jar, the hydrogen diffused outwards, and water was drawn up the wide tube.

Cooper's Hill, May 29.

HERBERT MCLEOD.

NOTES UPON THE HABITS OF SOME LIVING SCORPIONS.

THE literature which treats of the habits of living scorpions is not voluminous, but it labours under the disadvantages of being based largely upon undetermined species, and of being often of questionable trustworthiness with regard to the statements that are made. Even accounts that have been given of late years of the same species of scorpion differ widely as to facts of no small importance. Mons. L. Becker, for instance, asserts that the senses of hearing and seeing are highly developed in *Prionurus australis*, the thick-tailed yellow scorpion of Algeria and Egypt; Prof. Lankester, on the contrary, declares exactly the opposite to be the case. Discrepancies such as these and the deficiencies above mentioned show the need for fresh observations upon the subject, and no further excuse need be offered for publishing the following notes upon the habits of some specimens of two species of scorpions, *Parabuthus capensis* and *Euscorpium carpathicus*, which I was fortunate enough to keep for some months in captivity.

For the specimens of *Parabuthus* I gladly take this opportunity of expressing my thanks to my friend Mr. H. A. Spencer, of Cape Town, who kindly collected them for me at Port Elizabeth, while acting as medical officer on board the Union Steam Ship Company's s.s. *Mexican*; while for the *Euscorpium* I am indebted to the kindness of Dr. Gestro, of the Natural History Museum at Genoa. This last genus of scorpion Prof. Lankester has also written about; many of my observations, therefore, merely confirm those of this author. No description, however, has to my knowledge ever been published upon the habits of any species of *Parabuthus*. This genus, however, belongs to the same family as *Prionurus*, and the behaviour of the two in captivity seems to be very similar.

There is an abundance of evidence that scorpions are nocturnal, and mine were no exception to the rule. They would spend the daytime huddled together in corners of their box or under pieces of wood; at night they would wander about, presumably in search of food. It was easy, however, at any time during the day to rouse them from their sluggishness by applying a little artificial warmth to the box. One end of the box containing the *Parabuthus* was closed with a plate of perforated zinc. If this box was placed in the fender at a distance of about a couple of feet from a moderate fire, with the zinc end turned towards the grate, the scorpions would climb upon the metal plate and bask in the warmth. But immediately the box was brought near the bars of the grate they would all clamber or tumble from their position with ludicrous haste. It must not be supposed, however, that the amount of heat required to make them retreat was at all great. As a matter of fact warmth that I could without inconvenience bear for several minutes upon my hand would throw these animals at once into a state of the greatest consternation.

When walking both *Parabuthus* and *Euscorpium* carry the large pincers or chelæ well in advance of the head; these appendages thus fulfil the office of antennæ or feelers. In *Parabuthus* the body, however distended and heavy with food, is raised high upon the legs exactly as Prof. Lankester has described in *Prionurus*, and the tail is usually carried, curled in a vertical plane, over the hinder part of the back. In *Euscorpium*, on the contrary, as has also been pointed out by Prof. Lankester, the ventral surface of the body is scarcely raised from the ground during progression, and the tail, which is very slender and relatively much lighter than in *Prionurus* or *Parabuthus*, is dragged along, extended, and with a slight curl only at its hinder end. This difference in the carriage of the tail depends possibly upon the difference in its size and weight. For it seems reasonable to suppose that the heavy, robust tail of a *Parabuthus* or *Prionurus*

is carried with less muscular effort when curled over the back than when stretched out behind as in *Euscorpium*.

When attempting to climb up the smooth sides of their box the *Parabuthus* would raise themselves upon the extremity of the fifth segment of the tail, and by keeping this organ perfectly rigid and in the same straight line as the body they could maintain themselves in a nearly vertical position, thus reaching considerably higher than if supported upon the hind legs alone.

The method of digging shallow pits or holes in sand, which Mons. Becker and Prof. Lankester have described in the case of *Prionurus*, is also practised by *Parabuthus*. Standing upon the first and fourth pairs of legs, and using the tips of the chelæ and the end of the tail as additional props, with the disengaged legs a scorpion rapidly kicks the sand backwards between the legs of the last pair, very much as a rabbit or rat does when burrowing. Then with the apparent intention of removing what would prove an obstacle to its vision when crouching in the hole, it sweeps aside with its tail the heap of sand that has been thrown up, until the area surrounding its lurking place is tolerably level.

