XXIX. OBSERVATIONS ON THE BIONOMICS OF FLEAS WITH SPECIAL REFERENCE TO *P. CHEOPIS*.

I. Development, length of life and breeding.
II. Relation to hosts.
III. Dispersal.
IV. Collection and examination.

FLEAS (*Aphaniptera, Siphonaptera*) are wingless insects which run or hop about. They are for the most part parasitic in their habits, being found only on the homoiothermic vertebrates, especially on those which build nests or have more or less fixed haunts or homes. Like the majority of other parasites they have the body flattened, but differ from most parasitic insects in that this flattening is in a lateral direction, so that the transverse diameter of the body is small and the vertical diameter great. Attention has already been drawn to certain other morphological peculiarities of these insects (vol. VII. p. 446).

I. DEVELOPMENT, LENGTH OF LIFE AND BREEDING.

Fleas undergo a complete *metamorphosis* in their development. The imago, perfect or adult female flea lays eggs. These find a resting place either on the ground or on some other suitable object, but are not attached to the fur of the host upon which the flea feeds.

The *eggs*. The eggs are said to be laid at all seasons, an observation which has been confirmed by us as regards *P. cheopis* in Bombay and in the Punjab. They are about as large as a small pin's head, ovoid or round in shape and of a waxy white or pearly colour. From one to five eggs, one after the other, are laid at a time. They generally hatch in a few days, in Bombay in about two days, after they have been deposited.

The *larva*. From the egg a worm-like larva emerges. It is furnished with chewing or biting mouth parts and lives upon almost any kind of

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refuse, animal or vegetable. The larvae are most easily detected among sand or bran in which the eggs have been laid by shaking these materials and watching for movements among the particles. They will be noted as minute, white, caterpillar-like creatures, endeavouring to conceal themselves from the light. They are liable to be confused with, and must be carefully distinguished from, the somewhat similar larvae of the Mycetophilidae, a family of minute flies, and also from the larvae of certain grain-eating weevils.

The larva is made up of a series of well-defined segments, fourteen in number including the head. Each segment is furnished with a number of hairs or bristles which are found on the ventral, dorsal and lateral surfaces of each segment except the first and last. The hairs on the dorsal surface of the penultimate segment are especially noteworthy, inasmuch as their length varies in the different species. They are, for example, remarkably long in the case of the larvae of *P. cheopis*, while they are comparatively short in the case of the larval human flea. On the ventral surface of the last segment two minute finger-like processes will be found: these are apparently used in progression.

The *pupa*. After a varying period, not less than a week, the larva, when full grown, becomes sluggish, ceases to eat and makes a cocoon. The cocoon is spun with fine, white, silk-like fibres and its surface is frequently covered over with dust, bran or other small particles of rubbish which adhere to the fibres.

The *imago*. The perfect flea escapes from the cocoon after a period of from seven to fourteen days. The young flea has now to seek for a host, for it is capable of living only on blood; its mouth parts, as we have already seen (vol. VI. p. 486), are so constructed that it can only feed on liquid food. Young fleas, that is to say those just escaped from the cocoon, are, however, endowed with a considerable amount of vitality, for they can live without food for from seven to fourteen days. Older fleas, which have sucked the blood of a host, die within a week if deprived of food.

The length of life of fleas.

With a view to finding how long *P. cheopis* could survive without food in different circumstances, we devised a number of experiments, in which these fleas were placed in various materials and we noted how long they were able to live in these surroundings. In one series of experiments (Table I) 150 fleas were added to each of the following

materials and the time when all, or nearly all, the fleas were dead was noted. They were kept without a host.

TABLE I.

Serial number of the experiment	Material in which the fleas were placed	Number of days the fleas survived
1	Bran	All dead in 6 days.
2	Bran	Ditto.
3	Bran with moisture	All dead in 7 days.
4	Cotton rags	All dead in 6 days.
5	Gunny bags or sacking	Ditto.
6	Rice and pulse	Ditto.
7	Sand, with moist cowdung in one portion of the box	15 alive on 6th day.
8	Ditto	3 alive on 8th day.
9	Ditto	All dead on 11th day.
10	Ditto	All dead on 14th day.
11	Ditto	4 alive on 11th day.
12	Ditto	1 alive on 13th day.

From these experiments it is obvious that *P. cheopis* is unable to live for many days in the absence of a liquid food supply. Some of the experiments, especially 11 and 12, show that in a box containing sand, but with a pat of moist cowdung in one portion, fleas could survive for a longer period than in circumstances in which they had not access to any moisture. In any case in the absence of their natural food they were unable to live for a fortnight.

We next endeavoured to find how long rat fleas could live when supplied with their natural food, the blood of a rat. In this experiment 36 fleas were placed in the usual glass box along with a rat on which they could feed. The number of fleas surviving on this rat and in the sand contained in the box was noted from time to time. Care was taken to change the glass box and the sand it contained approximately every tenth day, so that the count would not be vitiated by the development of new insects from eggs laid by the original fleas placed in the box. The details of the experiment are given in Table II.

TABLE II.

Date	Day of experiment	Number of live fleas found	Percentage alive
20. v. 06	1st day	36	100
30. v. 06	10th ,,	15	42
9. vi. 06	20th ,,	8	22
18. vi. 06	29th ,,	2	6
30. vi. 06	41st ,,	2	6
10. vii. 06	51st ,,	0	All dead.

From this experiment it will be seen that *P. cheopis* can live for at least 41 days when its food supply is derived from a rat. A similar series of six experiments (Table III) was carried out, in which a guinea-pig was used as the host for the rat fleas in place of a rat, with the following result:—

TABLE III.

