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SPECIES OF FIREFLIES IN JAMAICA (COLEOPTERA, LAMPYRIDAE)[1]

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The large collection of fireflies brought by Dr. John Bonner Buck from the West Indian island of Jamaica in 1936 as samples of the forms upon which he had made spectroscopic and other observations has been studied together with material from the same island brought back by Dr. G. S. Miller in 1931, by Dr. R. E. Blackwelder and Dr. E. A. Chapin in 1937, and with other material in the National Museum and the American Museum of Natural History. The writer attempted, in 1910, to identify the samples upon which Dr. E. J. Lund had made his studies in the same island, but the few specimens then available for reference (collected in 1877 by H. G. Hubbard) and uncertainties in the literature led him to seek the help of the French authority Ernest Olivier, who kindly examined all the Neotropical species of Lampyridae then in our National Collection. This identified collection was borrowed and used in 1922 by Leng and Mutchler in their revision of the West Indian Lampyridae (Bull. Amer. Mus. Nat. Hist., vol. 46, pp. 431–485), but several of Dr. Lund's forms are below described as new. The twelve Jamaican species hitherto described are now increased to fifty, but several of these are represented by uniques and there are in addition some doubtful forms which are inadequately represented and await samples of males in order that further complication of the literature may be avoided. It is therefore probable that less than half of the species which live on this small island are yet known. Only two of the species are known from other islands also, these belonging to genera our species of which can alight upon and fly from the surface of water. The record of a third species, native in Haiti, but cited as from Jamaica by Ernest Olivier 1912, requires verification.

Except for these three possible adventive forms, the Jamaican Lampyridae seem to accord with the very early isolation of this island, there being no definite affinities with Honduran or other Central American species. The large number of species may be a product of successive re-

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striction and enlargement of their habitat as Jamaica sank (Oligocene), leaving only the Blue Mountains in the East, and some small low islands in the West for their survival, and later (Miocene) emerged, bearing its great new layer of limestone which covers most of the island. The reoccupation of this new limestone area by vegetation and small animal life presented new environmental opportunities and permitted speciation to a degree not recognized on larger and older lands. Land snails, said to be also very numerous in species, doubtlessly nourish many species of native lampyrids, but actual observations on the preferred prey of glowworms elsewhere are very few and no such information from Jamaica is available. One minute slender and anomalous firefly, discovered accidentally in a sample of about 30 cc. of chironomid flies from a swarm about Dr. Miller's lantern far back (one-quarter mile or more) within the mouth of an underground passageway, suggests almost recent development of cavernicolous forms in the subterranean drainage systems which honeycomb this great 1,500-foot layer of limestone.

The taxonomy of the Lampyridae has been greatly retarded by the inadequacy and poor quality of samples which are regarded as standard. The softness of the integument permits collapse, distortion, or shrinkage of structures while drying and conceals characters which, if obvious, would have led to a better classification. The results here presented are possible only from the excellence of the fresh alcoholic samples, which have permitted rapid and easy extraction of the genitalia and the fixing of the form of the distended body without permitting its collapse while drying. About 200 samples, containing nearly 500 males, thus prepared contrast strongly with older collections in which these structures are concealed. Their display in ordinary dry specimens is unsatisfactory, even by long and tedious treatment. Although, surprising differences exist in genitalia, even in certain externally similar forms, it is necessary in the key to use color and other superficial recognition characters formerly considered as trivial or merely variational. When thus used, such characters unfortunately associate quite unrelated species or dissociate close allies. A few trinomials have been used to suggest affinity rather than to indicate evidence of intergradation of real subspecies. The males described as three forms of *Photinus* (*lucernula, euphotus, and cinchonae*) agree in genitalic and some other structures and should form a separate genus, but it is suspected that one of the last two will prove to be a synonym of the genotype of *Jamphotus,* here based upon an apterous female. *Photinus amplus* is superficially like but not congeneric with *euphotus.*

This paper is offered to validate names which Dr. Buck needs to use in recording the results of his observations. Except where otherwise stated, the types of the new species are in the U. S. National Museum. Paratype samples will be placed in the American Museum of Natural His-

tory and the British Museum. The writer's voluminous notes on the different species, their relationships, bibliographies, diagrams of genitalic structures, consideration of faunal affinities, etc., must remain for the present as rough draft. When, out of the probably large firefly fauna of Jamaica, good samples of other species become available, such a summary of the subject as was planned on this material may become possible. Gratitude is due to Dr. Buck for the quality of his samples and the opportunity of studying them.

Fourteen specific names have been applied prior to 1940 to Lampyridae from Jamaica, but two of these are synonyms correctly suppressed by their author. Only half of the twelve named species are identifiable in the available samples the others must, therefore, be omitted from the key to species actually studied. It is therefore necessary for a student attempting to identify samples to know that some of these unplaced names may eventually be used for species which have here been named as new. In so far as now understood, the data on these unrecognized named species are summarized as follows:

A Luminous organs confined to sternite 8 ..... B

Luminous organs well developed in sternites 6–7 C

B (A) Pale yellow; sternites 6, 7, and 9 black in male, but in the female the black color occupying apical margin of sternite 6, all of 7, and apical half of 8. Length 10–12 mm. Type locality, Santo Domingo; the record from Jamaica is doubted. (*Lampyris glaucus* Oliv. 1790; *Pygolampis glauca* Dejean 1833, Ern. Oliv. 1912; *Photinus glaucus* Laporte 1833, L. & M. 1922) ..... *Diphotus glaucus* (Oliv. 1790)

Oblong, black-brown, mouth piceous; antennae black, bases piceous, annulate; pronotum deeply canaliculate, yellowish white with two brown discoidal spots; scutellum yellow; elytra brown, suture narrowly, side margin broadly, yellow; feet white, knees and tarsi brown. Length 7–9 mm. Jamaica (probably Dunrobin District). (*Photinus pantoni* Ern. Oliv. 1902, 1907; *Pygolampis pantoni* Ern. Oliv. 1912) ..... *Diphotus pantoni* (Ern. Oliv. 1902)

C (A) Elytral margins dark ..... D

Elytral margins pale. Elongate, subparallel; head and antennae piceous; pronotum attenuate in front, margins profoundly punctate, yellow, the disc black, thinly punctate and fossulate; elytra not wider than pronotum, black, the external and scutellar margins yellow; breast piceous; abdomen lucid, last segments waxy; feet yellowish white, anterior tarsi and tibiae infuscate. Length 6 mm. Jamaica. .... *Photinus suavis* Ern. Oliv. 1907

D (C) Length 7–8 mm. ..... E

Length 12 mm. Oblong oval, yellow; pronotum anteriorly rounded, thinly punctate, disc infuscate; elytra oblong, rugulose, costate, brownish; feet infuscate; male with last three ventral segments long, waxlike; female venter lucid. Jamaica. *Photinus ebriosus* Ern. Oliv. 1907

E (D) Oblong, yellow, elytra black; antennae, tibiae, and tarsi infuscate; scutellum black, its apex narrowly pale; length 7–8 mm. Jamaica. ..... *Photinus maritimus* Ern. Oliv. 1899

Oblong, piceous; pronotum short, anteriorly attenuate, rugulose; female with last four segments white, lucid; length 8 mm., male unknown. Jamaica. ..... *Photinus contemptus* Ern. Oliv. 1907

Those species which can now be distinguished in the available samples are treated in the following dichotomous table:

1. Tarsal claws simple 2

Anterior claw on each foot bifid, or cleft at apex; head not greatly retracted into prothorax, and partly visible from above; aedeagus with long filiform processes from the side lobes of the tegmen, the lateral lobes connate and without middorsal suture in basal fourth .... (*Photuris*) 49

2. (1) Males known; the females usually fully winged and apparently capable of flight, their elytra rarely shorter than the abdomen in dry samples, but in some species the females degenerate and brachypterous 3

Male unknown, female without wings ..... (*Jamphotus*) 38

3. (2) Males with subintegumentary white reflector of luminous organ occupying all, or at least the median area, of sternites of abdominal segments 6 and 7 4

Sternites 6 and 7 not apparently luminous in either sex; sternite 8 well developed and conspicuously the source of light .... (*Diphotus*) 40

4. (3) Sternite 8 of male bilobed, retracted so that often only the two rounded lobes project beyond apex of the light organ; aedeagus with lateral lobes of diverse forms but apically descending below the tip of the median lobe, which usually curves upward between them .... (*Photinus*) 5

Sternite 8 of male longer, less emarginate; aedeagus more compact, subcylindrical, the lateral lobes short, contiguous dorsally to apices above the longer, projecting median lobe ..... (*Pyractomena*) 39

5. (4) Luminous area of male occupying all of sternites of the 6th and 7th abdominal segments 6

Luminous organ of male reduced in width, occupying median half or third of sternites 6 and 7; pygidium subtruncate, sinuate, lutescent or faintly mottled; pronotum with large, transverse discal infuscation suffusing outwardly and onto the inflated areas over the very large eyes, the margins nearly white; scutellum nearly black at base, the apex paler and very coarsely punctured, elytra reddish brown; female unknown. Length 10 mm., width 4 mm. Kensworth, Feb. 1937 (type and 4 paratypes), and Derry, Feb. 14, 1937, Blackwelder and Chapin (1 paratype); Jamaica, 1877, H. G. Hubbard (1 paratype identified by Ern. Oliv. 1911 and by L. & M. 1922 as *maritimus*) .... *Photinus lucernula*, n. sp.

