A COMPARISON OF THE METABOLIC RATES OF VARIOUS INSECTS AS DETERMINED BY CARBON DIOXIDE OUTPUT

WM. A. HIESTAND, Purdue University

Since insects represent such varied types of activity it is interesting to determine and compare the metabolic rates of different forms. The activity of the insect itself gives us a general idea of the animal's metabolism but measurements of its metabolic rate are far more impressive. It would appear logical to assume that such insects as the Hymenoptera and Diptera should have higher rates of metabolism than the Coleoptera since in general the former are more active forms. The following investigation was carried on with 14 different insects with which 23 determinations were made under similar conditions. The purpose of the work was: (1) to determine how great differences exist in the metabolism of insects of different groups; (2) to ascertain if there exists a standard rate of metabolism for each insect or each species; and (3) to note if a correlation exists between the "activity" of the insect and its metabolic rate.

Historical. A number of metabolic determinations have been made upon insects by various workers. In his important contribution to our knowledge of respiration, Krogh (1916) so admirably summed up the data of previous workers that the writer feels it unnecessary to include these references in this paper. Krogh lists the metabolism of some 12 insects as determined by measurements of oxygen consumption or carbon dioxide output.

Davis and Slater (1926) have demonstrated a higher metabolic rate in small cockroaches than in large ones. Sayle (1928) has likewise shown an inverse relationship between metabolism and body weight with dragon-fly nymphs. Many other investigators have recorded the metabolism of insects during different stages of metamorphosis. This paper is concerned, however, with insects in the imago state only.

Material and Methods. The insects studied are listed in the accompanying table. They represent four orders. In a few cases several determinations were carried out with the same individual and are so noted. In all determinations identical conditions were maintained as far as possible. The insects were placed in a wire screen cage and left in the constant temperature box for several hours (12 or more) to allow their metabolism to become normal. Handling of the insects was avoided as much as possible since it is generally known that this influences the metabolic rate of experimental animals. The effect of handling is perhaps more pronounced with vertebrates than with insects. The writer (1931) in a previous investigation with aquatic in-

"Proc. Ind. Acad. Sci., vol. 41, 1931 (1932)."

sects could not notice any marked effect on metabolism of carefully handling the insects in wire cages previous to an experiment.

Determinations of carbon dioxide were made by Lund's (1919) method. The only modification was the substitution of the wire screen cage to house the insect. $Ba(OH)_2$ of N/30 and N/100 strength was used, 10 cc. being placed in the insect jar and a like amount in the control jar. Titrations were carried out with N/100 HCl, with two drops of phenolphthalein as an indicator. In most instances the insect was confined in the jar for periods of one hour duration. With extremely small forms (e. g. *Chironomus*) the period was lengthened to two or four hours with the assumption that a better average could be obtained. The insect jars were of 100 cc. capacity which was believed to be sufficient to prevent any effects of diminished oxygen pressures. All determinations were made in a light-proof constant temperature box at $22° \pm 1°$ C. The insects were weighed and the carbon dioxide output per hour recorded. From these data the metabolic rate was determined. It is given in terms of mgr. of carbon dioxide per hour per gram body weight which is identical with gr. carbon dioxide per kilogram hour, the latter designation being commonly applied to larger animals.

Insect	Wt. in grams.	CO_2 per hour. mgr.	Metabolic rate. CO_2/gr. body wt./hr. mgr.
Coleoptera:			
1. Tetraopes	.155	.034	.220
2. Coccinella	.115	.036	.313
3. Coccinella	.115	.051	.443
Diptera:			
4. Musca	.028	.110	3.928
5. Musca	.028	.088	3.142
6. Chironomus	.0067	.013	1.940
Orthoptera:			
7. Microcentrum	.583	.294	.505
8. Microcentrum	.583	.435	.746
9. Melanoplus	.282	.242	.858
10. Melanoplus	.282	.349	1.240
11. Blatta	.088	.151	1.710
12. Blatta	.068	.134	1.970
13. Periplaneta	.502	.396	.788
14. Periplaneta	.502	.376	.749
15. Periplaneta	.475	.327	.689
16. Periplaneta	.475	.382	.804
17. Periplaneta	.475	.407	.855
Hymenoptera:			
18. Vespa	.035	.552	15.770
19. Polistes	.180	.455	2.518
20. Polistes	.179	.625	3.490
21. Polistes	.146	.466	3.190
22. Polistes	.146	.561	3.842
23. Polistes	.146	.514	3.520

Results and Discussion. The results of the determinations are given in the table. There is apparent a very great range of rates for different species, the two extremes being those of *Tetraopes* and *Vespa*. The metabolic rate of the hornet is therefore over 75 times as great as that of the milkweed beetle. Similar extremes in rate are listed in Krogh's summary table of "metabolism of cold-blooded animals at temperatures about 20°." The metabolic rates of the insects listed in the above mentioned table correspond in general to those of the insects used in this investigation.

Not only is there a very great difference in the rates of different types of insects but also a variation in the more closely allied groups. For example, the average metabolic rate of the common *Blatta* is about twice as great as that of its larger relative, *Periplaneta*. The latter insect would average about six times as heavy as the former so the difference can not be accounted for by size alone.

A variation in rate is also apparent with different individuals of the same species and also with different determinations of the same individual. The question arises at this point as to whether or not the carbon dioxide output is an accurate index of metabolism. Assuming that the respiratory quotient is constant for a given individual we can possibly account for the variations in carbon dioxide output as due to slight variations from time to time in the ability of the insect to dispose of its carbon dioxide. This might easily be explained by the air sacs in connection with the tracheae. Lee (1929) has suggested that the air sacs allow a considerable volume of air to be inhaled and exhaled, thus causing a ventilation of the tracheal trunks. Herber and Slifer (1928) have shown that the respiratory movements of the Locustidae are variable. Thus we can easily see a reason for variations in the carbon dioxide output of insects from time to time under similar conditions.

CONCLUSIONS

It has been shown that a considerable difference in metabolic activity exists among the various groups of insects. The highest rate among the groups investigated existed with the Hymenoptera and Diptera. The lowest rates occurred with the Coleoptera; the Orthoptera lying somewhere between.

There is evidence to indicate that a correlation exists between the activity of the insect and its metabolic rate.

By means of carbon dioxide determination a standard metabolic rate can not be shown to exist in a given species or individual. Slight variations in rate occur with each determination under practically identical conditions.

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