Day of experiment	Number of fleas found	Percentage alive
1st day	240	100
5th ,,	114	48
10th ,,	41	17
20th ,,	3	1

Again, another series of experiments was made to ascertain how long rat fleas could live on man as a host. This series was carried out in the following way. Forty fleas were put into a long, wide-mouthed, glass bottle which contained some sterile sand in the bottom. Twice daily, for 15 minutes each time, a man's hand and arm were introduced into the bottle. The fleas hopped on to the hand and sucked the man's blood. Those which crawled up the arm were gently returned to the bottle. The fleas were caught and removed to a fresh bottle with fresh sand approximately every tenth day to avoid multiplication by breeding. From the subjoined details (Table IV) of the experiment it will be seen that *P. cheopis* can live for 27 days when fed on human blood alone.

TABLE IV.

Day of experiment	Number of fleas alive	Percentage alive
1st day	160	100
22nd ,,	9	6
25th ,,	5	3
27th ,,	1	1
28th ,,	0	All dead.

If we compare the figures in Table II with those in Table IV we note that while 6 per cent. of the fleas were alive on the 41st day when they were fed on a rat, the same precentage, namely 6 per cent., were alive only up to the 22nd day when they were fed on man. Again, all the fleas were dead on the 28th day when fed on man, but two out of 36 fleas were still alive on the 41st day when they were fed on a rat. It is evident, then, that rat's blood is a more suitable food than human blood for rat fleas.

Certain points of difference require to be noted in the behaviour of rat fleas when fed on the rat and when fed on man:—

(1) It was noted that the fleas were much more readily attracted by the rat than by man.

(2) Although the fleas jumped on the man's hand they took some time to begin to feed. They crawled about and seemed to have some difficulty in selecting a suitable spot on which to begin their sucking operations.

(3) The fleas much more readily fell off the man's arm, when he moved it, than they did when the rat moved; they were able to get a firmer hold on the rat than on man. It is interesting to note in this connection the larger claws of the human flea.

The time necessary for the completion of the cycle of development.

We have attempted to determine experimentally the time required for the completion of the cycle of development from the egg to the imago. We found that this time varied, one of the chief conditions which caused the variation being the nature of the food supply of the larva. Under the most favourable conditions from 21 to 22 days were necessary for the completion of the cycle, as the following experiments show.

Some sand mixed with guinea-pig droppings was placed in a glass box. Care in the first instance was taken to ensure that no fleas had had access previously either to the sand or to the droppings, so that these substances contained no flea's eggs. Into boxes of this description a number of pregnant female fleas, together with some males, were placed. The fleas were not supplied with a host so that within a week they were all dead. The cages were now carefully observed for the development of adult fleas, with the result that in three boxes these appeared in 21 days and in two cages in 22 days. In another series of experiments a single female was placed in a small entomological box containing a similar mixture of sand and rubbish as was used in the previous experiment. In two of these boxes adult insects were found on the 21st day. In other experiments, where larvae were fed on bran alone, adult fleas developed at intervals varying from four to six weeks.

Climatic conditions, also, appear to affect the development of some species of fleas. Thus, we found in the Punjab that, while *Ceratophyllus fasciatus* could be captured on rats from the beginning of November throughout the winter months, they began to disappear in

the beginning of April, and only one isolated flea of this species, the last of the season, was taken on a rat on the 15th of May. From this date to the beginning of November these fleas had entirely disappeared. In what form, egg, larva, pupa or perfect flea, this species tided over the hot and rainy seasons we were unable to ascertain.

Breeding places of fleas.

Fleas are most abundantly found in the haunts of their hosts, owing to the fact that the houses or nests of the hosts are par excellence the breeding places of these insects. Here eggs, larvae, pupae and adult fleas are unusually numerous. The breeding places of the different species of fleas, of course, vary with the habits of their host. Thus, birds' nests are the breeding places of fleas found on birds, human habitations the breeding places of *P. irritans*.

In the case of rats the breeding places of their fleas vary with the habits of the species of rat; thus, those found on *M. decumanus* breed in the burrows made by this rat, those on *M. rattus* in all sorts of situations which afford a shelter to these animals. We have on several occasions examined the earth and rubbish collected by *M. decumanus* in their burrows, where their young ones are found, and have noted the presence of a large number of adult and larval fleas. A nest made by *M. rattus* on a grain bag was also examined and a number of larvae of *P. cheopis* was found in the sacking in its neighbourhood. Where a trade is carried on in gunny bags this means of distributing *P. cheopis* should be kept in mind.

Dampness in the surroundings of a breeding place hinders the development of the insects. Adult fleas, also, appear to dislike wetness. A number of our failures in our early experiments to transmit plague from animal to animal by means of fleas, and possibly in the experiments of others, can be attributed to this cause, viz., the death of the fleas because of the wet surroundings. This difficulty was overcome by placing a layer of sand in the cages containing the experimental animals. The sand served to keep the cages dry and allowed the fleas to live and indeed to multiply. Long glass boxes with a layer of sand in the bottom in which a white rat or a guinea-pig was confined served as excellent breeding places for fleas.

Breeding season of fleas.

The question of the seasonal prevalence of fleas is discussed in full below. We propose now, however, briefly to record some observations which were made in the laboratory on the breeding season of fleas and on the effect of a high mean temperature on breeding.

