

Privy Council

MEDICAL RESEARCH
COUNCIL

REPORT OF THE
COMMITTEE ON BED-BUG INFESTATION
1935-1940



LONDON
HIS MAJESTY'S STATIONERY OFFICE

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PREFACE

In 1934 the Ministry of Health issued a Report on the Bed-Bug (*Reports on Public Health and Medical Subjects*, No. 72) which gave the recommendations of a departmental committee as to methods of dealing with infestation by this parasite. The information and advice contained in that document were necessarily based on the knowledge of the subject then existing, and one of the conclusions reached was that further research on the problem was required. The Ministry accordingly invited the Medical Research Council to promote new investigations with a view to a better understanding of bed-bug infestation and of practical methods for dealing with it. To assist them in this task the Council appointed a research committee, under the chairmanship of Sir John Ledingham, and including four members of the former departmental committee of the Ministry.

The Bed-Bug Infestation Committee of the Council began work in 1935. An extensive scheme of investigation was planned, and various members of the Committee undertook the direction of different parts of it, with the aid of grants for expenses and assistance provided by the Council.

These investigations were concluded in 1940. Although they have not exhausted the subject, they have added to knowledge of several aspects of the problem. Some of the results were published as the work proceeded, in papers contributed to scientific journals by the several investigators, and the Committee have put together a summary of all the findings in the following report. The decision to publish this at the present time is based on the view of the Ministry of Health that the matter is of particular importance under war conditions.

The preparation of the report on behalf of the Committee was undertaken by Professor G. R. Cameron as editor, with the assistance of a sub-committee of whom the other members were Sir John Ledingham, Major A. W. McKenny-Hughes and Mr. S. A. Ashmore. Of the services of these and the other members of the Bed-Bug Infestation Committee, and of all who took part in the investigations or provided facilities, the Medical Research Council wish to make grateful acknowledgment.

MEDICAL RESEARCH COUNCIL,
c/o London School of Hygiene and Tropical Medicine,
Keppel Street, W.C.1.

16th April, 1942.

REPORT
OF THE
COMMITTEE ON BED-BUG INFESTATION
1935-40

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INTRODUCTION

The investigations described in the following symposium were undertaken with the primary object of solving some of the problems raised in the Report on the Bed-Bug issued by the Ministry of Health in 1934 (*Rep. publ. Hlth med. Subj.*, No. 72).

The research programme of the Committee on Bed-Bug Infestation continued from 1935 to 1940, and during this period a number of scientific papers on different aspects of the problem were published either by members of the

Committee or by workers under their direction who received grants from the Council. These papers are marked with asterisks in the list on pp. 56-57 below; they include an account of five years' experimental work on the biology of the bed-bug which was carried out by Dr. (now Major) C. G. Johnson under Professor Buxton's direction; it was decided by the Council that Dr. Johnson's detailed report would be more usefully published in a journal than as part of the present symposium, and it has now, thanks to the good offices of Dr. G. S. Graham-Smith, F.R.S., appeared in full in the *Journal of Hygiene* (December, 1941). Its place below is taken by a summary review of Dr. Johnson's findings, compiled by Professor Buxton and himself, in which a special attempt is made to emphasise those parts of the work having a direct bearing on practical methods of controlling bed-bug infestation.

Next in the symposium follow sections by Professor Munro and Dr. Page, and by Mr. Ashmore and Mr. (now Major) McKenny-Hughes, respectively, on the chemical properties of insecticides in relation to their toxicity to the bug and its eggs, and on the development of methods for disinfesting houses and furniture.

In Glasgow much good has been accomplished by purely preventive methods, particularly in houses newly taken over by evacuated slum-dwellers. Adequate supervision of such houses, together with instruction of housewives in simple methods of domestic hygiene, are notable features of this organization, which is fully explained by Dr. (now Colonel) William Gunn.

It is of cardinal importance that insecticides used for the disinfestation of houses should have no immediate or cumulative toxic action either on persons engaged in the disinfestation or on others—such as the tenants of the houses—who may be inadvertently exposed. Professor G. R. Cameron joined the Committee to advise upon the question of the potential toxicity to man of new substances put forward as likely insecticides, and an account of his experimental methods in testing such substances is given in Section V below. The subsequent section—contributed by the Building Research Station of the Department of Scientific and Industrial Research and by the Ministry of Health—relates to building design from the points of view of the prevention of bed-bug infestation and of its early eradication should it occur. In this section is discussed also the construction of air-raid shelters from the same standpoints. An instruction of the Ministry of Home Security regarding the treatment of interior surfaces of air-raid shelters against bed-bug infestation is included as Appendix B (I) of this Report. A joint meeting of the Bed-Bug Infestation Committee and of Lord Horder's Committee on shelter conditions took place in October, 1940, when the question of infestation of public shelters was fully considered. The recommendations of the Bed-Bug Infestation Committee regarding insecticides for use in air-raid shelters have been published in the medical press and are printed here as Appendix B (II).

Appendix A consists of a list and summary of selected publications on the bed-bug and its eradication, which has kindly been compiled for the Committee by Dr. John Smart, of the British Museum (Natural History). His bibliography constitutes, in fact, an extension of that published in the Ministry of Health Report of 1934 to which reference has already been made.

I.—ECOLOGY OF THE BED-BUG: A SUMMARY OF NEW KNOWLEDGE*

BY

Professor P. A. BUXTON, M.A., M.R.C.S., and C. G. JOHNSON, Ph.D.
(*Department of Medical Entomology, London School of Hygiene and Tropical Medicine*)

There are perhaps two ways in which the biologist may help the health officer and his staff, whose object is the effective destruction of bed-bugs. The biologist should be able to provide a general survey of the whole problem, emphasizing the points which are essential; he must, in the second place, answer specific questions, such as "How long can bugs survive in an empty house?", "Can bugs feed on mice or poultry?", "What temperature kills bugs and eggs with an exposure of 30 minutes?"

The first of these tasks is the more difficult, because it is general and rather indefinite; moreover, there is a danger that the essential principles may be obscured by the large body of detailed facts which the biologist must collect. In the present note an attempt is made to emphasize these principles, and to interpret modern entomology to the sanitarian. The writers hope to be successful interpreters, because they have been closely associated in the experimental work for over five years, one of them (C. G. J.) planning and carrying out the very numerous experiments, the other influencing the general course of the investigation.

It appears necessary to consider the present state of applied entomology and the direction in which it is developing. In the early days the applied entomologist had to discover what insect pests occurred in each country, and to give an outline of their life. That work was a necessary foundation, though it had no direct relation to the problems of hygiene or agriculture. But the centre of the problem nowadays, and the point of greatest interest to the health officer, whether he knows it or not, is the question of *insect population*; to him the important question is whether the bed-bug (or other pest) is abundant enough to cause harm or annoyance, or to transmit disease. It therefore seems certain that future work on the bed-bug, and on many other sides of applied biology, will become more and more quantitative, demographic, and mathematical, because the object of study is the normal, wild bed-bug population. The group of papers here discussed shows the direction in which inquiry is turning. The first studies were carried out under simplified, precise, but unnatural conditions; for instance, pairs of bugs were kept in tubes under controlled climatic conditions and fed at regular intervals, so that records might be kept of length of life and production of eggs. Many other features in the life of the bug have since been investigated; for example, factors which influence the speed and success with which bugs develop, the highest and lowest temperatures which limit hatching, feeding, moulting and egg laying, and the effects of climate on many other phases in the life of captive bugs. The factors accumulated in this section of the work are the essential units of knowledge on which the general theory of population biology is based and without which rational interpretations of happenings to natural populations

* The greater part of the work described here was carried out by C. G. Johnson, working with a research grant from the Medical Research Council in the London School of Hygiene and Tropical Medicine from 1935 to 1940. A fuller account is given in the *J. Hyg. Camb.*, 1941, 41, 345, and in Johnson's earlier papers (see page 57 below). The illustrations and tables used here are taken from the paper of 1941, by kind permission of the Editor of the *Journal of Hygiene*. The data on which the curves are based will be found in that paper.

are impossible. They also answer many questions of detail which constantly confront the sanitarian.

On that foundation the work develops and passes to observations made on small half-natural populations of bugs, such as those which may be established in the hollow wall of a specially designed mouse-cage. That type of work has been amplified in experiments carried out with bugs living freely in a hut of the size of a small bedroom.

We may hope that future research, based on precise experiments and careful thought, will be extended to include field studies on wild populations; the results of a few of these are already available (Mellanby, 1939; Johnson, 1941, p. 419). Studies of this sort must be continued throughout the year, and in buildings of many types. Precise information is wanted on the seasonal fluctuations in the bug population, and that entails further studies on the presence or absence of eggs, the total number present, the proportion of nymphs to adults, and the proportion of females which are fertile. There is also need for careful observations on the movements and "homing instincts" of bugs, on what they do if the available resting spots become crowded, and on what powers they have of colonizing fresh areas.

But it will also become necessary to develop the subject in a completely different direction. It shows little wisdom on our part that we employ contact poisons and fumigants to control bugs, but neglect the study of the insect's cuticle and respiration. It is the insect physiologist who must help here. It is also certain that observations made in the field, on the bug's movements, and on its powers of finding a crack or host, will require to be interpreted by analytical studies of behaviour, the insects' reactions to single stimuli being isolated and tested in the laboratory.

THE COMMUNITY OF BUGS IN NATURE

Knowledge of the ecology of the bed-bug made it possible to discuss the seasonal changes which might occur in populations of this insect in houses in England (Johnson 1941, p. 433). Though the author himself is diffident about this section of his work, it is clear that enough is now known to give a new and very interesting view of events. There are reasons for thinking that, provided a source of blood is available, temperature is much the most important

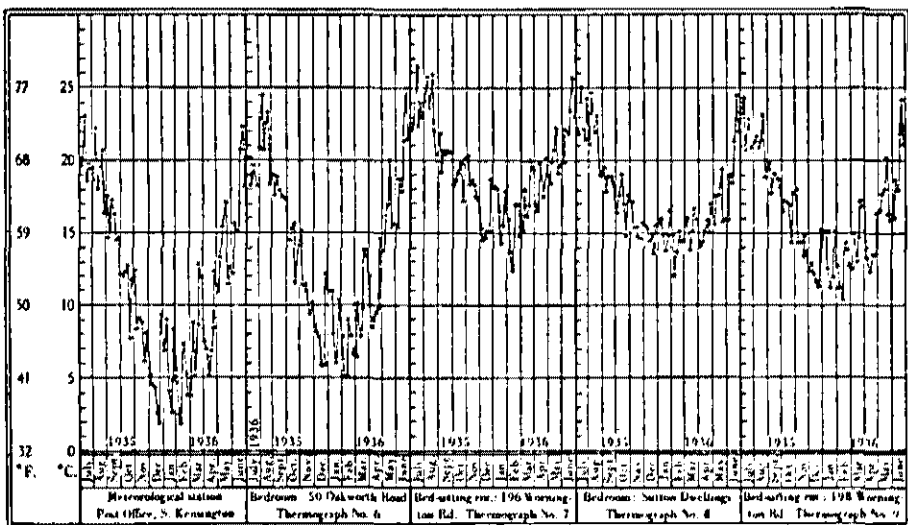


FIG. 1. Temperatures in rooms of various houses in Kensington for 1935-36, expressed as means for 5-day periods.

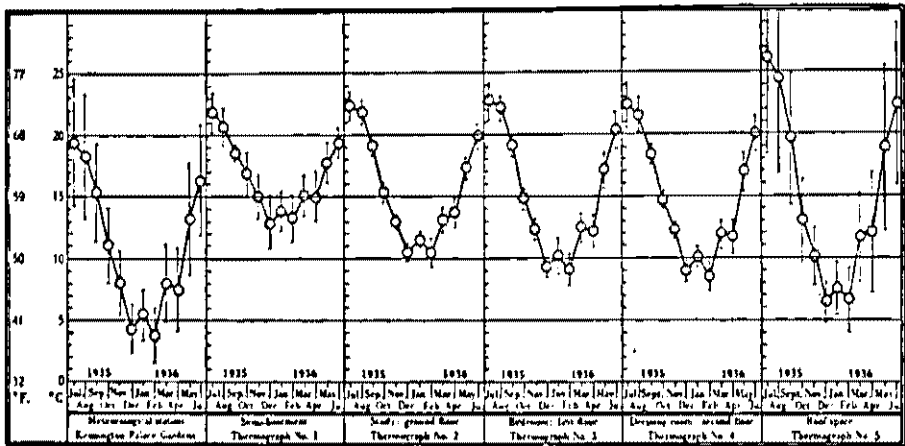


FIG. 2. Mean monthly temperatures, and mean maximum and mean minimum monthly temperatures, in rooms of 54, Palace Gardens Terrace, London, for 1935-6. Circles indicate mean monthly temperatures. Vertical lines through circles indicate mean maximum and mean minimum monthly temperatures.

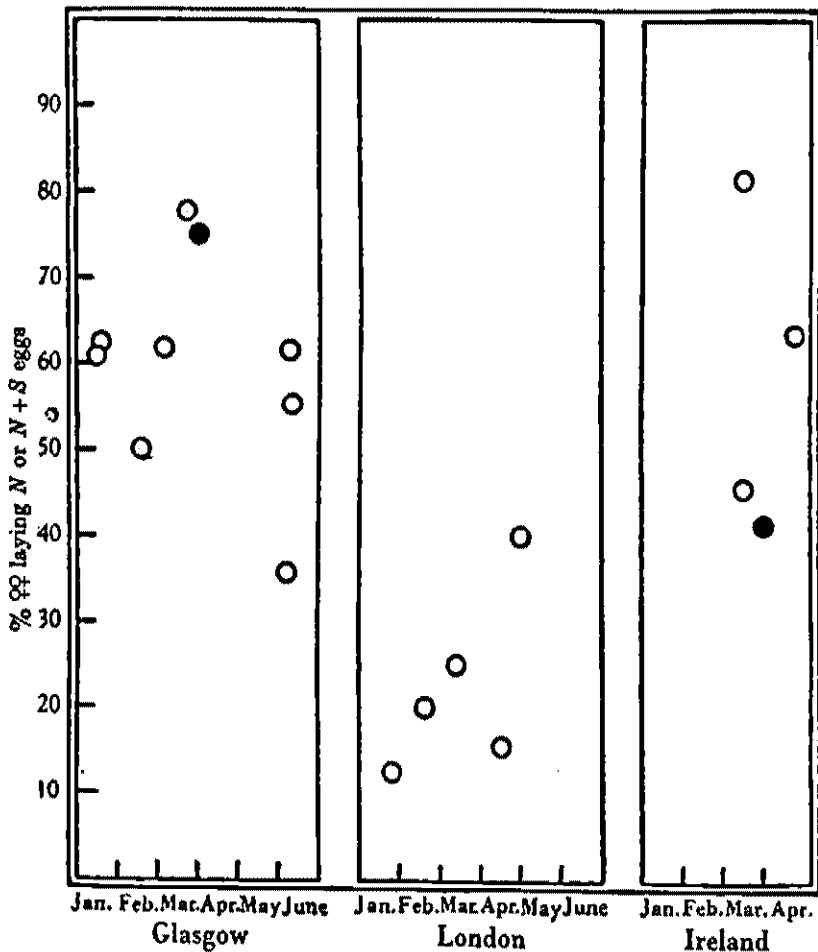


FIG. 3. Percentage of females in samples from wild populations which laid normal or a mixture of normal and sterile eggs when fed and placed at 23°C. Black circles are pooled values for several very small samples (J. and S., Table I). Date collected along abscissa. (See Johnson, 1941, Table 38.)

element in the bug's environment. Temperature has been measured, throughout the year, in rooms of different types (figs. 1 and 2), including one or two unheated bedrooms. There is also a large body of data on the effect of temperature on the growth and activity of the egg, nymph and adult of the bed-bug—for instance, its effects on the rate of development, on moulting and on frequency of feeding, etc. Taking the temperature measurements in houses, and the mass of biological fact obtained in the laboratory, and putting them together, one may develop an interesting picture. At the end of winter the bug population in an unheated bedroom will consist mainly of adults and large nymphs; there will be few small nymphs, and a very high proportion of the adult females will be unfertile (Table I and fig. 3). A small overwintered population might consist of 40 adult bugs (20 females) and half a dozen large nymphs. It is unlikely that the bugs will feed till the temperature rises to 16° C., in the middle of May.

TABLE I
Proportions of nymphs (instars I to V) in samples of overwintered populations of Cimex lectularius

Collection			Nymphs					
Sample	Date	New eggs	I	II	III	IV	V	Adults
<i>Glasgow</i>								
A	14th January	—	—	—	—	—	—	72
B	19th January	—	—	—	—	—	—	46
C	19th February	—	—	—	2	6	15	67
D	3rd March	—	3	3	6	6	6	58
E	23rd March	—	—	—	—	1	—	40
F	5th April	Several	—	—	—	—	—	40
G	7th June	"	1	—	1	2	4	53
H	7th June	"	—	—	—	—	7	54
J	January to June	"	18	—	9	8	22	76
	Total	"	22	3	18	23	54	506
		"	(4	1	4	5	11	100)
<i>London</i>								
K	24th January	—	—	—	—	—	—	62
L	18th February	—	—	—	1	3	15	175
M	12th March	—	—	—	2	8	16	67
N	15th April	—	—	—	2	13	50	340
O	1st May	—	—	—	1	5	6	41
	Total	—	—	—	6	29	87	685
		—	—	—	(1	4	13	100)
<i>Ireland</i>								
P	24th March	—	1	2	4	13	13	123
Q	25th March	—	—	3	23	27	33	164
R	28th April	—	—	—	2	12	16	25
S	March to April	—	—	—	9	10	21	124
	Total	—	1	5	38	62	83	436
		—	—	(1	9	14	19	100)

The bugs may be supposed to feed once a fortnight in the early summer, once a week in August and then once a fortnight in September and October; after that feeding ceases, owing to the low temperature. From the temperature

and number of feeds the production of eggs may be calculated. Account must be taken of the fact that some of the females which came through the winter had not been fertilized, and that the large nymphs have to become adult, before fertilization, so that they start laying eggs at different dates. Taking all that into account, we are justified in thinking that the first egg will be laid in the latter part of May, and we may calculate the weekly production of eggs from all those bugs which came through the winter (Johnson 1941, Table 54); the production rises to a peak of just over 90 eggs per week in August. Knowing the effect of temperature on the rate of development and mortality of the eggs, we may estimate the number of nymphs which will hatch from eggs in successive weeks, similarly, the number which will reach the adult stage. It will be noted (Johnson 1941, Table 55) that the first adults of this F_1 generation are not produced till the second week in August; the number becoming adult reaches a peak of over 60 a week early in October, after which the temperature falls below the moulting threshold. These adults, produced from the middle of August onwards, lay large numbers of eggs (F_2); but from the end of September onwards the low temperature will lead to such a high mortality among the eggs that they will not contribute much to the population (Johnson 1941, fig. 36).

Owing to the low temperature the bugs cease to feed at the end of October, and in November, when egg laying has also ceased, there are a large number of nymphs and adults, of generations F_1 and F_2 together. In the unheated house no F_3 generation would be produced. Laboratory experiments and observations on natural population lead to the belief that nearly all the small nymphs (stages 1, 2 and 3) will die of starvation during the winter; there will also be a considerable mortality among large nymphs and adults; indeed it is not unreasonable to put the natural mortality during winter as high as 80 per cent. (Johnson 1941, Table 38).

Now these conclusions are founded on the consideration of a very large body of data, though doubtless they are liable to some modification in the light of future research. They lead to the supposition that if a population of 40 adults and a few nymphs survived the winter, it might multiply to a peak of about 950, a twentyfold increase (fig. 4), but that natural winter mortality would reduce it almost to its original level, a remarkable and extremely interesting conclusion. It points to the desirability of concentrating on the destruction of bugs at the end of winter and in early spring, when the numbers are very low; at the same season there are no live eggs (which are more resistant to some fumigants than are nymphs or adults), for it has been shown that even under the most favourable conditions eggs are unlikely to survive for more than three months. Here it may also be mentioned that, after winter fumigation, one inspection of dwellings after so short a period as two or three weeks (a common practice with sanitarians) is unlikely to reveal bugs even if they are present. For the bugs are extremely sluggish in the winter and a residual population surviving fumigation would be difficult to detect after so short a time. The efficacy of a fumigant cannot be fully tested by such a cursory reinspection.

