A FURTHER STUDY OF HERD MORTALITY UNDER EPIDEMIC CONDITIONS.

By M. Greenwood, E. M. Newbold, W. W. C. Topley and J. Wilson.

In previous memoirs of this series we have studied the course of mortality in our herds of mice principally in two ways. We have used as the abscissa either secular time or individual time. The former method, that of the ordinary chronology of epidemics, measures contemporaneous events, tells us what did really happen in a community within particular identifiable calendar weeks. The latter method does not give the history of a community of really existing contemporaries, for it brings together happenings which may belong to widely separated intervals of calendar time, but occurred at the same point in the lifetime of all individuals represented. This second method, that of the life table, cannot therefore throw light upon the effect of changes of environment within a community during the period which furnishes the data. We have, let us suppose, the individual records of all mice which entered a herd during a period of a year and we evaluate by the life-table method the rate of mortality experienced during the first three months of life within the community. Then the rate of mortality after, say, 30 days' exposure will be based upon all who entered before the last 30 days of the year and will bring into the same category mice who entered the community at 11 months apart. But, as we know that the secular rate of mortality waxes and wanes, this means that we throw into the same group animals really exposed to quite different "real" risks of dying. In fact what we are doing is to substitute for a variable risk a fictitious average risk. By paying this price, however, we can obtain materials for studying an aspect of exposure not obtainable in a more satisfactory shape because the individual groups of entrants upon each day are too small to permit of separate tabulation in life-table form. That has, of course, been the justification of the life-table method in human epidemiological practice. One constructs a life table from the experience of, say, 1920–2 and another from the experience of 1923–5 and makes comparison of the results, ignoring the facts that the risk of dying at each age has varied, or may have varied, within each triennium as well as from triennium to triennium. In this memoir we shall try to deduce the lessons taught by such life-table experience.

Since our last publication*, material for the construction of other life tables than those already reported upon has accumulated and we now have available for use the following:

(1) Herds in which Pasteurellosis was the principal or only infection and the immigrants numbered 1, 2, 3 and 6 daily. These (all published before) may be called P_1, P_2, P_3 and P_6.

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Table I. *Epidemic life-table constants and data.*

	P_1	P_2	P_3	P_6	B_1
Average daily population	40·8	60·6	63·5	155·7	32·7
No. of mice concerned	549	396	2,354	990	703
No. which die	514	367	2,292	778	609
No. which die of specific deaths (= $P+NE$ in P's and $B+NE$ in B's)	366	294	1,827	678	554
No. of mice killed for post-mortem examination	—	—	—	—	—
No. of mouse days exposed to risk	19,900	12,059	49,880	25,697	23,061
No. of calendar days	488	199	786	165	705
Expectation of life at entry:					
Specific (total) unlimited	55·47	39·53	28·45	39·03	43·44
„ limited to 60 days	34·33	30·77	22·49	29·03	—
„ limited to 120 days	—	—	—	—	37·45
Total unlimited	37·92	—	21·48	—	—
„ limited to 60 days	—	—	—	—	—
„ limited to 120 days	—	—	—	—	—
Life-table death rate (daily):					
(*a*) Specific deaths only	0·0180	0·0253	0·0352	0·0256	0·02300
(*b*) All deaths	0·0264	—	0·0466	—	—

	B_6	P_{3N}	P_{3l}	B_3
Average daily population	237·2	108·9	58·8	103·1
No. of mice concerned	2,226	1,095	912	1,369
No. which die	1,907	1,049	881	1,190
No. which die of specific deaths (= $P+NE$ in P's and $B+NE$ in B's)	1,766	964	830	1,081
No. of mice killed for post-mortem examination	—	—	—	80
No. of mouse days exposed to risk	86,569	39,864	17,883	40,197
No. of calendar days	365	366	304	390
Expectation of life at entry:				
Specific (total) unlimited	52·52	40·92	23·73	38·30
„ limited to 60 days	—	29·45	15·46	27·47
„ limited to 120 days	38·90	—	—	—
Total unlimited	47·13	—	—	33·00
„ limited to 60 days	—	—	—	26·31
„ limited to 120 days	36·91	—	—	
Life-table death rate (daily):				
(*a*) Specific deaths only	0·0190	0·0244	0·0421	0·0261
(*b*) All deaths	0·0212	—	—	0·0303

Table I A. *Epidemic life tables* ${}_5q_x$. (*Probability of dying in the next 5 days—specific deaths only.*)

Exp.	Height of maximum ${}_5q_x$	Day of maximum ${}_5q_x$	Out of 10,000 on day 0, number alive on day 60	Ratio of maximum ${}_5q_x$ to average value of q_x* for life table
B_1	·215	14	1803	9·35
B_3	·414	24	768	15·86
B_6	·311	25	1763	16·37
P_1	·155	3	3158	8·58
P_2	·156	5	2214	6·17
P_3	·241	5	1422	6·85
P_{3N}	·274	18	1766	11·23
P_{3l}	·380	7	840	9·03
P_6	·221	3	2315	8·63

Data arranged in order of maxima.

B_3	·414	B_6	25	P_1	3158	B_6	16·37
P_{3l}	·380	B_3	24	P_6	2315	B_3	15·86
B_6	·311	P_{3N}	18	P_2	2214	P_{3N}	11·23
P_{3N}	·274	B_1	14	B_1	1803	B_1	9·35
P_3	·241	P_{3l}	7	P_{3N}	1766	P_{3l}	9·03
P_6	·221	P_2 and P_3	5	B_6	1763	P_6	8·63
B_1	·215	P_1 and P_6	3	P_3	1422	P_1	8·58
P_2	·156			P_{3l}	840	P_3	6·85
P_1	·155			B_3	768	P_2	6·17

* This average was approximated to by $1/e_0$.

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(2) Herds in which infection with *Bact. aertrycke* caused most of the deaths and the additions were 1, 3 and 6 daily. These are B_1, B_3 and B_6.

(3) In addition we have tables based upon communities recruited respectively by 3 healthy quarantined animals (the infection was due to *Pasteurella*) or by 3 animals from another infected cage. These are distinguished as P_{3N} and P_{3I}. A general summary of the fundamental data and statistical averages is given in Table I, and some further particulars in Table I A. These tables will orientate the reader as to the scale and (to some extent) reliability of the data; he will, comparing the two largest and comparable series, viz. P_3 and B_3, also conclude that epidemiologically *Bact. aertrycke* is less formidable than *Pasteurella*.

For the sake of completeness P_{3I} has been included in this table but an analysis of the experiment shows that the table is incomparable with the others. When the data are divided in accordance with the length of previous exposure to infection, it appears that the high general death rate is really due to the transfer of mice which have been long enough exposed to infection in another cage to be sick to die but not long enough actually to die. The average daily specific death rate of mice which had passed from 9 to 15 days in the testing cage was in the observational cage 0·0595; of those in the testing cage 15 to 25 days 0·0587; but of those who had been 26 or more days in the testing cage only 0·0234. Omitting the experiment from further consideration in this paper, we notice that the new *Pasteurella* experiment P_{3N} falls rather better into line with the old series than did the original P_3, if we take it that the average rate of mortality should increase with the number of daily immigrants, although even so the rate is insignificantly less than in P_2. In the *Bact. aertrycke* series the rate of mortality with 3 daily additions exceeds that with 6 which itself is less than when a single daily immigrant entered. One cannot say that these results warrant a belief that there is any high positive correlation between average rate of mortality and rate of immigration, although study of the *secular* changes has suggested that such a correlation exists.

Whichever characteristic of a life table is taken for study, whether q_x or d_x, one finds that the course of mortality with age, that is cage age, in these herds is fundamentally unlike the course of mortality with age under normal conditions. In our 1925 paper we contrasted the herd tables with a table of human mortality and in 1928 one of us* showed that the contrast was as striking when comparison was made with a mortality table for mice brought up under less dangerous conditions. The data for normal mice were certainly scanty—too scanty perhaps to make it probable that normal mice and normal men died in different ways—but quite sufficient to prove that these epidemic phenomena are *sui generis*. Here we may refer to a quite just criticism which has been passed upon our work, viz. that it is straining terminology to speak of life tables when neither the ages nor the genetic histories of our animals under experiment are known, when we do not even distinguish between the sexes.

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That criticism was expressed vigorously in the first paper of the series by ourselves and we have never underrated its importance. We wish we *could* use only animals the precise ages and histories of which were known to us, we hope in time to be able to do so. But we cannot refrain from saying that what we have learned of the normal mortality of mice, scanty as it is, does convince us that, for the immediate purposes of our studies, the heterogeneity of the material is of very little importance. It is, we believe, certain that the weight of the age factor in the rate of mortality is so trifling in comparison with that of other factors that it can fairly be disregarded. It is possible to form some idea of the age distribution of mice admitted to the cages by means of the following data. The weight distribution of mice received by us from the dealers is accurately known. That of a representative sample is shown in Table II.

Table II. *Weights of mice as received from breeders.*

Grm.	Frequency
9·5–10·4	1
10·5–11·4	7
11·5–12·4	79
12·5–13·4	33
13·5–14·4	310
14·5–15·4	422
15·5–16·4	642
16·5–17·4	381
17·5–18·4	250
18·5–19·4	154
19·5–20·4	48
20·5–21·4	24
21·5–22·4	15
22·5–23·4	9
Total	2375

Mean weight 16·081 grm.
Standard deviation 1·893 grm.

We also know approximately (from the work of Robertson and Ray)* the means and standard deviations of weights of mice at different ages. It also appears from the work of one of us that, under favourable conditions, the mortality of mice in the first three or four months of life is very small. If therefore we suppose that the dealers select mice from their standing stock by the conditions imposed by us, viz. that we only accept mice from 14 to 22 grm. in weight, and further suppose that the distribution of weights around the mean weight of each age group is effectively given by a normal curve of error, one can compute from the data the probable age composition of the received sample. Such a calculation leads to the conclusion that of the mice received by us 63 per cent. fall within the limits of 4 and 10 weeks of age, 73·7 per cent. within the limits 4–12, 81·2 per cent. within the limits 4–14.

This is the probable age distribution of the mice as received. On receipt they are quarantined 3 weeks and the actual entrants to the herds will therefore be on the average 3 weeks older and will also have suffered a further selection by the application of the rules as to suspected infection detailed in

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our previous paper. We have weighings of 1283 mice at the time of entrance to the herds and, as was to be expected, the mean weight is 2·5–3·5 grm. more than the mean at arrival from the dealers, while the coefficient of variation is slightly reduced. We seem, therefore, entitled to conclude that, on entrance to the herds, the age distribution of the mice at reception is still applicable, the ages being, of course, advanced 3 weeks. In other words, we may say that about 80 per cent. of the entrants are from 7 to 15 weeks old. This is a range of life for which normal mortality is very small. We are naturally aware that the basis of this computation is precarious; but we are only concerned with the order of magnitude of the result and do not believe that a more refined analysis would substantially modify the broad conclusion indicated.