(*a*) *Observations on the breeding season of P. cheopis in Bombay.* These experiments were carried out with the view of ascertaining if there was a definite season of the year at which this species of flea breeds, and if there was a season at which breeding does not take place. The method employed was as follows. In a long flea-proof cage of the same pattern, but much larger, as that figured in the first report (vol. VI. p. 435 and Plate IV), a wild rat was either allowed to run free or placed in a wire cage inside the glass cage. Forty rat fleas, taken from rats caught in Bombay, were placed in the cage along with the rat. A cage of this description was prepared every month from February 1906 to February 1907. The cages were all kept at laboratory temperature. Each week a census of the fleas in each cage was made in the following manner. The rat was removed from the cage and the fleas taken on it were enumerated, the latter being kept in a test tube. The rat was put back into the cage and left there for half an hour. It was then removed and the fleas on it again counted. This process was repeated a third time. The total number of fleas got on the three counts was taken as the census number; at the end of the operations the rat and the fleas were returned to the cage.

An analysis of the results, which it is unnecessary to reproduce, showed that breeding took place in one or more of the cages at all seasons of the year. While this was so, it would appear that in the month of June breeding was not so vigorous as during the rest of the year. From these observations, therefore, we can conclude that under the conditions of the experiments, which, it is to be remembered, were quite artificial, *P. cheopis* can breed at any season of the year in Bombay. It would be fallacious, however, to draw from these results any conclusion as to what occurs in nature.

(*b*) *Observations on the effect of temperature on the breeding of P. cheopis.* Several series of experiments with this object in view were carried out simultaneously (1) at room temperature, namely 75° to 80° F.; (2) in a specially constructed hot room, the temperature of which was kept at from 88°—90° F.; and (3) in a specially constructed

cool room, the temperature of which was maintained at about 72° F. These observations may be detailed as follows:—

Series 1. This series was designed to ascertain if a high mean temperature influenced the development of the flea from the egg to the perfect insect. The technique was as follows: Into each of eight flea-proof cages with sand at the bottom there were placed a rat and 40 fleas. At the end of 24 hours the rat was removed and the sand with those fleas not on the rat tipped out on to a tray, such as is described below (p. 256). The fleas were carefully removed and the sand replaced in the cage. There were, therefore, only eggs left in the sand. The cages were now divided into two lots, four cages kept at room temperature (75°—80° F.) and the other four in the hot room (88°—90° F.). At the end of three weeks the cages were opened and the fleas enumerated by means of the tray in the manner to be described. In the cages kept at room temperature, 21 adult fleas were found; in those kept in the hot room, none.

Series 2. This series of observations was made with the same object in view as that just described, but the technique was somewhat different. Into a long flea-proof cage, supplied as usual with sand in the bottom, a wild rat and forty fleas were placed. The rat and fleas were left in the cage. Some of the cages were kept at room temperature and an equal number in the hot room at 88°—90° F. At the end of three weeks, four weeks, five weeks and six weeks, the fleas were enumerated in the usual manner. In all, five cages at each temperature were treated in this way. The combined results of the flea census for each week is given in Table V.

TABLE V.

No. of fleas taken after	Room temperature (75—80° F.)	Hot room (88—90° F.)
3 weeks	86	23
4 ,,	329	57
5 ,,	527	72
6 ,,	456	68

It would appear then from this table that breeding went on at both temperatures, but much more vigorously at the lower temperature than at the higher.

Series 3. This series of experiments was made with the object of ascertaining if a high mean temperature had any effect on the imago as regards the laying of eggs. The following was the technique:— Twenty young fleas, which had been bred in the laboratory, were placed along with a guinea-pig in a flea-proof cage. One such cage

was kept at room temperature and another, prepared in exactly the same manner, in the hot room. At stated intervals between the third and eleventh day the guinea-pig was removed from the cage and the fleas found on it placed in a test tube, which was now kept for two hours at the same temperature at which the cage had been kept. The fleas were then put back into the cage and the number of eggs deposited in the test tube were enumerated. The guinea-pig was also returned to the cage.

In all three pairs of experiments were made in this way. The following Table summarises the results:—

TABLE VI.

No. of days from beginning of experiment on which eggs were counted	Room temperature (75—80° F.)		Hot room (88—90° F.)	
	No. of fleas put into test-tube	No. of eggs deposited	No. of fleas put into test-tube	No. of eggs deposited
3	37	16	24	0
4	18	9	5	0
6	15	5	5	0
9	28	22	15	0
11	10	19	10	0

Series 4. The last series of experiments was made with the object of ascertaining if temperature had any effect on the development of the egg into the larva. The following was the method of experimentation:— Fleas recently taken from their host were allowed to remain in a test tube for from two to three hours. They were then removed, and the eggs which they had deposited were collected. The eggs were then divided into three batches, one of which was kept at room temperature, another in the hot room, and the third in the cold room. At the end of seven days the larvae which had developed out from the eggs were counted. Table VII contains the results of this series of experiments.

TABLE VII.

	Room temperature (75—80° F.)	Hot room (88—90° F.)	Cool room (72° F.)
No. of eggs put in	461	420	128
No. of larvae which hatched out	33	2	43
Percentage of larvae on eggs	7·2	0·5	33·6

From a study of all these series of experiments we must conclude that a high mean temperature affects the breeding of fleas to a considerable extent, that it appears not only to restrain the imago from depositing eggs but also to be deleterious to the development of the eggs into larvae. There would seem also to be an optimum temperature at which breeding takes place more vigorously than at other temperatures.

II. The Relation of Fleas to Their Hosts.

Distribution of fleas, geographically and on animals.