A totally different state of affairs prevails in centrally heated flats, or warmed living rooms (*see* fig. 4, Sutton Dwellings). In these the winter temperature is much higher than in the unheated bedroom; the mean temperature of the coldest week is not much below 13°C . (fig. 1), which is close to the bug's threshold for egg-laying, moulting, etc. The summer temperatures are close to those of the unheated room. It follows that there is no long "winter" in which activity would cease and mortality would be high, though, even in the warmed room, a considerable mortality among eggs is probable. In the colder months fasting bugs would survive very well, for 13°C . is about the optimal temperature for their survival, and some feeding might occur throughout

the year. There are two consequences of this: the increase in the first summer and autumn would be much greater than in the unheated room, perhaps 70-fold rather than 20-fold, in nymphs and adults (fig. 4); and as there would be little decrease of population in winter, the total number of bugs in the second or subsequent years might become enormous.

The reader will observe that there is an interesting relation between the biology of a population of bugs, and the housing of their human host. If the host is forced by poverty to live in one bed-sitting room in an ordinary dwelling house, he may be able to warm it by day (for comfort, or by cooking), and the bugs will remain active throughout nearly all the year, attacking him by night. But

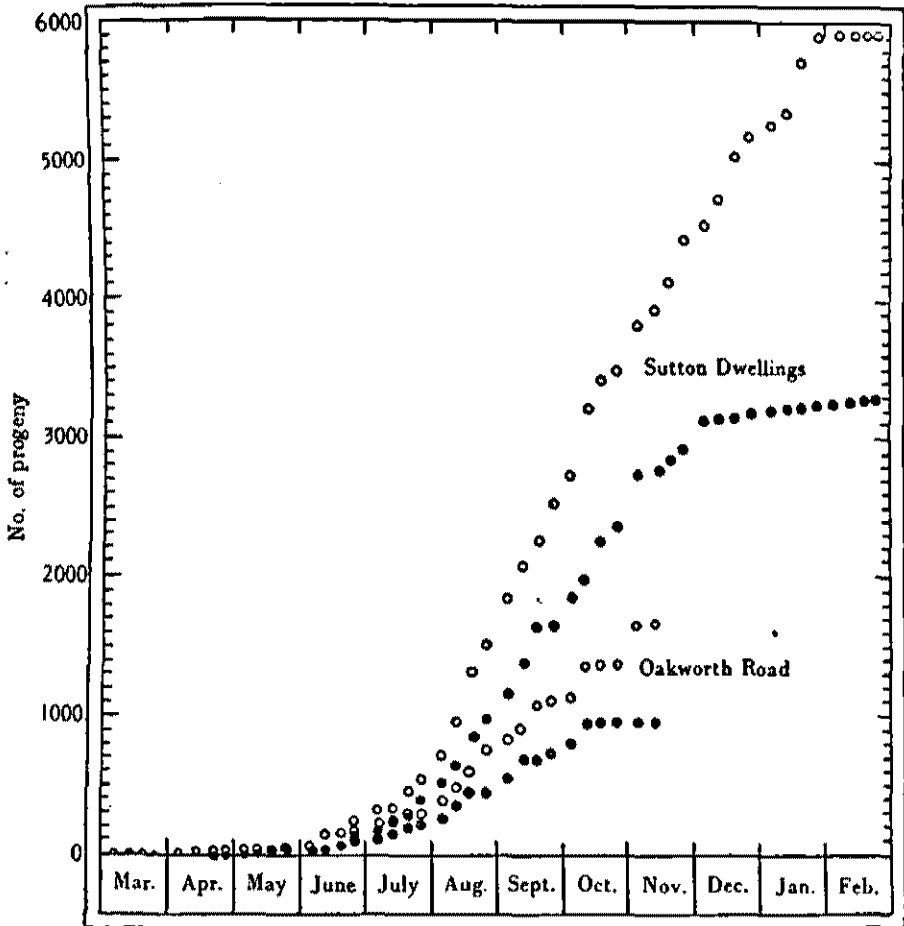


FIG. 4. Hypothetical population growth for Oakworth Road and Sutton Dwellings in terms of number of organisms. ○ = total progeny. ● = ditto, excluding eggs (*i.e.* adults and nymphs). (See Johnson, 1941, Table 59.)

if he can afford to live in two or more rooms, the fact that he warms the sitting room will not help the population of bugs which operates in the bedroom; if the bedroom is cold the bugs in it may increase in summer but will be numbed by the winter cold; indeed many of the bugs and all the eggs will die during the winter. In blocks of flats, however, a bedroom without a separate source of heat may be built between two living rooms or kitchens and it may then maintain a winter temperature as high as that in a bed-sitting room. We may therefore expect such blocks of flats to be especially liable to heavy infestation, because even their unheated rooms may harbour populations of bugs which breed all the year round.

INFORMATION ON SPECIFIC POINTS

We may now turn to certain particular points on which recent research provides information which the practical sanitarian may use. In almost every case increase of knowledge reveals unsuspected complexity; it is in vain that the practical man asks for a "simple answer to a plain question," for no one with any knowledge of the truth can produce simplicity from nature's complexity.

It has been shown that temperature is a most important factor in the life of a population of bed-bugs. We may proceed from that to consider the effect of temperature on rate of development, on the survival of bugs which are starved, and on the hatching of eggs; also facts relating to temperatures which are fatal on short exposure.

A—The rate of development of the bed-bug

Besides the egg there are five nymphal stages; the last and fifth stage moults into the adult. An individual in each stage must take one full meal of blood before it can pass into the next stage. Provided a host is easily accessible and the temperature about 20–30° C. bugs will feed within two days after a moult. At 18° C. this pre-feeding period is somewhat longer (about five days perhaps), while at 15° C., which is very close to the moulting threshold, the period is longer still. By allowing for these periods in an arbitrary fashion, the rate of development, from the laying of eggs of one generation until eggs are laid by the next generation, can be calculated. The periods are shown in fig. 5.

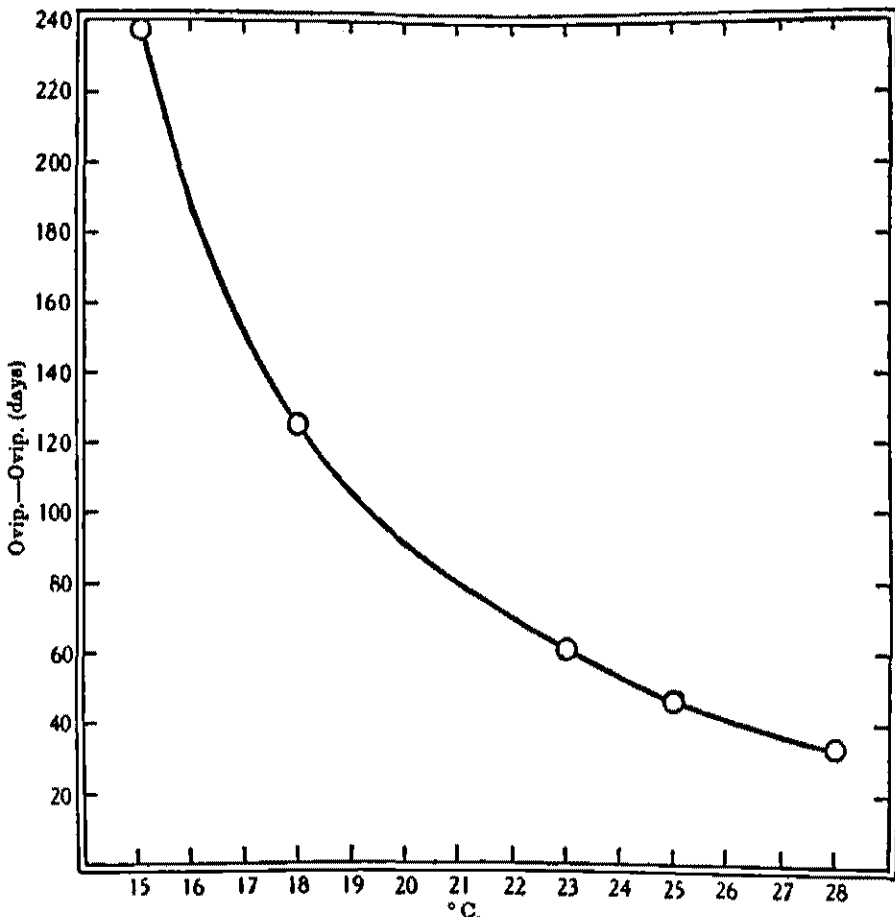


FIG. 5. Mean period from oviposition to oviposition: pre-feeding periods arbitrarily fixed. (See Johnson, 1941, Table 8.)

But if a host is found only with difficulty the periods shown in this figure may be greatly lengthened for a considerable proportion of the bug population. Thus when bugs were kept in an experimental hut in which a chicken was placed each night, the periods for development were much longer than in laboratory experiments in which a minimum of time is wasted in finding the host (fig. 6).

Another interesting point on which further details are required is the effect of low temperatures on nymphs. Low temperatures not only arrest development of the particular instar, but affect its ability to moult after a feed even if subsequently placed at a higher temperature (Johnson 1941, p. 373).

B—Activity and temperature

Mellanby (1939) has shown that the maximum numbers of bugs are active in the hours just before dawn, and that most of them return to their resting places after daybreak. But observations in the experimental hut show that temperature also has a marked effect on the number of bugs which wander from their harbourages. From fig. 7 we see that the higher the temperature, the greater the number of active bugs; not only do rises and falls of no more than 1° C. produce an effect but it appears that a very slight amount of activity goes on at temperatures between 7° and 10° C., that is to say, under conditions such as occur in unheated rooms in winter.

C—Survival of starving bed-bugs

The survival of bugs in the absence of a host is a matter of great practical interest. It is the maximum period of survival, rather than the mean, which is generally required, but in considering the facts it should be remembered that towards the end of a long period of starvation bugs may be so weak that it is doubtful if they would be able to find a host, pierce skin and take blood. For this reason, and because bugs in these experiments could not run about to any extent and so use up energy, the maxima that are quoted may considerably exceed what one might call the effective maximum period of survival.

From the data set out fully elsewhere (Johnson 1941, p. 401 and onwards) it seems that a temperature of about 13–14° C. is most favourable to long life without food; both above and below this figure life is materially shorter at comparable humidities; for long life humidity must be high, so as to reduce loss of water by evaporation. The large nymphs (fifth stage) and adults outlive the smaller nymphs, and among adults virgin females and mated males live the longest. The following figures give mean and maximum length of life of adults, at high humidity (90% R.H.) and various temperatures; the maxima are approximate, but correct within a few days (Johnson 1941, Table 41).

Temperature		Male, mated (days)		Female, mated (days)		Female, virgin (days)	
C.	F.	Mean	Max.	Mean	Max.	Mean	Max.
7	44.5	220	386	286	465	317	552
13	55.4	338	470	360	565	—	—
18	64.4	152	260	143	225	—	—
23	73.4	85	136	69	127	121	184

Broadly speaking, we may conclude that the mean period of survival of fasting adults may equal one year, under climatic conditions close to the optimum; the maximum greatly exceeds one year, under several conditions, but it is not known to reach two years.

It is a matter of some interest to observe that even such an apparently simple thing as mean length of life is affected by many variables, and therefore not easy to determine. Some of these variables, *e.g.* temperature, humidity,

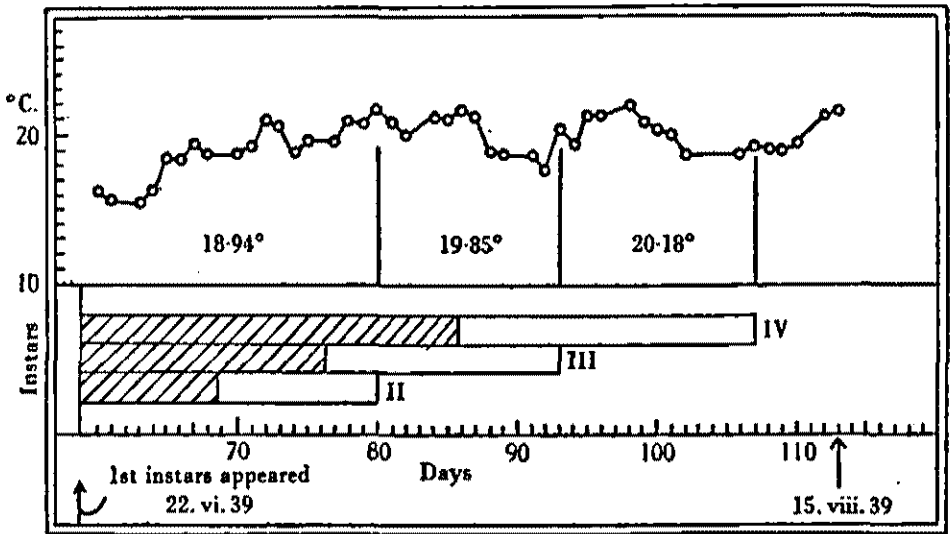


FIG. 6. Temperatures (above) in the experimental hut from June to August 1939; below, dates at which one would expect successive instars (II, III, IV) to appear, and dates of observed occurrence. ▨ expected; □ observed.

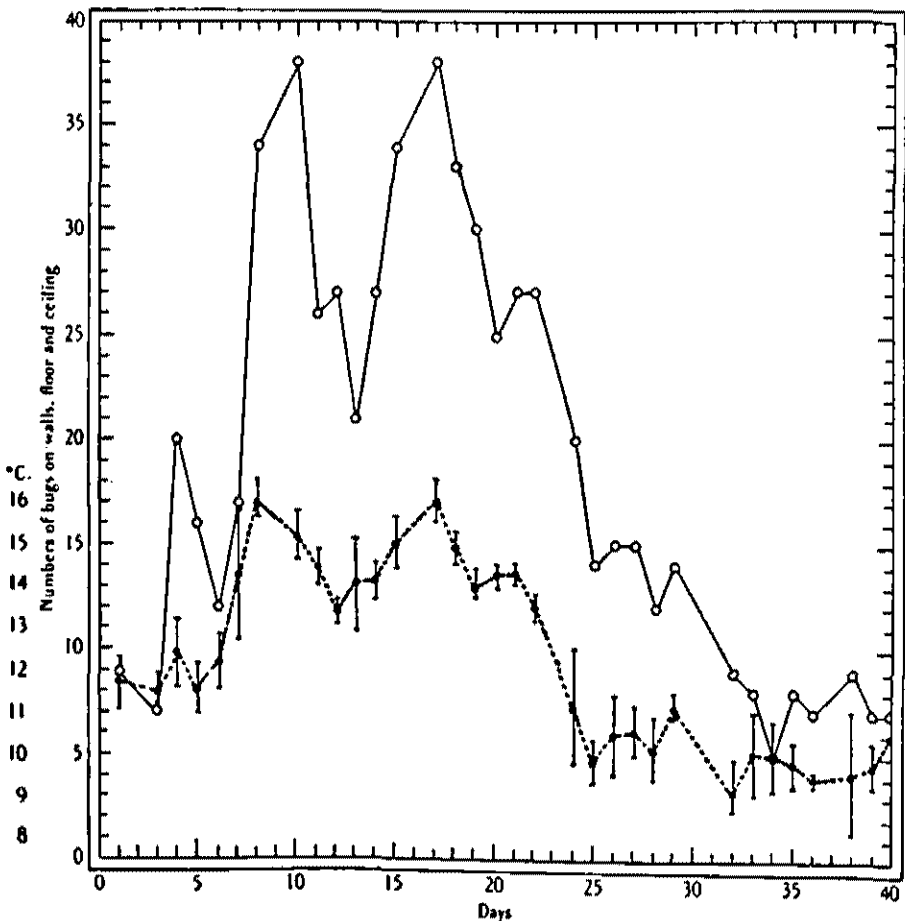


FIG. 7. Correlation of activity in experimental hut. Dotted line represents mean daily temperature; vertical lines indicate mean maximum and mean minimum daily temperatures. Unbroken line: number of bugs daily on walls, floor and roof. (For further details see Johnson, 1941, Tables 46, 52 and 53.)

activity, age, sex, virginity, have been taken into consideration, but others have not. The nutrition of the insects, the species of host, the temperature at which the insects had previously been bred, and many other factors would affect the result.

From the practical point of view, information is also needed about the survival of eggs. It is found that at 13° C. eggs develop and hatch, the mean period being 49 days (fig. 8). At temperatures even as low as 4° C. they develop very slowly, but they cannot hatch provided the temperature remains always below 13° C. Furthermore, if eggs have nearly completed their development at 13° C. or higher temperatures, the nymphs can emerge from the egg-shell even if the temperature is as low as 8° C. The whole matter is complex, and many variables are involved. There seems to be satisfactory evidence that at a fluctuating temperature about 11.5° C. some eggs may survive for up to about 80 days, though they do not hatch; it seems that there is no temperature at which survival much exceeds 80 days. It follows that survival of eggs through the winter in unheated houses in England appears to be very improbable. The point is well brought out in Table II.

TABLE II

Exposures for 99.99 per cent. mortality for Cimex lectularius eggs at temperatures between 1° C. and 13° C. and various humidities

Mean		Per cent. R.H.	Sat. def. mm. Hg.	Exposures in days
° C.	° F.			
1.0 ± 0.8	33.8	89	0.5	39
1.1 ± 0.8	34.0	5	4.7	40
4.1 ± 0.8	39.4	89	0.7	66
4.2 ± 0.8	39.6	70	1.8	56
4.0 ± 0.8	39.2	60	2.4	59
4.0 ± 0.8	39.2	15	5.1	61
4.3 ± 0.8	39.7	5	5.8	47
6.7 ± 1.0	44.1	65	2.6	52
6.9 ± 1.0	44.4	29	5.3	54
7.7 ± 1.0	45.9	90	0.8	68
7.8 ± 1.0	46.0	9	7.2	50
9.1 ± 1.1	48.4	72	2.4	62
9.3 ± 1.1	48.7	42	5.1	51
9.8 ± 1.1	49.6	89	1.0	55
9.8 ± 1.1	49.6	6	8.5	53
11.7 ± 0.8	53.1	89	1.1	73
11.7 ± 0.8	53.1	5	9.8	56
12.1 ± 1.0	53.8	73	2.9	80
12.1 ± 1.0	—	46	5.7	63
12.1 ± 1.0	—	25	7.9	49
12.1 ± 1.0	—	0-1	10.6	44
13.0 ± 0.2	55.4	0-1	11.1	62

D—Lethal temperatures

In disinfestation, one needs to know the lethal high temperature (*i.e.* the lowest temperature above normal which will kill an insect), on a certain period of exposure. From data set out fully elsewhere (Johnson 1941, p. 418) it is

concluded that the following temperatures are fatal to all bugs, and that slightly lower temperatures are not :—

		Degrees C.	Degrees F.	
For the egg	45.0	113.0	1 hour.
		41.0	105.8	24 hours.
For nymphs	45.0	113.0	15 minutes.
		44.4	111.5	1½ hours.
For adults	44.0	111.2	1 hour.
		40.0	104.0	24 hours.

In practice we seldom need to know the lethal low temperature, though it might be valuable, particularly in countries with very cold winters. For eggs, no body of data exists; for nymphs and adults it seems that -17°C . (1.4°F .) is fatal in two hours, and -18°C . (-0.4°F .) in one hour. Further research is needed in respect of the zone between -5 and -15°C .