I never saw a *Euscorpium* digging in the sand. They were usually to be found during the daytime under pieces of wood, to which they were nearly always clinging belly uppermost. It is difficult to explain why this attitude should be assumed. Many terricolous arthropods, however, have the same habit, and I see no reason for thinking that in the case of *Euscorpium* it has any connection with the copulation of these animals as Prof. Lankester suggests.

All scorpions appear to be carnivorous, and there seems to be little doubt that they live principally upon insects or other articulated animals. My specimens of *Euscorpium* would eat blue-bottles and small flies, small cockroaches (*E. germanicus*), wood-lice, small spiders, and centipedes (*Lithobius* and *Geophilus*). The *Parabuthus* were fed principally upon the common house-cockroach and upon blue-bottles. It is interesting to note in connection with this last fact that Prof. Lankester's examples of *Prionurus* would not eat this common cockroach, nor did they seem to care for blue-bottle flies. This difference of instinct in the choice of food is remarkable, seeing how similar these two scorpions are in other particulars, both of habit and structure.

No one acquainted with the agility of a cockroach and the usual sluggishness of a scorpion would think that the latter would often succeed in capturing the former. Yet in truth, when placed in the same box, the insect seldom has a long lease of life. Its ultimate fate is always due to its ignorance of the scorpion's nature, and to the latter's adroitness in seizing anything that comes within reach. Wandering round the box, and exploring every inch of its new quarters with its antennæ, the cockroach soon discovers the presence of the scorpion by touching it with the tips of these organs. The scorpion's sense of touch, however, is as delicate as the insect's, and the latter's antennæ, or any part of it that happens to be near, is quickly seized by the pincers of the scorpion. Should the latter be disinclined for food and take no notice of the cockroach's first approach, the insect, continuing its wanderings, will fearlessly creep over the scorpion, just as a rabbit will over a python. Obviously this fearlessness must prove its destruction in the end, if not immediately. By means of its agility and strength, a cockroach sometimes eludes the scorpion's first clutch, and sometimes, but not often, breaks away from the latter's hold. But it does not readily learn from its narrow escape the advisability of giving its enemy a wide berth the next time they meet.

Although usually trusting to their heels for escape, cockroaches occasionally resort to a method of self-defence which is sufficiently curious to be described. Advancing upon an adversary rear end foremost, and at

the same time wagging from side to side this region of the body, they deliver vigorous backward kicks with their spiny hind-legs. This novel and humiliating mode of fighting, although not likely to prevail long against jaws and stings, is sufficient, nevertheless, to gain sometimes for the insects a temporary reprieve. I have indeed seen a fine female *Madeira tarantula* spider retreat in discomfiture before a big cockroach of the same sex, which assaulted her in the way described.

As soon as a cockroach is seized the use of the scorpion's tail is seen; for this organ is brought rapidly over the latter's back, and the point of the sting is thrust into the insect. The poison instilled into the wound thus made, although not causing immediate death, has a paralyzing effect upon the muscles, and quickly deprives the insect of struggling powers, and consequently of all chance of escape. If the insect, however, is a small one, one in fact that can be easily held in the pincers and eaten without trouble while alive, a scorpion does not always waste poison upon it. Thus I have seen a *Parabuthus* seize a blue-bottle fly, transfer it straight to its mandibles, and pick it to pieces with them when still kicking. Prof. Lankester only rarely saw his scorpions feed. I was more fortunate and repeatedly watched the operation, which is always performed exactly as this author has described. An insect is literally picked to pieces by the small chelate mandibles, these two jaws being thrust out and retracted alternately, first one and then the other being used. The soft juices and tissues thus exposed are drawn into the minute mouth by the sucking action of the stomach. It would seem, however, that some hard chitinous pieces are also introduced into the alimentary canal, for the entire exoskeleton of a cockroach is rarely, if ever, left after the meal is finished.

Feeding is a slow process; a good-sized cockroach will last a *Parabuthus* for upwards of two hours or more. But although voracious eaters when the chance presents itself, they are able to endure with impunity starvation of several weeks' duration. Unlike spiders, which are notoriously thirsty creatures, scorpions never seem to need anything to drink. At least none of mine were ever seen to touch water, although a supply of it was at first always kept in their box.