Fleas are found in all climates from the arctic regions to the tropical zones. With regard to the geographical distribution of particular species it appears that, while some species have a more or less universal geographical distribution, such as *P. irritans*, others are found in more or less limited areas, such as *Sarcopsylla penetrans*, the chigger or sand flea. Attention has already been drawn to the geographical distribution of rat fleas in a paper by the Hon. N. C. Rothschild in these reports (vol. VI. p. 483). He concludes his paper by stating that "his opinion with regard to the different species of fleas that are found on house and port rats all over the world is that, except in Northern and Central Europe, *P. cheopis* is the commonest rat flea and in some localities is almost the only flea found upon rats." Fleas from rats in Northern and Central America had, however, not been examined. It is sufficiently important to point out here that the same host may have one species of flea commonly living on it in one part of the world and a different species in another part. For example, *Ceratophyllus fasciatus* is the common flea found on *Mus decumanus* in Western Europe, where *M. decumanus* is the common rat, while in India on this rat *P. cheopis* is found. Again, while *P. cheopis* is practically the only flea found on *M. rattus* in Bombay, in the Punjab during the cold weather *Ceratophyllus fasciatus* is present to the extent of about 2% of the fleas found on this rat (see these Reports vol. VII. p. 916). It would appear, therefore, that *M. decumanus* is probably the true host of *Ceratophyllus fasciatus*, and *M. rattus* the true host of *P. cheopis*, but that climatic conditions (geographical position) may to some extent favour the presence of a particular species of flea.

How long fleas remain on their host. Fleas, unlike many parasitic insects, do not remain constantly upon their host. A considerable part of their existence is passed on the ground, generally in what may be termed the home or nest of the host. In this respect, however, considerable differences exist among different species of fleas. We need only remark that such a species as, for example, *Sarcopsylla penetrans*, inasmuch as the female burrows into the skin of its host, remains of necessity upon its host for the largest part of its life. On the other hand, the human flea, *Pulex irritans*, apparently visits its host only for the purpose of obtaining food, and after a

satisfactory meal leaves its host, probably to lay its eggs in a suitable environment for the development of the larvae. In this case a considerable part of the life of the flea is spent apart from its host.

Selection of particular hosts by fleas.

It will have been observed in the remarks made above that certain species of flea have been associated with certain species of host. So much is this the case, that in common parlance the host has occasionally given the name to the flea. Thus, we have spoken of the human flea when we refer to *Pulex irritans* and of the rat flea when we mean *Pulex cheopis*. In theory each species of flea has its own particular host, generally known as its true host. In practice, however, it is often difficult to define this host, especially for certain species of fleas, owing to the fact that the flea commonly found on one host is often found on another host of a different species.

Thus for example, *Pulex felis* has been found by us on the dog, the cat, the tiger, the panther, the goat, the horse, the rat, the hedgehog, the kangaroo, the deer, the guinea-pig, the rabbit, the monkey, and on man and some other animals. While this species of flea is found on such a wide range of animals, yet it has a distinct preference for particular hosts. If a number of these fleas were given the choice of a meal on, say, the blood of a dog, a man, or a guinea-pig, they would select these animals in the above order. There is, however, very little difficulty in defining the true host of some other species of fleas; the human flea, *Pulex irritans*, for example, is seldom found on any other host than man. We have rarely noted it on rats and guinea-pigs.

The selection exercised by a particular species of flea for a particular host has obviously an important bearing on the spread of plague among men if this is effected by means of the rat flea *P. cheopis*. We propose therefore to enlarge on this selective habit of fleas and we shall confine our attention to the selection exercised by three species of fleas, viz. *P. irritans*, *P. felis*, and *P. cheopis* for three particular hosts, viz. man, rat and guinea-pig. We shall record our observations on each species of flea separately under the following heads:

(1) The animals on which the flea has been found by us:
(2) Experiments with fleas confined in test tubes:
(3) Experiments with fleas kept in large glass boxes:
(4) Observations in houses.

A. *Pulex irritans, the human flea.*

1. *The animals on which P. irritans has been found by us.* This flea is very select in the choice of its host. We have found it almost exclusively on man. On one or two occasions only has a human flea been noted on a rat or on a guinea-pig.

2. *Experiments with P. irritans confined in test tubes.* When this flea is confined in a test tube and allowed to feed upon the body of a man, rat or guinea-pig through a piece of muslin placed over the mouth of the tube it readily feeds on any of these animals.

3. *Experiments with P. irritans kept in glass boxes.* We have already (vol. VII. p. 413) drawn attention to the fact that human fleas kept in boxes with rats or guinea-pigs as their food supply rapidly die out. We have seen that after 24 hours only 1·2 % of the fleas originally put in could be recovered and that after 72 hours this number was further reduced to 1 %.

4. *Observations in houses on P. irritans.* We had frequent opportunities for observing this species of flea in the houses we visited in Bombay, in some of which it was present in such large numbers that we had only to enter the houses for a few seconds to find our legs covered with them. On one occasion two guinea-pigs, placed in a house which had been vacant for some days and in which the fleas must have been short of food, failed to attract any of this species, while a man who entered the house shortly afterwards acted as an admirable trap. Using man as a trap for this flea we have been able to capture in vacated houses large numbers for experimental purposes, as the following examples show :—

In one house on April 19th the following fleas were caught on a man's legs, namely, 84 *P. irritans*, 8 *P. felis*, and 1 *Sarcopsylla gallinacea*. In another house on 20th April, 31 *P. irritans* were taken on a man's legs in a few minutes. Again, in a third house 150 *P. irritans* and four *P. felis* were captured in a short time. From the tanglefoot experiments already recorded (vol. VI. p. 479) it will be seen that, judged from the number of human fleas found on the tanglefoot, white rats attract *P. irritans*, but it is noteworthy that very few of this species were caught on the animals which were not protected with tanglefoot. It is possible that the rat attracted the fleas, but that after feeding upon its blood they left it to return to the room, where perchance they might find a more suitable host.