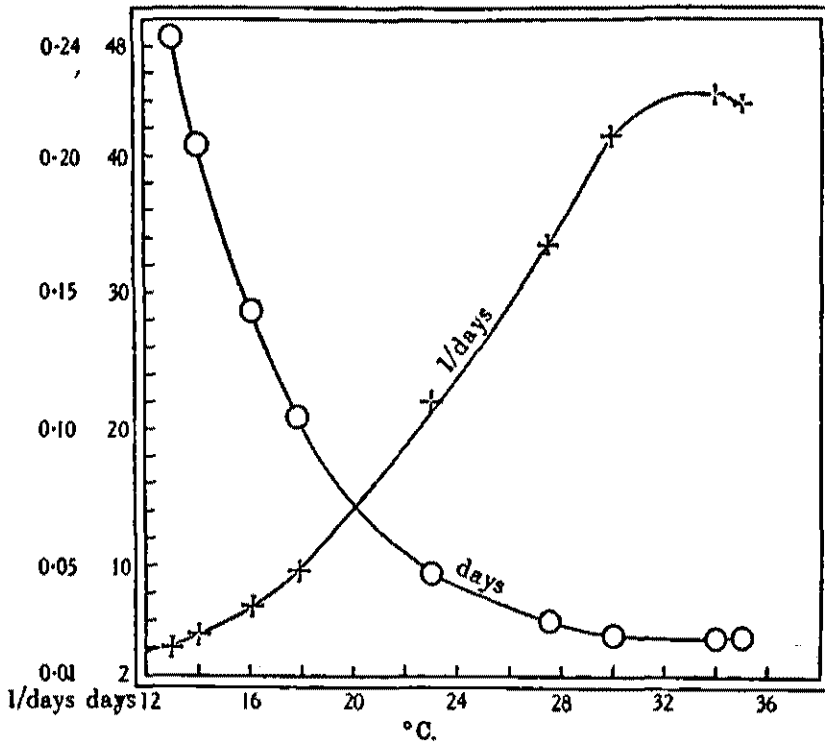


FIG. 8. The mean duration of the period from oviposition to hatching of *C. lectularius* eggs at constant temperatures and the reciprocals of these values plotted against temperature. O = duration; + = reciprocal.

E—Food

It is generally known that the principal host of the bed-bug is man, but that large and apparently healthy communities of bugs may be found in chicken houses, and occasionally in places where rabbits, experimental rats, etc., are kept. It is also known that bugs will feed readily, at least under artificial conditions, on a number of common "laboratory" animals and birds, and that such bugs grow and lay eggs.

A part of the present investigation has been given to a further study of these problems, and particularly of the question whether a community of bugs

maintained for several generations on some lower animal differs significantly from a similar community fed on human beings; for instance, is the one group more successful than the other, or capable of more rapid multiplication? The mouse, the fowl, and two individual human beings were selected as hosts, and their efficiency compared in a number of ways; the bugs were fed on them through several generations, and the rate of development, the proportion of insects which reached maturity, etc., were recorded. It was found that the efficiency of the hosts differed in a number of points. For instance, bugs fed on the mouse tended to take larger meals, develop more quickly, become larger adults and lay more eggs; those fed on the fowl, tended to take smaller meals, so that (provided they were limited to one meal in each stage of growth) a smaller proportion reached maturity; if they were starved, however, they survived longer than those fed on mice but not so long as those fed on man. It is also interesting to note that, in several respects, the two individual human beings differed as hosts.

The differences between communities of bugs fed on animals of different species are observed under precisely defined conditions in the laboratory. In nature, the temperature is not controlled and the bugs may be able to find a host at will. Some of the differences observed in the experiments may therefore disappear, but other differences, due to the choice and behaviour of the free insects, would become important. But at least the work shows that if bugs are reared on these three species of host, the effects are small: the bug is truly a non-specific parasite. As to whether bugs infesting chicken houses, rabbit hutches, etc., are a source from which human beings are commonly infested, nothing definite seems to be known, although crowded animal houses are much more easily infested than uncrowded ones. It has been shown in the experimental hut that populations do not increase rapidly with a single animal as host. Moreover, in free living populations of bugs with mice the insects suffer a high mortality due to the mice eating them.

F—Other points

Minor points of some interest may be recorded. The bugs of pigeons (*Cimex columbarius* Jenyns) possess morphological characters by which populations of this insect may be distinguished from populations of the bed-bug (*Cimex lectularius*). Many of the individuals of both *lectularius* and *columbarius* are, however, apparently indistinguishable morphologically (Johnson, 1939). But bugs found in fowl-houses were always *C. lectularius*, as were those in rabbit hutches, rat cages, etc. It has been shown also that there is no truth in the common belief that cockroaches eat bugs; the two live together in amity, even in a small cage (Johnson and Mellanby, 1939).

II.—CHEMICAL PROPERTIES OF INSECTICIDES, IN RELATION TO THE CONTROL OF BED-BUGS

BY

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KIND OF INSECTICIDE REQUIRED

The habit of the bed-bug of creeping into narrow cracks and crevices, and of hiding behind pictures, skirting-boards and even in the wall-plates of gas brackets, makes the bug itself and its habitat difficult to reach except by insecticides which are commonly called fumigants, or by liquid insecticides which readily penetrate through cracks and through the pores of building materials.

The efficiency of these insecticides depends on three main factors: their inherent toxicity, the ease with which they reach the insect and the extent to which their toxic components penetrate its body-covering, either through this covering or cuticle itself or through the openings in the cuticle such as the mouth and the spiracles and tracheae. In selecting an insecticide, or in comparing the efficiency of two or more insecticides, all these factors must be considered. The study of the first lies in the field of work of the physiologist, the study of the other two in that of the physical chemist.

The choice of insecticides for use against the bed-bug is severely limited. The insecticide should not be harmful to those handling it, nor to those who may live in premises treated with it; it should not be inflammable nor explosive, and it should not injure furniture, fabrics and building materials. The insecticides dealt with here are sulphur dioxide, heavy naphtha and hydrogen cyanide. Some comments are also made on the uses of pyrethrum and of certain organic thiocyanates.

TOXICITY OF INSECTICIDES TO BED-BUGS

The toxicity of a substance to insects varies with a number of factors, of which the most important is probably the physiological state of the insects treated. In general, the more active the insect, the more susceptible it is to toxic substances; and in laboratory practice, when determining the toxicity of any substances to any species of insect, special precautions must be taken to ensure that the insects used are as nearly as possible physiologically uniform and comparable. To meet the needs of experimental work on the toxicity of fumigants, Bovingdon (1934) devised a special apparatus, and this, modified and improved as experience showed necessary, was used by Gough (1940) in his work on sulphur dioxide referred to below. The apparatus was made of glass, with rubber joints, and included a number of stopcocks and a mercury pump. Its defects were the small size of the insect chambers it contained, the small size of the gas reservoir, the risk of loss of fumigant on rubber connections and in grease on stopcocks, and the risk of poisoning the insects by mercury vapour (Gough, 1938). To overcome these defects, Page devised a different type of apparatus, which was described by Page and Lubatti (1940). In this the gas reservoir had a capacity of about 130 litres. It was constructed of mild steel, lined with vitreous enamel. The gas was kept in circulation by a centrifugal vane, and ebonite connections were used. The whole system is relatively non-absorptive and resistant to corrosion; rubber connections are reduced to a minimum and the use of mercury is avoided.

These two pieces of apparatus ensured uniform exposure of the insects to the action of the fumigants, under uniform conditions of temperature, pressure and humidity, and the results obtained by their use may be regarded as reasonably significant.

A more difficult problem in studying the toxicity of insecticides is the establishment of a criterion of damage lethal to the insect. Drummond and Powell, working in the Imperial College with a grant from the Agricultural Research Council, have studied the damage caused to insect tissues by various insecticides and have made some progress in locating the mode and site of action of these substances; nevertheless, in practice the only sure criterion of insecticidal action is the death of the insect. This is not readily determined except by observing cessation of twitching movements, and it may sometimes be necessary to wait up to three weeks to see whether insects do or do not recover after exposure to an insecticide.

The toxicity of sulphur dioxide to the bed-bug

Gough (1940), working at the Imperial College, concluded from his experiments that sulphur dioxide is a poor ovicide, that it is not very effective against the nymphal stages of the bed-bug, and that its use necessitates repeated fumigation. In view of the risk of causing corrosion of metal-work, and fading and rotting of fabrics, frequent or repeated fumigation with sulphur dioxide is undesirable, and the use of this fumigant may therefore be regarded more as a palliative than a radical measure against the bug.

The toxicity of heavy naphtha to the bed-bug

In a study of the influence of chemical constitution on the toxicity of certain organic compounds to wireworms, Tattersfield and Roberts (1920) found that, of the hydrocarbons, pseudocumene had a moderately toxic effect, and Ashmore and McKenny-Hughes (1937) have reported that heavy naphtha of boiling range from 160–190°C. is fairly rich in this compound. The Committee accordingly decided that heavy naphtha should be investigated as an insecticide against the bed-bug, although they realised that the complexity of its various fractions made fuller knowledge of its constitution, and of the toxicity of the more important constituents, essential.

Heavy coal tar naphtha is a fraction of coal tar light oil, of boiling range 160–190°C. Its components may be divided roughly into four classes: aromatic hydrocarbons such as pseudocumene, mesitylene and xylene; cycloparaffins; paraffins which appear to be branched chain hydrocarbons in the undecane-dodecane range; and unsaturated compounds of various types, such as indene, coumarone, dicyclopentadiene and styrene. It will be realized that the investigation of the toxicity of such a complex organic substance presents many difficulties. Heavy naphtha from different sources varied in constitution and toxicity, although conforming to the original specification; and that in itself indicated the need for some further standardisation or definition of the fraction of coal tar light oil to be used. Apart from this, however, the various constituents in the four classes not only differ in toxicity among themselves but have a colligative toxicity, *i.e.* their combined effect is greater than the sum of the effects of the components individually. These facts require for their interpretation and understanding a fuller knowledge of the mode of action of insecticidal substances in general. The proper study of heavy naphtha therefore required observation of the behaviour of its various constituents by themselves and in combination, as substances having a lethal toxic effect on the bed-bug, as well as an inquiry into the extent to which the various fractions of coal tar light oil of boiling range 160–190°C. had similar toxic effects on the insect.

In the course of this investigation various hypotheses regarding the toxic values of different constituents were formulated, only to be modified as work progressed. As has been explained, heavy naphtha was chosen as an insecticide on the assumption that pseudocumene was the effective constituent. Soon it seemed that xylene and indene were also important toxic agents, and that the paraffins might be regarded merely as inert diluents. Then it was established that the toxicity of unsaturated compounds such as indene might be materially increased by the addition of paraffins and cycloparaffins (Hurst 1940).

The study of the toxicity of the constituents in the four classes of compound found in heavy naphtha individually and together is highly complex and technical, but may be summarised as follows.

In the early part of Hurst's work eggs of the bed-bug were used because their physiological state was more readily determined, by the pigmentation of the "eye spot," than that of the nymphal stage. The eggs were placed in small glass containers and "acclimatized" for at least a quarter of an hour before being exposed to the fumigant vapours. Exposure was made by placing the eggs, and later the nymphs and adults, in their containers in a tin vessel. The fumigant was introduced absorbed on blotting paper, and, while a certain loss of vapour occurred in this process, it was found that if the same procedure were adopted throughout the experiments the results could be reproduced reasonably well.

In determining the effect of the fumigant allowance was made for anaesthetic or narcotic action, and permanent cessation of peristalsis of the gut, and of twitching of the appendages, was used as the criterion of death. It is worth noting that both in nymphs and adults there was close correlation between twitching of the appendages and peristalsis of the gut and oviduct. Clark (1933) has expressed doubt regarding the fitting of toxicological data to curves based on mathematical computation where large numbers of variables are involved. In view of the complexity of heavy naphtha, Clark's criticisms were accepted and the methods used by Coward in the biological standardisation of vitamins were adopted. A particular sample of naphtha was selected as a standard, and the dosage-mortality regression curve computed, a large number of insects being used for this purpose. When other samples were tested the standard was always included. The various dosage-mortalities were converted into probits, using the method of Bliss (1935), and referred to the standard regression curve.

The toxicity to the bed-bug of the following pure compounds was determined: xylene, pseudocumene, mesitylene, indene and styrene. Later, when Sarsfield succeeded in synthesising coumarone, its toxicity too was determined. The toxicity of the mixed paraffins, separated from heavy naphtha, was also determined.

The toxicities of these components to first stage nymphs were in the following order:—

$$\text{Xylene} > \text{Styrene} > \left\{ \begin{array}{l} \text{Pseudocumene} \\ \text{Mesitylene} \end{array} \right\} > \left\{ \begin{array}{l} \text{Indene} \\ \text{Coumarone} \end{array} \right\} > \text{Mixed Paraffins}$$

The toxicities of these to the egg stage were similar, except for indene, which in this case took precedence of styrene, pseudocumene, mesitylene, coumarone and the mixed paraffins.

The toxicity of fractions of heavy naphtha supplied by Messrs. Yorkshire Tar Distillers, Ltd., was determined. The early fractions containing toluenes and xylenes were the most toxic. There was a decided maximum on the toxicity-boiling point curve, which probably coincided with a maximum proportion of xylenes. This was followed by a continuous fall in toxicity, the curve exhibiting no clear breaks, which corresponds with the absence of definite separation as shown by Sarsfield's analyses.

A series of binary synthetic mixtures of mixed paraffins, aromatics, unsaturated compounds, and phenols was investigated. When paraffins were mixed in varying proportions with the other substances they exerted a diluent action on all except indene and phenols.

The relative susceptibility of the various stages of the bed-bug to a sample of heavy naphtha supplied by Messrs. Yorkshire Tar Distillers, Ltd., was studied, and the results afford a good illustration of the variation in susceptibility of different stages of development in a single species of insect. The first three nymphal stages were more susceptible, and roughly to the same degree, than the later stages and the adult. Susceptibility decreased markedly with the fourth stage and continued to decrease in the fifth and adult stages. The adult female was more susceptible than the male, and the egg stage showed average resistance exactly comparable with that of the fourth stage nymph.

Full accounts of the work by Hurst on the physiological side and Sarsfield on the chemical side will shortly be published.* Except for the high toxicity of a fraction of heavy naphtha produced by Messrs. Dorman Long, Ltd., which is still unexplained, sufficient knowledge of the insecticidal behaviour of most of the constituents of heavy naphtha, both by themselves and in combination, has been obtained to justify the Committee in specifying the characters of a heavy naphtha which will be reasonably uniform in action. It is worth noting that the "disinfestation naphtha", as now specified by the Committee, is not the usual fraction of coal tar light oil termed heavy naphtha by the gas industry but a fraction of slightly lower boiling range, modified by the addition of carbolic acid containing 90 per cent. of cresols. This specification is the outcome of discussion and collaboration between ourselves and Mr. Ashmore to whom we are indebted for much helpful advice and some criticism.

Apart from its direct bearing on the devising of an insecticide for the control of bed-bugs, the work on "heavy naphtha" has led to a better understanding of the mode of action of certain insecticides. In nearly all liquid insecticides the toxic principle or ingredient forms only a small part, either by weight or by volume, of the insecticide. The greater part consists of a carrier with, it may be, the addition of substances ("wettors and spreaders") designed to ensure better spread or adhesion of the insecticide on the body of the insect or on the surface on which the insect rests.

In "heavy naphtha" while indene, for example, might be regarded as one toxic principle, its effect is governed by the presence of certain of the paraffins, and we are dealing here with phenomena only recently recognised by insecticide workers, and which are still only partially understood. The paraffins in heavy naphtha act as carriers and spreaders. Hurst (*loc. cit.*) has shown that they also help other substances to penetrate the skin or cuticle of the insect, and he has extended this observation and formulated the hypothesis that the permeability of the insect cuticle as a whole to polar compounds (compounds having a relatively high affinity for water) is increased by the presence of apolar substances (substances, such as the paraffins, having a low affinity for water). This hypothesis suggests that the function of the carriers of toxic substances cannot be neglected, and that in any insecticidal mixture any or all of the ingredients may contribute to the final toxic effect.

Pyrethrum and the Alkyl Thiocyanates

One of the insecticides most widely used in the control of household insects, notably flies and mosquitoes, is pyrethrum, and this forms the chief toxic ingredient of many of the fly sprays now widely marketed in this country and in the U.S.A. In general, these fly sprays consist of extract of pyrethrum (pyrethrins I and II) carried in paraffin or kerosene.

* Sarsfield's results are now published (see Sarsfield, 1942 a and b).

Unfortunately, the toxicity of pyrethrum extracts varies greatly and uniform performance of these sprays has not always been attainable. The killing effect is sometimes slow, and recently pyrethrum sprays have been "boosted" by adding to them small amounts of certain organic compounds, such as iso-butyl undecyleneamide, rotenone and certain alkyl thiocyanates. Further research in this field is urgently needed. Such work as has been done on the use of pyrethrum and of the alkyl thiocyanates in the control of bed-bugs in this country is still too scanty for the assessment of the best mixtures of these substances, and of the best methods of applying them. Potter (1938), Callaway and Musgrave (1940), and Musgrave (1940) have done some preliminary work on the subject, but in the light of Hurst's studies, and in view of the need for better biological methods of testing insecticides, the whole field of work in the use of contact sprays requires consideration. Tattersfield (1939) has recently summarised the position regarding biological methods of testing insecticides and this, together with Hurst's work, might well form the basis for the co-ordinated research required.

CHEMICAL INVESTIGATION OF HEAVY NAPHTHA

Work carried out by Sarsfield and Page at Imperial College, London, has been directed to the correlation of toxicity with chemical composition. Mesitylene and styrene were synthesised without difficulty, by well established methods. Pseudocumene was separated from a naphtha of narrow boiling range by the method of Smith and Cass (*J. Amer. Chem. Soc.*, 54, 1607) and regeneration from the purified sulphonate by distillation of a solution in 80 per cent. sulphuric acid. An attempt was made to obtain coumarone by depolymerisation of crude coumarone resin. Crude coumarone was obtained, but all attempts to purify it, through its picrate, were unsuccessful. It was eventually synthesised from coumarin by the formation of the dibromide, which was converted into coumarilic acid, which, in turn, passed into coumarone on distillation with soda-lime in an iron vessel heated in an electric furnace.

The paraffins were separated by treatment with sulphuric acid, based on a study of its action on the aromatic, unsaturated and aliphatic hydrocarbons of heavy naphtha. Attempts to prepare "white naphtha" (*i.e.* heavy naphtha with the unsaturated compounds removed) by the action of sulphuric acid have proved that it is exceedingly difficult to effect complete removal of the unsaturated compounds by any of the procedures so far suggested, without loss of aromatic hydrocarbons by sulphonation and by coupling with the unsaturated compounds. Some paraffins may also be attacked and there is always considerable action on naphthenes and chain paraffins if oleum is employed.

For each component, fraction and sample, the density and refractive index were determined. The values served as criteria of purity or, in conjunction with other data, as guides to composition. Vapour pressure and relative rate of evaporation were determined for a number of components and samples, in order to indicate the saturation concentration and the relative rate of attaining it—two quantities of importance in the field work. Some satisfactory values for pure components were obtained by a modification of the method of Ramsay and Young, and by a bubbling method. Owing to the fractionation of heavy naphtha, it is desirable, for each sample, to make determinations after various proportions have been evaporated. For this, the bubbling method proved too cumbersome; measurements of the rate of evaporation relative to that of a pure component were, therefore, substituted, and the equivalent vapour pressures were calculated on the assumption that de Heen's finding was valid, *viz.*, that the relative rates of evaporation were proportional to the product of the vapour pressure and the molecular weight. Values of the vapour pressure

of many samples have also been calculated from the boiling points of the samples at two points on the Engler distillation curve relative to that of pseudocumene, Ramsay and Young's rule having been shown to hold for the components of heavy naphtha. The values of the saturation concentration corresponding to these values of the vapour pressure for 10 per cent. evaporation agree well with those given by Ashmore and McKenny-Hughes (p. 28). The values of saturation concentration for complete evaporation are, of course, decidedly lower.

As mentioned above, the action of sulphuric acid cannot be regulated well enough to serve as a means of determining accurately either paraffins or unsaturated compounds. The bromination method of Rosenmund, and a modification of the bromate-bromide method described in the Standard Methods of Testing Tar and Its Products, 1939, were used to determine the unsaturation values. When account was taken of the effect of excess of reagent in Rosenmund's method, good agreement was obtained between the two methods. Phenols interfered with the bromate-bromide method and were first removed. The bromate-bromide method is the more rapid.

Paraffins were determined by making use of the aniline cloud-point principle. A study of neutral solubilities in mixtures of the various components of heavy naphtha with aniline permitted the development of a simple and rapid titration method of determination. A series of solubility curves was obtained for different unsaturation values and boiling ranges. The unsaturation value and boiling range of a particular sample were first determined, and the appropriate curve selected for the determination of the paraffin content. This method appeared to be uniformly satisfactory over a wide range of samples.