With regard to the higher senses, the only one that seems to be highly developed is that of touch. Mons. L. Becker declares that sight and hearing are excessively developed; but I cannot substantiate this statement in either particular. With regard to hearing, my observations agree entirely with those of Prof. Lankester, who could not detect the existence of any sense of this nature. None of my scorpions ever gave the slightest response to any kind of sound, although they were tried with tuning forks of varying tone and with shouts of both high and low pitch. These animals, in fact, resemble the hunting spiders in being apparently devoid of auditory organs. They further resemble them in the development of their visual powers, being able to see a moving body, like a living cockroach, at a distance of only about three or four inches. Even at a distance less than this they do not seem able to distinguish form. Thus a specimen of *Parabuthus* excited by the presence of cockroaches in the box, was seen to rush at one of its fellows that crossed its line of vision about two inches off, evidently not recognising by sight a member of its own species, for directly the pincers came in contact with the latter the mistake was discovered, the pugnacious attitude dropped, and no further notice was taken. This last observation shows that more is learnt from the sense of touch than from that of sight, an inference which is further supported by the habit, above referred to, of carrying the pincers well in front of the head as if to feel the way. There is no doubt that the external organs of touch in scorpions are the hairs which thickly or sparingly cover various parts of the body. The tail is often very thickly studded

with setæ, and the poison vesicle always has some upon it. Their use upon this latter organ is very plainly seen during the act of stinging. For this act is not by any means a random thrust delivered indiscriminately at any part of a captured insect. On the contrary, a scorpion generally feels carefully for a soft spot, and then with an air of great deliberation delicately inserts its sting into it. There can be little doubt that this care is taken that there may be no risk of damaging the point of the sting against a substance too hard for it. A reckless stab against the resisting chitinous exoskeleton of a beetle, for instance, might easily chip this point and thus deprive the scorpion of its most efficient weapon of attack and defence. The same care of the sting is shown in the carriage of the tail, this organ being curled in such a way that the point cannot come into contact with any foreign bodies. Even when teased with a piece of stick or irritated by being crawled upon by a cockroach, a scorpion is not often sufficiently provoked as to use the sting. The tail is certainly used to knock aside the instrument or sweep off the insect, but the sides or lower surface of the organ are employed, the vesicle being carefully tucked down. Upon one occasion a *Parabuthus* was seen to kill a cockroach and retire to a corner to eat it in peace, beginning at the tail end. Presently a smaller example of the same species coming along and finding the opposite extremity of the insect disengaged, started feeding on its own account. So quietly was the process carried on by the two, that not until nothing but a few shreds remained did the larger discover the presence of its messmate. Thereupon it quickly brought its tail into use and by beating off its unwelcome guest secured for itself the remains of the meal. But although the provocation was great the defrauded one never attempted to use its sting to punish the intruder.

In connection with the organs of touch, the pectine or ventral combs must not be forgotten. Of the function of these appendages something is known, though no doubt much remains to be learnt. Their situation near the generative aperture, their larger size in the males, and the modification of their basal portion in the females of some species, e.g. *Parabuthus*, suggest that they are tactile sexual organs of some importance, and Gaubert's discovery of the nervous terminations in the teeth is a satisfactory confirmation of this supposition. But apart from sexual functions it is highly probable that they are useful organs of touch in other relations of life, enabling their possessor to learn the nature of the surface over which it is walking. In favour of this view may be adduced the fact that these animals have been seen to touch the ground with their combs. Moreover, it is a very noticeable circumstance that scorpions which, like *Euscorpius*, creep along with their bellies close to the ground, have very short combs; while in others which, like *Parabuthus*, stand high upon their legs, the combs are exceedingly long. I once noticed a *Parabuthus* marching over a piece of a dead cockroach. When she had half crossed it, instead of going straight ahead as was expected, she halted abruptly, backed a little, and, stooping down, started to devour the fragment. From the height at which the body was being carried, I am persuaded that no portion of its lower surface, except the combs, could have come into contact with the piece of food; so there can be little doubt that its presence was detected by means of the organs in question.

Creatures which, like snakes, are both carnivorous and venomous, and present at the same time an appearance which is by no means reassuring, are always held in bad repute by mankind in general, and suffer in accordance with the principle laid down in the adage, "Give a dog a bad name and hang him." But amongst creatures of this description it is probable that scorpions qualify for first place with respect to the number and enormity of the vices with which they have been charged. Those