For the purpose of studying mortality conditions in the front line trenches during a war, it might be useful to set out the exposed to risk in life-table form and to determine the series of q_x's when the unit of x is day of exposure at the front. For such a purpose to ignore differences of age of men drafted to the front, to treat men aged 20, 30 or 40 years as differentiated *only* in respect of "trench age" would be legitimate. That is the justification of our procedure. But that it is only justified by the abnormality of the conditions of life of our herds we freely admit and, as a corollary of that admission, we agree that if and when we succeed in interpreting these results we shall still be far from a knowledge of the epidemiology of this race and these infections under more natural conditions. But the characteristics of *these* mortality tables* are surely functions of the epidemic development so that it is of epidemiological importance to be able to explain them. Roughly the salient features are these. After a more or less rapid rise to a maximum, q_x decreases and tends to approximate to a constant value. All the curves show fluctuations but the evidence points to the conclusion that these fluctuations are due to random error and that, under conditions of environment such as ours, a population ultimately dies out logarithmically. In terms whether of selection or of immunisation (or both) it seems that the final state of equilibrium is of a steady average of liability. By this method of exposure we cannot secure an ultimate resistant population. The surviving "fittest" are not effectively immune and do not improve above a not very high level. There is also evidence that the environmental conditions *at entrance* are of more importance than those experienced subsequently. That this is so we shall now show to be probable. The subjects of Life Table B_0 were under observation a whole year during which only *Bact. aertrycke* infection was present and the 6 daily entrants were exposed to varying secular risks. Some lived their lives out when mortality was high, some when it was low. To test the effects of the environment, so far at least as a general mortality rate measures environment, the following expedient was adopted. Each batch of 6 formed a unit and the average length of cage life of the batch could be

* In the Mortality Tables III to VI A, in order to reduce the heavy expense of printing, the tabular entries for cage ages greater than 50 have only been given at wider intervals. Complete tables can be sent to any workers interested.

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Table III. B_1 *experiment*.

1 mouse period. 27. vi. 24 to 4. i. 25 + 6. vi. 25 to 31. x. 26, *i.e.* *B. a.* period. Omitting the mice existing in the cage at the beginning of each period.

SPECIFIC DEATHS. (703 mice.)

Cage age in days	l_x	d_x	q_x	e_x
0	10,000·00	14·23	·0014225	43·44
1	9985·78	28·53	·0028571	42·51
2	9957·24	71·84	·0072150	41·63
3	9885·40	72·37	·0073206	40·92
4	9813·04	14·58	·0014859	40·22
5	9798·45	73·56	·0075075	39·28
6	9724·89	59·12	·0060790	38·58
7	9665·78	88·95	·0092025	37·81
8	9576·83	104·42	·0109034	37·15
9	9472·41	211·17	·0222930	36·36
10	9261·24	151·58	·0163666	36·38
11	9109·66	274·20	·0301003	35·98
12	8835·46	338·05	·0382609	36·08
13	8497·41	339·90	·0400000	36·49
14	8157·51	435·07	·0533333	36·99
15	7722·44	468·97	·0607287	38·05
16	7253·47	361·89	·0498915	39·48
17	6891·58	349·34	·0506912	40·52
18	6542·24	271·26	·0414634	41·66
19	6270·98	319·95	·0510204	42·44
20	5951·03	251·23	·0422164	43·70
21	5699·80	194·31	·0340909	44·60
22	5505·49	227·37	·0412979	45·16
23	5278·12	229·48	·0434783	46·08
24	5048·64	214·48	·0424837	47·15
25	4834·15	248·33	·0513699	48·22
26	4585·82	167·37	·0364964	49·81
27	4418·46	151·20	·0342205	50·68
28	4267·26	135·47	·0317460	51·45
29	4131·79	153·66	·0371901	52·12
30	3978·13	172·21	·0432901	53·12
31	3805·91	138·40	·0363636	54·50
32	3667·52	192·11	·0523810	55·54
33	3475·41	87·76	·0252525	57·58
34	3387·64	194·08	·0572917	58·06
35	3193·56	89·21	·0279330	60·56
36	3104·36	90·77	·0292398	61·28
37	3013·58	73·06	·0242424	62·11
38	2940·53	73·51	·0250000	62·64
39	2867·01	165·40	·0576923	63·24
40	2701·61	37·01	·0136986	66·08
41	2664·60	37·27	·0139860	65·99
42	2627·33	74·53	·0283688	65·92
43	2552·80	38·10	·0149254	66·83
44	2514·70	38·39	·0152672	66·83
45	2476·31	19·35	·0078125	66·86
46	2456·96	19·35	·0078740	66·38
47	2437·61	19·50	·0080000	65·91
48	2418·11	39·32	·0162602	65·43
49	2378·79	78·64	·0330579	65·51
50	2300·16	79·32	·0344828	66·73
60	1802·80	—	—	73·81
70	1505·01	—	—	77·28
80	1357·02	—	—	75·11
90	1250·02	27·17	·0217391	71·00
100	1107·01	—	—	69·45
110	837·46	33·50	·0400000	80·38
120	701·87	—	—	85·37
130	586·12	—	—	98·26
140	544·26	—	—	88·12
150	498·90	—	—	85·36
160	408·19	—	—	93·11
170	408·19	45·35	·1111111	83·11
180	362·84	—	—	83·44
190	317·48	—	—	84·14
200	272·13	—	—	87·92
210	272·13	—	—	77·92
220	272·13	—	—	67·92

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Table III A. B_1 *experiment.*

27. vi. 24 to 4. i. 25 + 6. vi. 25 to 31. x. 26, *i.e. B. a.* period. Omitting the mice existing in the cage at the beginning of each period.

Specific deaths.

Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days	Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days
0	37·45	·0202 ± ·0036	61	56·22	·0877 ± ·0212
1	36·58	·0261 ± ·0041	62	56·11	·0763 ± ·0201
2	35·75	·0293 ± ·0043	63	57·52	·0534 ± ·0174
3	35·06	·0312 ± ·0045	64	57·50	·0818 ± ·0215
4	34·39	·0347 ± ·0048	65	58·31	·0849 ± ·0222
5	33·50	·0548 ± ·0059	66	57·53	·0849 ± ·0222
6	32·82	·0633 ± ·0064	67	56·75	·0849 ± ·0223
7	32·08	·0859 ± ·0074	68	56·77	·0864 ± ·0227
8	31·01	·1127 ± ·0084	69	58·51	·0455 ± ·0173
9	30·42	·1388 ± ·0093	70	59·53	·0315 ± ·0147
10	30·16	·1662 ± ·0102	71	58·74	·0479 ± ·0180
11	29·72	·2038 ± ·0111	72	57·94	·0813 ± ·0230
12	29·69	·2200 ± ·0117	73	58·03	·0840 ± ·0236
13	29·92	·2301 ± ·0121	74	57·22	·0840 ± ·0238
14	30·22	·2313 ± ·0124	75	57·33	·0690 ± ·0223
15	31·49	·2294 ± ·0128	76	57·50	·0530 ± ·0200
16	32·57	·2142 ± ·0129	77	58·78	·0185 ± ·0124
17	33·32	·2011 ± ·0130	78	59·08	·0000
18	34·16	·1932 ± ·0132	79	58·28	·0196 ± ·0130
19	34·71	·1949 ± ·0135	80	57·48	·0196 ± ·0130
20	35·64	·1877 ± ·0135	81	56·68	·0392 ± ·0183
21	36·28	·1954 ± ·0143	82	55·88	·0392 ± ·0183
22	36·65	·1974 ± ·0146	83	55·08	·0588 ± ·0222
23	37·30	·1915 ± ·0148	84	55·37	·0604 ± ·0227
24	38·08	·1916 ± ·0153	85	54·58	·0604 ± ·0227
25	38·86	·1771 ± ·0151	86	54·89	·0621 ± ·0233
26	40·06	·1701 ± ·0153	87	54·10	·0621 ± ·0233
27	40·69	·1700 ± ·0156	88	54·43	·0426 ± ·0199
28	41·23	·1856 ± ·0165	89	54·82	·0217 ± ·0145
29	41·70	·1801 ± ·0167	90	54·04	·0217 ± ·0145
30	42·42	·1972 ± ·0177	91	54·45	·0233 ± ·0152
31	43·44	·1843 ± ·0176	92	53·67	·0471 ± ·0215
32	44·19	·1783 ± ·0178	93	52·90	·0947 ± ·0298
33	45·74	·1539 ± ·0173	94	52·12	·0947 ± ·0298
34	46·04	·1537 ± ·0176	95	51·34	·0947 ± ·0301
35	47·96	·1540 ± ·0182	96	51·77	·0732 ± ·0274
36	48·46	·1417 ± ·0180	97	52·30	·1000 ± ·0320
37	49·05	·1282 ± ·0176	98	54·26	·0789 ± ·0295
38	49·41	·1319 ± ·0180	99	53·51	·1060 ± ·0337
39	49·83	·1229 ± ·0177	100	52·75	·1331 ± ·0372
40	52·01	·0834 ± ·0154	101	52·00	·1873 ± ·0427
41	51·88	·0779 ± ·0151	102	54·13	·1707 ± ·0423
42	51·76	·0722 ± ·0147	103	54·90	·1471 ± ·0410
43	52·42	·0528 ± ·0130	104	55·78	·1538 ± ·0424
44	52·37	·0540 ± ·0133	105	56·74	·1273 ± ·0397
45	52·34	·0711 ± ·0153	106	59·74	·1064 ± ·0380
46	51·91	·0961 ± ·0176	107	61·04	·1141 ± ·0413
47	51·49	·1138 ± ·0192	108	60·30	·1141 ± ·0413
48	51·06	·1400 ± ·0211	109	61·88	·1200 ± ·0438
49	51·08	·1344 ± ·0209	110	61·15	·1200 ± ·0438
50	51·98	·1137 ± ·0199	111	62·97	·1270 ± ·0458
51	52·99	·0820 ± ·0176	112	64·97	·0890 ± ·0401
52	53·63	·0854 ± ·0182	113	64·27	·0890 ± ·0401
53	54·87	·0704 ± ·0171	114	66·47	·0476 ± ·0306
54	54·58	·0925 ± ·0194	115	65·78	·0476 ± ·0313
55	54·30	·1157 ± ·0218	116	68·37	·0000
56	53·48	·1157 ± ·0219	117	67·69	·0526 ± ·0345
57	54·36	·0988 ± ·0209	118	67·01	·1053 ± ·0475
58	54·72	·1139 ± ·0226	119	66·34	·1053 ± ·0475
59	55·80	·0954 ± ·0215	120	65·66	·1053 ± ·0475
60	57·02	·0877 ± ·0212			

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Table IV. B_3 *experiment.*

1. xi. 27 to 24. xi. 28.