6. (5) Elytra usually whitish, or mostly pale with well-defined infuscate markings on a generally yellowish ground color 7

Elytra wholly pale brown, brown, or black, or with margins narrowly bordered with yellow 11

7. (6) Elytra entirely pallid or darkened only at base 8

Elytra ornamented with well-defined infuscate areas 9

8. (7) Size large (about 16 mm.); pronotal infuscation consisting of a discal cloud which includes paired paler spots and a pair of small dark spots at lateral fourth and basal third, scutellum white at tip, strongly infuscate at base, the scutum white; frontal interocular space white, the occiput infuscate; antennal joints dark, their apices paler; maxillary palpi, anterior tarsi and tibiae, and fourth tarsal joint of middle and hind legs conspicuously infuscate; aedeagus short, robust, conical, acuminate, with white lateral lobes and no ventrobasal tubercles on median lobe; sternite 9 apically broad and emarginate (*P. melanodactylus* Ern. Oliv. 1888) ..... *Photinus pallens* (F. 1798)

Size smaller (under 10 mm.); pronotum with small infuscate paired spots grouped at center of disc and a pair of darker oblique spots at basal fifth and lateral third; scutellum and scutum entirely white; front rufopiceous; antennae shorter, the joints not obviously paler at their ends; aedeagus elongate, depressed, the lateral lobes and the broad median lobe strongly bicolored, the median lobe with well-developed convex ventrobasal tubercles produced inwardly so as nearly to cover the median membranous area. Length 8–9 mm. Stony Hill, Feb. 10, 1937, Blackwelder and Chapin, Sta. 394 (type and 6 paratypes); Moneague, Aug. 5, 1936, Buck no. 140 (1 paratype), Montego Bay, E. J. Lund, 1910 (this paratype of *P. ceratus* L. & M. 1922 apparently belongs here.) ..... *Photinus naevus,* n. sp.

9. (7) Elytral infuscation consisting of a narrow, usually entire median vitta, anteriorly slightly excurved in basal third to humerus, thence following base of elytra to and involving base of scutellar lobe, the apex of which is pale 10

Elytral infuscation consisting of two pairs, basal and apical, of slightly oblique curved vittae usually coalescent near middle of elytra, the basal pair joining the suture at middle as well as at base, where it extends from humerus almost to the entirely infuscate scutellar lobe; the apical pair of curved vittae reaching the suture near apex; aedeagus short, compact, rounded, the white lateral lobes strongly curved and broadly truncate at apices, which meet vertically beneath the black, narrowly compressed apical process of the median lobe .... *Photinus commissus* Ern. Oliv. 1907

10. (9) Size larger (8–10 mm.), metasternum pallid; aedeagus strongly bicolored, somewhat resembling that in *naevus* but much more compact and less depressed, the median lobe laterally compressed and black in apical third, its lower side margin expanded near apex and armed with six or more slightly recurved sharp hooks on each side, the lateral lobes robust in basal half, apically depressed, their side margins not abruptly convergent, the excavated inner surface black and asperate in apical third, the apices, sides, upper basal and lower surfaces pale, the latter feebly convex and polished with inner margins produced to meet in a straight line below median lobe in apical half and

strongly angulate at middle so as to expose the median lobe in subbasal third through a subcircular opening. Kensworth, Feb. 19, 1937, Blackwelder and Chapin (♂ type, 1 ♀ paratype), between Mocho and Catadupa, July 19, 1935, Blackwelder (1 ♀ paratype), Pepper, Mar. 12–22, 1931, G. S. Miller (1 ♂ paratype), Chestervale, June 1936, Buck no. 84 (2 ♂ paratypes) .... *Photinus blackwelderi,* n. sp.

Size smaller (5–6 mm.), meso and metasterna piceous; aedeagus feebly bicolored, white except small infuscate subapical spot on inner surface of each lateral lobe and the flattened sides of median lobe in its apical third; median lobe flattened above, emarginate and membranous at apex, the expanded side margins asperate; lateral lobes subulate apically, deflexed and acuminate, meeting only at their tips below the ascending median lobe. Kensworth, Feb. 21, 1937, Blackwelder and Chapin (2 ♂, type and paratype) ..... *Photinus chapini,* n. sp.

11. (6) Elytra normally pallescent or very light brown as if immature 12

Elytra normally black, black with a narrow sutural and broader side margin yellow, or in a few forms uniformly dark reddish brown 16

12. (11) Abdomen entirely pale above and below 13

Abdominal tergites mostly or all black 14

13. (12) Size larger (9–10 mm.); aedeagus relatively broader. Type locality, Cumberland district, Clarendon. (Similar forms from Catherines Peak, Cinchona, Bath, etc., now confused under this name are tentatively placed here.) Buck nos. 88, 89 ..... *Photinus ceratus* L. & M. 1922

Size smaller (7–7.5 mm.); aedeagus relatively narrower (see also couplet 38). Montego Bay, Aug. 2, 1936, Buck no. 145 (type and 3 paratypes), June 23, 1910, E. J. Lund (9 paratypes) (*suavis* L. & M. part) ..... *Photinus lobatus morbosus,* n. subsp.

14. (12) Anterior mesonotal areas and scutellum dark 15

Anterior mesonotal areas (scutum on either side of the median membranous area) and apical half of scutellum conspicuously pale; elytra pale brown, darker basally; pronotum with discal brown spot occupying median fourth, and a pair of small postmedian spots at lateral fourths; sternites 2–5 and pygidium black, sternites 6, 7, 9, and middle of 8 pale; antennae black, the 11th joint pale at apex; aedeagus white, with slender lateral lobes; length 7–8 mm. Chestervale, 3,200 ft., June 1936, Buck nos. 36, 37, 39, 40, 41, 56, and 131 (type and 16 paratypes); Whitfield Hall, July 13, 1936, Buck no. 102 (2 paratypes) ..... *Photinus gracilobus,* n. sp.

15. (14) Pygidium of male and sternites 8 and 9 white; sternite 5 not pallescent near the light organs; pronotum pale with an elongate median brown clouded area occupying median fifth in basal half, and with a pair of small spots at lateral fourth near base. Length 5–6 mm. Mandeville, Mar. 5, 1931, G. S. Miller (type and 16 paratypes), Nov., Dec. 1919, Jan. 1920, Watson (50 paratypes in Amer. Mus. Nat. Hist. as *suavis* L. & M. 1922), Buck no. 159 (1 ♂ paratype), Buck no. 14 (3 ♂ paratypes); Mocho, 1935, Blackwelder (1 ♂ paratype) .... *Photinus leucopyge,* n. sp.

Pygidium black; sternite 5 with sides and base black, the middle area white as if luminous; sternite 8 largely infuscate; sternite 9 white; pronotal infuscation occupying median fourth in basal half without the small supplementary spots. Length 5–6 mm. Near Bath, St. Thomas, Mar. 2, 1937, Chapin and Blackwelder (type and 6 paratypes); Bath, St. Thomas, Jan., Feb. 1920, Watson (16 paratypes as *suavis* L. & M. 1922 in Amer. Mus. Nat. Hist.); Manchioneal, July 23, 1935, Blackwelder (7 paratypes) .... *Photinus melanopyge,* n. sp.