that are most frequently alleged against them are general ferocity, murder, cannibalism, infanticide, and suicide. And yet in spite of this serious charge-sheet, there is no doubt that they are much-maligned animals. For in defence of the accusation of ferocity I can say that I never saw a scorpion use its destructive weapons except with the legitimate object of killing prey for purposes of nutrition, or as a reasonable means of defence when molested. Naturally enough they will not tolerate handling, but when allowed to crawl upon the hand they make no attempt to sting it, and merely evince a desire to escape to surroundings more natural and congenial than human skin. From the charges of cannibalism and murder, however, these animals cannot be so easily cleared. For there is an abundance of evidence that they do sometimes, when in captivity, both kill and eat each other. Nevertheless, so far as my experience goes, members of the same species do for the most part live together in perfect harmony. Once only did I see a large *Euscorpius* eating a small one. But since the latter showed no signs of violence, there are no reasons for supposing that it had died other than a natural death. Like many other animals, scorpions may be made to fight by artificial means, and when roused to a high pitch of excitement by too much heat, they will clutch and grab at each other with the appearance of the greatest ferocity. But I never saw any evil result from these tussles. The combatants always seemed to prefer to part company without bloodshed.

As for the accusation of infanticide, it appears to be quite groundless. For it is well known that a mother-scorpion protects her young by carrying them about on her back until they are able to shift for themselves.

The question as to whether scorpions do or do not commit suicide by stinging themselves to death, when placed in a circle of fire, or otherwise tortured by that element, is one which has excited a considerable amount of discussion. The belief that they do so, with the object of escaping from the pains of burning, is of long standing, and probably has many adherents at the present time. But the experiments of Mr. Bourne upon some Madras species have shown (firstly) that the poison has no effect upon the scorpion that possesses it, nor yet upon a member of the same or of a closely allied species, and (secondly) that these animals are easily and quickly killed by a moderately warm temperature (50° C.). Moreover, when distressed by a too warm atmosphere, or, according to Lankester, by chloroform vapour, these animals have a habit of waving their tails in the air and of thrusting the sting forwards over the head, as if to punish some unseen enemy. And if the sun's rays be focussed with a lens upon the back of a scorpion, the animal immediately brings its tail over, and attempts to remove with it the cause of irritation. So that the true account of at least some of the so-called cases of suicide by scorpions seems to be this: the animals in reality have died from the heat to which they were exposed, and the observers have erroneously inferred that the thrusts of the tail were intended to put an end to the animal's sufferings. My own experiments are all in favour of this conclusion. I held a specimen of *Euscorpius* in a corked test-tube over a low fire. As soon as the air in the tube began to grow warm the animal, apparently in great distress, struggled about the confined space for a few seconds, brandishing its tail the while, then lapsed into insensibility. The glass of the tube at this period was only slightly warm to my hand. Taken out of the tube and placed near an open window, the animal quickly revived; but it died the third time the experiment was tried. On no occasion, however, did it attempt to sting itself. I also experimented upon *Euscorpius* and *Parabuthus* by focussing the sun's rays upon them, and by placing mustard upon the membrane between the plates of the back. Both the species attempted to remove the cause of

irritation by scraping at the burning spot with the sting of the tail; but they seemed particularly careful not to sting themselves.

There seems, however, to be sufficient evidence to prove that some scorpions have been seen to sting themselves during the course of experiments of a nature similar to those described above. One observer indeed mentions, in the case of an Indian scorpion, that blood issued from the wound made by the sting—a piece of corroborative detail which enhances the probability of the accuracy of the observation. But it is *à priori* improbable that the scorpion has any intention of killing itself. It seems, however, not improbable that a random blow meant for an unseen enemy might accidentally strike and pierce the deliverer; or that when the irritation is localised, as in the cases of burning with a lens, acid, whisky,¹ or mustard, the scorpion, failing to remove the substance by the ordinary means of scraping with the tail, might thrust its sting into the spot affected, with the intention, not of killing itself, but of destroying the agent that is causing the pain. Or, indeed, it is conceivable that the mental faculties are so deranged by torture and the approach of death, that the scorpion does not recognise its own body by its sense of touch, and stings it as it would sting any other object within reach of its tail. If a blow inflicted in either of these ways were to pierce the brain, or were to seriously lacerate the great dorsal blood-vessel, it might, one can suppose, cause death of itself, independently of the burning.

So that if it be admitted that scorpions have sometimes killed themselves, our verdict, it would seem, must be—accidental suicide, or suicide while of unsound mind.

R. I. POOCK.

NOTES.

WE greatly regret to have to record the death of Dr. Charles Pritchard, F.R.S., Savilian Professor of Astronomy at Oxford. He died at Oxford on Sunday morning last in his eighty-fourth year. We hope to give on a future occasion some account of his career as a man of science.