ALL DEATHS (1369 mice).

Cage age in days	l_x	d_x	q_x	e_x
0	10000·00	42·74	·0042735	33·00
1	9957·27	—	—	32·14
2	9957·27	17·01	·0017079	31·14
3	9940·26	33·93	·0034130	30·19
4	9906·33	25·60	·0025840	29·29
5	9880·73	51·06	·0051680	28·36
6	9829·67	25·49	·0025929	27·51
7	9804·18	110·16	·0112360	26·58
8	9694·02	59·16	·0061029	25·88
9	9634·86	110·65	·0114841	25·03
10	9524·21	144·43	·0151650	24·32
11	9379·78	160·99	·0171635	23·68
12	9218·79	236·60	·0256645	23·09
13	8982·19	227·50	·0253283	22·68
14	8754·69	243·65	·0278311	22·26
15	8511·04	335·08	·0393701	21·88
16	8175·96	258·63	·0316326	21·76
17	7917·33	275·02	·0347369	21·45
18	7642·31	377·09	·0493421	21·21
19	7265·22	304·13	·0418605	21·28
20	6961·09	456·19	·0655340	21·19
21	6504·91	361·85	·0556274	21·64
22	6143·05	452·56	·0736698	21·89
23	5690·50	520·37	·0914454	22·59
24	5170·13	586·56	·1134522	23·81
25	4583·57	633·37	·1381818	25·79
26	3950·20	380·94	·0964361	28·85
27	3569·36	336·72	·0943396	30·88
28	3232·54	313·92	·0971129	33·04
29	2918·61	266·89	·0914454	35·54
30	2651·72	232·46	·0876623	38·07
31	2419·26	240·21	·0992908	40·68
32	2179·05	144·70	·0664063	44·10
33	2034·35	153·86	·0756303	46·21
34	1880·49	188·91	·1004566	48·95
35	1691·58	127·51	·0753769	53·36
36	1564·08	118·36	·0756757	56·66
37	1445·72	67·64	·0467836	60·26
38	1378·08	84·54	·0613497	62·20
39	1293·54	68·08	·0526316	65·23
40	1225·45	85·70	·0699301	67·83
41	1139·76	17·01	·0149254	71·89
42	1122·75	85·06	·0757576	71·97
43	1037·69	68·05	·0655738	76·83
44	969·65	33·15	·0341880	81·18
45	936·49	49·73	·0530973	83·04
46	886·77	41·05	·0462963	86·67
47	845·72	41·05	·0485437	89·85
48	804·66	24·63	·0306122	93·41
49	780·03	8·21	·0105263	95·34
50	771·82	16·42	·0212766	95·35
60	607·71	26·04	·0428571	110·02
70	491·85	—	—	124·86
80	436·60	—	—	130·16
90	413·49	—	—	127·28
100	389·85	—	—	124·64
110	349·24	8·12	·0232558	128·84
120	316·75	—	—	131·72
130	284·69	—	—	135·97
140	253·06	—	—	142·18
150	237·72	—	—	140·97
160	223·93	—	—	139·40
170	203·76	—	—	142·65
180	190·18	—	—	142·70
190	177·29	—	—	
200	160·66	—	—	

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Table IVA. B_3 *experiment.*

1. xi. 27 to 24. xi. 28.

ALL DEATHS.

Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days	Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days
0	28·83	·0119 ± ·0021	61	67·59	·0849 ± ·0225
1	27·98	·0128 ± ·0022	62	67·90	·0859 ± ·0228
2	27·01	·0154 ± ·0024	63	67·23	·1140 ± ·0258
3	26·09	·0248 ± ·0031	64	67·54	·1153 ± ·0259
4	25·21	·0274 ± ·0032	65	69·92	·0900 ± ·0238
5	24·30	·0361 ± ·0037	66	70·32	·0760 ± ·0222
6	23·45	·0458 ± ·0041	67	70·76	·0769 ± ·0223
7	22·54	·0597 ± ·0047	68	72·33	·0476 ± ·0181
8	21·83	·0734 ± ·0052	69	72·85	·0799 ± ·0232
9	20·98	·0914 ± ·0058	70	73·39	·0965 ± ·0255
10	20·26	·1064 ± ·0062	71	72·75	·0965 ± ·0255
11	19·58	·1283 ± ·0068	72	73·32	·0975 ± ·0256
12	18·95	·1412 ± ·0071	73	72·69	·0975 ± ·0256
13	18·47	·1492 ± ·0074	74	75·80	·0508 ± ·0193
14	17·97	·1701 ± ·0078	75	77·83	·0175 ± ·0117
15	17·50	·1821 ± ·0082	76	77·21	·0175 ± ·0117
16	17·23	·2044 ± ·0087	77	77·96	·0182 ± ·0119
17	16·81	·2241 ± ·0091	78	77·35	·0357 ± ·0166
18	16·44	·2554 ± ·0097	79	76·74	·0357 ± ·0166
19	16·29	·2884 ± ·0104	80	76·12	·0529 ± ·0200
20	16·02	·3415 ± ·0111	81	75·48	·0529 ± ·0204
21	16·15	·3927 ± ·0118	82	76·26	·0354 ± ·0167
22	16·12	·4190 ± ·0123	83	77·01	·0179 ± ·0121
23	16·40	·4319 ± ·0128	84	76·39	·0179 ± ·0120
24	17·05	·4355 ± ·0135	85	77·16	·0000
25	18·22	·4215 ± ·0142	86	76·55	·0000
26	20·13	·3876 ± ·0150	87	75·94	·0000
27	21·29	·3895 ± ·0160	88	75·31	·0179 ± ·0120
28	22·53	·3707 ± ·0167	89	74·68	·0179 ± ·0120
29	23·98	·3557 ± ·0175	90	74·04	·0179 ± ·0120
30	25·43	·3621 ± ·0185	91	73·41	·0371 ± ·0172
31	26·93	·3535 ± ·0192	92	72·78	·0371 ± ·0170
32	28·94	·3365 ± ·0199	93	73·46	·0196 ± ·0129
33	30·09	·3226 ± ·0204	94	72·84	·0196 ± ·0130
34	31·63	·3121 ± ·0211	95	72·21	·0400 ± ·0185
35	34·24	·2756 ± ·0214	96	73·02	·0208 ± ·0136
36	36·13	·2713 ± ·0220	97	72·40	·0616 ± ·0229
37	38·20	·2234 ± ·0215	98	71·78	·0820 ± ·0264
38	39·22	·2470 ± ·0228	99	71·16	·1228 ± ·0320
39	40·92	·2504 ± ·0237	100	72·05	·1042 ± ·0301
40	42·36	·2358 ± ·0239	101	71·44	·1042 ± ·0297
41	44·70	·2220 ± ·0242	102	73·93	·0652 ± ·0246
42	44·57	·2467 ± ·0253	103	74·97	·0444 ± ·0207
43	47·39	·2246 ± ·0255	104	77·87	·0000
44	49·91	·1956 ± ·0247	105	77·29	·0000
45	50·89	·1758 ± ·0241	106	76·69	·0233 ± ·0155
46	52·95	·1481 ± ·0231	107	76·09	·0233 ± ·0155
47	54·75	·1553 ± ·0241	108	75·50	·0233 ± ·0155
48	56·78	·1429 ± ·0238	109	74·90	·0698 ± ·0262
49	57·81	·1262 ± ·0230	110	74·30	·0698 ± ·0262
50	57·69	·1379 ± ·0240	111	75·47	·0714 ± ·0268
51	58·20	·1518 ± ·0252	112	74·89	·0714 ± ·0268
52	60·80	·1031 ± ·0220	113	74·28	·0714 ± ·0268
53	62·23	·0710 ± ·0188	114	77·36	·0250 ± ·0166
54	62·25	·0957 ± ·0217	115	76·76	·0250 ± ·0166
55	63·04	·0867 ± ·0211	116	78·13	·0000
56	64·75	·0922 ± ·0220	117	77·53	·0000
57	64·04	·1051 ± ·0233	118	76·94	·0000
58	63·34	·1051 ± ·0233	119	76·35	·0513 ± ·0238
59	65·12	·0833 ± ·0221	120	75·76	·0513 ± ·0238
60	65·36	·1107 ± ·0253			

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Table IV B. B_3 *experiment.*

1. xi. 27 to 24. xi. 28.

SPECIFIC DEATHS.

Cage age in days	l_x	d_x	q_x	e_x
0	10000·00	34·19	·0034188	38·30
1	9965·81	—	—	37·43
2	9965·81	8·51	·0008540	36·43
3	9957·30	25·49	·0025597	36·46
4	9931·81	8·55	·0008613	34·55
5	9923·26	17·09	·0017227	33·58
6	9906·16	25·69	·0025929	32·63
7	9880·48	111·02	·0112360	31·72
8	9769·46	51·10	·0052310	31·07
9	9718·36	94·44	·0097173	30·23
10	9623·92	137·36	·0142730	29·52
11	9486·56	154·25	·0162602	28·94
12	9332·31	222·40	·0238313	28·41
13	9109·90	188·01	·0206379	28·10
14	8921·90	196·93	·0220729	27·68
15	8724·96	309·15	·0354331	27·29
16	8415·81	223·28	·0265306	27·28
17	8192·53	241·46	·0294737	27·01
18	7951·07	340·01	·0427631	26·81
19	7611·06	318·60	·0418605	26·99
20	7292·46	477·90	·0655340	27·14
21	6814·55	370·26	·0543338	28·01
22	6444·29	448·38	·0695771	28·59
23	5995·92	512·92	·0855457	29·69
24	5482·99	550·97	·1004863	31·42
25	4932·03	654·61	·1327273	33·88
26	4277·41	412·50	·0964361	37·99
27	3864·91	346·38	·0896226	40·99
28	3518·53	304·75	·0866142	43·97
29	3213·78	284·41	·0884956	47·09
30	2929·37	228·26	·0779221	50·62
31	2701·11	249·04	·0921986	53·85
32	2452·07	162·83	·0664063	58·27
33	2289·24	173·14	·0756303	61·38
34	2116·10	202·91	·0958904	65·36
35	1913·19	134·60	·0703518	71·24
36	1778·59	134·60	·0756757	75·60
37	1644·00	76·91	·0467836	80·74
38	1567·08	86·53	·0552147	83·68
39	1480·56	77·92	·0526316	87·54
40	1402·63	88·28	·0629371	91·38
41	1314·36	9·81	·0074627	96·48
42	1304·55	79·06	·0606061	96·21
43	1225·48	50·22	·0409836	101·38
44	1175·26	30·13	·0256410	104·69
45	1145·12	60·80	·0530973	106·43
46	1084·32	40·16	·0370370	111·37
47	1044·16	50·69	·0485437	114·64
48	993·47	30·41	·0306122	119·46
49	963·06	10·14	·0105263	122·22
50	952·92	20·28	·0212766	122·51
60	768·66	32·94	·0428571	140·90
70	651·92	—	—	155·42
80	578·69	—	—	164·59
90	558·02	—	—	160·57
100	535·68	—	—	156·95
110	501·21	11·66	·0232558	157·55
120	454·59	—	—	163·38
130	419·62	—	—	166·51
140	372·99	—	—	176·54
150	350·39	—	—	177·54
160	330·06	—	—	178·23
170	310·34	—	—	179·30
180	289·65	—	—	181·96
190	279·67	—	—	
200	267·51	—	—	

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Table IV c. B_3 *experiment.*

1. xi. 27 to 24. xi. 28.