16. (11) Elytra very dark, with sutural and expanded side margins conspicuously yellow; form more elongate 17

Elytra black or brown without yellow margins 19

17. (16) Tergites 1 to 5 black, 6 to 8 white, length 6 to 8 mm. 18

Tergites 1 to 7 wholly black, the 8th with sides and apex pallescent; sternite 5 with apical margin white at middle; pale sutural margin of elytra posteriorly evanescent, not passing middle; pronotal disc entirely infuscate except a pair of reddish transverse spots each about one-fifth of the pronotal width and separated from each other by about the same distance. Length 5 mm. Cinchona to Morces Gap, July 28, 1936, Buck no. 91 (type and paratype ♂), Chestervale, July 25, 1936, Buck no. 162 (1 ♂ paratype), below Woodcutters Gap, July 27, 1936, Buck no. 8 (1 ♂ paratype) ..... *Photinus nothus,* n. sp.

18. (17) Aedeagus somewhat depressed (resembling that of *nothus*), the lateral lobes sinuously tapering with narrowly rounded contiguous apices extending conspicuously below and beyond the black, heavily sclerotized, apically widened and dorsally strongly carinate median lobe. Length 6–7 mm. Catherines Peak, June 26, 1936, Buck no. 87 (type and 11 paratypes), no. 95 (6 paratypes); Morces Gap to Cinchona, Buck nos. 70, 91, (7 paratypes), no. 160 (1 paratype); above Woodcutters Gap, June 27, 1936, Buck no. 16 (1 paratype) *Photinus flavolimbatus,* n. sp.

Aedeagus more cylindrical, the lateral lobes not tapering, their apices vertically obliquely truncate; the narrow cylindrical black median lobe curving upwards to between the truncate apices of the lateral lobes and armed with acute lateral denticles at middle and near apex. 1 ♂, Buck no. 50, Blue Mt. Peak, 7,000–7,300 ft., July 11, 1936 .... *Photinus alticola,* n. sp.

19. (16) Basolateral areas (scutum) of mesonotum pale on each side of the median membranous area, in strong contrast to the deeply infuscate scutellar lobe and elytra 20

Basolateral areas of mesonotum infuscate and concolorous with the scutellum and the elytra 27

20. (19) Aedeagus in ventral aspect distinctly elongate, the length of the lateral lobes greater than the width across their base 21

Aedeagus in ventral aspect distinctly short and blunt, the width across base of lateral lobes greater than their length 26

21. (20) Very large (15–18 mm.) and broad (about 6.5 mm.); the ventrobasal knobs of the median lobe of the aedeagus separated by from one-ninth to one-fourth of the width across base of lateral lobes 22

Size smaller (12 mm. or less) 23

22. (21) Female with elytra shorter, often exposing several segments of the infuscate abdomen; tergite 8 triangular or ogival, luteous, with pair of fuscous spots sometimes coalescent; male with aedeagus relatively shorter. Western Jamaica. (*P. opulentus* Ern. Oliv. 1907.) .... *Photinus xanthophotis* (Gosse 1848)

Female with elytra long, covering the pale abdomen; tergite 8 trapezoidal, its sides sinuate, its apex strongly biemarginate; male form more elongate and with aedeagus relatively longer. Blue Mountains, Catherines Peak, 5,000 ft., June 26, 1936, Buck no. 97 (type and 10 ♂, 3 ♀ paratypes); Cinchona, Morces Gap, 5,000 ft., July 28, Buck no. 91 (2 ♂, 2 ♀ paratypes); Whitfield Hall, 4,300 ft., July 13, Buck no. 99 (2 ♂, 1 ♀ paratypes); Buck no. 102 (1 ♂ paratype); Chestervale, Buck no. 40 (1 ♂ paratype); locality not listed, Buck no. 104 (4 ♂ paratypes), no. 142 (2 ♂ paratypes) .... *Photinus xanthophotis catherinae,* n. subsp.

23. (21) Larger (12 mm.), more elongate and less depressed; elytra reddish brown, all tergites black; aedeagus with ventrobasal membranous area of median lobe narrowly oval and at base (i. e., between the prominent sclerotized knobs) about one-fourth as wide as the base of the lateral lobes. Cinchona, Clydesdale, Blue Mountains, July 28, 1936, Buck no. 94 (2 ♂ ♂, type and paratype) .... *Photinus brunescens,* n. sp.

Smaller (8 mm. or less), more oval and depressed; aedeagus with ventrobasal membranous area between the prominent sclerotized knobs broadly oval, more than two-fifths as wide as base of lateral lobes, the median lobe shorter, broader, and laterally angulate above the internally angulate lateral lobes 24

24. (23) Larger (8 mm.), sternite 5 mostly luminiferous 25

Smaller (6 mm.), tergites black, sternites 2 to 5 black, 6, 7, 8 white with sides narrowly margined with black; form narrower, elongate, the pronotum narrower at base, conspicuously wider at apical third, the front margin broadly rounded, sometimes straight or almost emarginate at middle. Montego Bay, June 1910, E. J. Lund (type and 8 paratypes) (*suavis* L. & M. part) .... *Photinus lundi,* n. sp.

25. (24) Tergites black, sternites 2, 3, 4, black, 5 mostly lucid, its sides infuscate, 6, 7 white with narrow black side margins, 8 lucid at middle, laterally infuscate. Near Bath in St. Thomas, Mar. 2, 1937, Blackwelder and Chapin (type and 12 paratypes); near (8 mi. NW. of) Manchioneal, July 13, 1935, Blackwelder (16 paratypes) .... *Photinus melanurus,* n. sp.

Abdomen pallid, tergites 6, 7, 8 more or less infuscate at middle, side margins of sternites, 5, 6, 7, 8 not infuscate. Ridge of Blue Mountains, Chestervale (type locality), Whitfield Hall, Cinchona, Morces, Silver Hill, June 10–July 28, 1936 (type ♂, 46 paratypes including 2 ♀ ♀), Buck nos. 4, 15, 23, 42, 45, 46, 47, 53, 55, 69, 71, 76, 77, 92, 94, 102 ..... *Photinus variabilis,* n. sp.

26. (20) Larger (12 mm.), less convex, the lateral elytral punctures confused and not forming a conspicuous sulcus; body and dorsum of abdomen

almost entirely whitish; tergite 8 subtruncate, bisinuate; aedeagus with median lobe broader, subparallel, lateral lobes not internally produced before their apices and below the apex of the median lobe. Mandeville, Aug. 1, 1936, Buck no. 123. (1 ♂) .... *Photinus hypoleucus,* n. sp.

Smaller (9 mm. or less), more convex, elytra with lateral series of punctures forming a distinct submarginal sulcus; aedeagus with median lobe strongly conical in dorsal aspect and with lateral lobes internally angulately produced below apex of median lobe, meeting in a straight line in their apical third. Mandeville, Mar. 2–11, 1931, G. S. Miller (type and 38 paratypes); Buck nos. 18, 119, 122, 134, 157 and probably females 43 and 131 are placed here tentatively. (*maritimus?* Barber det., Miller 1935, Science, vol. 81, p. 590) .... *Photinus synchronans,* n. sp.

27. (19) Large (13–15 mm.), broadly oval, reddish brown; pronotal margins yellow, disc feebly tuberculate, brownish; antennae short 28

Smaller (5–10 mm.), more narrowly oval; antennae longer, reaching the hind coxae; elytra black 31

28. (27) Discal tubercles on pronotum more evident, tergites 1–7 black; the pygidium apically truncate, bisinuate and pallescent; sternites 2–5 shorter, pallescent with sides more or less infuscate, 6–7 unusually large; aedeagus very small, the lobes slender, subcylindrical and free 29

Discal pronotal tubercles feeble; tergites 6–8 yellowish white, sternites 2–5 longer, 6–7 normally developed; aedeagus nearly as in *ceratus,* the lobes flattened above and beneath and compactly fitted together 30

29. (28) Eyes larger, the interocular width below the antennal sockets about two-fifths the width of one eye in the same aspect; sternites 2–5 mostly pale, excessively short, together about as long as the greatly enlarged first luminous segment, sternite 5 more infuscate on hind margin near sides; sternites 6 and 7 of unusual width and length, each with a pair of sublateral foveae unusually large and sharply defined; pygidium infuscate, the apex pale. (♀ unknown). Length 13–14 mm. Whitfield Hall, July 13, 1936, Buck no. 102, ♂ type; doubtfully identical males from near Manchioneal, and Mocho (in U. S. Natl. Mus.) and from Bath (as *ebriosus* L. & M. in Amer. Mus. Nat. Hist.). (This may be a synonym, male, of *Jamphotus tuberculatus,* see couplet no. 44) ..... *Photinus euphotus,* n. sp.