Two samples were fractionated, using a vacuum still with reflux ratio of 25 : 1 and a 7 plate packed column. This still was capable of separating xylene from the trimethyl benzenes but produced only partial separation amongst the trimethyl benzenes. A special pseudocumene fraction which had been prepared by vacuum distillation by Messrs. Dorman Long, Ltd., gave little further separation. An ordinary heavy naphtha sample supplied by Messrs. Yorkshire Tar Distillers, Ltd., was separated into thirty fractions, many of which had widely differing properties. The lowest fraction contained toluene and xylenes, the next four or five fractions contained a large proportion of xylenes. These were followed by some mixed fractions, and those by about eight trimethyl benzene fractions; the last, of course, contained also some paraffins and some unsaturated compounds. Owing probably to the formation of constant boiling mixtures, there was little separation of the higher fractions into separate compounds. At the end of the distillation, however, naphthalene crystallised out. The paraffins separated from the heavy naphtha by treatment with sulphuric acid were of higher average boiling point than that of the naphtha, and some of them boiled beyond the upper limit. This agreed with the analysis, which showed a concentration of paraffins in the higher fractions. There was an apparent concentration around the decane boiling point, but analysis showed that there was, in fact, no concentration of paraffins there. It is probable that the paraffins and naphthenes contain, for the greater part, 11-13 carbon atoms to the molecule.

An analysis has been made of the data expressing chemical composition and toxicity. The method used gives a high correlation coefficient and a small deviation. The results substantiate the principles of individual and combined toxicity put forward by Hurst. No factor affecting toxicity appears to have been overlooked. It is clear that the improved specification is adequate, except that some samples conforming to it could be improved by the substitution of a proportion of the aromatic hydrocarbons by paraffins.

HYDROGEN CYANIDE

One of the most efficient and widely used fumigants is hydrogen cyanide. It is rapidly and highly toxic to insects, penetrates well into cracks and crevices; and more is known of its mode of action both on insects and on other animals, including man, than of any other insecticide. Hydrogen cyanide is, however, dangerous except when properly handled, and accidents arising from its less careful use have occurred during the recent campaign against the bed-bug which accompanied the evacuation of slum dwellings.

In June, 1935, certain problems arose concerning the fumigation of houses in Rochester with hydrogen cyanide. Workmen reconditioning houses there, which had been given the customary 24-hour aeration after fumigation with hydrogen cyanide "disks," had complained of sickness during their work. The Committee approved an investigation of the problem of ventilation of houses after fumigation with hydrogen cyanide, and this work was entrusted to Dr. Page and Dr. Lubatti, of the Entomology Department, Imperial College, with Mr. F. P. Gloyns as research assistant; financial assistance and general co-operation were provided by the Ministry of Health.

The first study undertaken was a review of methods of measuring the concentration of hydrogen cyanide remaining in air spaces after fumigation and ventilation. This work was carried out by Page and Gloyns (1936*a*), and their published results relate to the maximum concentration of hydrogen cyanide which is tolerable by man, to current methods for detecting and determining hydrogen cyanide in air (with reference to the benzidine acetate-copper acetate paper test), and to the development of a new method of testing, based on the iodine reaction. Subsequently Page, Lubatti and Gloyns (1939) further studied the benzidine acetate-copper acetate paper test. They standardised the preparation of benzidine acetate, preparation of the solutions, the paper used for the test and the method of testing. A series of standard colours for comparison of test papers was also prepared.

The second part of the work dealt with the determination of hydrogen cyanide evolved from disks of wood pulp, a form of this fumigant which is frequently used. The results of this study have also been published (1936*b*). Apparatus designed for the work is described, two brands of "disks" are compared, and data are included on the rate of evolution of hydrogen cyanide from the disks at room temperature and on the residual hydrogen cyanide in disks at various temperatures. This work has special significance in indicating the precautions which should be taken to ensure safe use of these disks in practice, in particular the need to see that all disks are collected after the operation.

The third of these studies related to the conditions prevailing in houses during and after their fumigation according to normal commercial practice (Page, Lubatti and Gloyns, 1939). The methods of measuring concentrations of hydrogen cyanide in the air spaces (both free and confined), in plaster and in clothes, mattresses and upholstery are described. The airing of houses, both those fumigated and those adjoining them, the airing of plaster and the efficacy of the fumigations are fully discussed in the light of the results obtained, and the following recommendations are made regarding the precautions to be observed in house fumigation.

(a) *Fumigation*

1. Care should be taken to ensure that cupboards, drawers, boxes, etc., receive an adequate initial dose of fumigant. If disks are used, great care should be taken to see that they are all collected after the fumigation.

2. Where it is considered that the roof space cannot be fumigated with hydrogen cyanide but is likely to be infested, it should be treated in some other manner.

3. A longer period of exposure than six hours is advantageous, particularly in promoting the penetration of lethal concentrations of fumigant into hidden spaces.

4. Access to unventilated floor spaces, and, to some extent, to plaster partitions, should be obtained by lifting one or two floorboards close to the walls in the upstairs rooms, or by easing skirting boards. This precaution should ensure that the concentration beneath the floor reaches a value not materially less than that in the main free space of the room. The lifting or easing of one or two floorboards only is required.

(b) *Ventilation*

1. After the fumigation all windows should be kept open for 24 hours unless this would lead to the entry of rain or snow.

2. A ventilation period of 24 hours is generally sufficient for an empty house of normal construction. A longer period may be required for a furnished house or for a house which (a) is damp, (b) contains an unusual proportion of dead space, (c) contains rooms without windows providing adequate communication with the open air.

3. During the period of ventilation, all windows and other openings should be so secured as to prevent the entry into the house of any unauthorized person. In addition, the premises should be kept under continuous observation by a responsible person.

(c) *Precautions*

1. Fumigation of clothing, and particularly of bedding, in a house is definitely undesirable as a regular practice.

2. Upholstered furniture should be placed in such a position as will best facilitate airing. Cushions, etc., should be spread out singly on furniture which is not upholstered.

3. The customary tests with benzidine acetate-copper acetate should be made, following the procedure detailed below. A blue colour, in all air spaces, indicating a concentration of 0.01 oz./1000 cu. ft., 0.0009 per cent. by vol., or less, gives a margin of safety.

4. If the house contains a considerable quantity of absorbent material or if the fabric is likely to be unusually absorptive, e.g. if partitions of insulating boards are employed, or if the construction of the house, or any other circumstances, suggest that a period of 24 hours airing may not be sufficiently long, all doors and windows should be closed after performing the tests with benzidine acetate-copper acetate, and these tests should be repeated after the house has remained closed for two hours. This will allow absorbed gas to be given off and to build up a concentration in the air spaces. If the resulting concentration is still not greater than 0.01 oz./1000 cu. ft., 0.0009 per cent. by vol., reoccupation may be permitted.

5. Houses, other than detached houses, should preferably be fumigated in blocks. Failing this, however, in the houses adjoining those being fumigated, a few floor-boards should be removed in the upstairs rooms next to the fumigated house, and the windows of these rooms should be opened. In some instances it may be sufficient to ease the skirting boards, instead of raising the floorboards. Bedding and clothing should be removed to the far side of the house. All rooms and cupboards, the roof space and the floor spaces in adjoining houses should be tested frequently during the fumigation and ventilation.

7. The precautions recommended to be taken in adjoining houses are based on experiments carried out upon a particular type of house and may not be sufficient in all cases. Peculiarities of construction, or other factors, may necessitate the adoption of special precautions.

These recommendations emphasise the need for the conduct of fumigation on scientific lines, and form a basis for the regulation of fumigation practice. Recently the Home Office have issued, under Section I of the Hydrogen Cyanide (Fumigation) Act, 1937, certain statutory rules and orders regulating hydrogen cyanide fumigation (Statutory Rules and Orders, 1938), No. 1578, Hydrogen Cyanide (Fumigation)).

A fourth investigation, incomplete as yet, concerned the transference of fumigants through building materials. The purpose of this work was to assess the loss or leakage of fumigant from houses, and the penetration of fumigant through hollow walls and similar structures. The results should also provide information useful in the selection of materials for the construction of fumigation chambers.

Transference is due partly to diffusion and partly to bulk movement under pressure. It will vary with the concentration gradient across the material, and with its temperature and water content. Special apparatus was devised for the measurement of these factors. The kind of variation in rate of transference of hydrogen cyanide through materials is shown by the following figures for $\frac{1}{2}$ inch fibre-board, parchmented paper, and wood ($\frac{3}{8}$ -in. deal), namely 64:5:1. This work, begun under the aegis of the Committee, is being continued at Imperial College as time and staff permit, and the results so far obtained await publication.

III.—DEVELOPMENT OF METHODS FOR DISINFESTING HOUSES AND FURNITURE

BY

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During recent years increasing attention has been paid to the eradication of the bed-bug from houses and their contents. Perhaps the factor which has had the most influence in bringing the problem of disinfestation to the fore has been the general adoption of slum clearance schemes. Numerous municipal estates have sprung up around most of the large cities, whether for slum clearance or for other purposes under the various Housing or Overcrowding Acts. In these circumstances, the local authorities have become landlords in a large way, and a higher standard of cleanliness has been set up.

Unfortunately, soon after the arrival of tenants transferred from slum quarters, these new housing estates have too often become heavily infested with bed-bugs. Various measures have, accordingly, had to be adopted in an attempt to combat this menace. One of the problems that confronted the Committee was to find a substance for eradication that was cheap, easy to use, not dangerous to human beings, and of which sufficient quantities were easily available. The difficulty was to find an insecticide which would not damage the dwelling or its fittings, would not be harmful to people living in adjacent quarters and would not, through any residual action, affect the tenants of the treated house.

REVIEW OF INSECTICIDES IN USE IN 1935

Among the insecticides in use when the Committee began work the most effective, but unfortunately the most dangerous, was hydrogen cyanide. So far as insecticidal properties are concerned, there is no doubt that HCN will give complete control if properly applied. In flats and tenement dwellings it was obvious that this gas could not be used, nor was it suitable in terrace

houses unless adequate evacuation could be carried out. Sulphur in various forms is another insecticide which has been widely tested. This, however, lacks effectiveness, since it is a very poor ovicide, and there have been cases where repeated treatment with sulphur has failed to eradicate the pests. There is the further disadvantage that sulphur bleaches and rots fabrics and tarnishes certain metals.

On the whole, it was considered that the best chance of complete eradication of the bed-bug was by means of a vapour rather than by a contact insecticide. It should be explained that, in this report, contact insecticides mean those liquids which have to come into direct contact with the insect in order to kill it; they have their uses for slight infestations, but in all probability they would only act as palliatives where the insects and their eggs were numerous.

At this time orthodichlorobenzene was found an extremely effective vapour. It was at first thought that concentrations of 0.02 per cent. v/v would not be harmful to human beings. (To check the concentration of vapour in the air, members of the staff of the Government Laboratory adapted the lamp used for the detection of leakage in refrigeration plants; this lamp, burning methyl alcohol as fuel, gave a blue flame in pure air; when, however, the air contained a concentration of the vapour above 0.02 per cent. v/v the flame turned green.) Later, however, Imperial Chemical Industries questioned the safety of orthodichlorobenzene, of which they were manufacturers, and cited figures which seemed to show that it was toxic to laboratory animals in much smaller quantities than had been expected. Professor Cameron and his colleagues, working in University College Hospital Medical School, confirmed this (see p. 48). They showed that concentrations of orthodichlorobenzene as low as 0.005 per cent. v/v in the air were on occasion lethal to rats and presumably dangerous to human beings, and they suggested that the utmost caution should be exercised in the use of this chemical. Experiments carried out at the same time in the Metropolitan Borough of Woolwich showed that in rooms sprayed with orthodichlorobenzene, and subsequently ventilated for three days, a concentration of 0.005 per cent. v/v persisted at the end of that period. As a result of these investigations the Ministry of Health issued Circular No. 1544, dated 22nd May, 1936, to local authorities, advising against the use of orthodichlorobenzene for disinfestation of inhabited houses.

INVESTIGATION OF PSEUDOCUMENE AND OTHER COAL TAR HYDROCARBONS

It was obvious that a substitute for orthodichlorobenzene must be sought, which would be harmless to human beings but lethal to all stages of the bug and its egg. Tattersfield and Roberts had shown the effect of pseudocumene (1.2.4 trimethylbenzene) on wire-worms, and its properties seemed such as to merit a trial against bed-bugs. The preliminary tests gave promising results, and subsequent experiments in Professor Cameron's laboratory, on the action of pseudocumene on small animals, indicated that no harm to human beings from the use of this chemical need be feared. The question of supplies of pseudocumene was next considered, and while it was found that the amount available was relatively small, a large potential source existed in heavy coal tar naphtha having a boiling range of 160–190° C. Accordingly, the Gas Light and Coke Company were asked to provide a number of special fractions rich in pseudocumene. Good results against the bed-bug and its eggs were obtained with these fractions, both in the laboratory and in the field. Comparative tests, however, with these close boiling fractions and with the whole fraction known as heavy naphtha showed that if anything the latter was the more effective. A cheap supply was, therefore, readily available, and Professor Cameron showed that dangerous toxic effects need not be feared when using this substance.

To ensure that suitable naphtha was used the following preliminary specification was drawn up:—

- (1) *Colour*.—Shall not be darker than a freshly prepared solution of 1 ml. of N/10 iodine in 1,000 ml. of distilled water.
- (2) *Specific gravity*.—Not less than 0.835 and not greater than 0.910.
- (3) *Water*.—Shall be free from water and other visible impurities at 15.5° C.
- (4) *Distillation range*.—Method as defined in B.S.I. Specification No. 479 for coal tar naphthas.
Up to 160° C. not more than 5 ml.
Up to 190° C. not less than 90 ml.
- (5) *Flash-point (Abel)*.—Not less than 105° F.
- (6) *Tar acids and tar bases*.—Not more than 0.25 per cent. of tar acids and 0.25 per cent. of tar bases.

APPLICATION OF HEAVY NAPHTHA TO HOUSES

Heavy naphtha is a useful contact insecticide but its vapour action is much more effective, and for this reason doors, windows and ventilators of houses under fumigation are sealed in the ordinary way. In the early experiments heavy naphtha was sprayed on to walls, woodwork, etc., special attention being given to likely bug harbourages. The naphtha was used at the rate of 1 gallon per 750 cub. ft. of room space. The houses remained sealed overnight and the following day were ventilated by opening doors and windows. The vapour cleared very rapidly and showed no tendency to "build up" when the house was closed for several hours (see Table V). With this technique good results were obtained in the initial summer months, but in the autumn, with lower temperatures, failures occurred. The vapour concentration at different temperatures was then investigated and the minimum vapour concentration lethal to the bed-bug with an exposure of 24 hours determined.

The results are shown in Tables III and IV.

TABLE III

Vapour concentration of heavy naphtha at different temperatures

Temp. °F. °C.		Vapour concn. per cent. v/v.
50	10	0.16
61	16.1	0.21
70	21.1	0.29
75	23.9	0.36

The vapour concentrations will vary slightly with different samples.

TABLE IV

Effect of vapour concentration of heavy naphtha on bed-bugs. 24 hours exposure at room temperature (20° C. approx.)

Vapour concn. per cent. v/v.	Condition of bugs after 24 hours exposure
0.05	All alive, some sick.
0.10	Few survive test, but died after keeping in fresh air for 48 hours.
0.15	All dead.
0.20	do.
0.25	do.
0.30	do.

Controls all alive.

The minimum lethal concentration of vapour for an exposure of 24 hours is 0.15 per cent. (Table IV) and reference to Table III shows that this obtained at slightly below 50° F.

It was thus evident that for the satisfactory fumigation of a house in cool weather some preliminary heating was necessary. Cheap and effective heating was found in primus stoves burning paraffin. By this means houses could be pre-heated and, to allow a margin of safety, it was decided never to use heavy naphtha at a temperature of less than 60° F. The reasons for this are shown later. Heating is a factor which deserves further consideration, since it may well be that more radiant heat would give better results, and furthermore, if temperatures as high as 90–100° F. could be maintained throughout the fumigation period, the time of exposure might be greatly reduced.

Owing to the inflammable nature of naphtha, all lamps must be extinguished and removed before spraying is begun, and smoking and naked lights must be prohibited whenever naphtha is being handled. Gas must be turned off at the meter.

A survey by chemical analysis was taken of the gas concentration in a room of a house under fumigation. The results are shown in Table V.

TABLE V
*Concentration of heavy naphtha in a room after varying periods of
fumigation and ventilation*

	<i>Vapour concn. per cent. v/v.</i>	<i>Degree of saturation, per cent.</i>
Start of fumigation	0.27	100
End of 24 hours	0.10	Approx. 33
After 8 hours ventilation	0.009	—
After room closed for 15 hours at conclusion of ventilation	0.009	—

The quantity of naphtha used (1 gallon per 750 cub. ft. of room space) was very much in excess of the theoretical quantity required to produce saturation, but, in spite of this, the concentration at the end of 24 hours was only approximately one-third saturated, and moreover was sub-lethal (see Table IV).

Use of screens

It was realised that conditions such as these might cause failures in fumigation. The difficulty was overcome to a large extent by the use of light cotton diffusion screens, combined in some cases with an automatic delayed-action sprinkler.

When naphtha is sprayed on walls, ceilings or other plaster work a considerable proportion is absorbed and is not available for vaporisation when the concentration in the air of a room drops below saturation. In an attempt to provide a reservoir, woollen blankets wetted with naphtha were hung in the room. While this helped to produce a somewhat higher vapour concentration at the end of 24 hours, it was not ideal for the purpose. As the result of a number of experiments, cotton fabrics having the following characteristics were chosen :—

	<i>Fabric I</i>	<i>Fabric II</i>
Wt. per sq. yd. (ozs.)	2	1½
Threads per inch : warp	102	86
weft	90	78

Naphtha dropped on to this fabric spreads in much the same way as ink spreads on blotting paper and, when screens wetted with naphtha are hung near the walls, a high concentration of vapour is rapidly produced where it is most needed. The fabric of the diffusion screens was usually purchased in strips 36 in. wide; these were cut into 16 ft. lengths and thrown double over the top rail of a light scaffolding erected in the room, three inches away from the walls.

For maintaining a concentration in a roof space sufficient to kill any bugs which may be there, or to prevent bugs from escaping from rooms that have been treated, woollen blankets are laid upon the joists and the whole area sprayed with naphtha. The slower diffusion from woollen materials is advantageous in a draughty place such as a roof space.

In the early work, although linseed oil paints were not affected by the naphtha, it was found that certain other types of paint were removed or showed a tendency to run. By spraying the screens and taking care that the naphtha in the liquid state does not come in contact with paintwork this difficulty can be overcome. Analysis of air samples from rooms so screened showed a considerably increased concentration of vapour at the end of 24 hours fumigation.

Delayed action sprinkler

To meet the unfavourable conditions presented by a leaky house the screens were re-wetted about halfway through the 24-hour period without unsealing the room. A delayed action sprinkler was designed for this purpose. This works by means of an alarm clock mechanism which, at a pre-determined time (8–11 hours), allows naphtha to be thrown on to the diffusion screens from a centrifugal sprinkler driven by a clockwork motor.

The improvement resulting from the new technique is demonstrated in Table VI.

TABLE VI

Concentration of naphtha vapour in the air of rooms at the end of 24 hours

	<i>Vapour concn. per cent. v/v.</i>	<i>Approx. degree of saturation, per cent.</i>
Room I	0·14	50
Room II	0·22	80
Room III	0·25	90

A temperature of 67° F. was maintained throughout all the experiments. All rooms were treated with 1 gallon per 750 cub. ft. room space.

Room I.—Walls, woodwork, etc., sprayed, but no screens in room (original technique).

Room II.—Walls draped with cotton screens, room sprayed and screens thoroughly wetted.

Room III.—As for room II, but in addition the delayed action sprayer, charged with $\frac{1}{2}$ -gallon of naphtha, was set to deliver a reinforcing charge 11 hours after the room was sealed.

The above Table shows that the concentration of vapour is considerably higher in the rooms with screens. Since Table IV shows that the minimum lethal concentration is 0·15 per cent. for 24 hours exposure, rooms II and III are therefore well above this figure, whereas the concentration in room I is sub-lethal.