SPECIFIC DEATHS.

Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days	Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days
0	30·87	·0077 ± ·0017	61	74·95	·0710 ± ·0207
1	30·02	·0060 ± ·0015	62	75·42	·0721 ± ·0210
2	29·07	·0086 ± ·0018	63	74·82	·0863 ± ·0228
3	28·14	·0189 ± ·0027	64	75·31	·0729 ± ·0211
4	27·25	·0215 ± ·0029	65	76·95	·0606 ± ·0198
5	26·32	·0302 ± ·0034	66	77·53	·0462 ± ·0176
6	25·40	·0424 ± ·0040	67	78·51	·0471 ± ·0177
7	24·52	·0555 ± ·0045	68	78·78	·0323 ± ·0150
8	23·83	·0675 ± ·0050	69	78·21	·0799 ± ·0232
9	23·00	·0820 ± ·0055	70	78·91	·0965 ± ·0255
10	22·26	·0934 ± ·0059	71	78·34	·0965 ± ·0255
11	21·62	·1129 ± ·0064	72	79·07	·0975 ± ·0256
12	21·01	·1221 ± ·0067	73	78·51	·0975 ± ·0256
13	20·57	·1272 ± ·0069	74	81·99	·0508 ± ·0193
14	20·04	·1469 ± ·0074	75	84·31	·0175 ± ·0117
15	19·52	·1642 ± ·0078	76	83·77	·0175 ± ·0117
16	19·27	·1903 ± ·0085	77	84·72	·0182 ± ·0119
17	18·83	·2134 ± ·0090	78	84·18	·0182 ± ·0119
18	18·43	·2459 ± ·0096	79	83·64	·0182 ± ·0119
19	18·29	·2796 ± ·0103	80	83·10	·0357 ± ·0166
20	18·11	·3237 ± ·0110	81	82·56	·0357 ± ·0169
21	18·40	·3723 ± ·0117	82	83·55	·0179 ± ·0120
22	18·49	·4003 ± ·0122	83	83·03	·0179 ± ·0121
23	18·89	·4132 ± ·0128	84	82·50	·0179 ± ·0120
24	19·68	·4139 ± ·0134	85	83·46	·0000
25	20·91	·4061 ± ·0141	86	82·94	·0000
26	23·12	·3685 ± ·0149	87	82·42	·0000
27	24·62	·3656 ± ·0158	88	81·88	·0000
28	26·09	·3494 ± ·0165	89	81·34	·0000
29	27·62	·3416 ± ·0174	90	80·79	·0000
30	29·38	·3469 ± ·0183	91	80·24	·0196 ± ·0126
31	30·95	·3415 ± ·0190	92	79·69	·0196 ± ·0125
32	33·19	·3295 ± ·0198	93	79·14	·0196 ± ·0128
33	34·66	·3155 ± ·0203	94	78·59	·0196 ± ·0130
34	36·62	·3003 ± ·0209	95	78·04	·0400 ± ·0185
35	39·63	·2669 ± ·0211	96	79·05	·0208 ± ·0136
36	41·78	·2610 ± ·0218	97	78·51	·0412 ± ·0190
37	44·35	·2065 ± ·0209	98	77·97	·0412 ± ·0192
38	45·72	·2180 ± ·0218	99	77·43	·0838 ± ·0270
39	47·58	·2062 ± ·0221	100	78·54	·0644 ± ·0242
40	49·44	·1836 ± ·0218	101	78·01	·0644 ± ·0239
41	51·97	·1750 ± ·0221	102	79·14	·0444 ± ·0205
42	51·62	·1996 ± ·0235	103	78·62	·0444 ± ·0207
43	54·18	·1893 ± ·0239	104	81·76	·0000
44	55·76	·1806 ± ·0240	105	81·24	·0000
45	56·48	·1678 ± ·0237	106	80·71	·0233 ± ·0155
46	58·91	·1399 ± ·0225	107	80·17	·0233 ± ·0155
47	60·46	·1456 ± ·0234	108	79·64	·0233 ± ·0155
48	62·83	·1330 ± ·0231	109	79·11	·0698 ± ·0262
49	64·12	·1161 ± ·0222	110	78·57	·0698 ± ·0262
50	64·12	·1280 ± ·0232	111	79·91	·0714 ± ·0268
51	64·83	·1311 ± ·0237	112	79·39	·0714 ± ·0268
52	67·11	·0916 ± ·0209	113	78·85	·0714 ± ·0268
53	68·83	·0591 ± ·0173	114	82·23	·0250 ± ·0166
54	68·98	·0841 ± ·0204	115	81·69	·0250 ± ·0166
55	70·00	·0749 ± ·0197	116	83·25	·0000
56	71·12	·0922 ± ·0220	117	82·72	·0000
57	70·47	·1051 ± ·0233	118	82·20	·0000
58	69·83	·1051 ± ·0233	119	81·67	·0256 ± ·0171
59	71·94	·0833 ± ·0221	120	81·15	·0256 ± ·0171
60	72·33	·0972 ± ·0239			

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Table V. B_6 *experiment.*

1. xi. 26 to 31. x. 27.

ALL DEATHS (2226 mice).

Cage age in days	l_x	d_x	q_x	e_x
0	10000·00	36·53	·0036530	47·13
1	9963·47	50·34	·0050528	46·30
2	9913·13	32·11	·0032392	45·53
3	9881·02	50·58	·0051187	44·68
4	9830·44	60·22	·0061263	43·90
5	9770·21	55·78	·0057088	43·17
6	9714·44	102·45	·0105465	42·42
7	9611·98	130·71	·0135988	41·86
8	9481·27	121·68	·0128332	41·43
9	9359·60	150·81	·0161128	40·97
10	9208·79	198·55	·0215606	40·63
11	9010·24	189·59	·0210416	40·51
12	8820·65	190·10	·0215517	40·37
13	8630·55	161·94	·0187638	40·25
14	8468·61	253·15	·0298928	40·01
15	8215·46	263·47	·0320700	40·23
16	7951·99	230·63	·0290030	40·55
17	7721·36	240·84	·0311915	40·74
18	7480·52	241·46	·0322789	41·04
19	7239·05	308·57	·0426252	41·39
20	6930·49	260·32	·0375620	42·21
21	6670·17	359·88	·0539542	42·84
22	6310·28	341·23	·0540752	44·25
23	5969·05	406·19	·0680498	45·75
24	5562·86	362·26	·0651204	48·06
25	5200·60	363·64	·0699234	50·37
26	4836·96	425·61	·0879917	53·12
27	4411·35	306·48	·0694761	57·20
28	4104·86	304·44	·0741656	60·43
29	3800·42	256·44	·0674764	64·23
30	3543·99	247·25	·0697674	67·84
31	3296·73	252·80	·0766823	71·89
32	3043·93	191·54	·0629252	76·82
33	2852·39	139·77	·0490018	80·95
34	2712·62	103·53	·0381679	84·09
35	2609·08	57·06	·0218688	86·41
36	2552·03	103·95	·0407332	87·33
37	2448·07	109·15	·0445860	90·02
38	2338·92	82·98	·0354767	93·19
39	2255·95	31·26	·0138568	95·60
40	2224·69	72·77	·0327103	95·94
41	2151·92	57·32	·0266344	98·17
42	2094·60	31·26	·0149254	99·84
43	2063·34	47·01	·0227848	100·34
44	2016·33	21·06	·0104439	101·67
45	1995·27	42·12	·0211082	101·74
46	1953·15	42·23	·0216216	102·92
47	1910·92	26·39	·0138122	104·19
48	1884·53	47·51	·0252101	104·64
49	1837·02	31·67	·0172414	106·33
50	1805·34	10·56	·0058480	107·19
60	1617·82	22·16	·0136986	109·02
70	1460·73	5·68	·0038911	110·23
80	1301·37	5·71	·0043860	113·07
90	1226·14	17·43	·0142180	109·67
100	1114·61	18·58	·0166667	110·26
110	1033·87	6·19	·0059880	108·53
120	953·03	12·22	·0128205	107·24
130	873·49	6·15	·0070423	106·70
140	836·58	—	—	101·27
150	786·96	13·01	·0165289	97·37
160	701·56	—	—	98·73
170	654·07	—	—	95·40
180	610·88	7·36	·0120482	91·80
190	558·52	7·76	·0138889	90·03
200	535·02	—	—	83·86

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Table V A. B_6 *experiment.*

1. xi. 26 to 31. x. 27.

ALL DEATHS.

Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days	Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days
0	36·91	·0230 ± ·0022	61	74·76	·0492 ± ·0086
1	36·14	·0250 ± ·0023	62	74·67	·0567 ± ·0093
2	35·42	·0304 ± ·0025	63	74·31	·0641 ± ·0098
3	34·62	·0405 ± ·0029	64	74·48	·0540 ± ·0091
4	33·88	·0479 ± ·0031	65	75·22	·0477 ± ·0087
5	33·18	·0575 ± ·0034	66	75·41	·0409 ± ·0081
6	32·46	·0725 ± ·0038	67	75·92	·0417 ± ·0083
7	31·89	·0823 ± ·0041	68	76·17	·0384 ± ·0080
8	31·42	·0897 ± ·0043	69	75·54	·0461 ± ·0088
9	30·92	·0952 ± ·0044	70	75·81	·0467 ± ·0089
10	30·51	·1079 ± ·0047	71	75·47	·0586 ± ·0099
11	30·26	·1174 ± ·0050	72	76·06	·0556 ± ·0097
12	30·00	·1246 ± ·0052	73	76·05	·0641 ± ·0104
13	29·75	·1333 ± ·0054	74	76·03	·0646 ± ·0105
14	29·41	·1452 ± ·0056	75	76·35	·0655 ± ·0107
15	29·41	·1564 ± ·0059	76	77·00	·0541 ± ·0098
16	29·48	·1612 ± ·0061	77	77·37	·0506 ± ·0096
17	29·44	·1827 ± ·0065	78	78·08	·0343 ± ·0080
18	29·49	·2021 ± ·0069	79	78·17	·0260 ± ·0071
19	29·57	·2315 ± ·0074	80	78·59	·0132 ± ·0051
20	29·99	·2496 ± ·0078	81	78·35	·0223 ± ·0066
21	30·26	·2748 ± ·0082	82	78·45	·0317 ± ·0079
22	31·09	·3009 ± ·0087	83	77·86	·0362 ± ·0084
23	31·97	·3123 ± ·0090	84	77·27	·0362 ± ·0085
24	33·43	·3168 ± ·0094	85	76·68	·0452 ± ·0094
25	34·87	·3185 ± ·0097	86	77·12	·0459 ± ·0096
26	36·62	·3184 ± ·0101	87	77·95	·0421 ± ·0093
27	39·29	·3100 ± ·0105	88	77·72	·0423 ± ·0093
28	41·38	·3051 ± ·0109	89	77·13	·0612 ± ·0111
29	43·86	·2862 ± ·0112	90	77·26	·0619 ± ·0112
30	46·22	·2638 ± ·0113	91	77·77	·0581 ± ·0109
31	48·88	·2259 ± ·0112	92	78·32	·0543 ± ·0107
32	52·15	·1958 ± ·0110	93	78·11	·0547 ± ·0108
33	54·89	·1800 ± ·0110	94	79·08	·0407 ± ·0095
34	56·97	·1684 ± ·0110	95	79·28	·0310 ± ·0084
35	58·50	·1473 ± ·0107	96	79·51	·0372 ± ·0092
36	59·08	·1568 ± ·0111	97	79·74	·0326 ± ·0087
37	60·86	·1444 ± ·0109	98	79·56	·0386 ± ·0095
38	62·98	·1178 ± ·0102	99	79·39	·0334 ± ·0090
39	64·59	·1062 ± ·0100	100	78·79	·0334 ± ·0090
40	64·81	·1031 ± ·0099	101	79·52	·0284 ± ·0084
41	66·31	·0924 ± ·0096	102	79·38	·0343 ± ·0093
42	67·44	·0877 ± ·0095	103	79·71	·0346 ± ·0094
43	67·79	·0867 ± ·0096	104	79·12	·0346 ± ·0094
44	68·71	·0889 ± ·0098	105	78·53	·0404 ± ·0101
45	68·78	·0952 ± ·0102	106	78·85	·0349 ± ·0095
46	69·60	·0811 ± ·0096	107	79·19	·0294 ± ·0087
47	70·49	·0718 ± ·0092	108	79·54	·0179 ± ·0069
48	70·83	·0728 ± ·0093	109	78·96	·0298 ± ·0088
49	72·01	·0603 ± ·0086	110	78·85	·0299 ± ·0089
50	72·63	·0527 ± ·0081	111	78·73	·0241 ± ·0080
51	72·42	·0561 ± ·0084	112	78·62	·0302 ± ·0090
52	72·64	·0571 ± ·0085	113	78·03	·0481 ± ·0112
53	73·08	·0459 ± ·0078	114	78·39	·0435 ± ·0108
54	73·34	·0468 ± ·0079	115	78·27	·0497 ± ·0115
55	73·40	·0540 ± ·0085	116	77·67	·0619 ± ·0127
56	73·47	·0581 ± ·0089	117	78·02	·0750 ± ·0140
57	73·78	·0527 ± ·0086	118	78·88	·0701 ± ·0137
58	73·39	·0529 ± ·0086	119	78·86	·0696 ± ·0137
59	73·73	·0506 ± ·0086	120	79·27	·0641 ± ·0132
60	74·36	·0518 ± ·0087			

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Table V B. B_6 *experiment*.

1. xi. 26 to 31. x. 27.

SPECIFIC DEATHS.

Cage age in days	l_x	d_x	q_x	e_x
0	10000·00	18·27	·0018265	52·52
1	9981·74	27·51	·0027561	51·62
2	9954·22	23·03	·0023137	50·76
3	9931·19	27·73	·0027920	49·87
4	9903·47	42·00	·0042413	49·01
5	9861·46	37·53	·0038059	48·22
6	9823·93	80·06	·0081496	47·40
7	9743·87	104·11	·0106848	46·79
8	9639·26	109·43	·0113524	46·29
9	9530·32	139·16	·0146022	45·81
10	9391·16	183·20	·0195072	45·48
11	9207·96	179·22	·0194634	45·38
12	9028·75	189·72	·0210129	45·27
13	8839·03	146·34	·0165563	45·23
14	8692·68	235·34	·0270728	44·98
15	8457·35	246·57	·0291545	45·22
16	8210·78	218·29	·0265861	45·56
17	7992·49	229·35	·0286962	45·79
18	7763·13	240·56	·0309877	46·13
19	7522·51	305·38	·0405954	46·59
20	7217·19	250·63	·0347271	47·54
21	6966·56	370·73	·0532151	48·23
22	6595·83	346·33	·0525078	49·92
23	6249·50	399·35	·0639004	51·66
24	5850·15	370·53	·0633363	54·15
25	5479·63	383·15	·0699234	56·77
26	5096·47	432·62	·0848862	60·01
27	4663·85	318·71	·0683371	64·53
28	4345·14	311·52	·0716935	68·22
29	4033·62	255·84	·0634278	72·45
30	3777·78	263·57	·0697674	76·32
31	3514·21	258·48	·0735524	81·01
32	3255·73	199·33	·0612245	86·40
33	3056·40	144·22	·0471869	91·01
34	2912·18	100·04	·0343511	94·49
35	2812·14	61·50	·0218688	96·83
36	2750·64	106·44	·0386965	97·98
37	2644·20	117·89	·0445860	100·91
38	2526·31	89·63	·0354767	104·59
39	2436·68	33·76	·0138568	107·42
40	2402·92	78·60	·0327103	107·93
41	2324·32	61·91	·0266344	110·56
42	2262·41	33·77	·0149254	112·57
43	2228·65	50·78	·0227848	113·27
44	2177·87	22·75	·0104439	114·90
45	2155·12	45·49	·0211082	115·10
46	2109·63	39·91	·0189189	116·58
47	2069·72	28·59	·0138122	117·81
48	2041·13	51·46	·0252101	118·46
49	1989·67	34·30	·0172414	120·51
50	1955·37	11·44	·0058480	121·61
60	1763·23	24·15	·0136986	124·30
70	1615·30	6·29	·0038911	125·23
80	1457·17	6·39	·0043860	128·25
90	1372·93	19·52	·0142180	125·78
100	1261·12	21·02	·0166667	126·62
110	1169·76	7·00	·0059880	126·17
120	1086·01	13·92	·0128205	125·43
130	1015·88	7·15	·0070423	123·87
140	980·11	—	—	118·30
150	929·17	15·36	·0165289	114·55
160	842·95	—	—	115·84
170	801·36	—	—	111·45
180	764·91	9·22	·0120482	106·46
190	699·35	9·71	·0138889	106·07
200	669·93	—	—	100·60

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Table V c. B_6 *experiment.*

1. xi. 26 to 31. x. 27.

SPECIFIC DEATHS.

Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days	Age x	Expectation of life limited to 120 days	Probability of dying in the next 5 days
0	38·90	·0139 ± ·0017	61	78·63	·0389 ± ·0077
1	38·08	·0158 ± ·0018	62	78·35	·0463 ± ·0084
2	37·29	·0211 ± ·0021	63	78·06	·0537 ± ·0091
3	36·47	·0293 ± ·0025	64	78·04	·0470 ± ·0086
4	35·68	·0377 ± ·0028	65	78·60	·0442 ± ·0084
5	34·94	·0477 ± ·0031	66	78·90	·0373 ± ·0078
6	34·17	·0627 ± ·0036	67	79·21	·0417 ± ·0083
7	33·56	·0734 ± ·0039	68	79·54	·0384 ± ·0080
8	33·02	·0831 ± ·0041	69	78·97	·0461 ± ·0088
9	32·50	·0879 ± ·0043	70	79·31	·0428 ± ·0085
10	32·08	·0994 ± ·0046	71	79·05	·0508 ± ·0093
11	31·82	·1083 ± ·0048	72	79·73	·0478 ± ·0091
12	31·56	·1148 ± ·0050	73	79·81	·0523 ± ·0095
13	31·33	·1217 ± ·0052	74	79·88	·0529 ± ·0096
14	30·96	·1346 ± ·0055	75	79·97	·0575 ± ·0100
15	30·93	·1466 ± ·0058	76	80·40	·0501 ± ·0095
16	30·96	·1515 ± ·0059	77	80·84	·0466 ± ·0092
17	30·92	·1747 ± ·0064	78	81·32	·0343 ± ·0080
18	30·94	·1950 ± ·0068	79	81·48	·0260 ± ·0071
19	31·05	·2223 ± ·0073	80	82·00	·0132 ± ·0051
20	31·47	·2408 ± ·0077	81	81·82	·0223 ± ·0066
21	31·73	·2684 ± ·0081	82	82·01	·0317 ± ·0079
22	32·64	·2929 ± ·0086	83	81·47	·0362 ± ·0084
23	33·58	·3047 ± ·0089	84	80·93	·0362 ± ·0085
24	34·99	·3105 ± ·0093	85	80·38	·0452 ± ·0094
25	36·49	·3106 ± ·0097	86	80·92	·0459 ± ·0096
26	38·39	·3105 ± ·0100	87	81·88	·0421 ± ·0093
27	41·11	·3019 ± ·0104	88	81·72	·0423 ± ·0093
28	43·30	·2966 ± ·0108	89	81·18	·0612 ± ·0111
29	45·83	·2780 ± ·0111	90	81·41	·0619 ± ·0112
30	48·15	·2556 ± ·0112	91	82·04	·0533 ± ·0105
31	50·98	·2173 ± ·0110	92	82·70	·0444 ± ·0097
32	54·27	·1878 ± ·0109	93	82·57	·0448 ± ·0098
33	57·08	·1734 ± ·0109	94	83·69	·0307 ± ·0083
34	59·19	·1633 ± ·0109	95	84·00	·0208 ± ·0069
35	60·58	·1455 ± ·0106	96	83·88	·0322 ± ·0086
36	61·25	·1550 ± ·0110	97	83·77	·0326 ± ·0087
37	63·02	·1444 ± ·0109	98	83·68	·0486 ± ·0107
38	65·27	·1178 ± ·0102	99	83·59	·0334 ± ·0090
39	67·00	·1062 ± ·0100	100	83·05	·0334 ± ·0090
40	67·29	·1031 ± ·0099	101	83·90	·0284 ± ·0084
41	68·91	·0924 ± ·0096	102	83·85	·0343 ± ·0093
42	70·15	·0852 ± ·0094	103	84·30	·0346 ± ·0094
43	70·59	·0841 ± ·0094	104	83·77	·0346 ± ·0094
44	71·61	·0864 ± ·0097	105	83·23	·0404 ± ·0101
45	71·75	·0927 ± ·0100	106	83·68	·0350 ± ·0095
46	72·69	·0785 ± ·0094	107	84·14	·0294 ± ·0087
47	73·47	·0718 ± ·0091	108	84·61	·0179 ± ·0069
48	73·91	·0700 ± ·0091	109	84·09	·0237 ± ·0079
49	75·22	·0575 ± ·0084	110	84·07	·0240 ± ·0080
50	75·93	·0499 ± ·0079	111	84·04	·0181 ± ·0070
51	75·80	·0533 ± ·0082	112	84·03	·0242 ± ·0081
52	76·10	·0542 ± ·0083	113	83·49	·0423 ± ·0106
53	76·44	·0429 ± ·0075	114	83·47	·0425 ± ·0107
54	76·79	·0437 ± ·0077	115	83·45	·0488 ± ·0114
55	76·93	·0509 ± ·0083	116	82·92	·0610 ± ·0126
56	77·09	·0551 ± ·0087	117	83·40	·0679 ± ·0133
57	77·50	·0462 ± ·0080	118	84·44	·0566 ± ·0124
58	76·94	·0496 ± ·0084	119	84·45	·0571 ± ·0124
59	77·38	·0438 ± ·0080	120	85·02	·0515 ± ·0119
60	78·12	·0416 ± ·0079			

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Table VI. P_{3N} *experiment.*

24. ii. 27 to 24. ii. 28. Omitting the 50 original mice at beginning of the experiment.