B. *Pulex felis, the dog or cat flea.*

1. *The animals on which P. felis has been found by us.* The long list of animals on which this flea has been found by us has already been given (p. 246).

2. *Experiments with P. felis confined in test tubes.* Cat fleas confined in test tubes and allowed to feed on the body of a rat, guinea-pig or man, through a layer of muslin placed over the mouth of the tube, readily sucked the blood of all three animals.

3. *Experiments with P. felis in glass boxes.* Cat fleas kept in a glass box, where they have access to a guinea-pig for a host, rapidly die out as the following table shows:—

TABLE VIII.

Number of fleas present on

1st day	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day
233	64	9	3	2	2	1	0

4. *Observations in houses on P. felis.* During our visits to plague infected houses we frequently came across rooms in which cat fleas were abundantly present. In some of the houses in Sion village we had to leave a room because of the large number of these fleas which attacked us. On one occasion in house I. 5. 12 in Sion Koliwada we found twelve cat and ten rat fleas on a dead plague infected rat. This, however, was an altogether unusual phenomenon, as cat fleas were rarely found on rats.

Only twelve cat fleas were captured on guinea-pigs placed in the houses of Sion village, although some of the houses were swarming with these fleas (vol. VII. p. 826). In a goat stand, where cat fleas were numerous, a man and a guinea-pig were simultaneously used to trap the fleas. A large number was captured on the man and only a few on the guinea-pig. It would appear then that man is selected in preference to the guinea-pig by the cat flea. Moreover, it is a common observation that a cat or a dog may be badly infested with fleas while man, living with these animals, does not suffer from the bites of the insects unless they are very numerous. The cat flea, therefore, prefers to feed on a dog or a cat rather than on man.

C. *The Indian rat flea (Pulex cheopis).*

1. *The animals on which P. cheopis has been found by us.* We have found *P. cheopis* on rats (*Mus rattus, M. decumanus, Nesokia bengalensis*), musk rats, guinea-pigs, cats, rabbits, an Indian antelope, a kangaroo, and on man.

2. *Experiments with P. cheopis confined in test tubes.* This flea readily sucks the blood of man, guinea-pig or rat when confined in test tubes and given the opportunity to feed on these animals.

3. *Experiments with P. cheopis kept in glass boxes.* We have already detailed experiments in which rat fleas were shown to have lived on man for 27 days, on a guinea-pig for 20 days, and on a rat for at least 41 days. We shall now record some experiments which illustrate the selection of certain hosts by the rat flea. For the purpose of these experiments in some cases we used long glass boxes in which rat fleas were breeding freely and in which the number of fleas varied considerably:—

(*a*) In a flea breeding cage, in which the fleas were numerous, we placed for an equal time a rat and a guinea-pig. The fleas found on the animals were counted. The first count gave 65 fleas on the rat, and 106 on the guinea-pig. The relative positions which the rat and the guinea-pig had occupied in the box were now reversed and the animals were again put into the box for a few minutes; they were taken out together and the fleas were counted on each animal. This second count gave 50 fleas on the rat and 38 on the guinea-pig. There appeared, therefore, to be little preference in either direction.

(*b*) In another flea breeding box, in which the number of fleas was great, the following experiment was carried out.

A *M. rattus*, which had been confined in the box for some days to supply food for the fleas, was kept in, while other animals were put into other portions of the cage. In the first place a man's hand was introduced for five minutes. In that time eight fleas had jumped on to it and five of them had bitten him, leaving marks where they had fed. A guinea-pig was next placed in the box for five minutes. It was then taken out and examined for fleas, 41 being captured. Thirdly a white rat was placed in the box for the same period; it was then examined for fleas, 24 being captured on it. Finally, the *M. rattus*, which had been present in the box during the whole experiment, was removed and on it 133 fleas were found.

(*c*) In another flea breeding box, in which the number of fleas was comparatively small, and in which as in the previous experiment a *M. rattus* had been present for some days to supply food for the fleas, the following experiments were carried out.

Experiment I. The *M. rattus* being present in the box, other animals were placed in it. First, a white rat was put in for five minutes. It was then taken out and 13 fleas were found on it. A guinea-pig was then placed in the box for five minutes and on it 18 fleas were caught. Lastly, a man's hand was introduced into the cage for five minutes, but no fleas came on it in this time. The *M. rattus* which had been in the cage throughout the experiment was then removed and examined for fleas, 69 being taken on it.

For the purposes of the following experiments the fleas, but not the rat, were returned to the box.

Experiment II. The fleas having been starved for 24 hours, a man's hand was introduced into the box for five minutes. One flea came on to it and bit him. Then a white rat was placed in the cage for five minutes; 14 fleas were caught on it at the end of that period. Lastly, a guinea-pig was put into the cage for five minutes and nine fleas were captured on it. All the fleas were returned to the box.

Experiment III. The fleas having now starved for 48 hours the same procedure was adopted as in the previous experiment. On this occasion one flea came on to the man's hand and filled itself with blood. On the rat 28 fleas were captured and on the guinea-pig 16 fleas.

In the above experiments we had no definite knowledge of the number of fleas present in each box as they were being used as flea hatcheries. The number of fleas, therefore, varied to some extent from day to day, as new fleas were hatched out and old ones died off. In another series of experiments, which was carried out as follows, we used a fixed number of fleas.