Eyes smaller, the interocular width below antennal sockets more than three-fifths the width of one eye in same aspect; sternites 2–5 longer, together about as large as the two luminous sternites united, strongly infuscate except median fourth pallescent; sternites 6–7 not unusually expanded, the foveae normal; pygidium yellow, very faintly infuscate at extreme base. Length 15 mm. Cinchona, 5,000 ft. (type in Amer. Mus. Nat. Hist.). (This may be a synonym, male, of *Jamphotus tuberculatus;* see couplet no. 44.) .... *Photinus euphotus cinchonae,* n. subsp.

30. (28) Habitus, size and color as in *P. euphotus* but abdomen of male of normal proportions; sternites 2–4 brownish, 5–9 whitish; tergites 5–8 whitish, the pygidium rounded; female more broadly oval, the pronotum feebly

emarginate in front; sternites 2–4 pale brownish, 5–7 whitish, the luminous organ occupying median half of sternite 6; sternite 8 nearly equilaterally triangular, pale yellowish white, narrowly emarginate. Length 13–14 mm. Mandeville, Nov. 26, 1919, Watson (*ebriosus* L. & M. 1922, not E. Oliv., type in Amer. Mus. Nat. Hist.); Mandeville, Aug. 1, 1936. Buck no. 127 (♀ allotype) ..... *Photinus amplus,* n. sp.

31. (27) Median lobe of aedeagus with a pair of obliquely transverse, oval, subconvex or flattened, contiguous, ventrobasal plates 32

Median lobe of aedeagus beneath broadly membranous to its base, its sclerotized side margins without ventrobasal plates but with very slight broadening of the sclerotized side margin close to base 34

32. (31) Size larger (8–10 mm.); ventrobasal plates of median lobe larger, more flattened and nearly transverse; sternite 5 entirely white. Chestervale, 3,200 ft., June 13, 1936, Buck nos. 21, 42, 45, 54, 90, 161 (type and 14 ♂ paratypes), and nos. 41 and 163 (♀ ♀) ..... *Photinus lobatus lobatus,* n. subsp.

Size smaller (6–7 mm.); ventrobasal plates of median lobe strongly oblique and smaller. (A wholly pallid form possibly referable to this group is above named *P. lobatus morobsus,* see couplet 19) 33

33. (32) Sternite 5 pallid, its basolateral areas more or less faintly infuscate; aedeagus shorter with median lobe broad. Stony Hill about 1,400 ft., Feb. 10, 1937, Blackwelder and Chapin (type and 7 ♂ paratypes) ..... *Photinus lobatus obscurellus,* n. subsp.

Sternite 5 usually wholly black; aedeagus more attenuate and depressed, the median lobe more slender, its width in ventral aspect about one fourth its length. Windsor, Trelawney, Apr. 1–10, 1931, G. S. Miller (type and 8 ♂ paratypes) ..... *Photinus lobatus rapidus,* n. subsp.

34. (31) Sternite 5 pallid 35

Sternite 5 black, the hind margin often pallescent 37

35. (34) Tergites moderately infuscate; aedeagus narrower, more compact, the median lobe in ventral aspect more than three times as long as wide with its sclerotized side margins practically contiguous with inner margins of lateral lobes and with the vestiges of the ventrobasal plates very feeble or wholly obsolete. Length 5½–6½ mm. Chestervale, June 6–13, 1936, Buck nos. 2, 21, 40, 41, 45, 57, 58 (type and 14 paratypes). Cinchona, July 28, Buck no. 91 (1 ♂), Morces, Buck no. 93 (1 ♂), Woodcutters Gap, July 27, Buck no. 12 (3 ♂ paratypes) ... . *Photinus evanescens evanescens,* n. subsp.

Tergites paler (at least the three apical ones); aedeagus broader, the lateral lobes more arcuate, the median lobe broader, about twice as long as wide in ventral aspect with the vestiges of the ventrobasal plates evident and the dorsoapical membranous area more broadly U-shaped 36

36. (35) Slightly larger (7–8 mm.); tergites 6–8 pale; lateral lobes of aedeagus very slender and moderately arcuate in apical third, and usually curving away from or not contiguous with the median lobe, which shows

slight vestiges of the ventrobasal plates. Bath, St. Thomas, Mar. 2, 1937, Chapin and Blackwelder (type and 9 ♂ paratypes) .... *Photinus evanescens dubius,* n. subsp.

Slightly smaller (6–6½ mm.); posterior tergites somewhat infuscate; lateral lobes of aedeagus with outer margin feebly or not arcuate, the apices more flattened internally beneath the apex of the median lobe, the ventrobasal sclerotized margins of which are expanded into narrow convex fusiform areas. Moneague, Aug. 5, 1936, Buck nos. 107, 118, 124 (type and 5 paratypes). Jamaica, H. G. Hubbard, 1877 (identified as *contemptus* by Ern. Oliv. in 1911 and as *maritimus* by L. & M., 1922, 1 paratype) ..... *Photinus evanescens moneague,* n. subsp.

37. (34) Tergites 6–7 infuscate, the pygidium pale or basaly infuscate; aedeagus slightly variable in proportions and in the degree of evanescence of the ventrobasal lobes; possibly two forms in mixed population; in the typical form the aedeagus narrower in all proportions, the outer margins of the narrow apical part of the lateral lobes being straight or feebly emarginate and convergent (40°), the apical part of the median lobe obviously longer than wide with the ventrobasal enlargements usually imperceptible. Montego Bay, Aug. 2, 1936. Buck Nos. 121, 133, 154 (type and 28 paratypes). June 18, 1910, E. J. Lund (8 ♂ paratypes, identified as *contemptus* by Ern. Oliv., 1911, and as *maritimus* by L. & M. 1922; 2 ♀ paratypes referred to *suavis* by L. & M.), Lucea, July 25, 1910, E. J. Lund (2 ♂ paratypes, identified as *contemptus* by Ern. Oliv. 1911 and as *maritimus* by L. & M. 1922) ..... *Photinus evanescens montego,* n. subsp.

38. (2) Large (17 mm.) apterous female, the short dehiscent subtriangular yellow elytra hardly reaching the first tergite and exposing most of the metanotum, which is pale and transversely marked with a dark-brown band; pronotum dark brown, a little wider than long, hind margin nearly straight, the narrowly explanate margins almost evenly rounded; disc shining, very coarsely and irregularly wrinkled but very finely punctulate, and pubescent; scutellum broad and more strongly punctulate, the apex obtusely notched; abdomen broad with fine median carina, the tergites, except the reduced 8th, brown, each with a narrow, apically broader, median stripe, and broad triangular spot at each hind angle pale yellow, the surface densely punctulate with numerous irregular tubercles and with posterior margin strongly acutely tuberculate at outer angle and at median third, forming four equidistant rows of teeth on upper surface of abdomen; tergite 8 trapezoidal, yellow, with disc basally infuscate, apex truncate, feebly bisinuate, hind angles, acute, sides sinuate; sternite 7 almost wholly pale, the subcutaneous whitish reflector emarginate basally and apically but extended laterally beyond the submarginal fold as supplementary luminous areas in the pleural area below the spiracle; sternites 8 and 9 also pale but without the subcutaneous reflector layer. Catherines Peak, July 27, 1936, Buck no. 6, (1 ♀) .... *Jamphotus tuberculatus,* n. gen., n. sp.