SPECIFIC DEATHS (1095 mice).

Cage age in days	l_x	d_x	q_x	e_x
0	10000·00	18·27	·0018265	40·92
1	9981·74	45·87	·0045956	40·00
2	9935·86	73·87	·0074349	39·18
3	9861·99	83·42	·0084586	38·47
4	9778·57	102·74	·0105062	37·79
5	9675·84	178·14	·0184109	37·19
6	9497·70	160·18	·0168651	36·88
7	9337·52	66·36	·0071066	36·50
8	9271·16	152·45	·0164440	35·76
9	9118·70	191·37	·0209864	35·35
10	8927·33	134·10	·0150215	35·09
11	8793·23	183·19	·0208333	34·62
12	8610·04	125·76	·0146067	34·35
13	8484·28	232·71	·0274286	33·85
14	8251·56	184·88	·0224057	33·79
15	8066·68	371·11	·0460049	33·55
16	7695·58	363·65	·0472541	34·15
17	7331·93	335·96	·0458221	34·82
18	6995·96	376·02	·0537482	35·46
19	6619·94	417·47	·0630631	36·45
20	6202·47	359·56	·0579710	37·87
21	5842·91	370·82	·0634648	39·17
22	5472·09	410·91	·0750916	40·79
23	5061·18	261·09	·0515873	43·06
24	4800·09	241·01	·0502092	44·38
25	4559·08	272·33	·0597345	45·70
26	4286·74	221·90	·0517647	47·57
27	4064·84	91·23	·0224439	49·14
28	3973·61	163·44	·0411311	49·25
29	3810·17	144·56	·0379404	50·34
30	3665·61	113·90	·0310734	51·31
31	3551·71	146·25	·0411765	51·94
32	3405·46	104·46	·0306748	53·15
33	3301·00	62·68	·0189873	53·81
34	3238·32	125·35	·0387097	53·85
35	3112·97	146·74	·0471380	54·99
36	2966·23	126·22	·0425532	56·69
37	2840·01	84·46	·0297398	58·19
38	2755·55	52·79	·0191571	58·95
39	2702·76	52·79	·0195313	59·10
40	2649·97	42·23	·0159363	59·26
41	2607·74	73·90	·0283401	59·22
42	2533·84	53·23	·0210084	59·93
43	2480·60	96·23	·0387931	60·20
44	2384·37	64·15	·0269058	61·61
45	2320·22	42·77	·0184332	62·30
46	2277·45	85·94	·0377358	62·46
47	2191·51	75·57	·0344828	63·89
48	2115·94	32·55	·0153846	65·16
49	2083·39	43·63	·0209424	65·17
50	2039·76	32·72	·0160428	65·55
60	1765·65	—	—	64·98
70	1474·64	22·69	·0153846	66·77
80	1372·09	22·87	·0166667	61·40
90	1222·37	23·28	·0190476	58·45
100	1034·14	—	—	58·34
110	867·73	—	—	58·58
120	771·78	—	—	55·18
130	710·70	—	—	
140	624·93	12·25	·0196078	
150	538·88	—	—	
160	426·09	12·53	·0294118	
170	325·83	—	—	
180	275·70	12·53	·0454545	
190	237·45	—	—	
200	196·99	14·07	·0714286	

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Table VI A. P_{3N} *experiment.*

24. ii. 27 to 24. ii. 28.

SPECIFIC DEATHS.

Age x	Expectation of life limited to 60 days	Probability of dying in the next 5 days	Age x	Expectation of life limited to 60 days	Probability of dying in the next 5 days
0	29·45	·0324 ± ·0036	31	32·16	·1648 ± ·0136
1	28·68	·0485 ± ·0044	32	32·87	·1660 ± ·0139
2	27·99	·0602 ± ·0049	33	33·23	·1652 ± ·0141
3	27·37	·0599 ± ·0049	34	33·22	·1654 ± ·0142
4	26·76	·0675 ± ·0052	35	33·89	·1487 ± ·0139
5	26·21	·0774 ± ·0056	36	34·92	·1209 ± ·0131
6	25·87	·0742 ± ·0056	37	35·83	·1078 ± ·0128
7	25·47	·0779 ± ·0058	38	36·30	·0998 ± ·0125
8	24·82	·0849 ± ·0060	39	36·39	·1178 ± ·0136
9	24·39	·0951 ± ·0064	40	36·49	·1244 ± ·0140
10	24·06	·0964 ± ·0065	41	36·48	·1267 ± ·0143
11	23·59	·1248 ± ·0074	42	36·93	·1351 ± ·0149
12	23·25	·1484 ± ·0080	43	37·11	·1470 ± ·0157
13	22·76	·1754 ± ·0087	44	38·01	·1262 ± ·0150
14	22·56	·1977 ± ·0092	45	38·46	·1209 ± ·0149
15	22·24	·2311 ± ·0099	46	38·58	·1187 ± ·0150
16	22·48	·2407 ± ·0103	47	39·49	·0941 ± ·0138
17	22·76	·2537 ± ·0108	48	40·31	·0773 ± ·0129
18	23·02	·2766 ± ·0113	49	40·35	·0682 ± ·0123
19	23·52	·2749 ± ·0117	50	40·63	·0644 ± ·0121
20	24·29	·2650 ± ·0119	51	40·72	·0710 ± ·0128
21	24·98	·2663 ± ·0123	52	40·60	·0829 ± ·0138
22	25·89	·2572 ± ·0126	53	40·70	·0787 ± ·0136
23	27·21	·2149 ± ·0123	54	40·36	·0734 ± ·0132
24	27·93	·2062 ± ·0125	55	40·47	·0748 ± ·0135
25	28·67	·1960 ± ·0126	56	40·86	·0530 ± ·0116
26	29·75	·1715 ± ·0123	57	41·28	·0485 ± ·0112
27	30·66	·1622 ± ·0124	58	41·23	·0616 ± ·0127
28	30·65	·1693 ± ·0128	59	40·67	·0803 ± ·0144
29	31·27	·1501 ± ·0125	60	40·86	·0757 ± ·0141
30	31·82	·1508 ± ·0128			

correlated with the rate of mortality of the herd at the day of entrance of the batch. n days later a batch will have been reduced by death to perhaps 5, 4, 3, 2, 1 or even no survivors, but the average after lifetime could be computed and correlated with the rate of mortality prevailing in the cage at day n, or on any day before the nth. Data were so prepared with reference to the day of entrance, to day 0, and to days 5, 10, 15, 30, 40 and 50. As will be seen from Table VII even for the later ages the numbers, although they naturally diminish, are not inconsiderable. In Table VIII we have the results of the calculations. In it are shown the correlation between length of after-life from age x and the measure of conditions in the cage immediately before x or, alternately, the general average of conditions before x from the day of entry of the batch. It will be seen that, while all the coefficients are negative in sign they tend to decrease in absolute magnitude and at cage age 40 days are insignificant. A rougher but perhaps more striking way of bringing out the point is shown in Table IX, where we merely contrast the mean after-life times when the prevailing death rates were low (under 0·012) or high (over 0·026). It will be noticed that the advantage accruing to the entrants or exposees when the relevant rate of mortality was low is considerable until cage age 40 when it disappears.

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Table VII. B_6 *experiment.*

No. of days in which 1, 2, ... 6 mice were used in batch for obtaining the average length of after-life from day x. x = no. of days after day of entry.

	$x = 0$	$x = 5$	$x = 10$	$x = 15$	$x = 20$	$x = 25$	$x = 30$	$x = 35$	$x = 40$	$x = 50$
No. of days when the average was based on:										
1 mouse	1	1	3	6	21	52	94	102	97	85
2 mice	4	4	4	12	40	83	75	64	55	49
3 „	7	10	20	49	83	87	63	39	27	15
4 „	24	31	56	94	88	64	34	13	9	5
5 „	56	83	108	120	91	37	10	5	5	4
6 „	273	236	173	82	34	12	3	2	1	—
No. of days when 1 or more mice survived beyond day x	365	365	364	363	357	335	279	225	194	158
No. of days without an observation, *i.e.* no survivors at day x	—	—	1	2	8	30	86	140	171	207
No. of mice concerned, *i.e.* mice who lived beyond day x ...	2044	1994	1873	1645	1361	992	637	436	355	268

Table VIII. B_6 *experiment.*

x = day of cage age at which after-life begins	Correlation of after-life (unlimited) from day x with the average specific death rate in the (i) Total lifetime before day x	(ii) Last 5 days before day x	(iii) First 5 days after day x	Life-table expectation of life at this age (limited to 120 days)	Life-table probability of dying in the next 5 days
Day					
0	—	− ·411 ± ·029	− ·326 ± ·032	38·9	·014
5	—	− ·315 ± ·032	− ·305 ± ·032	34·9	·048
10	− ·329 ± ·032	− ·288 ± ·032	—	32·1	·044
15	—	− ·322 ± ·032	—	30·9	·147
20	− ·273 ± ·033	− ·220 ± ·034	—	31·5	·241
25	—	− ·223 ± ·035	—	36·5	·311
30	− ·146 ± ·040	− ·137 ± ·040	—	48·2	·256
35	—	− ·201 ± ·040	—	60·6	·146
40	− ·070 ± ·048	− ·073 ± ·048	—	67·3	·103
50	− ·081 ± ·053	—	—	75·9	·050

Table IX. B_6 *experiment.*

Age x	Mean length of after-life from age x for (i) Low death rate (under 0·012) just before day x	(ii) High death rate (over 0·026) just before day x	Difference	Nos. of groups: Low death rate	High death rate
0	66·5	29·2	37·3	53	93
5	57·05	29·96	27·09	50	97
10	55·00	25·53	29·47	45	100
15	52·42	18·51	33·91	40	104
20	50·26	18·48	31·78	35	107
25	51·00	19·16	31·84	29	98
30	60·62	32·93	27·69	22	73
35	51·55	39·96	11·59	15	53
40	61·30	61·29	0·01	14	44

We conclude that exposure to risk of infection, so far as this factor is measured by the prevailing mortality rate, has a steadily decreasing importance as cage age advances. This might have been inferred from the asymptoting of q_x, but the decreasing value of r permits a second inference, viz. that the *increase* of q_x from q_0 to a maximum about q_{20} is probably not due or not mainly due to anything occurring at or about that cage age but more probably to what happens very early in cage life.