The house in which these experiments were carried out was of good construction, and diffusion losses were therefore at a minimum. In an old,

leaky house, or, as shown later, under adverse weather conditions such as a high wind, the difference in concentration between room II and room III would in all probability have been greater.

COMPOSITION OF HEAVY NAPHTHA IN RELATION TO TOXICITY TO BED-BUGS

Heavy naphtha supplied to the original specification by a number of tar distillers showed marked differences in toxicity to the bed-bug when compared with the results indicated in Table IV.

Work done under the direction of Professor Munro (p. 20) indicated the high toxicity to the bed-bug of indene, one of the unsaturated constituents of heavy naphtha. Indene and coumarone represent the major unsaturated constituents of heavy naphtha, and it is significant that in all but one case insecticidal power appeared approximately to follow the degree of unsaturation as measured by the bromine absorption test. The amount of indene and coumarone present in heavy naphtha is governed mainly by the degree of acid washing in the works. For many other purposes for which naphtha is used it is desirable to remove the unsaturated constituents as far as possible, by washing with concentrated sulphuric acid.

In the light of this information, and with the co-operation of the Gas, Light and Coke Company, a number of naphtha fractions were tested for insecticidal power before and after refining with concentrated H_2SO_4 . In all cases a marked drop in activity followed removal of the unsaturated constituents and clearly it was desirable to retain them in the heavy naphtha to be used for disinfestation.

To this end a new specification was framed, in which it was insisted that at no stage of manufacture or refining should the naphtha be washed with H_2SO_4 of more than 35 per cent. strength.

A number of tar distillers prepared samples of naphtha to this new specification and all samples except one were of uniformly increased toxicity to the bed-bug. The exception was outstandingly potent, and chemical examination showed it to contain 1·8 per cent. of phenols, probably left behind by imperfect alkali washing. Test experiments indicated that a small proportion of phenols added to heavy naphtha caused a further marked increase in potency.

It was evident, therefore, that the presence of phenols was desirable, and it was decided to amend the specification to include an addition of 2 per cent. of liquid carbolic acid containing at least 90 per cent. of cresols.

Professor Cameron's work (p. 48) on the toxicity of heavy naphtha has included concurrent tests of all modifications used in the experiments, and has shown that no serious effects on human beings are to be anticipated from their use. The new specification is therefore as follows:—

SPECIFICATION FOR DISINFESTATION NAPHTHA

(1) *General*

This specification refers to heavy naphtha made by the distillation of crude heavy naphtha obtained from crude benzole and tars, and which shall not have been in contact with sulphuric acid of over 35 per cent. strength; the distillate, before final rectification, shall have been washed with 5–10 per cent. caustic soda solution and with sulphuric acid, preferably of 25 per cent. strength.

(2) *Colour*

The colour of the naphtha shall not be darker than a freshly prepared solution of 8 ml. of N/10 iodine solution in 1,000 ml. of distilled water.

(3) *Specific gravity*

The specific gravity of the naphtha at 15·5° C./15·5° C. shall not be lower than 0·855, nor higher than 0·910.

(4) *Water*

The naphtha shall be free from separated water.

(5) *Distillation Range*

When 100 ml. of the oil are distilled by the standard* method, the initial drip point shall not be lower than 155° C., and the volume of distillate collected when the temperature has reached 165° C. (running point) shall not be lower than 20 ml. nor exceed 40 ml. Similarly, the volume collected at 180° C. (running point) shall not be lower than 80 ml., nor exceed 90 ml.

(6) *Flash Point*

The flash point of the naphtha as determined by Abel's closed test, shall not be below 95° F.*

* The methods of test herein referred to shall be carried out in accordance with "Standard Methods of Testing Tar and Its Products", S.T.P.T.C., Revised Edition, 1938.

(7) *Bases*

The naphtha shall not contain more than 0.25 per cent. by volume of tar bases.

(8) There shall be added to the naphtha 2 per cent. by volume of liquid carbolic acid containing at least 90 per cent. of cresols.

DETECTION OF LEAKAGE OF NAPHTHA VAPOUR

Some occupants of premises adjacent to houses being disinfested with heavy naphtha by local authorities, having noticed a certain amount of smell in their dwellings and being apprehensive of the consequences, naturally complained. A simple portable apparatus was adapted to measuring the quantity of vapour leaking into adjacent property. By means of an exhaust pump, a sample of the air is bubbled through concentrated H_2SO_4 containing a small quantity of formaldehyde. This reagent is colourless, but in the presence of very small quantities of naphtha vapour, it changes to a dark brown or mahogany colour. Concentrations as low as 0.002 per cent. v/v can be measured.

CLIMATIC CONDITIONS AND FUMIGATION WITH HEAVY NAPHTHA

In Plymouth some council houses treated with heavy naphtha were situated on a hillside and were much exposed to the prevailing wind. On entering the houses at the end of 24 hours exposure, it was found that the screens were completely dry, so that a saturated atmosphere had not been maintained. It was therefore decided to investigate the saturation concentration of naphtha vapour in rooms under varying conditions, at the end of 24 hours exposure. A convenient and rapid method of doing this was by means of a whirling hygrometer, somewhat similar to that used for the measurement of water vapour in air. To those unfamiliar with the instrument it may be explained that in shape it resembles a "policeman's rattle" and consists of two thermometers mounted on a board, with a handle which allows the whole apparatus to be rapidly whirled. The bulb of one thermometer is covered with a piece of muslin which, just before the test, is wetted with a little naphtha. If the apparatus is now whirled in air free from naphtha vapour the thermometers will show a difference in temperature which varies with the temperature of the air. Thus, for example, at 75° F. the wet bulb thermometer will read 2.8 degrees lower than the dry bulb, while at 65° F. the difference will be 1.8 degrees. If the air is 100 per cent. saturated with naphtha vapour the difference between the two thermometers at all temperatures will be nil, and partially saturated atmospheres will show a proportional difference between the two readings.

With this apparatus a number of rooms in L.C.C. tenements were tested at the end of 24 hours fumigation with heavy naphtha, and in many cases where

the screening should have been adequate, and naphtha had been used at the rate of 1 gallon per 750 cub. ft. of room space it was found that full saturation was not maintained.

While it is known that many difficulties inherent to construction must be overcome for successful fumigation, consideration must also be given to external factors such as climatic conditions. In windy weather a greater number of air changes per hour will occur, with a consequently greater loss of naphtha vapour. This, in certain circumstances, may produce a sub-lethal concentration.

To ensure the introduction of definite quantities of heavy naphtha, the absorptive capacity of one standard screen (16 ft. × 3 ft.) was measured. The dry screen was weighed, dipped in heavy naphtha, wrung free from residual naphtha and quickly re-weighed. Under these conditions a screen absorbs 1 pint. Three empty rooms of approximately 1,050 cub. ft. capacity were sealed in the usual way. Screens were suspended in each room, as indicated in Table VII. At the end of 20 hours the degree of saturation in each room was measured with the whirling hygrometer.

TABLE VII

Relation between quantity of naphtha used and degree of saturation at the end of 24 hours

Room	No. of screens	Gallons naphtha on screen per 750 cub. ft. room space	°F. Dry Bulb	°F. Wet Bulb	Concn. per cent. v/v.	Approx. saturation per cent.
I	12	1.0	60.0	59.2	0.10	50
II	16	1.4	60.0	59.5	0.14	66
III	21	1.8	60.1	60.0	0.21	100

The weather was dry, with a certain amount of wind blowing, throughout the 20 hours' test.

It was concluded from these experiments :—

- (a) that, even though a room may have a temperature as high as 70° F. at the end of fumigation, this will not necessarily guarantee the presence of a lethal concentration of vapour unless steps have been taken, as indicated at (c) and (d), to ensure that there is sufficient naphtha in the room to make good diffusion losses.
- (b) that, under adverse climatic conditions, the use of 1 gallon of naphtha per 750 cub. ft. of room space may be insufficient.
- (c) that, in these conditions, by doubling the quantity of naphtha (2 gallons per 750 cub. ft.) 100 per cent. saturation may be maintained and the concentration never becomes sub-lethal unless the temperature falls below approximately 50° F. (Tables III and IV).
- (d) that this saturation may be obtained by increasing the number of screens and thus increasing the evaporation area.

Since the weather conditions may change during the fumigation, the quantity of naphtha should be such as to give satisfactory results under the most adverse conditions. The amount of heavy naphtha used should, therefore, be increased to 1½–2 gallons per 750 cub. ft. of room space.

The L.C.C. have now introduced additional horizontal screens, hung just below the ceiling. Readings with the hygrometer in houses so treated have indicated much more satisfactory conditions at the end of 24 hours.

SUMMARY OF TECHNIQUE

The improved technique for using heavy naphtha in an unoccupied dwelling may be summarised as follows :—

- (1) Thoroughly examine the houses or flats to be disinfested, for likely harborage. Care should be taken to ensure penetration of vapour into all places where the bed-bug or its eggs are likely to be present. Pre-heat the houses in cold weather. Close windows, doors and ventilators.
- (2) Turn off the gas at the meter. Naphtha is inflammable.
- (3) Lay wool or shoddy blankets in roof space on top of joists and spray these thoroughly with naphtha.
- (4) Drape walls with light cotton diffusion screens. The importance of using sufficient screens cannot be over-emphasized.
- (5) Thoroughly wet each screen with naphtha, using at least 1½ gallons of naphtha per 750 cubic feet of room space.
- (6) At the end of 24 hours remove screens and ventilate.

FUMIGATION CHAMBERS AND VAN FUMIGATION

In 1937 a request was received from the Borough of Heston and Isleworth for help in disinfesting bedding and mattresses. A small experimental fumigation chamber, constructed of a wooden framework covered with Tentest, was built, and electric heaters were installed. A blanket was suspended from the inside of the roof, and the temperature was maintained at 100° F. Small muslin bags containing live bugs were concealed in various portions of the bedding to be fumigated, and naphtha was sprayed on to the blanket in the room and inside the chamber. All these experiments were successful in 6 hours. Subsequent ventilation of the building was rapid. After it had been shown that naphtha could be used in this way, a larger fumigation chamber, with thermostatic control, was built on similar lines and proved satisfactory.

It seemed reasonable from these experiments to hope that furniture and bedding could be disinfested in transit in vans. Dr. D. H. Geffen, Medical Officer of Health for Enfield, kindly had a van fitted with tubular electric heaters and a thermostatic control, adjusted to keep a temperature of 100° F. No live bugs were found when verminous furniture, and furniture containing bugs concealed in crevices, had been exposed to naphtha vapour for 6 hours. A number of experiments indicated that no difficulty should be experienced in the desorption of vapour from furniture and bedding which had been treated in the van.

In view of the success of these preliminary tests, full-sized vans were constructed for the L.C.C. and Woolwich Borough Council. Tubular electric heaters under a duck board flooring were used in the former, while in the latter electric immersion heaters were arranged along the sides. The temperature was again controlled thermostatically at 100° F. At this temperature the concentration of naphtha vapour is well below the minimum explosive concentration. An extractor fan is fitted, to remove residual vapour at the end of heating.

Originally, the furniture was loaded into the van and ordinary diffusion screens, suspended from the roof and sides, were sprayed with naphtha. This did not prove entirely satisfactory, because drips from the screens occasionally damaged furniture and bedding through staining and other causes. The difficulty was overcome by having the screens made removable and spraying them outside. A further problem was that, with this high temperature, much absorption of vapour by furniture and bedding took place and the evaporating surface of the screens was insufficient to maintain saturation. By pleating the screens a largely increased evaporating surface was obtained.

The present practice is as follows. A load of furniture and bedding is collected and brought to a suitable electric supply point. Heat is switched on,

diffusion screens wetted with naphtha introduced, the doors of the van sealed, and the whole kept under these conditions for 6 hours. The back doors are then opened and the screens removed. The doors are left slightly ajar and the extractor fan switched on. The heaters remain on during this process, to assist removal of vapour, which should be accomplished in about 45 minutes. The time required for disinfestation may vary slightly, depending on the nature and quantity of the goods contained. The furniture can thereafter be at once returned to the owner.

Vans fitted with tubular heaters under the floor appear more satisfactory than those with heaters at the side, as more careful loading is necessary with side heaters, to avoid damage to furniture by heat. In this connection, also, a trailer van appears to have advantages over some lorries, since the floor is on the same level throughout and the heaters can extend the full length.

NOTE ON CONTACT INSECTICIDES CONTAINING ORGANIC THIOCYANATES

Certain organic thiocyanates (*e.g.* lauryl thiocyanate and "lethane") dissolved in a mineral oil base have been used as contact insecticides in houses where for various reasons gaseous fumigants were impracticable. Whilst not fulfilling the same functions as fumigants, contact insecticides serve a useful purpose where evacuation during the fumigation period cannot be obtained, or where through sickness or other conditions the minimum of disturbance of the occupiers of the infested premises is desirable. Sprays containing low concentrations of these thiocyanates are not injurious to human beings. With some insecticides of this type there would appear to be some residual effect and bugs not killed by immediate spraying may subsequently die by coming in contact with the residue up to several days afterwards.

It is unlikely that any contact insecticide will give 100 per cent. kill after one application only, except in very light infestations; preparations must, therefore, be made to repeat the process from time to time, until complete eradication is obtained.

FURTHER RESEARCH

Problems on which further research might usefully be undertaken include the following. (1) Improvement of pre-heating methods, (2) development of heating unit to maintain temperature throughout fumigation period, (3) determination of minimum fumigation time for houses at high temperature, (4) development of technique for occupied houses, (5) determination of the active principles in naphtha, (6) possible inter-relationships of various constituents of heavy naphtha, (7) reinforcement of the action of heavy naphtha by other chemicals, (8) development of heaters and screens for van and chamber fumigation, (9) examination of new potential insecticides, as produced, with special reference to their use against bed-bugs, (10) determination of the best time of year for disinfestation (*c.f.* p. 10).

1. Primus stoves have been used for pre-heating, but they have disadvantages. For instance, it is largely the air that is heated and the walls take up heat from the air very slowly. Further, much of the available oxygen is used up, and this makes the subsequent spraying more difficult for workmen. Some form of heater designed to give the maximum of radiant heat, and which would not use up the oxygen so rapidly, might well heat the structure of the building rather than the air, and thus the rapid drop in temperature often found when the lamps are removed might be avoided.

2. It has commonly been found that on cold nights the temperature in houses under fumigation drops, so that the concentration of naphtha becomes sub-lethal after a relatively short exposure. This problem may be partly solved by better methods of pre-heating, but probably not completely. Where there is an electric supply a tubular heater or heaters may maintain the temperature at considerably higher levels, but where no electricity supply is

available nothing so far has been devised to replace it. Some experiments have been carried out to see whether temperatures in the region of 100° F. can be maintained in houses. When a Copperad heater was used in one room, a temperature of 100° F. was obtained in 2 hours from an atmospheric temperature of 60° F. and a gradual rise to 120° F. took place during the night. This opens up a new prospect both for unfurnished houses and also, perhaps, for occupied houses.

3. If high temperatures can be maintained, it will be necessary to find out what in practice is the minimum exposure for the most difficult cases of infestation likely to be encountered. It might then be possible to disinfest houses in one day and thus avoid the provision of alternative accommodation for the inhabitants.

4. The technique for disinfecting occupied houses has not been developed. They can at present be treated by removing the furniture to a van and fumigating the empty house, but in large blocks of flats this is unsatisfactory for various reasons; for instance, the removal of furniture from a five-storey block of flats would be likely to dislodge bugs on the stairs, so that possibly clean flats would become infested. The treatment of one family's goods and house necessitates two operations, but if furniture were treated *in situ* this could be avoided. Probably with better heating and more screening a satisfactory technique could be worked out for occupied houses and flats.

5 and 6. The active constituents in naphtha toxic to the bed-bug are still not fully determined. There may be an optimum relationship between constituents, or there may be one or more extremely active ingredients which if isolated might be used more effectively. Questions of price versus the amounts used would then have to be considered.

7. Heavy naphtha has been found to be greatly increased in toxicity to the bed-bug by the addition of 2 per cent. by volume of liquid carbolic acid, containing at least 90 per cent. of cresols. It is possible that there may be other chemicals which could increase this activity still further. Pathological tests should be carried out concurrently, to ensure the safety of human beings.

8. Heaters in vans and fumigation chambers should be investigated, so that the best type may be chosen. For instance, some of the aluminium alloy heaters may be worth investigating. The best method of providing the maximum evaporating surface on removable screens is also an important question.

IV.—DOMESTIC HYGIENE IN THE PREVENTION AND CONTROL OF BED-BUG INFESTATION

BY

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When property becomes bug-infested its value is seriously threatened, and if infestation is allowed to proceed unchecked, demolition of the building may be the only effective remedy.

In practically every community throughout Great Britain and elsewhere there are bug-infested dwelling houses which need not have been allowed to degenerate into this deplorable condition had an efficient system of supervision been exercised by those responsible for their maintenance. Within recent years, especially during the past decade, when slum clearance and the rehousing of the displaced tenants has been one of the major activities of all local authorities, the need for protecting the new houses from infestation has stimulated Housing and Public Health Authorities to take preventive measures

against invasion by the bed-bug. In this crusade many of these authorities have pinned their faith to the use of gaseous and liquid insecticides; chief among the chemical methods employed are fumigation with hydrogen cyanide or sulphur dioxide and the application by various spraying methods of liquid insecticides, such as heavy naphtha, paraffin, or a mixture of paraffin and petrol, with such a substance as pyrethrum added to enhance their killing power. But much more than the use of these insecticides is required, no matter how skilled may be the technique of their application. In fact, the use of chemicals in clearing a house of bed-bugs may result in tenants adopting an attitude of indifference to their responsibilities in maintaining such a standard of cleanliness in their houses as will ensure immunity from re-infestation.

DOMESTIC CLEANLINESS

Chemicals cannot succeed if their use in disinfection is not supported by domestic and personal cleanliness. This axiom reaches the root of the problem. No one who keeps a clean house need fear its invasion by the bed-bug. If by chance bugs gain an accidental footing in a house which is properly kept, they cannot thrive for any length of time. They will steadily be worn down by a process of attrition and will disappear for good.

It is common knowledge that where there is cleanliness there are no bed-bugs, and it is also a fact that the degree of household cleaning required from the housewife to achieve complete immunity from the bug for her household need not be of that striking degree which may even be uncomfortable. Good ventilation is another essential. Steady and methodical cleaning will obtain the desired effect, but, on the other hand, neglect of the routine household duties may open wide the way to the invaders and land the housewife in a maze from which she can see no way out. The bugs by instinct make for all neglected corners of the beds, furniture and woodwork. There can be little doubt that lack of domestic cleanliness is the principal factor in bed-bug infestation.

IMPORTANCE OF A KNOWLEDGE OF THE LIFE-HISTORY AND HABITS OF THE BED-BUG

A reasonable knowledge of the life history and habits of the bed-bug is of great assistance (see section I). Such knowledge would go far to prevent the infestation of houses, did those concerned possess it. It is worth while knowing that the bug feeds only by sucking blood, human by preference, and that it is mainly a night forager. When starved, it will feed by daylight, but as a rule relays of the attackers make their way to their sleeping victims in the darkness. It is believed that bugs will travel comparatively long distances for their ration, certainly from one part of a house to another, and from one house to its neighbours in the same block. The extent of "trekking" has not yet been fully worked out, but so far there is no convincing evidence that bugs "hive off" to neighbouring buildings from infested houses that are being demolished, as most of the bugs and their eggs perish during the process, through exposure to the weather and from rough handling. Workmen on such a task may, however, transport a few on their clothing, and many more may be transferred on portions of the infested woodwork pilfered for firewood; such wood should therefore be burned on the site and a close watch should be kept for would-be pilferers.