39. (4) Color ochreous with darker longitudinal dorsal markings as follows: A pair of entire, closely approximate medial pronotal vittae basally joining a pair of abbreviated basolateral vittae; the discal elytral in-

fuscation divided into a broader submarginal vitta, a narrow median, and a narrower sutural vitta by the ochreous costae, the inner one of which becomes evanescent near the middle of elytral length, the outer one nearly attaining the apex. Length 8 mm. Type locality, Cuba; Montego Bay (1 ♂ in Amer. Mus. Nat. Hist.) .... *Pyractomena gamma* (J. Duval 1857)

40. (3) Prothorax, elytra, and habitus as in *Photinus;* form usually rather broad with margins expanded; sternite 8 whitish with a pair of sublateral oval subcutaneous white reflectors .... (*Diphotus* n. gen., type, *D. bucki,* n. sp.) 41

Habitus not as in *Photinus.* Form slender, size small, 3 mm.), margins not expanded, sternite 8 uniformly pallid .... (*Microdiphot* n. gen., type M. *cavernarum,* n. sp.) 48

41. (40) Pronotum conspicuously tumid on each side of the median sulcus; pronotal disc and elytra very dark, their margins and suture conspicuously pale; male with sternite 9 apically widened and distorted, its apex narrowed and armed dorsally with a pair of recurved hooks, aedeagus unusually long (3 mm.), narrow, apically attenuate. Length 12 mm. Blue Mountain Peak, 7,350 ft., July 11, 1936, Buck no. 50 (type); Cinchona, Aug. 4, 1923, C. C. Gowdey; Catherines Peak, 5,000 ft., July 27, 28, 1936, Buck nos. 66, 67 (6 paratypes) .... *Diphotus bucki,* n. sp.

Pronotal gibbosities and median sulcus feeble or obsolescent; sternite 9 normal; aedeagus short 42

42. (41) Pronotal disc with median line, or entire surface pale 43

Pronotal disc and elytra deep black, only the margins and suture conspicuously pale as in the last species, eyes moderate. Length 7 mm. Blue Mountain Peak, 7,300 ft., July 11, 1936, Buck no. 50 (1 ♂, type), 6,500 ft., on trail up Blue Mountain Peak, July 13, 1936, Buck no. 51 (1 ♀ flying 3.30 p.m.) ..... *Diphotus flavomarginatus,* n. sp.

43. (42) Pronotum with infuscate markings 44

Pronotum entirely yellow 47

44. (43) The large pronotal infuscation divided by a narrow median pale line .. 45

Pronotal infuscation reduced to two parallel and widely separated vittae, the latter broad at base over the elytral articulation, abruptly narrowed anteriorly reaching middle of pronotal length; elytra pale brown, the broadly expanded sides slightly paler; basal abdominal segments luteous; segments 6 and 7 of male black 46

45. (44) Mesonotum sharply bicolored, the scutellum and elytral articulations white in contrast to the black sclerotized areas on each side of the anterior notch; elytra and pronotal disc very dark brown with broad pale-yellow margins; legs very pale; body uniformly dark brown, tergite 8 pale in apical two-thirds; first two antennal joints pale, the outer joints wholly piceus. Length 7 mm. Catherines Peak, 5,000 ft., June 12, 1936, Buck no. 85 (1 ♀) ..... *Diphotus lucivolans* n. sp.

Mesonotum infuscate only in small lateral area close to elytral articulation, the scutellar lutescence extending forward on each side of the median notch; elytral and pronotal infuscation pale brown; the two

pronotal maculae each more or less divided by a vague sinuous pale line, into a larger inner and a narrower outer infuscate area; the median pronotal sulcus feeble; elytral side margins broadly, the suture narrowly margined with yellow and a fainter, somewhat evanescent, oblique median vitta extending from near humerus almost to the apex; pygidium black (female) or apically yellow (male); antennal joints black with base and usually also with apex pallescent. Length 7–12 mm. Cinchona to Morces, 5,000 ft., July 20, 1936, Buck no. 72, 116 (type and 7 paratypes); Whitfield Hall, July 13, Buck no. 96 (10 paratypes); Chestervale, June 8, Buck nos. 21, 39, 81, 82, 115 (16 paratypes); Cinchona, June 10, 1910, E. J. Lund (3 paratypes) ..... *Diphotus montanus,* n. sp.

46. (44) Larger (9–12 mm); elytra entirely pallescent but appearing darker over the wings; pronotal infuscate lines very narrow; aedeagus broader, the lateral lobes carinate internally, the carina produced into a lamellate hook applied to the sides of the upcurved, subcylindrical apical part of the median lobe. Mandeville, Aug. 1–4, 1936, Buck nos. 11, 120 (type and 5 paratypes); Mandeville, Dec. 11, 1919, Watson (1 ♀ in Amer. Mus. Nat. Hist. as *P. ebriosus,* (Mutch. 1923); between Mocho and Catadupa, July 7, 1935, Blackwelder (3 paratypes) .... *Diphotus ornicollis,* n. sp.

Smaller (7 mm.); elytra with faint broad median brownish vitta; pronotal infuscation broader; aedeagus narrow, the laterally compressed apex of the median lobe meeting the internally unarmed apices of the lateral lobes. Bath, Feb. 1–4, 1920, Watson (*Photinus pantoni* L. & M., part) (1 ♂) ..... *Diphotus mutchleri,* n. sp.

47. (43) Larger (male 10 mm.), the expanded margins of pronotum and elytra broader, the pale margins of the latter shading into the infuscate vitta, which is only about half as wide as the elytron. Catherines Peak, June 26, 1936, Buck no. 65 (type and 2 paratypes); St. Helens Gap to Morces, July 28, 1936, Buck no. 68 (paratype) .... *Diphotus semifuscus,* n. sp.

Smaller (male 5 mm.), the pronotal and elytral margins less expanded, the pale margins of the latter narrow so that the nearly black vitta occupies three-fourths of the width. Cinchona, July 28, 1936, Buck 35; Whitfield Hall, July 13, Buck nos. 3, 32; Silver Hill to Woodcutters Gap, July 27, Buck no. 34 (probably *Photinus unicus Mutchler* 1923, Amer. Mus. Novitates no. 63, p. 4) .... *Diphotus unicus* (Mutch. 1923)?

48. (40) Body yellow, the eyes black, elytra very slender, dark brown, shining, minutely asperate, with very narrow yellow sutural margin, and with outer margin deflexed and not expanded; tergites 4 to 6 infuscate, shining; antennae, stout, cylindrical, about four-fifths as long as elytra. Length 3½ mm. One ♂ in cave at Windsor, Apr. 10, 1931, G. S. Miller ..... *Microdiphot cavernarum,* n. sp.

49. (1) Pale, except antennae, labrum, front tibiae and apices of leg joints, an elongate discoidal pronotal spot, and two tapering and posteriorly obsolete vittae on each elytron, which are more or less strongly infuscate. Sexes similar with sternites 6 and 7 strongly luminous. Length 10–14 mm. ..... *Photuris jamaicensis* Ern. Oliv. 1886

STUDIES ON THE FIREFLY. III. SPECTROMETRIC DATA ON THIRTEEN JAMAICAN SPECIES[1]

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INTRODUCTION

It is a matter of common observation that the light emitted by different species of fireflies seems to differ in color. Among our common North American lampyrids, for example, the light of *Photuris pennsylvanica* appears greenish, while that of *Photinus pyralis* is definitely yellowish. On the other hand the intensity of firefly light is very low (ca 1/400 candle, Coblentz, 1912) suggesting the possibility (Knab, 1905) that the color "differences" may be a partly subjective consequence of the physiology of the human retina. As is well known, with light sources of less than 10 millilamberts brightness (which is of the order of magnitude of firefly light) the region of maximum sensitivity of the eye, i. e., the apparent color, shifts toward the blue, as vision shifts from the foveal cone vision to peripheral rod vision ("Purkinje phenomenon"). Thus a carefully controlled spectroscopic study is necessary to give objective proof of the range of color of the light of a given species or of a difference between species. Several such studies have been made, beginning with the relatively crude observations of Pasteur (1864) and culminating in the precise measurements of Coblentz (1912). These are summarized in table 1. The net result of these investigations has been to establish that the light emitted by fireflies consists of a broad structureless band, differing in extent in different species, but lying always wholly within the visible spectrum.[2]

The results tabulated in table 1 were obtained by such a variety of investigators and methods that they are of doubtful comparative value. In the present study advantage was taken of the excellent opportunity offered by the tropics for studying many species of living fireflies simultaneously, and the questions of species and sex differences in emission were investigated under comparable conditions.

[1] Received for publication October 1, 1940.

[2] For the sake of completeness, mention should be made of the fantastic reports that fireflies emit a penetrating radiation similar to X-rays. Thus Muraoka (1896) described the light of fireflies as penetrating sheets of copper, brass, zinc, etc., while Singh and Maulik (1911) found them to penetrate leather, paper and meat. Present-day photographic experience makes it nearly certain that the above-mentioned effects, like many of the so-called "mitogenetic ray" effects, were due simply to chemical vapors from the wood, paper or cardboard used to mask the photographic plates, as would have been apparent had not the investigators neglected to perform control experiments without fireflies.