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We think this is an important result and shall discuss some of its possible interpretations, but desire to be on our guard and to put our readers upon their guard against exaggeration. We are only examining the relations noticed in our particular experience, using a particular measure of exposure to risk, we must not extrapolate beyond that experience. Suppose we accept, for argument's sake, as proved, that, in the actual experience of each herd, variations of severity of exposure after a certain period of residence do not affect subsequent mortality at all, that admission does not commit us to the view that, in a herd taken as a going concern, the discontinuous introduction of—say—a batch of heavily infected immigrants would not increase the risk to life of all the members of the herd then older than some assigned age. We have indeed good reason to think that it would greatly increase the risk. All that the work described suggests is that the variations of risk naturally occurring when the government of the community is not changed are of relatively little importance.

We have now reached the point that mortality with age is less and less affected by the environmental conditions as age increases. One obvious biological interpretation would be that all mice become infected within a few days of entrance but it is not the only possible interpretation. Here we reach the most difficult part of our enquiry, viz. the interpretation of the form of the mortality curve. Although our data are relatively extensive and the product of years of observation, they are extensive only relatively to the scale of other published data, not to the complexity of problems offered for solution. Contrasting the *Pasteurella* with the *aertrycke* series we are entitled to say that in the former the maximum of q_x is reached sooner than in the latter and that when like is compared with like (in respect of the immigration rate) the difference is striking. No other clear-cut distinction is apparent and even here two *Pasteurella* series, P_3 and P_{3N}, differ more than the latter does from B_3. The exact day of a mode is of course subject to large casual errors. But the biological mechanism of an intestinal infection must differ greatly in physiological detail from that of a respiratory infection so that in practice other factors complicate the matter seriously. Indeed although it is not hard to theorise, and one may have confidence that the true can only be separated from the false by the statistical analysis of herd experimentation, we do not think that we can yet venture to hope for a satisfying interpretation. However, it may not be uninteresting to run through some of the ideas which have occurred to us.

Perhaps the simplest hypothesis to entertain is that the number of deaths occurring in the interval of time from x to $x + dx$, $\phi(x)\,dx$, is a resultant of two functions one giving the probability law of infection, the other that of death after infection, viz. $\phi(x) = \int_0^x f(r)\,F(x-r)\,dr$ where $f(r)$ measures the probability that a mouse is infected on the rth day of its sojourn and $F(x-r)$ the probability that if infected it will die on the $x-r$th day after. If our distribution of life-table deaths be based upon a sufficiently large experience,

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$\phi(x)$ is known and if we can from *a priori* considerations assign $f(r)$ the integral equation proposed may be solved. Arithmetical and graphical trials have suggested that a resolution is not impossible. Our colleague Mr H. E. Soper has provided us with an elegant example of the application of such a notion. Mr Soper took the d_x column of the complete table of which Table V is an excerpt and averaged into 5-day groups down to the 125th day. He drew a smooth curve, the differences of the ordinates of which from the observational histograms were within the errors of sampling. At cage age 125, 1030 of 10,000 are still alive, about one-tenth of the entrants. Taking for convenience a 2-day unit so that the experience may be regarded as a survivorship table of lives (out of 5000) centred at each tabular age, one can proceed as follows. Using the letter A as a mere logical symbol the index of which gives the number of unit intervals survived, then the lives from entry are represented by $d_0 + d_1A + d_2A^2 + d_3A^3 + \ldots.$ If q be the chance of an attack during any interval and $p = (1 - q)$ that of escape, then, if the attacks are fortuitous, the chances of *first* attack occurring in the 0, 1, 2, 3, etc., interval are given by q, pq, p^2q, p^3q, etc., so that the chances of life before attack are

$$q + pqA + p^2qA^2 + \ldots.$$

If now d_0', d_1', d_2', etc., replace d_0, d_1, d_2, etc., when the origin of measurement is not entry but date of attack, the lives subsequent to attack have array $d_0' + d_1'A + d_2'A^2 + d_3'A^3 + \ldots.$ But the whole life must be the sum of life before and after attack so that the identity

$$d_0 + d_1A + d_2A^2 + \ldots = (q + pqA + p^2qA^2 + \ldots)(d_0' + d_1'A + d_2'A^2 \ldots)$$

results; or, inverting,

$$d_0' + d_1'A + d_2'A^2 + \ldots = (1/q - p/qA)(d_0 + d_1A + d_2A^2 + \ldots).$$

We accordingly infer that the required lives from first attack are to be obtained from the d_x curve by taking $1/q$ times the corresponding ordinate of that curve and subtracting p/q times the preceding ordinate.

We have now to select a value of q and if we wish to argue the hypothesis that the slow downsweep of the curve is due to deferred first attacks, we shall so choose q as to steepen this part of the curve as much as possible without, however, producing impossible (viz. negative) frequencies in the deduced d_x' curve. This end is attained by taking $q = 2/7$ as the chance of attack in a 2-day interval and therefore $1/6{\cdot}45$ as the chance of attack per day.

Taking 7 times the ordinate of the d_x curve and subtracting 5 times the preceding ordinate and dividing by 2, one has the entries of Table A. The d_x' column of this table represents, on the given hypothesis, the dying-out quotas from time of infection, and asserts that the results (measured by death) of a first attack is exhausted in 36 days. In this period 3975 out of 5000 or 79·5 per cent. are dead. The 1025 survivors may now be assumed subject to the same chance law of attack. The second period of 36 days shows in the column 261 deaths; the last value being 13 and that preceding the first value

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Table A.

x	d_x	d_x'	x	d_x	d_x'
0	0	0	46	36·5	20
2	16	56	48	30·5	16
4	48	128	50	27	18
6	78	153	52	23	13
8	110	190	54	20	12
10	142	222	56	17·5	11
12	172	247	58	15	9
14	205	287	60	14	11
16	238	321	62	13·5	12
18	270	350	64	13	12
20	301	378	66	13	13
22	333	413	68	13	13
24	365	445	70	13	13
26	383	428	72	13	13
28	338	226			(261)
30	268	93	74	13	13
32	203	40	76	12·5	11
34	145	0	78	12·5	12
36	103	− 2	80	12·5	13
		(3975)	82	12·5	12
38	73	− 2	84	12	11
40	60	27	86	12	12
42	50	25	88	12	12
44	43	25	90	11·5	10

being sensibly zero. Applying the transformation again we shall estimate the deaths in the second period of illness as approximately

$$261 + 5/2 \times 13 - 5/2 \times 0 = 293{\cdot}5$$

or 28·5 per cent. of the exposed to risk, 1025. This result might be interpreted as measuring the advantage of selection or immunisation by previous attack or a combination of the two. But we cannot, of course, put much stress upon so simple an hypothesis. Biologically it is rather too simple to be plausible.

We are assuming a sharp distinction between the "infected" and the "not infected," that probably does not exist. A more credible mental picture of what happens in a herd is the following. An entrant to the herd is exposed to a bombardment of shots of infective material—let us call them quanta of infection—and may receive in a unit of time 0, 1, 2, 3, etc., etc., quanta. We may fairly suppose that (during the period of observation) no animal which fails to receive at least 1 quantum dies at all. The mice which receive in the first unit of time of observation a single quantum will fall into two main classes. (1) Those whose effective resistance, at the moment when they receive the quantum, is so low that they will die wholly as a result of the infection. Their survival period may be short or long, death may be hastened by a second or subsequent dose, but they are doomed. (2) The other class falls into a number of sub-classes. First there will be animals who simply ignore the dose and are, in the next time unit of exposure, precisely in the position of new animals. Next there will be animals whose resistance is lowered but not to the point of death and who will be more sensitive to a second dose than unscathed animals. Then there will be animals whose resistance is increased. From what we know of immunity processes it is probable that a large number of animals will be in this last group. Such animals, if the interval between the receipt of the

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first and second quantum be not too short, will be more resistant to the second than similarly constituted animals were to the first quantum. One sees therefore that interval between doses is of importance in a special way. To make the argument clear let us take a simple arithmetical example. Let us suppose that all animals receiving within a time unit interval of exposure more than 1 quantum of infection are thereby at once destroyed, but that some or all of those not receiving more than 1 quantum per unit of time will survive. Let us assume also that the unit of time selected is sufficiently long to allow an effective immunity to develop as the result of non-fatal infection. If we enumerate the possible orders of receiving, say, 3 quanta in 5 time units, there are 10 possible distributions, viz. (where A denotes the receipt of a quantum):

$AAA00$	$00AAA$	$AA00A$	$A0AA0$	$0A0AA$
$0AAA0$	$AA0A0$	$0AA0A$	$A00AA$	$A0A0A$.

If we assume that the receipt of a quantum destroys a certain proportion of animals and confers some measure of immunity upon the survivors, the total havoc wrought by the first order may be quite different from that done by the last. The survivors of one dose who receive another in the next unit of time may experience a lower rate of mortality than the group of which they are the survivors, while the survivors who are not again infected until the lapse of a free interval may have lost their acquired immunity. The illustration is a trivial one but suggests at once the nature of the problem. There is no difficulty in proposing some scheme such that, premising a random distribution of 0, 1, 2, ... r quanta of infections in unit time, death is to follow the receipt of some limiting number of quanta and in comparing the expected with the actual distributions of deaths. If, however, we are to distinguish the *order* of receipt, in such wise that the receipt of r quanta in one order may produce fewer deaths in the exposed population than the receipt of r quanta in a different order, the mathematical expression of the problem becomes much more arithmetically complex and involves many precarious assumptions. A very simple application of the principle has been tested. The assumptions were: (1) That the receipt of 2 or more quanta within a unit of time is fatal. (2) That of the survivors of 1 quantum, those who receive another in each successive time unit survive. (3) That the survivors of 1 quantum who do not receive another until after the lapse of one or more free intervals are subject to the same mortality rate as animals receiving a first quantum. It was found that the curve of life-table deaths should then be capable of representation by the difference of two exponentials, which is not true of our own data.