When bugs are rapidly increasing in numbers in a house, overcrowding is avoided for a time by the establishment of colonies in various parts of the infested room. Firstly, the bed is most favoured, whether it be of wood or metal, so long as it is not disturbed by cleaning. Here the bugs are right on the site of their supply depot, and the better the feeding the more prolific they are. From the bed they spread out over the walls, behind the picture

rails, into the picture frames, and under the seats of uncleaned chairs or sofas. They reach the height of their activities during the summer months. Their eggs are deposited in large numbers, probably several hundreds per female during the season. These hatch under favourable conditions of warmth and moisture within a few days, and as soon as the embryos emerge they set out for their first feed of human blood. They cannot grow unless they obtain blood, but they can live after emergence from the egg case for many months without food of any sort, so great is the reserve with which they have been endowed. In fact, the endurance of the bug is one of its many remarkable characteristics. The skin is moulted five times before maturity is reached, but growth will not proceed at any stage unless a feed of blood has been obtained. Growth stimulates the urge to attack, and the more regular the supply of rations the shorter is the period required by the bug to grow from the minute freshly-emerged larva to the mature mahogany-brown adult. It is only after the fifth or final moulting that the sex of the insect can be determined, the male then being equipped with its more pointed stern, and the female being slightly larger and more rounded, with her eccentric sex pouch on the undersurface of the right side of the abdomen.

Growth can be prevented by starvation, and the completed life-cycle delayed for many months. But under natural conditions the life-cycle is accomplished within two or three months at favourable temperatures and humidities. It is not known precisely how long bugs live when meals are infrequent and taken at long intervals, but it would not be improbable that life could be extended to more than two years in the case of adult bugs. An insect of such tenacious viability must necessarily command the respect of those who set out upon a campaign of extermination.

HOW TO PREVENT INFESTATION

(a) A knowledge of the life-history and habits of the bed-bug is essential to success. The bug will elude those ignorant of its ways. All concerned with the protection of property, or with the guidance of tenants in preventing infestation, must be equipped with the necessary information about the bug, and be able to impart useful instruction to those who require it. Thus, it is essential that the sanitary inspector, the health visitor, the resident agent or factor, and others in equally responsible positions should be trained to know the ways of the insect.

(b) Useful propaganda can be initiated by public exhibitions of housing pests. This method of instruction has already been successfully exploited in the Annual Housing and Health Exhibitions held under the direction of the Corporation of Glasgow. The exhibits which have attracted most notice are live specimens, displayed under fairly large low-power lenses and suitably illuminated; large wax models illustrating the life-cycle of the more important and aggressive insects, such as the house-fly, the louse, the flea, and the bed-bug; drawings in colour, and enlarged photographs. Visitors to such exhibitions are halted by their natural curiosity to look and pass comments upon these striking objects, whereas they have been observed to pay little or no attention to exhibits which involve much reading, no matter how well these are displayed. This was also clearly proved at the Empire Exhibition in Glasgow in the summer and autumn of 1938, when the Ministry of Health and the Public Health Department of Glasgow staged such exhibits.

(c) The control of the anti-bug campaign, and the instruction of the various officers concerned with the application of the preventive measures, must be delegated to someone who knows the subject well and practically, and who is keen enough to maintain the interest of all. A half-hearted approach to the task will result only in a waste of time and public money. This instruction in

the bionomics of the bug can only be considered complete when the sanitary officers can recognise the signs of the earliest stages of infestation.

CONDITION OF INFESTED HOUSES

In old property invaded by the bed-bug a serious degree of infestation is usually found, and this very often has been aggravated by the insanitary nature of the house, in which such grave faults as lack of light, deficiency in ventilation, cracked and crumbling plaster, and worn woodwork may exist. These contribute to the nuisance, by creating for the housewife an impossible task in cleansing. The bug readily finds shelter under these conditions. In spite of such difficulties, however, the industrious and cleanly tenant can overcome the bed-bug to the extent of maintaining a fairly reasonable degree of comfort and freedom from its attacks. Much help can be given to these willing ones by well-trained and sympathetic inspectors and health visitors.

SYSTEM OF INSPECTION AND PREVENTION

A complete system of house-to-house inspection for vermin, in the areas most likely to be infested, would require a larger staff of trained inspectors and health visitors than most local authorities are prepared to support. Nevertheless, all sanitary inspectors should be so trained that, wherever their housing and other public health duties may lead them, they can readily observe the presence of the bed-bug and give advice and help. Only when they know where to detect the insect, and understand much of its life-history, will they find themselves sufficiently well-equipped to ensure good results from whichever method of extermination may be favoured.

Their manner of approaching the backward and lazy tenants must be carefully cultivated. An officious attitude is bound to fail, whereas a sympathetic though firm handling of even the most careless tenants will ultimately in most cases gain their willing co-operation. Sanitary officers should also remember that the campaign of attrition will extend over a considerable period of days or even weeks. They will find that, as the standard of cleanliness rises, the number of bed-bugs steadily diminishes. Therefore, they should exercise patience and never forget that the task set the housewife is a severe one, which will also make a great demand on her energies. As the good results appear, the hope of final peace from the enemy usually calls forth a greater effort, and all the while the inspector must co-operate until the desired result is obtained.

THE UNINHABITABLE HOUSE

When houses are so hopelessly infested that they cannot be cleansed, it is time to consider their demolition. Such houses more often than not have many other defects which bring them into the category of the uninhabitable insanitary dwelling. An inspection of the houses while in process of demolition will readily prove the hopelessness of success from disinfestation, even by hydrogen cyanide (HCN), which is probably our most potent chemical weapon for killing vermin generally. The extent of the infestation in such cases can rarely be gauged by surface evidence.

Nevertheless, many heavily infested houses can be successfully tackled by methods other than demolition. Having pointed out the distribution of the bed-bugs on beds, furniture, and in their other shelters, the inspector should instruct the tenant in what needs to be done. This usually amounts to an intensive "spring cleaning", although the method is sound at any season of the year.

THE METHOD

Washing and scrubbing with soap and water wherever these cleansers can be applied is the simple prescription. Many, however, will find it difficult to

keep up the necessary supply of hot water for the scrubbing of tick mattresses, bed boards, dismantled metal bedsteads, spring mattresses, picture frames, the undersurfaces of neglected chairs, the backs of chests of drawers which have held their accustomed stand next the bed for years, wooden chests stowed away under the bed, and all such like movables. The addition of a small quantity of lysol to the soap and water may assist the cleansing effort.

Woodwork, such as door facings and picture rails, may require stripping from the walls, in which case the blow-lamp can be readily applied to the colonies of bugs on the back of the woodwork and upon its bedding in the plaster of the wall. This is the surest killer of the insects and their eggs. If the woodwork is unnecessary to the structure of the apartment, it ought not to be replaced, and if replacement is essential, the woodwork should be renewed.

RESPONSIBILITY OF THE OWNER

Structural work is the responsibility of the owner of the property, and the sanitary or housing inspector should have enlisted his co-operation. The good house factor or owner usually helps, and if he does not seem willing to do so, a notice under the Public Health Act to remove the nuisance should succeed in stirring him to action. Cracked and infested plaster should be stripped and suitably restored. Infested wallpaper must be removed and burned, and for the redecoration of the walls, paint or distemper should take the place of wallpaper, which is often so badly applied to walls as to provide excellent shelter for bugs.

TREATMENT OF UPHOLSTERED FURNITURE

Upholstered and complicated furniture is difficult to cleanse; but it is remarkable how much of this type of furnishing can be successfully disinfested by cleansing *alone*. The bed-bug tends to remain near the surface of such articles, which after all are only its *points d'appui*. It does not penetrate upholstery as the flea does. The bug, being broad and flat, must confine itself to chinks and crevices or the surfaces of articles. The top of a rusty nail embedded in wood is a favourite retreat; it also provides excellent "camouflage". The eggs of the bug stick to the object upon which they are laid, because of the fine coating of cement on their surface, and eggs, therefore, will be found only where the bug can penetrate. Dilapidated upholstered furniture is best destroyed and, similarly, old worn canvas-covered straw mattresses are best burned. These are cheap to replace, and some local authorities undertake the replacement gratuitously in needy cases.

CONTACT INSECTICIDES

As an adjunct to simple but vigorous cleansing, the upholstered furniture should be sprayed with a good contact insecticide. Such a mixture as an extract of pyrethrum in good quality paraffin has been recommended, and within recent years very good results have been obtained from the use of heavy naphtha. The pyrethrum mixture is made by digesting $\frac{1}{4}$ lb. of fresh pyrethrum powder in 1 gallon of a good quality kerosene for 48 hours or so, the mixture being agitated frequently during that period. After settling, the clear straw-coloured supernatant fluid is decanted, and to this is added 4 oz. of methyl salicylate. After the article of furniture has been sprayed with whichever insecticide is favoured, it should be closely covered with a sheet for a day or two, to prolong the action of the insecticide.

Most fabrics used for upholstered furniture will come to little or no harm from scrubbing with soap and water. The moisture will dry out in a comparatively short time, and this process can be hastened if the house can be heated and aired. The more frequently and thoroughly such cleansing is carried out, the more likely are the results to be successful.

PREVENTION OF INFESTATION OF NEW HOUSES

Transference of tenants from the slum clearance areas to new houses presents the difficult problem of preventing the introduction of bugs along with the old furnishings. Prevention can be successfully accomplished in most cases if a proper system of supervision by trained officers exists. In one large city the following methods are part of the routine of rehousing.

About a fortnight before the tenants require to leave the condemned houses, the Public Health Department receives notice of this from the department responsible for the allocation of the new houses. The house to be vacated, and its furnishings, are examined in detail by a sanitary inspector, and if bugs are found, a process of intensive cleaning by the tenant is instituted. The actual details of the cleaning depend entirely upon the conditions found, and each house presents its own problems.

Disability, ill-health, and overcrowding with furniture frequently hamper the work. Mattresses, bed boards, trestles in bed recesses, chairs, picture frames, and any other article likely to provide shelter for the bugs must be carefully scrutinised. Reliance is placed mostly upon thorough scrubbing and cleansing of all articles with soap and water. The tenants must apply themselves to this task, and great destruction of bugs and their eggs can be accomplished by the application of the wash cloth and scrubbing brush. Most insecticides used against the bug must be directly applied before they can destroy, and this is precisely what is accomplished by dusting, washing and scrubbing. It is generally necessary for the process to be explained and supervised, and the results should be inspected so as to avoid half measures.

On the morning of the removal, the bedding is taken to the disinfecting station and sterilised by steam, after which it is returned to the new house on the same evening. The tenants are also warned against taking to the new house old, infested, useless articles of furniture, worthless pictures, and "junk". The likelihood of bug infestation arising from second-hand furniture is also impressed upon them.

The precautions taken are as comprehensive as possible, and are concentrated upon the articles to be removed. Much depends upon the standard of efficiency displayed by the sanitary inspector, as slackness on his part will defeat the object of the work.

PROCEDURE AFTER OCCUPATION OF THE NEW HOUSES

Even after the new house or flat is occupied, supervision must be continued. This work is admirably carried out by health visitors, well trained in the life-history of the bed-bug. It may happen that all the bugs and eggs were not destroyed before the removal of tenants from the old house. In the new house the health visitors again examine the articles in which the breeding places of the insect are likely to be found, and they continue the lessons in specific household cleanliness which were begun in the old slum house. Whenever the opportunity presents itself, it is useful to demonstrate to the tenants the different stages of the life-history of the bug, in order that their interest and support may be enlisted.

The health visitors and sanitary inspectors should carry with them a good electric torch and a lens, either mounted on the torch or carried separately, so that doubtful corners can be properly examined. A magnified flood-lit view of a bug and her eggs cannot fail to impress, and it will probably add to the hunter's desire to wipe them out.

One health visitor can look after about one thousand new houses which have been occupied by slum-cleared tenants. Within a short time she is able to exercise discrimination between good and backward tenants. A high percentage of them will only require a "look up" two or three times a year. This will allow the visitor to concentrate upon the unsatisfactory and backward

minority. Her job is one of instruction as well as supervision, and, as already stated, she must be sympathetic but firm in her methods of obtaining the maximum effort. Officiousness will bar the door to her and may cause trouble. In practice, there has been very little difficulty in obtaining an entry without applying compulsory powers. The visitor's skill in detecting the earliest stages of infestation will increase as time goes on, and a staff consisting of individuals with some years of experience behind them is invaluable for this work.

The health visitors prevent deterioration of property by keeping the bug out, and this easily justifies the annual wages bill. In addition, they reduce to a negligible minimum the cost of disinfection with lethal gases and other chemicals, because the necessity for these seldom arises. A close co-operation between health visitors, resident agents or factors, and the maintenance section of the Housing Department is essential to the success of this preventive system. It is hardly necessary to reiterate that the cold officious manner must be avoided by all these "anti-bug crusaders".

The figures in Table VIII afford ample evidence that a well run "follow-up" system, for which a carefully trained staff of health visitors and sanitary inspectors is available, can achieve very good and progressive results; in fact, such a system, or a modification of it, must be applied even after hydrogen cyanide fumigation of furniture, when tenants have been removed to new houses from their old dwellings. It will be seen that in 1934 the percentage of seriously infested new houses in a total of 8,670 was 7.1, and that the amount of serious infestation had been reduced to 1.7 per cent. in a total of 14,416 new houses in 1938 by means of the procedure described above.

TABLE VIII
Progress in preventing bug-infestation in rehousing schemes of a city

Year.	Number of houses inspected.	Number of houses in which bed-bugs were found		
		Trace of bugs.	Medium infestation.	Serious infestation.
1934	8,670	104 1.2 per cent.	210 2.4 per cent.	612 7.1 per cent.
		<i>Total</i> .. 926 = 10.7 per cent.		
1935	10,576	218 2.1 per cent.	368 3.5 per cent.	378 3.6 per cent.
		<i>Total</i> .. 964 = 9.2 per cent.		
1936	12,803	220 1.7 per cent.	296 2.3 per cent.	295 2.3 per cent.
		<i>Total</i> .. 811 = 6.3 per cent.		
1937	13,676	253 1.8 per cent.	165 1.2 per cent.	304 2.2 per cent.
		<i>Total</i> .. 722 = 5.2 per cent.		
1938	14,416	138 0.9 per cent.	69 0.5 per cent.	240 1.7 per cent.
		<i>Total</i> .. 447 = 3.1 per cent.		

Definition of the varying degrees of bug-infestation shown in the above Table :—

(1) *Trace* means that old hatched eggs, or moults, but no living bugs have been found on movable household belongings such as beds, furniture, pictures, etc.

(2) *Medium infestation* means that living bugs or eggs (identified by lens) have been found on movable household belongings but not yet in any part of the structure of the building, such as behind woodwork or in defects in plaster, etc.

(3) *Serious infestation* means that living bugs or viable eggs or both have been found in some part of the structure of the building as well as on the movable household belongings. Unless discovered early, this will cause much trouble in disinfection.

V.—INVESTIGATION OF THE TOXICITY TO MAN OF INSECTICIDES USED AGAINST THE BED-BUG

BY

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The object of a toxicity investigation is to obtain information from experiments, usually on animals, for predicting whether the substance tested is likely to be injurious to man. A spray or fumigant may be dangerous to handle or to come in contact with, even when diluted with an inert liquid. The risk may apply not only to men engaged in disinfestation but also to people living in neighbouring houses or rooms. Hydrogen cyanide, for example, has already been responsible for a number of fatal accidents in this way. There may be risk also for some days afterwards by residual action to people readmitted to treated dwellings. In some cases the ill effects may be delayed for weeks or longer. Continuous exposure to even very small amounts of a chemical substance may produce a cumulative effect on certain individuals possessing unusual susceptibility. And finally, though the substance may not kill, it may exert harmful effects on the organs, leading to ill-health. In carrying out a comprehensive laboratory investigation of a new agent, therefore, the pathologist should attempt to determine the following:—

- (1) The smallest fatal dose and the lowest toxic dose, when administered by various routes to a variety of animals.
- (2) The pathological changes in tissues and blood produced by toxic doses.
- (3) The differences between acute and chronic effects.
- (4) The effect on the growth of animals exposed for long periods to the agent.
- (5) Influence on reproduction, especially interruption of pregnancy and foetal changes.
- (5) Acquisition of tolerance (resistance) or susceptibility.
- (7) The factors which may modify the toxic action, *e.g.* fatigue, general nutrition (especially degree of fatness), sex, age, pregnancy.
- (8) Preventive, protective or curative measures which may affect any toxic action.
- (9) Interpretation of results in terms of hazards.

At the outset the most difficult question to be faced is the interpretation of animal tests in terms of human behaviour. In general, a safe procedure is to employ a variety of animals. Mice, rats, guinea-pigs, rabbits and cats are usually selected, and, in special cases, dogs and monkeys. Animals should be perfectly healthy, free from their naturally occurring diseases and parasites, well nourished, and kept under proper conditions of housing. The latter cannot be over emphasized. Most laboratories possess stock inbred for years, whose behaviour is well known. The use of a strain such as the Wistar rat greatly simplifies work, since the large body of information about it collected by Donaldson (1924) inspires confidence in results. Considerable attention must be paid to diet, for gastro-intestinal upsets and malnutrition readily vitiate experimental results. Warmth is equally important. After-care is just as necessary as preparation in an experiment. A sudden fall in the temperature of the animal house may be disastrous.

Since toxicity investigations require large numbers of animals, individual tests must of necessity be limited to comparatively small groups. Members of the experimental and control groups should be selected at random. With the smaller and cheaper animals seldom less than ten in a group are used, and

in assessing lethal doses a 50 per cent. mortality is required. In determining morbidity, *i.e.* pathological change in the organs and tissues, all the exposed animals are examined histologically.

Agents employed against insects fall into two main groups, according to whether they exert their effects by (1) fumigation or (2) contact. Probably the most satisfactory agent would act in both ways.

The essential investigation of such substances includes the recognition of a harmful action on animals and the determination of the range of dosage over which this action extends. The second feature is especially important, for only by the estimation of the smallest amount likely to kill or injure can the danger in the field be assessed. It is obvious, therefore, that field observations are essential because (1) they determine the risk to human beings in terms of amount of volatile substance in the room atmosphere over any length of time after treatment, and (2) with contact sprays study of actual conditions gives some idea of the likelihood of human contamination by residues.

Toxic effects are judged by changes in animal behaviour and alterations in animal tissues. There may be sudden or delayed death, preceded by mild or severe symptoms of respiratory, circulatory or nervous upset. Alimentary symptoms, such as salivation, retching movements, diarrhoea, bloody discharges from the bowel, loss of appetite, thirst, predominate in some cases, whilst urinary suppression or bleeding, irritation of the eyes, mucous membranes or skin may be outstanding in others. Especial attention should be paid in the female to reproductive disturbances, such as abortion, bleeding from the vagina, or sterility. With long-continued experiments, sterility in the male may be an important result. The possibility of changes in the offspring of mothers exposed to such substances must always be considered, so that it is wise at once to separate mothers with litters from the main group. On the other hand, useful information can often be obtained from subjecting new-born litters to the substance under investigation. With prolonged experiments it is necessary also to watch for the development of resistance to the agent, or of increased susceptibility. The latter may make its presence known by irritating skin rashes.

The microscopic examination of the tissues and blood is perhaps the essential part of a careful investigation. Naked-eye examination of organs is not sufficient. A microscopic examination not only discloses the first evidence of damage, and excludes the naturally occurring diseases of the animal concerned, but it frequently throws light on the mechanism by which the toxic agent produces its effects. A complete examination of the blood, if possible at daily intervals, should be carried out, preferably by an experienced haematologist. Since such work includes prolonged study of many normal animals for some time before the exposures are begun, a haematological investigation is not to be entered upon lightly. Such an examination includes both total red and white cell counts (for preference, with the Bürker counting chamber), haemoglobin estimations by the Haldane method, platelet and reticulocyte counts with supravital brilliant cresyl blue staining, and a differential leucocyte count on smears stained by Jenner's, Leishman's, or Giemsa's method. Information so gathered will show whether there has been serious disturbance of the red and white cell systems, and how such disturbances are being faced by the organism. A more detailed investigation may be suggested by the preliminary findings, *e.g.* the appearance under certain conditions of immature red and white blood cells. It is essential for the investigation of the tissues that careful attention be paid to the principles of histology. The need for proper fixation of material cannot be over-emphasized, and time devoted to finding out which fixatives are best for the individual tissues is well spent. For general purposes both 10 per cent. formol saline and 70 per cent. alcohol are recommended. Examinations are made of frozen and paraffin sections of the liver, kidneys, lungs, adrenals

and spleen of all animals; whilst the gut, brain, reproductive organs, bone-marrow, heart, skin and subcutaneous tissues at site of injection or application of the agent, are also sectioned from a few representatives from each group. Ehrlich's or Harris's haematoxylin and eosin, van Gieson's stain with Weigert's iron haematoxylin, Weigert's elastica method, Laidlaw's or Gömöri's reticulin stain and the usual fat methods, including the use of the polarising microscope, are suitable. The importance of examining material prepared by similar methods from healthy control animals must be stressed. Group variations may be considerable in certain organs, *e.g.* liver, and bone-marrow, and may lead to serious errors of observation if not appreciated. Such differences can be assessed only by the study of microscopic preparations.