THE gold medal of the Linnean Society has this year been awarded to Prof. Daniel Oliver, of Kew, to whom it was presented at the anniversary meeting of the Society held at Burlington House on the 24th inst.

A TABLET erected in Truro Cathedral to the memory of the late Prof. John Couch Adams was unveiled by the Bishop of Truro on Saturday last. Canon Mason, a companion of Prof. Adams at Cambridge, delivered an address, in which he spoke of the illustrious astronomer as "one of the greatest of Cornishmen." The tablet—the cost of which has been defrayed by public subscription—was designed by Mr. Pearson, R.A., and executed by Mr. Juleff, sculptor, of Cornwall. The Latin inscription, a translation of which will be placed near the tablet, is by the Archbishop of Canterbury.

THE new engineering and electrical laboratories at University College, Gower Street, were opened on Monday last by the Duke of Connaught. Many invited guests were present at the ceremony. Mr. J. E. Erichsen, the president of the college, in beginning the proceedings, said it was confidently anticipated that when the two laboratories which were about to be opened were fully equipped with mechanical appliances and electrical apparatus the college would possess every requirement for advanced research and thorough teaching. The cost would not fall far short of £20,000, and the council hoped that a liberal response would be made to the appeal for funds which had been issued, and especially that the great City Companies, which had

It is stated that in some parts of N. America scorpions sting themselves to death if a drop or two of whisky be placed upon their backs; and that from this manifestation of their dislike of alcohol, these animals are known to the natives as *teetotallers*.

done so much for education and were so deeply interested in the success of such an enterprise, would give their assistance. Engineering was all-important, not only from a scientific, but from a national point of view, and it was needless to dwell on the importance of increasing the opportunities of the youth of this country for the study of the wonderful science of electricity, which half a century ago was little more than a toy for the learned, but now, through the telegraph and the telephones, entered into the daily life of us all, and before which gas was, it would seem, destined to "pale its ineffectual fires" as an illuminant. It was to be hoped that such laboratories as these would lead to fresh scientific triumphs and further practical developments. The Duke of Connaught, before formally declaring the laboratories open, delivered a short address, in the course of which he said it had been his good fortune to see some of the greatest engineering works in different parts of the Empire, and he was certain that those who, like himself, had seen them would recognize the vast importance of a thorough study of the sciences on which they reposed. Foreign nations were competing with us on all sides, and if we were to maintain the proud position which we had hitherto held we should have to use every endeavour to increase the opportunities of study and of practical work. He trusted that the ceremony of to-day would mark a new era in the history of the college, and would tend to the prosperity and the increased power of engineering in this country.

THE death of Prof. Ernst Eduard Kummer is announced. He died at Berlin on May 14. Dr. Kummer was a Foreign Member of the Royal Society, and at the time of his death was in his eighty-fourth year.

A MEMOIR of the late F. A. Genth was read at a recent meeting of the Chemical Section of the Franklin Institute, and will be published in the June number of the Institute's Journal. It was prepared by a committee specially appointed for the purpose. Mr. Genth is described in the paper as one of the ablest mineralogists, and certainly the foremost mineral analyst, hitherto known in the United States. The writers also speak in high terms of his personal character, and of his remarkable power as a teacher.

MISS AGNES CRANE writes to us from Brighton with regard to an intimation she has just received from the "chief commissioner (Geology) of the Women's Auxiliary Branch of the World's Congress." It is to the effect that the last week in August has been set apart, for a short session during the day, for the presentation of specially-prepared geological papers by women. Such papers are not to exceed half an hour in reading. The co-operation of English workers in this science is invited, and an address to "geological women" will shortly be issued. The chief commissioner in geology is Mrs. Louisa F. Lowery, of 11, Gainsborough-street, Boston, Mass.

A GEOLOGICAL excursion to Dorking will be made by members of the Geologists' Association on Saturday, June 3, under the direction of Prof. Boulger and Mr. T. Leighton, the object being to examine the district described by the directors in a paper read before the Association on December 2, 1892. Arrangements for excursions on the remaining Saturdays of June have also been made.

THE following prize subjects have been recently announced by the Belgian Academy for 1894:—A. Mathematics and Physics. (1) Exposition and discussion of the various theories of diffusion of one liquid into another, with new facts bearing on this; (2) Estimate of theories explaining the constitution of solutions; new experiments throwing light on the subject, and especially on the existence of hydrates in aqueous solutions; (3) The investigations of modern geometers on the theory of the triple orthogonal system to be summarised and