(*d*) A large number of fleas which had just been taken off wild rats were placed in some sand. They were not supplied with any host to feed on. From this stock of fleas we were able to collect definite numbers, which had been starved for 24 or 48 hours, as they were required.

Experiment I, with fleas starved for 24 hours. Twenty fleas from the stock were placed in each of three boxes. A man's hand was introduced into one box, a guinea-pig into another and a rat into the third. The animals were left with the fleas for five minutes. On the man's

hand 10 fleas were captured, the other 10 fleas which had not fed being found in the sand in the bottom of the box. On the guinea-pig 16 fleas were caught, and on the rat 17 fleas.

Experiment II, with fleas starved for 48 hours. On this occasion 12 fleas were taken on the man's hand, 15 on the guinea-pig and 18 on the rat. It is noteworthy that in the case of the guinea-pig three fleas which had filled themselves with blood were found in the sand at the bottom of the cage. These fleas had apparently satisfied themselves and left their host within five minutes.

(*e*) In another experiment an attempt was made more nearly to simulate the conditions which occur in nature when a rat dies from plague and the fleas have left the corpse. In this case we placed 200 fleas, which had just been removed from live wild rats, in a glass box containing sand and introduced a man's hand into the box after certain intervals for the purpose of ascertaining how many fleas would attack him after they had been starved for different periods. The following observations were made:—(1) After the fleas had been starved for 24 hours, three fleas came upon the man's hand in five minutes; they all bit him. A large number of fleas were seen alive in the box but they did not go on to the man. (2) After the fleas had been starved for 72 hours a man's hand was introduced for five minutes. On this occasion a large number of fleas immediately jumped on to the hand and some of them crawled up the arm. These latter were gently brushed back into the box. At the end of the five minutes from 25 to 30 fleas adhered to the hand; most of these were feeding or had fed, but it was a matter of considerable difficulty to know exactly how many had fed. Many fleas were still alive in the sand. (3) After the fleas had been starved for 96 hours the same experiment was repeated. Again a large number of fleas at once jumped on to the hand and climbed up the arm. After five minutes 20 fleas, most of which had bitten the man, were found clinging to his hand. A fair number was still alive in the box. (4) After they had starved for 120 hours not many fleas were seen to be alive, but in five minutes six were found feeding on the man's hand, and soon their stomachs were seen to be full of freshly drawn blood.

4. *Observations in houses on P. cheopis.* We have already (vol. VII. p. 475) described some observations in which rat fleas were taken in large numbers on the legs of men who entered plague infected houses. We shall, therefore, confine ourselves now to certain experiments carried out in the godowns which have frequently been referred to (see vol. VI.

p. 450). Observations made in these buildings possess certain advantages over observations made in houses inasmuch as a "pure culture" of *P. cheopis* can be obtained, a condition which never obtains in houses, and further by the use of guinea-pig traps an approximate estimate of the number of fleas present at any particular time can be obtained.

Some experiments in the godowns have already been recorded (vol. VII. p. 474), but the following observations amplify these:—

Experiment I. On opening one of the godowns which had been closed for a week, many fleas were seen hopping on the floor. Four guinea-pigs were put into the godown by a man who stayed inside only for a minute or two. When he came out six fleas were caught on his legs. He felt the fleas biting him. Next day the guinea-pigs were examined for fleas and 352 were taken on the four animals.

Experiment II. On another occasion three guinea-pigs which had been in the godown over night were examined for fleas. They yielded 56, 97 and 92 respectively. One of the guinea-pigs after being freed from fleas was returned to the godown for three minutes and then examined. It had picked up 21 fleas in that time. On the legs of the man who went into the godown to fetch this guinea-pig, and who was in for only a few seconds, five fleas were caught.

Experiment III. In another godown on six guinea-pigs, which had been left in overnight, 194 fleas were taken. Three of the guinea-pigs were then inoculated with plague and with the 194 fleas were returned to the godown. Five days later all the inoculated pigs were dead. The man who went in to remove these animals was only in the godown for a few seconds; on coming out three fleas were captured on his legs.

In the above observations as well as in those previously recorded very many fleas were present in the godowns. When the fleas were less numerous man was not so readily attacked, as the following experiments demonstrate.

Experiment IV. Three guinea-pigs had been for some days in a godown known to contain only a few fleas. A man went into the godown and remained in it along with the guinea-pigs for five minutes. On coming out after that period no fleas were found on the man. The guinea-pigs, when examined, gave five fleas. The fleas were now returned to the godown but the guinea-pigs were removed from it. Twenty-four hours later the man again went into the godown for five minutes, this time without any guinea-pigs being present. On his coming out no fleas were found on his legs. A guinea-pig was then put

into the godown for five minutes and then examined for fleas, five being captured on it. The fleas were returned to the godown, which was closed for 24 hours longer. Next day, the fleas having now starved for 48 hours, a man went into the godown for five minutes, no guinea-pigs being present. On this occasion he picked up three fleas, all of which bit him. A guinea-pig put into the godown for five minutes after the man only picked up two fleas.

Experiment V. In another godown, in which from 100 to 200 fleas were judged to be present, two guinea-pigs had been living for some days. A man went into the godown for five minutes, while the guinea-pigs were still present. During this time only one flea came on his legs. The guinea-pigs were then removed and examined, 66 fleas being found on them. The fleas were returned to the godown but not the guinea-pigs. Next day, the fleas having now starved for 24 hours, a man went into the godown for five minutes; eight fleas came upon his legs. A guinea-pig placed in the godown for five minutes after the man had come out trapped 44 fleas. The fleas were returned to the godown and were starved for another period of 24 hours. A man then went into the godown for five minutes and picked up 40 fleas on his legs. A guinea-pig was put into the godown for five minutes after the man came out, and picked up 58 fleas.