The substance under investigation may be introduced into the animal's body : (1) by skin application, (2) intracutaneously, (3) subcutaneously, (4) intramuscularly, (5) intraperitoneally, (6) orally, (7) intravenously, (8) by inhalation, (9) by exposure to a mist, and (10) by "house" experiments. The most suitable methods are those which accurately reproduce the conditions under which human beings may be affected. For contact insecticides, skin application, "house" experiments and, in certain instances, mist exposure are most suitable. For fumigants the best methods are inhalation and "house" experiments. The other methods are, of course, designed for the accurate study of toxicity and the determination of quantitative data such as minimal lethal and toxic doses. Their main advantage is that they enable the investigator to say whether toxic effects are likely to occur after the absorption of minute amounts of the substance or only with relatively huge quantities. If a substance produces severe effects on several species of animals when administered subcutaneously or intravenously in very small quantities, it is likely that the absorption of quite small amounts will be harmful to man. On the other hand, when large amounts are required to produce death or injury in animals the substance will in all probability be innocuous to human beings. Care must be taken to reduce quantities to a common unit of comparison, such as mg. per kg. body weight, parts per million or mg. per cub. metre, though too much reliance cannot be placed upon strict comparisons. Other factors apart from bulk, such as degree of fatness, age, sex, detoxifying mechanisms, activity of animals, play parts which cannot be readily assessed. Great difficulty in interpretation arises when varying results are obtained with different species of animals. On the whole, most reliance is placed on tests with rats (especially the albino Wistar strain) and least on those with rabbits and mice.

Certain disadvantages associated with each of the above-mentioned methods of investigation may be briefly stated. With skin application it is difficult to prevent the animal licking off the agent, though this can be minimised by applying the substance to the back and allowing it to dry in before releasing the animal, or washing off after a given period. Thick fur prevents much of the agent from reaching the skin. With shaving the consequent erosions and congestion of the skin may alter the rate of absorption, so that it is better to wait a few days after these manipulations before carrying out tests. The thickness of the epidermis, and the vascularity of the underlying tissues, vary with different species and to some extent also with individuals. These sources of error can be reduced only by employing many animals. Intracutaneous and subcutaneous inoculation are influenced by structural variations, especially in vascularity, with consequent variations in rate of absorption. With some substances, absorption is very slow and may be further modified through the development of a local inflammatory reaction at the site of injection. When a good deal of the agent can still be detected at such a site days after application it is difficult to assess the value of the test. If a local subcutaneous reaction is marked and there is much tissue damage, the suspicion arises that the general

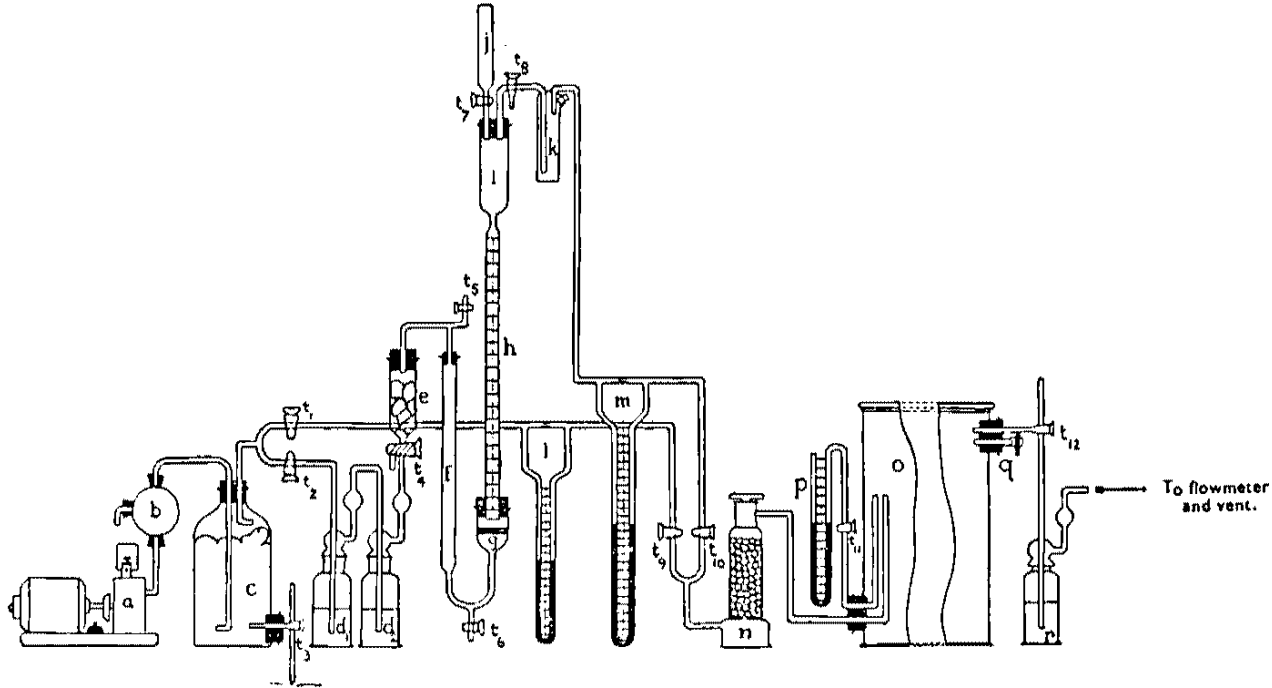


FIG. 9. Apparatus for exposing small animals to methylated benzenes.

- (a) Electric power blower.
 (b) Pressure valve.
 (c) Aspirator bottle packed with cotton wool for filtering air from motor.
 • (d_1, d_2) Wash bottles containing the liquid under investigation.
 (e) Tube packed with cotton wool soaked in the liquid.
 (f) Connecting tube.
 (g) Sintered porous glass plate.
 (h) Metre column of the liquid.
 (i) Wash bottle for trapping bubbles from (h).
 (j) Inlet for filling (h).
 (k) Wash bottles for collecting droplets of liquid carried over from (h).
 (l) and (m). Venturi meters.
 (n) Mixing tower filled with glass beads.
 (o) Animal chamber.
 (p) Pressure manometer.
 (q) Outlet to wash bottle, with sampling tube.
 (r) Wash bottle containing alcohol for absorption of liquid from air passing to flow meter.
 (t_1-t_{12}) Stopcocks for collecting samples of gas mixture for analysis.

(Redrawn from *J. Path. Bact.*, 1938, 46, 95, for reproduction by kind permission of Messrs. Oliver and Boyd,

features of intoxication are due rather to the local damage than to the actual agent introduced. In small laboratory animals it is often difficult, without a bacteriological examination, to exclude a septicaemia resulting from bacterial infection of such a damaged area. And finally, with slowly absorbed substances, excretion and detoxication may keep pace with absorption so that there is no evidence of general intoxication. Such tests may then be misleading. This latter criticism may not be very important, for in all probability the same argument will apply to man and the general risks will be slight. Intramuscular injection is perhaps the best of all tests for comparative purposes, for there is little species difference in highly vascular muscle; absorption, therefore, should proceed at about the same rate in most species; there is also less danger of infection from without. Intraperitoneal administration has the advantage of rapid and complete absorption of the substance, but local reaction, sometimes resulting in peritonitis, may obscure general effects. Very rapid absorption, too, sometimes misleads by the alarming intoxication which may suddenly set in. Interpretation of the result of oral administration is complicated by the conditions existing in the alimentary canal, especially by the presence of food, the diluting effect of gastric and intestinal juices, and faecal excretion. The intravenous method is applicable with safety only to water-soluble substances, for insoluble agents may produce embolism with misleading features, whilst small amounts are quickly segregated in the reticulo-endothelial system. Inhalation is the method of choice for the investigation of gases, highly volatile liquids or vapourised solids, the mist method for liquids of low volatility. The "house" method aims at reproducing conditions as they exist in actual practice, and is most useful for contact insecticides. Since some kind of diluent, such as kerosene, is generally used, it is important to make sure that the diluting substance is not toxic. This applies particularly to contact sprays.

The actual technique of introduction may be briefly described. For skin application a 1 c.c. dropping pipette or a fine camel-hair brush is convenient, the area of application being limited with a stencil when repeated exposures are to be studied. Any local effects can then be followed with certainty. Intracutaneous, subcutaneous, intraperitoneal, intramuscular and intravenous injections are carried out with the ordinary 1 c.c. graduated syringe or a tuberculin syringe. Soluble substances are diluted with sterile distilled water or normal saline, so as to introduce the same amount of fluid into each animal of the group. With insoluble substances, such as the higher thiocyanates or heavy naphtha, the smallest amounts delivered by the syringes mentioned above are the lowest limits of investigation for the small animals. With larger animals, such as rabbits, absolute alcohol or liquid paraffin may be used as diluting agents; adequate controls are then essential. With intraperitoneal injection, light anaesthesia is desirable. For inhalation tests, the introduction of known amounts of volatile liquids or gases into an air-tight chamber, *e.g.* a metre cube, or a constant flow apparatus such as that figured by Cameron *et al.* (1937, 1938) may be resorted to (fig. 9). Chemical estimation of concentrations so obtained is essential.

By the "house" method is meant the employment, for the investigation of contact sprays, of miniature rooms or houses in which small animals, preferably rats, can be kept for indefinite periods. The plastered inner walls of such a house are treated with the spray precisely as in the field. The roof is partly open, for purposes of ventilation and feeding. A water bottle is suspended from the roof. The floor is covered with peat and wood wool. The dimensions are roughly according to a scale in which the animal represents a human being. The house is kept in the main laboratory, under ordinary conditions of habitation. This method has been extensively used in the investigation of the thiocyanates (Cameron, Doniger and McKenny-Hughes, 1939).

TOXICITY TESTS ON SOME SUBSTANCES USED AGAINST BED-BUGS

During the last four years investigation of the toxic properties of a number of substances used against the bed-bug has been carried out by a group of workers at University College Hospital Medical School, London, and the results are summarised here.

o-Dichlorobenzene

Field experiments, made possible by the co-operation of Dr. J. Macmillan, M.O.H. for the Metropolitan Borough of Woolwich, and carried out by Messrs. Ashmore, Buchan and Warren of the Government Laboratory, showed that if a room is sprayed with commercial *o*-dichlorobenzene and shut up again after ventilation for six hours, a concentration of 0·026 per cent. v/v is reached within one hour. Even with free ventilation it does not fall below 0·005 per cent. in three days, and it persists at 0·001 per cent. for a fortnight. Since, in practice, people were allowed to re-occupy dwellings after 12 hours' ventilation, *i.e.* at a time when the concentration of *o*-dichlorobenzene is around 0·01 per cent., investigations were confined to this concentration and to those below it. In the gas chamber mentioned above, rats died after exposures of 24–48 hours to concentrations as low as 0·005 per cent., and mice were particularly susceptible to these concentrations. Subcutaneous and intravenous administration of *o*-dichlorobenzene to rats, mice and rabbits resulted in death sometimes after very small doses. Even when death did not occur, severe pathological changes were found in the organs. Thus, liver damage varied from patchy hydropic degeneration of liver cells and slight fatty change to intense focal, and sometimes confluent, massive necrosis, with destruction of the greater part of the organs; the extent of these changes was roughly proportional to the dose and, up to a point, to the interval after exposure, the maximal changes being seen in 24–48 hours; recovery from mild and moderate damage was rapid, but severe damage was usually fatal. The liver changes resembled those produced by chloroform. Renal damage was not constant and was relatively slight, taking the form of degeneration of the tubules, the glomeruli remaining unaffected. A certain amount of localised necrosis and oedema was liable to follow the subcutaneous or intracutaneous injection of large amounts of *o*-dichlorobenzene, but this passed off uneventfully. Lastly, the white corpuscles of the blood were destroyed when subcutaneous injections were given to rabbits, or when rats were exposed to the vapour, the effect resembling that produced by benzene. Almost complete agranulocytosis might result in about ten days after three successive doses of 0·5 c.c. per kg. body-weight. There was no significant alteration in the red count or haemoglobin percentage. The conclusion drawn from these experiments, therefore, was that it was inadvisable to expose human beings to the influence of *o*-dichlorobenzene, even in low concentrations, for any length of time.

Pseudocumene and heavy naphtha

Pseudocumene was used for a short time only, being replaced by heavy coal tar naphtha. Little need be said about its investigation. When inhaled, pseudocumene produced no ill effects. Forty-eight hours' continuous exposure to air saturated at room temperature (60° F.) with pseudocumene, and 14 exposures of eight hours each, did not produce symptoms in rats, and microscopical examination of their organs failed to disclose any change. Rats also tolerated large doses of pseudocumene subcutaneously and intraperitoneally. Its isomer, mesitylene, present in small amounts in commercial pseudocumene, proved toxic in high concentrations only. Prolonged exposure to the lower concentrations of pseudocumene and mesitylene did not interfere with growth. Female rats gave birth to healthy offspring, and these young

rats grew normally when separated from their mothers. Neither pseudocumene nor mesitylene appeared to produce any change in the blood of rabbits.

Ashmore and McKenny-Hughes (1937) showed that heavy coal tar naphtha, containing about 30 per cent. of pseudocumene, gave even better results in experiments against the bed-bug than commercial pseudocumene. With effective ventilation heavy naphtha rapidly disappears from rooms, even after the maintenance of air saturation for 24 hours. Eight hours ventilation was sufficient to reduce saturation (0.22 per cent. v/v at 60° F.) to 0.009 per cent. and there was no further "building up". Heavy naphtha also is much cheaper than pseudocumene. Laboratory experiments have been equally satisfactory. By means of the gas chamber with the special saturation unit the effect of inhaling heavy naphtha in high concentrations has been investigated, a number of British firms kindly supplying representative samples. Rats, mice, guinea-pigs and rabbits were exposed to heavy naphtha vapour from 12 hours to two months. In most instances the severe test of exposure to concentrations such as 0.18 per cent. at 20° C. (practically saturation) was employed. In addition, the effects of subcutaneous, oral, intravenous, intramuscular and intraperitoneal administrations were studied. The detailed results have already been published (Cameron, Paterson, de Saram and Thomas, 1938) and need only be summarised. Rats were found to be highly resistant to heavy coal tar naphtha vapour, remaining unaffected after two months exposure to air saturated with one variety of naphtha (from the Gas, Light and Coke Company, Beckton). Growth proceeded naturally and the offspring of exposed females were healthy. There was no evidence of any specific action on the blood. Mice were susceptible only to the higher concentrations of a few samples. Guinea-pigs and rabbits, though less extensively investigated, were apparently unaffected by air saturated with heavy naphtha for 12–21½ hours. Large doses administered by the other routes mentioned produced no effects. The only pathological change noted when large amounts were inhaled was fatty degeneration in the liver and kidneys occasionally, although mice, which proved more susceptible to some samples, sometimes showed severe liver damage. Taylor (1939), however, has obtained toxic effects in rats after administration of large doses of some samples of heavy naphtha.

In all these experiments the animals were either subjected to large doses administered subcutaneously, intravenously, etc., or exposed to air practically saturated with heavy naphtha at room temperature—a very severe test. Such adverse conditions were far in excess of anything likely to be encountered in the field. Except in mice, no untoward effects were experienced. Rats have been exposed for long periods to all the heavy naphthas used for disinfection purposes, including those containing phenols, and no ill effects have been observed. Moreover, the work of Ashmore and McKenny-Hughes, referred to above, offers the additional reassurance that with efficient ventilation only minute amounts of heavy naphtha remain in the treated room at the time of re-admission of occupiers. It is felt, therefore, that, provided the precautions laid down by these workers, and elaborated by Glover (1938, 1939) and Macmillan (1938), be observed, there is little reason to expect any danger to man. As an additional precaution, however, it might be wise to carry out toxicity tests on a wide range of animals with new samples of heavy naphtha before they are issued as insecticides.

The higher thiocyanates

Two of the higher thiocyanates, n-butyl carbitol thiocyanate and dodecyl thiocyanate (lauryl thiocyanate) have been tested against the bed-bug. They appear to be contact insecticides. The former is sold in the concentrated form as a 50 per cent. solution, under the trade name of "lethane 384." In ordinary practice lethane is further diluted 1:20, and lauryl thiocyanate 1:64.

Most of the experiments with lauryl thiocyanate have been carried out with the undiluted liquid, and in the tests of *n*-butyl carbitol thiocyanate undiluted lethane was used, but we have, in addition, kept rats in "houses" sprayed with the diluted solutions under conditions similar to those in the field.

"*Lethane 384*".—When applied to the shaved skin, lethane is very toxic to mice and rats, most of which died after 1–4 paintings with 0.1 c.c. Fur protects against it, unshaved guinea-pigs and rabbits surviving 3–4 applications of 0.1 to 0.5 c.c. Rats remained perfectly healthy when kept for long periods in "houses" painted with lethane. The females gave birth to normal offspring. The minimal lethal doses for mice, rats, guinea-pigs and rabbits by subcutaneous and intraperitoneal routes are given in Table IX. Rabbits appear most susceptible. The doses are rather small, so that it seems advisable to exert caution in dealing with undiluted lethane. A 1:20 kerosene solution was tested by the "house" method, but no ill effects were experienced by rats so exposed; our results are substantially in agreement with those of von Oettingen and his collaborators (1936). Because of the low minimal lethal dose of lethane, and of the danger of skin reactions, it is advised that great care should be exercised in handling the undiluted product. We know of several cases in human beings where skin rashes developed after the repeated handling of lethane.

Lauryl thiocyanate.—Painting the shaved or unshaved skin of mice, rats and guinea-pigs with 0.1 c.c. undiluted lauryl thiocyanate resulted in death of most of the animals after 1–4 applications. Severe skin irritation developed. Rats to which 0.1 c.c. was applied for one minute on four consecutive days developed marked reddening and swelling of the skin and subcutaneous tissues, and the fur came out. On the other hand, lauryl thiocyanate diluted 1:64 with kerosene or absolute alcohol could be applied to the skin without any ill effects beyond a little irritation. Of 20 rats kept in houses painted with undiluted lauryl thiocyanate, 3 died. Their organs showed no characteristic changes. Of 14 rats kept in houses painted with lauryl thiocyanate diluted 1:64 in kerosene, none died. The duration of exposure in all instances was two months. Rats, mice and guinea-pigs were exposed in a room at Bethnal Green to a thick mist of diluted lauryl thiocyanate for one hour, without any ill effects. The minimal lethal doses for the subcutaneous and intraperitoneal routes for mice, rats, guinea-pigs and rabbits are given in the table. These are high in comparison with those for lethane, except in the case of guinea-pigs. The results are similar to those of von Oettingen *et al.* (1936). It is concluded that there is little danger to be apprehended in man from the diluted solution, but caution is advised in handling undiluted lauryl thiocyanate.

TABLE IX

Minimal lethal doses of n-butyl carbitol thiocyanate and lauryl thiocyanate c.c. per kg. body weight

<i>Animals.</i>	<i>Subcutaneous n-butyl carbitol thiocyanate.</i>	<i>Intraperitoneal.</i>
Mice	0.15 c.c.	0.05 c.c.
Rats	0.1 c.c.	0.065 c.c.
Guinea-pigs	0.2 c.c.	0.025 c.c.
Rabbits	0.25 c.c.	0.025 c.c.
	<i>Lauryl thiocyanate.</i>	
Mice	2.0 c.c.	0.5 c.c.
Rats	10.0 c.c.	2.0 c.c.
Guinea-pigs	0.4 c.c.	0.08 c.c.
Rabbits	1.5 c.c.	0.3 c.c.

VI.—BUILDING DESIGN IN RELATION TO BED-BUG INFESTATION

(WITH A NOTE ON AIR-RAID SHELTERS)

(Contributed by the Building Research Station, Department of Scientific and Industrial Research, and by the Ministry of Health)

Until recent years insufficient attention in the design and construction of new dwellings has been paid to the risks and prevention of bed-bug infestation.