It appears probable that with more assumptions and these less violent *but of the same type*, we should still have some linear function of a set of exponentials. These *might* more satisfactorily describe the data, and we hope that our colleague Mr Soper, to whose expert advice we are deeply indebted, will continue the discussion of these and other possible descriptions. At present we do not feel that we have reached any mathematical interpretation of the

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facts sufficiently close to arithmetical reality to justify its detailed description and in what follows we do no more than indicate the *prima facie* interpretation of the data. If we accept the results described on p. 258 as evidence that a large proportion of a herd become infected very early in herd life, the most probable explanation of the earlier maximum in the *Pasteurella* q_x curve is that the average period of evolution of the morbid process from fatal infection to death is shorter in a disease of the respiratory than in one of intestinal type. Acceptance of this simple explanation does not commit us to suppose that all infections which will ultimately be fatal occur in the first days of herd life. It would be sufficient if a sensible proportion were so infected. The subsequent decline of the curve and its attainment of a constant level are to be attributed to the combined working of selection and positive immunisation.

In this connection reference may be made to a small experimental epidemic of mouse typhoid, described in an earlier report*, in which daily cultures were made from the faeces of each mouse exposed to risk. The number of mice submitted to the risk of contact infection during this experiment numbered 135. Of these only 13 failed to show evidence of infection, by dying of the disease, by excreting *Bact. aertrycke* in their faeces, by developing agglutinins acting on that organism, or by yielding cultures from the spleen, when killed and examined at the termination of the experiment; and of these 13 mice, 6 had resided in the cage for less than 14 days. Of the 135 mice, 96 excreted *Bact. aertrycke* on one or more occasions during their residence in the cage. The number of days elapsing between the date of entry to the cage and the date of first excretion varied between 1 and 50, with a mean value of 12·18. In 77 cases the date of first excretion fell within the first 3 weeks of residence in the cage, and in 64 cases within the first fortnight. The complete records of this experiment show clearly (*a*) that the majority of the mice were infected within 14 to 21 days of their entry to the cage, and (*b*) that the course of excretion in different mice varied widely, some excreting persistently during a short period terminating in death, others excreting intermittently over long periods while remaining in apparent health, others again excreting on one or two occasions only during the 115 days of observation. In this particular instance, therefore, the distribution and evolution of infection within the herd was demonstrably of the kind considered above.

Although the naked antithesis of selection and environment is not of much more than debating-society interest, the high, and constant, ultimate rate of mortality in these herds is a result of serious interest. Whether by virtue of selective mortality or of cumulative immunisation, the populations of these herds at later cage ages should, compared with members of a human herd, be in a remarkably favourable position to withstand the infectious diseases to which they are exposed. Yet it is obvious that their resistance—although much greater than that of unsalted animals—is very incomplete. Another way of bringing this out is to consider whether the proportional mortality from the

* Topley, Ayrton and Lewis, *J. Hygiene*, 1924, **23**, 223.

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Table X. *P experiments.*

Proportional mortality by causes of death at ages. (Assuming 1000 deaths in each age group.)

Age groups	P_1 Past.	P_1 N.E.*	P_1 Nil found	P_2 Past.	P_2 N.E.	P_2 Nil found	P_3 Past.	P_3 N.E.	P_3 Nil found	P_{3V} Past.	P_{3V} N.E.	P_{3V} Nil found	P_6 Past.	P_6 N.E.	P_6 Nil found
0–	652 ± 69	116 ± 29	232 ± 41	583 ± 78	250 ± 51	167 ± 42	585 ± 25	218 ± 15	197 ± 15	525 ± 61	284 ± 45	191 ± 37	636 ± 45	240 ± 28	123 ± 20
10–	468 ± 71	170 ± 43	362 ± 63	587 ± 88	280 ± 61	133 ± 42	662 ± 34	213 ± 19	125 ± 15	753 ± 50	177 ± 24	70 ± 15	630 ± 64	253 ± 41	117 ± 28
20–	525 ± 94	153 ± 51	322 ± 74	761 ± 129	87 ± 43	152 ± 58	609 ± 51	196 ± 29	196 ± 29	777 ± 54	174 ± 26	49 ± 14	602 ± 73	248 ± 47	150 ± 36
30–	634 ± 124	220 ± 73	146 ± 60	655 ± 150	310 ± 103	34 ± 34	566 ± 83	253 ± 55	181 ± 47	775 ± 87	176 ± 42	49 ± 22	600 ± 100	350 ± 76	50 ± 29
40–	703 ± 138	81 ± 47	216 ± 76	733 ± 221	133 ± 94	133 ± 94	679 ± 113	208 ± 62	113 ± 45	672 ± 103	219 ± 58	109 ± 41	615 ± 126	231 ± 77	154 ± 63
50–	588 ± 186	294 ± 132	118 ± 83	579 ± 175	421 ± 149	—	561 ± 100	228 ± 63	211 ± 61	778 ± 170	148 ± 74	74 ± 52	591 ± 164	273 ± 111	136 ± 79
60–	680 ± 165	120 ± 69	200 ± 90	521 ± 158	429 ± 143	48 ± 48	840 ± 101	74 ± 30	86 ± 32	641 ± 128	231 ± 77	128 ± 57	743 ± 146	229 ± 81	29 ± 29
80–	625 ± 161	250 ± 102	125 ± 72				778 ± 147	28 ± 28	194 ± 72	742 ± 155	194 ± 79	65 ± 45	533 ± 189	333 ± 149	133 ± 94
100–	720 ± 170	120 ± 69	160 ± 80	500 ± 224	300 ± 173	200 ± 141	860 ± 142	47 ± 33	93 ± 47	744 ± 132	209 ± 70	47 ± 33			
150–	750 ± 250	250 ± 144	—	—	—	—	889 ± 311	—	111 ± 111	750 ± 164	214 ± 88	36 ± 36			
200–	750 ± 250	167 ± 167	—	—	—	—	1000 ± 567	—	—	818 ± 273	182 ± 128	—	400 ± 282	600 ± 346	133 ± 94
250 and over	833 ± 373		—	—	—	—	—	—	—	—	—	—			

Table XI. *B. a. experiments.*

Proportional mortality by causes of death at ages. (Assuming 1000 deaths in each age group.)

Age groups	B_1 B. a.	B_1 N.E.	B_1 Nil found	B_3 B. a.	B_3 N.E.	B_3 Nil found	B_6 B. a.	B_6 N.E.	B_6 Nil found
0– ...	403 ± 75	292 ± 64	306 ± 65	482 ± 93	304 ± 74	214 ± 62	353 ± 46	406 ± 49	241 ± 38
10– ...	771 ± 59	179 ± 28	49 ± 15	567 ± 43	318 ± 32	115 ± 19	579 ± 35	351 ± 27	70 ± 12
20– ...	817 ± 80	135 ± 33	48 ± 19	667 ± 36	283 ± 23	51 ± 10	611 ± 30	357 ± 23	32 ± 7
30– ...	760 ± 101	200 ± 52	40 ± 23	711 ± 65	247 ± 39	42 ± 16	616 ± 49	357 ± 37	27 ± 10
40– ...	667 ± 167	208 ± 93	125 ± 72	667 ± 111	167 ± 56	167 ± 56	713 ± 94	275 ± 59	13 ± 13
50– ...	731 ± 168	192 ± 86	77 ± 54	750 ± 194	150 ± 87	100 ± 71	886 ± 159	57 ± 40	57 ± 40
60– ...	571 ± 165	333 ± 126	95 ± 67	619 ± 172	238 ± 107	143 ± 82	571 ± 101	304 ± 74	125 ± 47
80– ...	800 ± 283	100 ± 100	100 ± 100	667 ± 333	—	333 ± 235	688 ± 147	250 ± 88	63 ± 44
100– ...	700 ± 187	200 ± 100	100 ± 70·5	526 ± 166	316 ± 129	158 ± 91	698 ± 115	189 ± 60	113 ± 46
150– ...	600 ± 346	400 ± 282	—	455 ± 204	273 ± 157	273 ± 157	694 ± 139	139 ± 62	167 ± 68
200– ...	500 ± 500	—	500 ± 500	750 ± 433	—	250 ± 250	474 ± 158	263 ± 118	263 ± 118
250 and over	1000 ± 577	—	—	500 ± 189	143 ± 101	357 ± 160	353 ± 144	294 ± 132	353 ± 144

* *N.E.* refers to deaths of 'not examined' mice; *i.e.* the cadavera were too fragmentary for examination.

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main specific cause of death decreases with age, and material for the study of this is provided in Tables X and XI. The approximate values of the standard errors shown are merely of use to indicate the order of magnitude of the fluctuations attributable to chance. Judgment should be based upon the general run of the observations, and it is plain enough that there is no uniform tendency for the proportional mortality from the specific cause to decrease with cage age.

On the other hand, in the B_1, B_3 and B_6 experiments (Table XI) the specific deaths are in defect at ages 0–9 days, a result which seems to argue an incubation period as hinted (p. 262 *supra*). It appears, then, that the lower rate of gross mortality experienced by the older animals is not due to the substitution for the specific infection of some other infection of lower killing power within a population which, by selection and acquired immunity, has become relatively resistant to the original *materies morbi*. In other words, neither the elimination of the "unfit" by death nor the immunisation of the survivors will reduce the risk of death from the specific infection we have studied to negligible proportions. One often dreams of being able to render a population wholly immune from the risk of an infection by means of a routine method of prophylaxis; practical failures to achieve that end have been explained by the non-universality of application of the method. In this philosophy the reduction of opportunities to become infected—other than the resultants of immunisation —is of minor importance. Our experimental evidence, incomplete as it is, does not support that contention. We shall show in another communication that, although by purposive immunisation *before* exposure in a herd one can sensibly increase the expectation of life of the immunised, at least for a considerable range of x, we have not been able to extend it to a value even roughly approximating to what we take to be normal for mice shielded from the special risks which menace our herds. Nothing has emerged from our researches to suggest that under *any* conditions of selection or immunisation, environmental factors, in the sense of quality and quantity of infection, would become negligible.

Summary.

The results of this investigation may be summarised as follows:

1. The q_x or cage-age mortality curve of a herd increases rapidly to a maximum and thereafter descends to an approximately constant level which is much above the level of the q_x for normal mice of ages within the range of real, physiological, age of animals living in the herds.

2. At the latest ages under observation the principal factor of mortality is *still* the specific factor, so that the advantage produced by selective mortality and active immunisation is brought to a standstill far above the zero line. Exposure in a herd under the conditions of these experiments will not produce an ultimate population fully resistant to the specific factor of infection.

3. It is probable that a large proportion, perhaps a majority, of the members of a herd become infected early in herd life, and gradually increase their degree

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of immunity because variations of environmental conditions, so far as these are measured by the general herd mortality, become less and less influential on the ultimate mortality of the exposed to risk the later the point in time chosen for measurement.

4. Study of the form of the age-mortality curve is still proceeding; at present we cannot offer an adequate mathematical description of it which takes due account of the biological factors requiring attention.

5. Quite provisionally, we attribute the difference in time of the maxima of the q_x curves of *Pasteurella* and *aertrycke* epidemics to a difference of average interval between infection and death.

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