These godown experiments confirm the results obtained with fleas kept in glass boxes. We may conclude from all these observations :—

(1) That the guinea-pig is as readily chosen by *P. cheopis* for its host, as its true host, the rat.

(2) That when many rat fleas are present some of them will attack man, even when a rat is available for their food supply.

(3) That when the number of rat fleas is small and when their true host is present they will not attack man.

(4) That when rat fleas are starved they will readily attack all animals, not being particular in their choice of a host.

(5) That rat fleas deprived of food for from 72 to 96 hours attack and feed on man more readily than at other times.

(6) That rat fleas, even when starved, prefer their true host to man.

(7) That rat fleas may be attracted to man, jump on him but take some time to feed on him. Plague infected fleas might in this way be carried from one place to another without infecting the man, but would, when brought near a rat, attack it in preference to man.

III. Mode of Dispersal of Fleas.

Fleas being wingless insects and capable of travelling only short distances on the ground, the method of their dispersal from place to place is of interest. This may be effected

(*a*) through the host directly in its natural wanderings;

(*b*) with the host when the latter is carried in merchandise:

(*c*) by means of merchandise, clothing, grain, etc., the host not being transferred with the fleas.

We shall confine our remarks in this connection to rat fleas.

(*a*) *Dispersion of fleas by means of the host in its natural wanderings.* We have already drawn attention to the fact that a large part of the life of fleas is spent on the ground, the host being visited more or less temporarily for the purpose of obtaining food, so that rats in their wanderings are constantly picking up and dropping fleas. We took advantage of this fact to keep certain godowns supplied with rat fleas. Rats had access to the roof of the godowns, but were excluded from the interior thereof by a wire netting screen. The fleas on the rats, that moved about or rested upon this screen from time to time, left their host and fell through the wire netting upon the floor of the godown below. Their presence in the godown was readily ascertained by using guinea-pig traps. Some counts of the fleas obtained in this way are given in these reports (vol. vi. p. 453).

Sick rats especially harbour fleas and are therefore more frequently dropping them. On each of four plague-sick rats in Bombay from 80 to 100 fleas were taken (vol. vi. p. 482, Table III). Again, four rats which were found dying from plague in the Punjab village Kasel gave the following number of fleas on each rat, viz. 137, 80, 10 and 35, or an average of 65 fleas per rat. Further, it was a matter of common observation in our godown experiments to note that sick guinea-pigs especially harboured fleas. It will thus be easily understood that a sick rat, crawling with fleas, will probably leave a certain number of fleas behind it, even on passing through a room. Moreover, we have already shown that if this rat was moribund from plague some of these fleas would be plague infected. In other words, a plague-sick rat in its wanderings might well leave a trail of infected fleas behind it.

(*b*) *Dispersion of fleas with their host when the latter is carried in merchandise, etc.* This method by which fleas may be dispersed requires little more than mentioning. We would, however, like to draw attention to the ease with which rats with their fleas can be transported in certain

kinds of merchandise. We have seen rats dive, as it were, into bags containing bran and disappear, so that the bags could be moved without any evidence of the presence of the rats within. *M. rattus* from its habits is particularly liable to be transported in this way.

(c) *Dispersion of fleas by means of merchandise, grain and clothes in the absence of their host.* From what has been said above it will be apparent that merchandise and grain, which have been visited by rats, may have fleas deposited on them and these fleas may be transferred with these articles to distant places. It is necessary to qualify this statement by pointing out that adult fleas, in the absence of any host to feed on, rapidly die, generally in about five days. However, larvae, since they can feed upon almost any kind of organic rubbish, and pupae, which require no food, could be carried considerable distances in merchandise, *i.e.* for periods as long as one or two months. The larvae and pupae so carried would in course of time develop into adult insects, other circumstances being favourable, but would then require a host to feed upon. In the absence of a suitable host they would perish within a fortnight of the time of their development into the adult or imago state.

During our visits to infected quarters in Bombay City we had many opportunities of noting that we carried away fleas on our persons or on our clothing. These fleas were generally human fleas, but occasionally *P. cheopis* was obtained. Moreover, in a number of experiments in which we caused clothes to be brought to the laboratory from infected houses, we were able to capture not only human but also rat fleas.

Fleas will be more readily carried on the clothes of a person, in that the man who wears the clothes forms an attraction for the insects. A reference to a previous paper (vol. VII. p. 472) and a consideration of the experiments carried out in the godowns, to be detailed later, show how readily and in what large numbers rat fleas may, under certain circumstances, come on to man, and leave us certain that rat fleas must frequently be transported in this way from place to place, especially from plague infected houses, where they are more likely to take to man because of the absence of their true host.

In whatever way fleas are transported, whether in clothing or merchandise, etc., they will select, when carried to their new surroundings, their true host or the next best available animal.

IV. The Collection and Examination of Fleas.

The collection of fleas. All are familiar with the great agility of the flea. The nimbleness of the insect, together with its minute size and flattened body, capable of withstanding considerable pressure, helps it to elude its enemies, especially man. This observation, however, chiefly refers to the human flea which progresses by hopping more frequently than many other species. These other species prefer to run rather than hop, and display their agility to the best advantage among the hairs of their host. Practice, however, soon enables one to capture fleas with the unaided fingers. Once caught between a finger and thumb they are readily transferred to a test tube, if into the mouth of the tube a smooth glass funnel is inserted. The fleas dropped into this funnel are unable to obtain a footing on the smooth glass and fall down into the tube.