TABLE 1.

Summary of Literature on Spectral Extent of Firefly Light

"V" = visual spectrometry, "P" = spectrophotography

Observer	Species	Method	Result (Å)
Pasteur, 1864	Pyrophorus (th.)	V	continuous band in visible
Young, 1870	Photinus?	V	>6560–4870*
Secchi, 1872	Glow-worm	V	continuous band in visible
Severn, 1881	Indian firefly	V	"
Conroy, 1882	English glow-worm	V	6560–5180
Dubois, 1886	Pyrophorus noctilucus (th.)	V	>6870–4870*
Langley and Very, 1890	Pyrophorus noctilucus (th.)	V	6400–4680
"	" (abd.)	V	6630–4630
Ives and Coblentz, 1910	Photinus pyralis	P	>6400– <5250
McDermott, 1910	Photinus pyralis	V	ca. 6200–5350*
"	Photuris pennsylvanica	V	ca. 6150–5400*
"	Photinus consanguineus	V	ca. 6150–5500*
McDermott, 1911	Phengodes laticollis	V	>6450– <5110*
Coblentz, 1911, 1912	Photinus consanguineus	P	>6400– <5250*
"	Photuris pennsylvanica	P	>6100– <5100*
"	Glow-worm (P. penn.)	P	>6150– <5300*
Ramdas and Venkiteshwaran, 1931	Glow-worm	P	5860–5290
Brooks, 1940	Glow-worm	P	5879–4690

* These measurements are approximations, either converted into Ångstrom units by the present writer from data furnished in other units (usually compared to Frauenhofer lines), or recalculated from figures, graphs or arbitrary spectroscope scale units given by the original authors.

The author is greatly indebted to the late Professor D. S. Johnson for opportunity to use the facilities of the Seventh Tropical Expedition of The Johns Hopkins University; to Dr. C. E. Brambel for the loan of the spectroscope; to Professor A. H. Pfund for aid in calibrating the spectroscope; to Mr. H. S. Barber for undertaking the very laborious task of identifying the species used; and to the National Research Council of the U. S. A. for a grant-in-aid for traveling and laboratory expenses.

MATERIALS AND METHODS

Twelve species of lampyrid and one elaterid firefly, native to Jamaica, B. W. I. were investigated. With the exception of *Photinus synchronans*,[3] which is primarily a seacoast form, the species studied were those common during June, July, and August, 1936 around Chestervale, the expedition's headquarters, located at an altitude of 3,200 feet in the Blue Mountains.

The spectroscope used (text-figure 1) was a Browning straight-tube type, 9 cm. long, of just sufficient dispersion to separate the yellow doublet at 5770 Å and 5791 Å in the spectrum of the mercury arc. This spectroscope had an arbitrary scale, extending from 0 to 10 in tenths, and

[3] For taxonomy of forms studied see Barber, H. S. "Species of fireflies in Jamaica (Coleoptera, Lampyridae)" in the present number of these Proceedings.

this was standardized by adjusting the scale by means of the sliding lever (fig. 1, "A") until the 2 ("200") line of the scale coincided with the strong sodium D lines at 5893 Å (plate 1, fig. 1). The scale was then calibrated against the red lithium line at 6708 Å, and the principal lines in

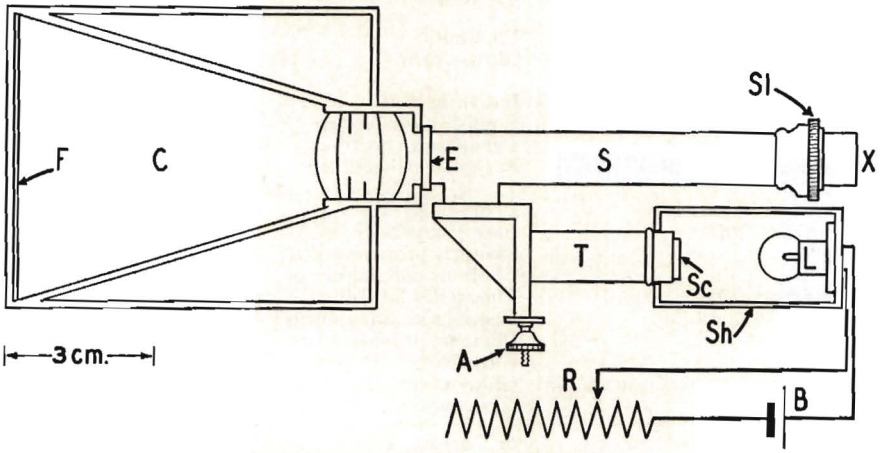

FIG. 1. Apparatus for measuring spectra of fireflies; top-view; semidiagrammatic. S, spectroscope; E. eyepiece; Sl, slit adjustor; X, position of firefly; T, side tube for scale; Sc, scale; Sh, shield for lamp; L, flashlight lamp; A, adjustor for setting scale; R, rheostat; B, dry cell; C, camera; F, film.

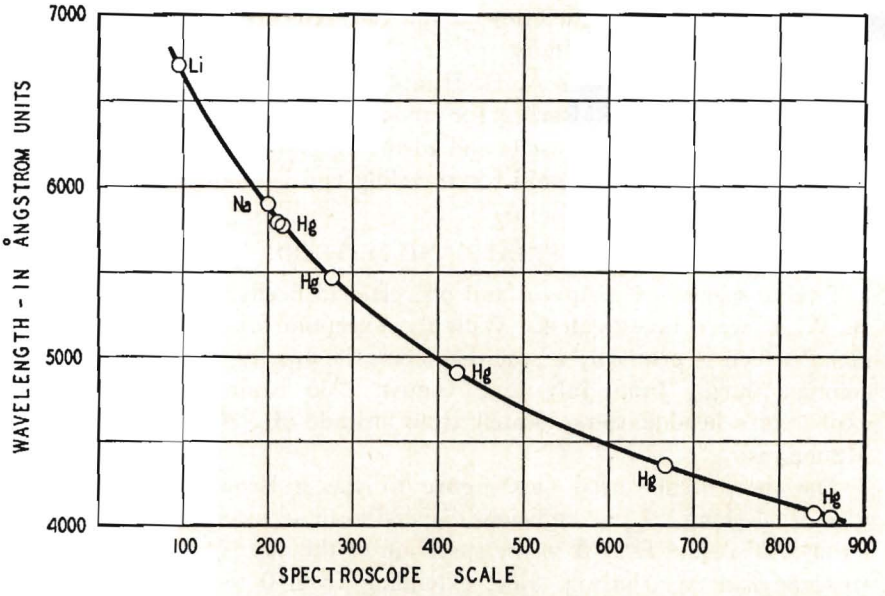

FIG. 2. Calibration curve for spectroscope: Abscissae, arbitrary units of spectroscope scale; ordinates, Ångstrom units. Calibration standards were the lithium and sodium flames, and the mercury arc.

the visible spectrum of the mercury arc (plate 1, fig. 4). The calibration curve is given in text-figure 2.

In measuring spectra all operations were conducted in total darkness. The procedures were as follows: The spectroscope scale was checked against the sodium flame, as described, and the width of the slit adjusted to 0.1 mm. The specimen to be examined was then attached by its dorsal surface to the ball of the index finger with rubber cement, and brought into position (text-figure 1, "X") in front of the slit so that the light from the light organ (ventral in the *Lampyridae*) was directed into the tube. Under such conditions the insects in their struggles ordinarily continued to flash at regular intervals for some time. For visual examination the spectrum was then viewed through the eyepiece (text-figure 1, "E") and the brightness of the scale adjusted (by means of the shielded ("Sh") flashlight lamp ("L") in series with a rheostat ("R") and dry cell ("B")) until it was too dim to interfere with observation, but bright enough to show the limits of the spectrum clearly. For photography a camera ("C") of 7.5 cm. focal length, loaded with Eastman Supersensitive Panchromatic film ("F") was attached to the eyepiece, the shutter was opened, and the firefly allowed to flash for some minutes after which the lamp was turned on for a few seconds to register the scale on the same negative with the spectrum. Where possible only one specimen was used for one spectrograph, and several individuals of each species were examined.

TABLE 2.