Bed-bugs may be introduced into dwellings in several ways, but infestation cannot occur unless suitable cracks, crevices or other harbourages are available in which the insects can hide. It is in this connection that building design has an important bearing on the problem, and the Committee wish to call attention to the desirability of keeping the following two practical points in mind :—

- (1) The building should be designed in such a way that as little harbourage as possible is provided for the vermin.
- (2) The building should be designed in such a way that, if infestation does occur, disinfestation may be carried out with as little expense and inconvenience as possible.

(1) DESIGN TO REDUCE HARBOURAGE TO THE MINIMUM

General construction.—Special consideration should be given to the concrete foundations of dwellings on difficult sites, in order to obviate cracks due to settlement. The risks of cracks occurring where the different materials join can be reduced by careful workmanship and selection of the materials to be used.

Floors and skirtings.—The inevitable crevices between floor boards and skirting, and between skirting and wall, caused by shrinkage and warping of the wood may be sealed, after shrinkage has occurred, with some suitable material, e.g. putty, bitumen, plastic wood, etc.

Pressed steel, burnt tile or cement and sand skirtings may be adopted instead of wood.

Walls and ceilings.—If cracks occur in plastered walls and ceilings they should be properly stopped as soon as possible.

Distemper is to be preferred to paper on the walls and ceilings, since the adhesion of paper often breaks down at the edges and a perfect harbourage for the bug is thus provided.

Roofs.—It is not safe to assume that the mortar joints of the party walls are sufficient to eliminate the possibility of the passage of vermin from one house to another. The walls of the chimney flues are usually rendered with plaster as an extra precaution against fire, and it is suggested that this rendering should be extended, at least on one side of the wall, to the small amount of rough walling of the party walls normally left unplastered.

Partitions.—These must be well supported, to prevent cracking. They should not be in timber; neither should they be covered with wall boards with cover strips, which are obvious harbourages. If possible, they should be of the same material as the outer shell but, where lightness is desirable, they should be of partition blocks of a type least liable to crack. The blocks, if of concrete, should be well matured.

Doors.—Internal door linings are usually thin, with door stops planted on to form rebates, and are fixed to the rough wall or partition opening by nailing to breeze or wooden fixing plugs. The open joints between the lining and the wall or partition are finally covered with architraves. This method provides many harbourages. It would be better if internal doors were fixed to stout solid rebated linings, wide enough to be rebated also for the plaster and themselves to form the architrave. If the joint between the lining and the plaster

opens it can then readily be seen and made good. The use of pressed steel door linings would also be a good alternative method.

Windows.—Casement windows of wood or steel are to be preferred to sash windows. The window frames if of wood should be stout, and the plaster should be returned to the frames in lieu of wood linings and without cover moulds. If it is desired to use cover moulds, they should be fully bedded in mastic. Quarry tiles set in cement and sand should be used instead of window boards.

Picture rails.—The usual wood picture rail provides a likely harbourage and a place where dust collects, so that it is better omitted. Most cottage wall decorations can be fixed with thin wire nails or pinhooks, which need do no damage to the plaster.

Fittings.—All shelving should be fixed half an inch clear of the wall, on built-in steel cantilevers and not the usual wooden gallows brackets. Similar methods should apply to hat and coat or cupboard rails. Dressers should be in two parts, both removable, and designed so that no long crevices between timber and plaster are provided. The upper shelving might be hung to the wall on steel cantilever brackets. Mantelpieces of cast iron or glazed tile are better than those of wood, but if wood is used the joints between wood and plaster should be carefully stopped from time to time until shrinkage has ceased. The joints between wood and plaster in wardrobe cupboards should be carefully sealed.

Hot and cold water services.—Back boards often provide convenient harbourages. All service pipes should be carried well clear of, or embedded in, the plaster, and special precaution should be taken to stop the holes where the pipes pass through walls.

Lighting.—In tenement dwellings where conduit piping is carried from one dwelling to another the holes for this purpose must be carefully sealed, to ensure that bed-bugs do not travel throughout the building by these ways.

(2) DESIGN TO FACILITATE DISINFESTATION

The planning of a building should be as straightforward as possible; the building should consist essentially of simple, rectilinear, accessible compartments which are easy to disinfest. Awkwardly shaped and situated compartments which are not accessible should be avoided. It is hardly necessary to particularise, for a designer who makes himself familiar with the various methods which are adopted for disinfesting a building (see the sections of this Report dealing with such methods) will appreciate readily the points to be observed.

The construction of a building should, so far as is in any way possible, be such that fittings such as joinery and sanitary fittings, slab wall and ceiling linings, etc., are easily removable. In short, wherever harbourages cannot be avoided, the construction should be such that the cavities are easily accessible for disinfestation.

NOTE ON AIR-RAID SHELTERS

In the autumn of 1940 the Committee were asked by Lord Horder for advice in connection with the construction and possible disinfestation of air-raid shelters.

In many of the existing shelters little attention has been paid to restricting bed-bug harbourages, and should these become bug infested the method or methods chosen for disinfestation must be related to the special circumstances in which shelters are used. The number of hours in which they may be vacated for treatment is very limited and, in consequence, disinfestation by certain lethal gases, which has proved so effective in peace-time work, cannot be applied.

In spite of this, much can be done to prevent infestation and—if prevention fails—to combat it by suitable methods of disinfestation. The following recommendations were therefore made :—

(1) *Construction*

In the construction of shelters, bunks and other fittings, measures should be taken to avoid cracks, crevices and other harbourages for bed-bugs. To this end all walls should be treated with impermeable paint, to render them impervious to bed-bugs.

In regard to the use of woodwork from demolished houses, all timber of this description should be treated before use either with an emulsion of cresol in soap and water or preferably, in order to secure greater penetration, with a solution of cresol in heavy coal tar naphtha (90/190).

(2) *Management*

Those in charge of shelters should know how to detect infestation in its early stages and how to deal with it if present. To this end, suitable short courses of instruction should be organised, for attendance by selected Shelter Marshals, who could then act as instructors in their own areas.

In addition, a short leaflet should be prepared, summarising the salient points in the life history of the bed-bug and indicating their relevance in combating infestation.

(3) *Disinfestation*

When a shelter is found to be infested the adoption of one or both of the following methods should ensure a large measure of success in eradicating bugs :—

- (a) An organised system of cleaning and scrubbing with soap and water containing cresol. In addition, the use of a painter's blow-lamp carefully applied to all cracks, etc., is an excellent simple method which is generally applicable for small infestations.
- (b) Where there is reason to think that harbourage exists in cracks and crevices, more especially in woodwork, these may be sprayed with a 5 per cent. solution of cresol in heavy coal tar naphtha (90/190). Alternatively, a solution of 1 part of lauryl thiocyanate in 64 parts of heavy white oil may be used in a similar manner.

In Appendix B (I) is given an instruction of the Ministry of Home Security regarding the treatment of interior surfaces against bed-bug infestation. Approved formulae of insecticides for the disinfestation of air-raid shelters, with technical details of their use, are given in Appendix B (II).

GENERAL SUMMARY AND CONCLUSIONS

(For earlier knowledge on the subject reference should be made to the "Report on the Bed-Bug" prepared by a departmental committee of the Ministry of Health and published in 1934 (*Reports on Public Health and Medical Subjects*, No. 72, H.M. Stationery Office, London).

Section I (BUXTON & JOHNSON) :—

1. Provided a source of blood is available, temperature is the most important factor in the bed-bug's environment. At the end of winter, the bug population in an unheated room will consist mainly of adults and large nymphs; there will be few small nymphs and a large proportion of the adult females will be unfertile. It is unlikely that many bugs will feed until the temperature rises to 16° C., in the middle of May. They may be supposed to feed, on the average, once a fortnight in the early summer, once a week in August, and then once a fortnight in September and October; after that feeding ceases, owing to the low temperature.

2. From the temperature and the number of feeds the production of eggs by a given bed-bug population may be calculated. The first egg will be laid in the latter part of May, and the production rises to a peak in August. The first adults of the next generation are not mature until the second week in August; the number attaining maturity reaches a peak early in October, and thereafter rapidly declines owing to falling temperature.

3. In November, when feeding and egg-laying have ceased in an unheated room, there will be large numbers of nymphs and adults, of generations F_1 and F_2 together. Nearly all the small nymphs, however, will die of starvation during the winter, and calculations indicate that the natural winter mortality in the bug population may be as high as 80 per cent. This emphasises the practical desirability of concentrating on the destruction of bugs at the end of winter and in early spring, when the numbers are lowest; at that time of year there are no live eggs (which are more resistant to some fumigants than are nymphs and adults).

4. The conditions described above are modified in centrally-heated flats or in warmed living rooms. While even here a considerable winter mortality among eggs is probable, fasting bugs could survive very well and some feeding might occur throughout the year. It follows that the bug population in warmed rooms tends to increase enormously from year to year.

5. Besides the egg there are five nymphal stages of the bed-bug, the fifth and last moulting into the adult. An individual in each stage must take one full meal of blood before it can pass into the next stage. The rate of development depends both upon environmental temperature and upon accessibility of host.

6. Environmental temperature has an important influence upon the activity of bugs—the higher the temperature of a summer night, the greater the numbers active. Slight fluctuations of temperature have a marked effect on activity. The threshold of activity may be as low as 7° to 10° C.

7. A temperature of 13–14° C. is most favourable to long life of the bugs without food; both above and below this level life is materially shorter at comparable humidities; for long life humidity must be high, so as to prevent loss of water by evaporation. Adult virgin females and mated males live the longest. The period of survival of fasting adults may exceed one year under climatic conditions close to the optimum.

At 13° C. eggs develop and hatch, the mean period being 49 days; they develop very slowly at temperatures even as low as 4° C., but they are unlikely

to hatch so long as the temperature remains always below 13° C. Survival of eggs through the winter in unheated houses is very improbable.

8. A temperature of 45° C. (113° F.) kills the eggs in one hour and nymphs in 15 minutes ; adult bugs are killed by a temperature of 44° C. (111·2° F.) for one hour.

9. The physiological differences between populations of bugs maintained by feeding on different hosts—man, mouse and fowl—are small ; the bed-bug is thus a non-specific parasite.

Section II (MUNRO AND PAGE) :—

10. Sulphur dioxide has proved a poor ovicide, and not very toxic to the nymphal stages of the bed-bug. Its bleaching and corrosive properties render it unsuitable as a general fumigant.

11. A study has been made of the insecticidal powers of heavy naphtha and its constituents. An important outcome of the work has been the light thrown on the mode of action of contact insecticides and heavy fumigants ; in nearly all liquid insecticides the toxic principle forms only a small part, either by weight or by volume. The greater part consists of a carrier with, it may be, the addition of substances ("wettters and spreaders") to ensure adequate spread or adhesion of the insecticide on the body of the insect or on the surface on which the insect rests.

12. The practical use of hydrogen cyanide as a fumigant has been thoroughly investigated, and a detailed technique for its safe application has been worked out.

Section III (ASHMORE AND MCKENNY-HUGHES) :—

13. An account is given of the circumstances leading to the abandonment of orthodichlorobenzene as a fumigant against the bed-bug.

14. Heavy naphtha is a useful contact insecticide, but its vapour action is much more effective. Details are given of the technique of using heavy naphtha vapour to disinfest houses, and of experiments on its practical application for this purpose. The Committee's official specification for disinfestation naphtha is set out (p. 31). The effects of climate and temperature upon heavy naphtha fumigation are discussed, and an account is given of van fumigation for infested furniture.

15. Suggestions for further research on disinfestation, and a note on contact insecticides containing organic thiocyanates, are appended.

Section IV (GUNN) :—

16. The value of domestic hygiene and cleanliness in the control of bed-bug infestation is emphasised. It is shown that bugs can often be eradicated from houses and furniture by simple though vigorous cleansing.

17. The cleansing of infested furniture and the structures of dwellings requires direction and supervision by competent officers, who must be well acquainted with the life history and habits of the bed-bug.

18. Infestation of new houses for slum clearance can be largely prevented by supervision of the cleansing of the household belongings in the old house immediately before the tenants are removed to the new. Prevention of infestation can be further ensured by a well-organised "follow-up" system operated by health visitors.

19. The tenants themselves profit by instructions from these officers ; educational efforts such as exhibitions of house pests are useful for instructing the public in domestic hygiene.

Section V (CAMERON) :—

20. Details are given of the experimental methods used to investigate different contact and fumigant insecticides for their probable toxicities to man.

21. Of the insecticides investigated, orthodichlorobenzene is shown to be dangerous and heavy naphtha relatively safe. It is considered that provided the precautions outlined in section III of this Report are carefully observed, there should be little reason to expect any danger to man from the use of heavy naphtha as a fumigant. As an additional safeguard, however, it is recommended that toxicity tests on a wide range of animals should be carried out with each new sample of heavy naphtha before it is issued as an insecticide.

22. A note is included on the toxic effects of the higher thiocyanate contact insecticides—"Lethane 384" and lauryl thiocyanate—and on the precautions to be taken in handling these substances.

Section VI (CONTRIBUTED BY THE BUILDING RESEARCH STATION, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH, AND BY THE MINISTRY OF HEALTH) :—

23. This section concerns building design in relation to bed-bug infestation. It is pointed out that new buildings should be constructed so as to give minimum harbourage for the bug, and so that, in the event of infestation occurring, eradication of the pest may be easily and cheaply effected. Detailed constructional suggestions are made from these points of view.

24. A note is given of the Committee's recommendations regarding the prevention of bed-bug infestation in public air-raid shelters (*see also* Appendix B).

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APPENDIX A
SELECTED BIBLIOGRAPHY OF THE BED-BUG

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This bibliography may be regarded as a continuation of, and a supplement to, that published as an Appendix to the Ministry of Health report on the Bed-Bug (*Rep. publ. Hlth med. Subj.*, No. 72, 1934). In that bibliography the references were arranged alphabetically in groups: I. Biological; II. Medical; III. Control; IV. Miscellaneous. This arrangement has been followed in the present case, except that the last group has been found unnecessary.

The references are mainly to papers that have been published since the date on which the bibliography referred to above was completed, up to the end of 1941 as far as was possible. It will be realised that world conditions prevented access to much of the continental and other literature for the last two or three years.

Certain important earlier references that were omitted from the previous bibliography have been added at the suggestion of Mr. W. E. China (Assistant Keeper in charge of Hemiptera, Department of Entomology, British Museum (Natural History)). Like its predecessor the present list makes no pretensions to being exhaustive.

Readers are reminded of the *Review of Applied Entomology* Series B which, published monthly by the Imperial Institute of Entomology, 41, Queens Gate, London, S.W.7, gives not only references to recent papers but also brief summaries of the contents of papers noticed.

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APPENDIX B

I.—MINISTRY OF HOME SECURITY INSTRUCTION REGARDING TREATMENT OF INTERIOR SURFACES OF AIR-RAID SHELTERS AGAINST BED-BUG INFESTATION (CIRCULAR CE/GEN/46)

A.—Prevention of infestation by painting

Circular CE/GEN/27 gave information about painting interior surfaces of shelters, in cases where it was desired to improve lighting conditions.

It may in some cases be desirable also to treat the interior surfaces so as to fill all mortar joints and any crevices which might harbour bed-bugs and other vermin. It is important to see that no treatment is applied which interferes with the normal absorption of condensed moisture into the wall-surface, and with this in view experiments have been carried out to ascertain the most suitable treatment.

As the result of these experiments it is recommended that a suitable treatment would be a coat of one of the lime/cement paints described below.

Paint 1.—Mix 1 volume Portland cement, 3 volumes white dry hydrated lime (or 6 volumes of lime putty) and 6 volumes fine plastering sand with water to a stiff mortar, then add more water until the mixture is of a thick cream consistency such that it can be applied by brush.

Paint 2 (for use if sand is not available).—Mix 1 volume of Portland cement and 8 volumes of white dry hydrated lime (or 14 volumes of lime putty) with water until a paint of thick cream consistency is obtained.

The paint should be of a thick creamy consistency and should be brushed on freely in such a way as to fill all holes and crevices and to cover the rest of the surface uniformly.

If the surface is very dry and absorbent and it is found that the paint is "sucked dry" and so tends to crack or flake off as soon as it is applied, the surface should first be well wetted by brushing with water only.

Paints of the compositions recommended will give a porous coating when dry and thus allow any moisture which condenses on the surface to be absorbed into the brickwork. The object of adding a proportion of cement to the limewash is to bind the coating and prevent it from powdering and rubbing off easily.

With either paint the mixture should be used within 2 hours of mixing.

The same treatments equally apply to concrete as well as to brickwork.

B.—Treatment of shelters found to be infested

The adoption of an organised system of cleaning and scrubbing and the liberal use of soap and water containing cresol should result in a large measure of success, and for small infestations the use of a blow lamp carefully applied to all cracks, etc., should prove generally efficacious.

(Sgd.) F. WEBSTER.
A/C. E.

9th January, 1941.

II.—INSECTICIDES AGAINST BED-BUGS IN AIR-RAID SHELTERS

Recommendations by the Bed-Bug Infestation Committee of the Medical Research Council

On the basis of a report from a sub-committee appointed to examine the question, the Bed-Bug Infestation Committee of the Medical Research Council recommend the following insecticide formulae as most suitable for use in shelters under the conditions now prevailing:—

1. *Pyrethrins in kerosene*

The preparation to have a guaranteed content of 0.6 per cent. to 0.8 per cent. of the pyrethrins described as I and II. Alternatively, a weaker pyrethrin solution made equally toxic for bugs by the use of an adjuvant *harmless to human beings* may be accepted.

2. *Thiocyanates*

(a) *Lethane in kerosene*—To have a guaranteed content of 6 per cent "Lethane 384".

(b) *Lauryl thiocyanate in kerosene*—To have a guaranteed content of 3 per cent. of lauryl thiocyanate.

3. Heavy coal-tar naphtha with liquid carbolic (cresylic) acid

The cresylic acid (5 per cent.) to be dissolved in heavy coal-tar naphtha complying with the following specification :—

- (a) *Specific gravity at 60° F*—Not less than 0·835 nor greater than 0·910.
- (b) *Distillation range (S.T.P.T.C. apparatus)*—Not more than 10 per cent. shall distil at 160° C. and not less than 90 per cent. at 190° C.
- (c) *Flash point (Abel)*—Not less than 100° F.
- (d) *Tar bases*—Not to exceed 0·25 per cent.

For various reasons it has not been considered desirable to attempt to estimate the cost of the various formulae, and it is assumed that local authorities, when ordering, will be guided by the supply position and will ensure that the composition of any insecticide they decide to use is fully disclosed by the makers and a guarantee obtained that such composition will not be changed without notification.

The following precautions should be observed when any of these preparations are used :—

- (i) that they should only be used when a shelter is empty, and that an interval of at least two hours should be allowed to elapse before the shelter is again occupied ;
- (ii) that to avoid any possible risks of fire, the use of naked lights and smoking should be strictly prohibited while handling and spraying these insecticides ;
- (iii) that owing to the interaction of hypochlorites and pyrethrins, or even traces of cresylic acid, air disinfection of shelters cannot be carried out concurrently when either formula (1) or (3) is used ; several days should elapse between the two forms of treatment ;
- (iv) that owing to the possible solvent action of heavy naphtha care should be taken when using formula (3) to prevent its coming into direct contact with rubber.

Methods of application

It is emphasised that proper atomisation of the insecticide is essential when sprayed. The use of power sprayers in large shelters is advocated, and hand sprayers of the Flit or similar types in smaller shelters. It is further considered that a brush might be usefully employed in the treatment of cracks and other harbourages where such are readily accessible. The appropriate treatment obviously depends on the local circumstances.

Obliteration of harbourages

It is considered that much may be done to prevent infestations by the avoidance or obliteration of harbourages. For the latter purpose cement washing, distemping and painting may all be useful if supplies and labour are available. Two suitable limewash-cement paints are recommended in the Ministry of Home Security (Engineers Branch) Circular CE/GEN/46 (printed above).

Educational Propaganda

Where a high standard of cleanliness is maintained in shelters the risks of serious infestations from bed-bugs are greatly lessened. The advice given in the Circular issued by the London Regional Commissioners on the 30th June, 1941, is endorsed.

27th January, 1942.

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