The use of chloroform. Fleas, however, are more easily captured with the aid of chloroform. A few drops of chloroform are placed on a small pad of absorbent cotton wool. As soon as a flea is seen the pad is placed over it and held there for half a minute or so. The flea becomes anaesthetised and can be readily picked up in the fingers or by means of a moistened brush. This method is most applicable to the capturing of fleas on man and other large animals. Another method can be adopted if the animal from which the fleas are to be taken is of comparatively small size. The animal is placed in a large glass bottle or jar upon the bottom of which a little chloroform has deen dropped. The fleas crawl out from among the hairs to fall upon the bottom of the jar or remain entangled among the hairs. As soon as the animal has become completely anaesthetised, it may be removed from the bottle and the fleas can be picked off it. The effect of the chloroform on the animal is a guide to its effect on the fleas. When transferred to a test tube, the fleas rapidly recover from the anaesthesia and can be used for experimental purposes.

The use of a tray. Another method which proved to be very convenient for the collection and handling of fleas, especially in our cage experiments, was to empty the contents of the cage, *i.e.* sand and rubbish, upon a large white tray, which had smooth vertical sides about six inches high and all angles rounded off. If this tray was placed near a window and the sand from a cage spread out in a thin layer upon it, the fleas tended to make their way to the side of the tray most distant from the light. Here the fleas could be readily captured as they unsuccessfully

attempted to climb up the smooth vertical sides of the tray. The sand contained in a cage could thus be effectively examined, those fleas which were not on their host at the time of examination being captured in this way. The method was of particular use when an animal had been dead some time before it was examined. Under these circumstances the fleas had left their host and were to be found in the sand contained in the cage. In our early experiments a fresh animal, generally a guinea-pig, was used to trap the fleas, but the adoption of the tray method avoided the loss of a considerable number of animals, which died of plague when they were used as traps for infected fleas.

Capture of fleas in houses.

1. *The use of animal traps.* While it is a comparatively easy task to collect fleas on an animal which harbours them, it would appear at first sight to be a much more difficult operation to capture them in rooms in which they may be present. This, however, can be readily accomplished by using animal traps. To detect the presence of a particular species of flea in a room or place where it may be present, it is necessary, in order to obtain the best results, to use an animal which, if not the true host of that species, is one which is readily selected by it in preference to other animals. For capturing rat fleas *P. cheopis*, the guinea-pig or man serves as a suitable trap. The former animal should be chosen in preference to the latter, not only because it is more acceptable to *P. cheopis*, but because of the danger to the latter in the presence of plague. We have, however, on unavoidable occasions used man as a trap for *P. cheopis*, taking care that he had been well immunised against plague with a suitable vaccine. The trap animals can either be allowed to move about freely through the room or be confined in suitable cages. In the former case a larger take of fleas will be made, because they are picked up in various parts of the room, while in the latter case only those fleas which have been attracted by the smell in the immediate vicinity of the host and have succeeded in reaching it will be captured. Figures illustrating the advantage of allowing the animals to run about freely will be found in vol. vi. p. 482, Tables I, II, V and VI. As fleas are more or less nocturnal in their habits it is advantageous to leave the animal traps overnight in a room. The animals which had been used to trap the fleas are examined in the way detailed above.

2. *The use of tanglefoot.* The above methods are most applicable for the capturing of fleas which spend some little time on their host, but especially in the case of the human flea, which spends only a short time on its host, another method may be adopted. This method consists in placing an animal in a cage surrounded on all sides by a layer of tanglefoot, a sticky resinous preparation spread on paper. Such a cage is illustrated at page 478 of vol. vi. The fleas, attracted to the animal within the cage, in their endeavours to reach it hop on to the tanglefoot where they remain fixed. They can readily be removed from the tanglefoot with a needle and freed from the sticky material by washing in methylated spirits.

By a series of experiments we determined that a flea was unable to hop a greater distance than 4½ inches and by allowing a layer of at least six inches all round, the animal was afforded complete protection from fleas.

Examination of fleas.

1. *Examination of living fleas.* The examination of living fleas is best accomplished when they are under the influence of chloroform. If a few drops of chloroform are placed on the cotton wool plug of a test-tube, the fleas contained therein soon come under the influence of the drug and remain helpless for from ten to twenty minutes, during which time they can be handled and examined. They should be placed in rows on an ordinary glass slide and examined under the ¼ inch objective of an ordinary microscope or under the stereoscopic dissecting microscope of Braus and Drüner. The former instrument is the better one for beginners as the magnification is greater and errors in identification are therefore less likely to be made. Increased experience, however, enables one to identify the majority of fleas either with a low power lens or even with the naked eye. It must be remembered, however, that some species of fleas so closely resemble one another that a complete dissection can alone enable one to make a correct diagnosis (see vol. vii. p. 446).

2. *Examination of dead specimens.* Dead specimens are most accurately identified by dissection. In this examination attention should particularly be directed to the eighth and ninth segments of the abdomen. Various methods have been devised to facilitate these dissections, such as boiling the fleas in caustic soda or potash. We have found, however, that dissections can most easily be made if the dead fleas are allowed to soak in water at a temperature of about

80° F. for from 24 to 48 hours so that they become partly decomposed. The chitin, withstanding as it does putrefaction for a longer period than the soft membranous portions of the body, can be readily separated into segments where these segments were jointed together by membrane.

Microscopical specimens can be readily prepared by boiling the fleas in glycerine and mounting them in that medium, or better in glycerine jelly. More conveniently they may be boiled in alcohol, cleared in cedar wood oil and mounted in Canada balsam.

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