Spectrometric Data on the Light Emitted by 13 Jamaican Species

Those spectrographs marked with an asterisk are considered particularly reliable because of superior negative density

Species	Extent of spectra in Å			
	Photograph	Fig. No. Plate 1	Visual	Maximum Å
Photinus xanthophotis catherinae ♂ ...	6400–5350	7	6550–5200	5850
" " " ♀ ...				5800
Photinus pallens ♂	6425–5150*	5	6650–5150	5775
" " ♀	6450–5200*	6	6550–5125	5775
Photinus synchronans ♂	6450–5150*	11	6550–5200	5850
Photinus variabilis ♂	6600–5200*	8	6650–5225	5800
Photinus flavilimbatus ♂			6200–5275	
Photinus ceratus ♂			6200–5350	
Photinus evanescens evanescens ♂ ...			6550–5350	
Photinus gracilobus ♂			6550–5075	
Diphotus unicus			6450–5050	
Diphotus montani			6200–5150	
Diphotus semifuscus			6550–5125	
Photuris jamaicensis ♂	ca. 1275[4]	10		
" " ♀			6550–5225	
Pyrophorus plagiophthalamus (Th.) .	6500–5050*	2	6550–4975	5850
" " (Abd.)	6450–5400	3	6550–5150	5950
Phengodes sp.[5]			5900–5100	

[4] Scale accidentally omitted from spectrograph, so that only the extent can be given.
[5] Specimen collected by Professor E. N. Harvey at Tuxedo, N. Y.

RESULTS AND DISCUSSION

The results obtained are presented in table 2 and in plate 1.

As is often true in spectrography, the determination of the extreme limits of the spectra described was somewhat arbitrary. Their extents depend upon the intensity of the light (visual) or duration of exposure (photography), upon the width of the slit, upon the sensitivity of the eye or of the film, upon the dispersion of the spectroscope, etc. Add to these the difficulties of determining visually the exact extent of the spectrum of a flash of light of short duration (ca. 0.2 sec.), even if repeated many times, and of calipering small spectrographs on coarse-grained film accurately, and it will be appreciated that the limits given in table 2 define only the approximate minimal extents of the spectra. That this is true also for the investigations listed in table 1 is made plain by the work of Coblentz (1912) in which even the most careful densitometer measurements did not permit the specification of the exact limits of the spectra studied. Coblentz's measurements do show, however, as do his figures and the spectrographs given in plate 1 of this paper, that the spectra of firefly light are characterized by an extraordinarily abrupt diminution in intensity near their limits. It was noted in the present study, for example, that above a certain minimal negative density the extent of a spectrograph underwent little increase with increased exposure. It is accordingly believed that the photographic measurements recorded in table 2 are probably not in error by more than $\pm$ 25 Å, particularly in the cases where dense negatives were obtained (marked with asterisks). The visual measurements, on the other hand, in nearly every instance somewhat exceeded the extents of the spectrographs of the same species. This may possibly be a spurious effect due to subjective error in measurement, but is more probably due to the superior sensitivity of the eye to low intensities (as compared with that of the film) and would disappear if the film were exposed sufficiently long. In instances where the comparative extents of two spectra are rendered questionable by reason of unequal negative densities, a more reliable index of comparison is perhaps offered by the regions of maximum emission. Coblentz, for example, has shown by densitometric means that there are sharply defined differences in the emission maxima of three American species of firefly. The "emission maxima" listed in table 2 represent only the regions of maximum density in the negatives (obtained by visual inspection) but are adequate for comparative purposes since the sensitivity of the film used is fairly uniform throughout the region studied.

With due regard to the above-mentioned limitations, the following general conclusions may be drawn from the data presented:

Comparative spectra of the light emitted by male and female of the same species.—Possible differences in the color of the light emitted by

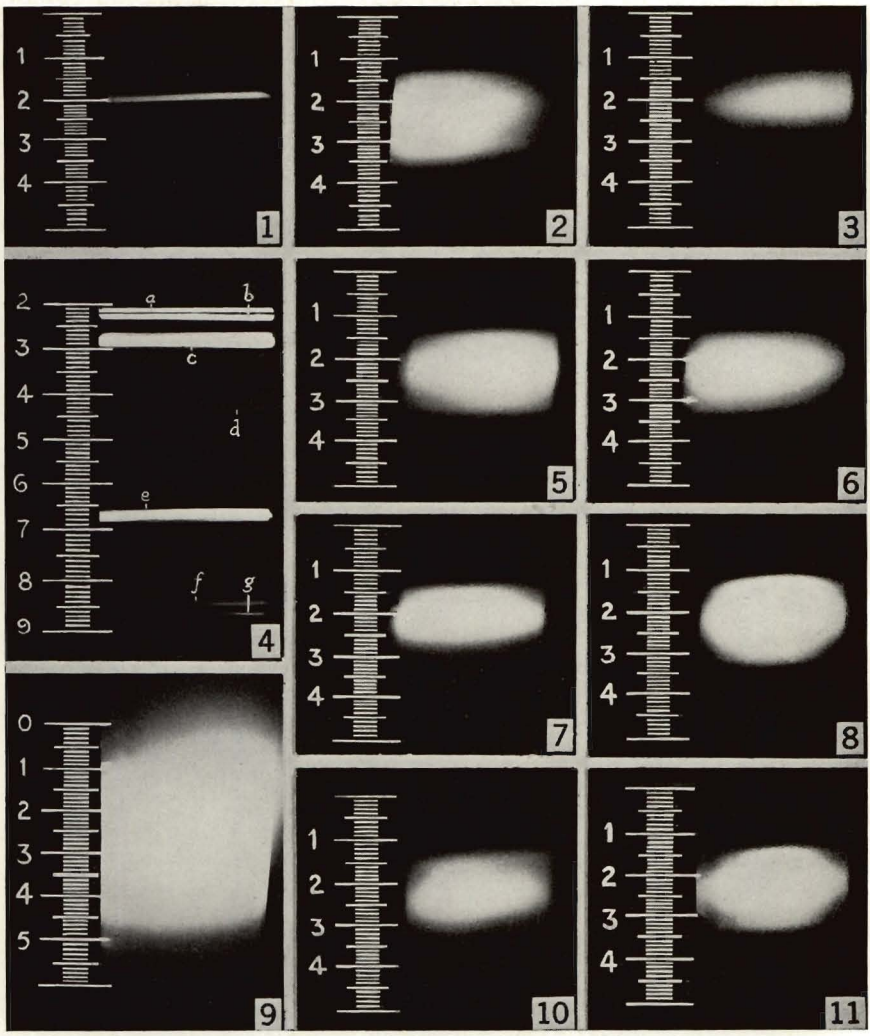

PLATE 1. Spectrophotographs of the light emitted by several species of Jamaican fireflies, and by standard comparison sources. The firefly spectra are probably very slightly less extensive than in the original negatives, due to loss in reproduction. In the original negatives the length of the scale from 0 to 4 is 1 cm. Fig. 1, sodium "D" line, used as the calibration standard. Fig. 2, thoracic organ of *Pyrophorus plagiophthalamus*. Fig. 3, abdominal organ of *Pyrophorus plagiophthalamus*. Fig. 4, spectrum of mercury arc used in calibration: a and b—the yellow doublets at 5791 and 5770 Å; c—the strong green line at 5461 Å; d—faint blue 4916 Å; e—blue at 4358Å; f and g—the violet lines at 4078 and 4046Å. Fig. 5, *Photinus pallens*, male. Fig. 6, *Photinus pallens*, female. Fig. 7, *Photinus xanthophotis catherinae*, male. Fig. 8, *Photinus variabilis*, male. Fig. 9, tungsten filament lamp. Fig. 10, *Photuris jamaicensis*, male; see footnotes 4 and 6. Fig. 11, *Photinus synchronans*, male. The scales in all the figures, and the lines in fig. 4 are slightly retouched to reduce the blurring effects of halation from over-exposure.

the two sexes of a given species have been suggested as factors in the system of mating signals, but no actual measurements have been recorded previously on this point. It was shown, however (Buck 1937a), that such possible differences are not factors in the mating signals of *Photinus pyralis.*

In the present investigation, good spectrographs were obtained from both male and female of *Photinus pallens,* and as will be seen in figs. 5 and 6, plate 1, and in table 2, they do not differ in extent by more than the experimental error, and the maxima appear to correspond exactly. In *P. xanthophotis catherinae* the spectrograph of the light of the female was somewhat lighter than that of the male, so that only maxima can be justifiably compared: these again are seen to be fairly close. In *Photuris jamaicensis,* as previously mentioned, the scale unfortunately was omitted from the spectrograph of the male[6] so that only the extent of the spectrum can be compared with that observed visually in the female: these however appear to be nearly equal.

In summary, then, it can be concluded that the light emitted by the two sexes of a given species is very similar, if not identical, in spectral characteristics.

Comparative spectra of the light emitted by different species.—The results presented in table 2 and plate 1 show the following: (1) As found also by previous workers, the light emitted by fireflies consists of a continuous band lying within the limits 5000 Å to 6600 Å. (2) Certain species, for example *Photinus xanthophotis catherinae, P. synchronans, Diphotus semifuscus and Photuris jamaicensis,* emit light of very nearly the same spectral extent. (3) Certain other species, for example *Photinus variabilis* and *Diphotus montani* emit light of markedly different spectra. The measurements confirm in this instance the striking observational difference between the rich yellowish light of *P. variabilis* and the distinct green of *D. montani.* (4) The light of some species, for example *Photinus pallens,* is comparatively wide in spectral extent, while other fireflies, for example *P. ceratus,* have a considerably smaller range. (5) There seem to be no characteristic differences in the spectra of the four genera examined, although histological work now in progress demonstrates that the structure of the light organs in the different genera does differ characteristically, and to an extraordinary degree. The fact that the light emitted by all the species studied appears to lie in the same general region of the spectrum appears to point to the same fundamental chemical reaction underlying the light production. However, the fact that there are distinct, though minor, differences in the light emitted by

[6] The scale in fig. 10, plate 1, is fitted by comparison with the spectrum of the female, and is included only to allow a rough comparison between the genera *Photuris* and *Photinus.*

different species, or even from different regions of the same individual (see below) indicates that there may be involved several types of luciferin and luciferase, the light producing substances (Harvey, 1920, 1940), much as there are many individual types of hemoglobin. Harvey (1917) has in fact demonstrated that in *in vitro* mixtures of luciferase and luciferin from different species of fireflies the color of the luminescence resulting is determined by that of the species furnishing the luciferase.

Comparative spectra of the light emitted by thoracic and abdominal organs of Pyrophorus plagiophthalamus.—The tropical elaterid beetle *Pyrophorus* is unique among fireflies in possessing a pair of circular light organs on the dorsal surface of the thorax (which emit light continuously while the insect is at rest or is walking, and are extinguished during flight), and a single larger rectangular organ on the anterior surface of the first abdominal segment (which is only alight during flight, when the abdomen is flexed so as to open the cleft between the thorax and the abdomen). It was early reported that the thoracic light organs emit "green" and the abdominal "red" light, and Langley and Very (1890) confirmed this difference by visual spectrometry (table 1), but so far as the writer is aware no photographic record of the spectra has been obtained previously. Figures 2 and 3, plate 1, show the striking difference in spectral extent between the light emitted by the thoracic and abdominal organs of *Pyrophorus plagiophthalamus.* Curiously enough, in this species the spectrum of the thoracic organ (6500 to 5050 Å)[7] extends if anything a little farther toward the red than that of the abdominal organ (6450 to 5400 Å) so that the much greener color of the former is due mainly to its greater extent toward the blue, and also to its different emission maximum. In *Pyrophorus noctiluca,* according to Langley and Very (table 1), the spectrum of the (greener) thoracic organ does not extend as far toward the red as that of the abdominal organ, and they are about equal at the blue end.

SUMMARY

Spectrometric data for the light emitted by 13 species of Jamaican firefly are presented. It is shown that each of these emits light consisting of a continuous band of greater or less extent within the limits 5000 to 6600 Å. There is no indication that the light emitted by males and females of the same species differs significantly in spectral characteristics. Some species have nearly identical spectra, some have quite different ones; some have relatively broad spectra, some narrow. The thoracic and abdominal organs of *Pyrophorus plagiophthalamus* have spectra of strikingly different extents and emission maxima, corresponding to their re-

[7] A re-measurement of the films changed the limits slightly from those contained in the preliminary report (Buck 1937b).

ported "green" and "red" colors. No consistent difference in spectral quality of the light of the four genera investigated was detected.

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THE SELECTIVE EFFECT OF CLIMATE ON THE FLOWERING BEHAVIOR OF SOLIDAGO SEMPERVIRENS L.[1]

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In the past few years biologists have been focusing their attention on the problem of micro-evolution or the study of speciation in its various aspects (Huxley, et al., 1940). The development of many experimental methods has contributed greatly towards an analysis of this obscure problem. The experimental garden has been used very effectively in Sweden by Turesson (1925, 1930, 1931) as a standard environment in which to establish genetic differences between various strains within a species. Extensive investigations of a similar nature have been carried out more recently in North America by Evans (1939) and Clausen, Keck and Hiesey (1940) in which plantings at different latitudes and at different altitudes have been employed. It has now been demonstrated by such methods that genetic differences in flowering time occur within the members of a number of species such as *Solidago virgaurea* L., *Bupleurum longifolium* L., and *Polygonum bistorta* L. in Europe (Turesson, 1931) and *Potentilla drummondii* Lehm. (Clausen, Keck and Hiesey, 1940) in North America. Individuals belonging to these species collected from northern stations or at high altitudes, where the growing season is short, flower earlier than specimens with more southerly distributions or from lower altitudes. In this paper is described a similar case of climatic differentiation of a species into a series of strains distinguishable on the basis of their flowering behavior.

Solidago sempervirens L. (plate 1C) is a species of golden-rod inhabiting salt marshes along the Atlantic Coast from Newfoundland to Mexico. In the north it appears only as the typical species, but between Massachusetts and Virginia it passes into *S. sempervirens* L. var. *mexicana* (L.) Fernald (plate 1A), and further south probably only the southern variety is found. Fernald (1935) distinguishes the variety primarily by its narrower, somewhat ciliolate leaves and smaller heads. It also grows somewhat taller than the species. Fernald states that in the overlapping ranges the variety tends to inhabit the more sheltered brackish localities, whereas the typical species grows characteristically on the saline outer beaches.

[1] Received for publication February 15, 1941.

This wide north-south range (from 25° to 50° north latitude) makes *S. sempervirens* and its southern variety very favorable material with which to study the selective effect of latitude on flowering time. Owing to its strictly maritime distribution, herbarium material can be readily used without having to consider complicating effects due to altitude. Data as to the flowering seasons in different portions of the range have been obtained from the dates of collection of all of the good flowering specimens available in the Gray Herbarium, the United States National Herbarium, the Herbarium of the New York Botanical Garden and the private collections of Dr. W. S. Phillips and of the writer. The data are presented graphically in figure 1, in which the range has been split up by states into convenient north-south sections. The species (solid black) and its southern variety (white) have been distinguished wherever possible. The shift in flowering dates—the median indicated by an arrow in each case—as one passes from north to south can be clearly seen. North of 45° north latitude, in Canada, plants are flowering about August 18, whereas south of 36½° north latitude, from the Carolinas southward, they are blooming about October 10. It will be noticed that south of 31° north latitude, in Georgia, Florida and Texas, there are two blooming seasons, one in October and the other in April. This is due to the mild winters which permit growth to occur throughout the year.

The classical paper of Garner and Allard (1920) demonstrating photoperiodic behavior in plants started research in a new field, the physiology of floral initiation. It has now been established that many species will flower only under a long photoperiod (long-day plants) whereas others will flower only under short photoperiods (short-day plants). Allard (1932) has pointed out that certain species of plants are limited in their northerly or southerly distribution by their photoperiodic requirements. Short-day plants may have insufficient time to complete their reproductive cycle in the short northern fall while long-day plants may never obtain a sufficiently long photoperiod in the south to initiate floral primordia.

In *Solidago* floral initiation takes place from four to six weeks prior to flowering time. From figure 1 floral initiation in *S. sempervirens* would be expected to take place in Florida in September and March when the photoperiod is approximately twelve hours in length. In Canada, on the other hand, this process must take place in early July during a photoperiod of about 16 hours. It is clear that the photoperiod at which the flowering phase is initiated is very different at the north and south extremes of the range of this species.

The question arises, could these different flowering dates at various latitudes be explained on the basis of genetic similarity of all the individuals of the species with respect to flowering behavior, the differences in dates being due to responses to different environments. This question

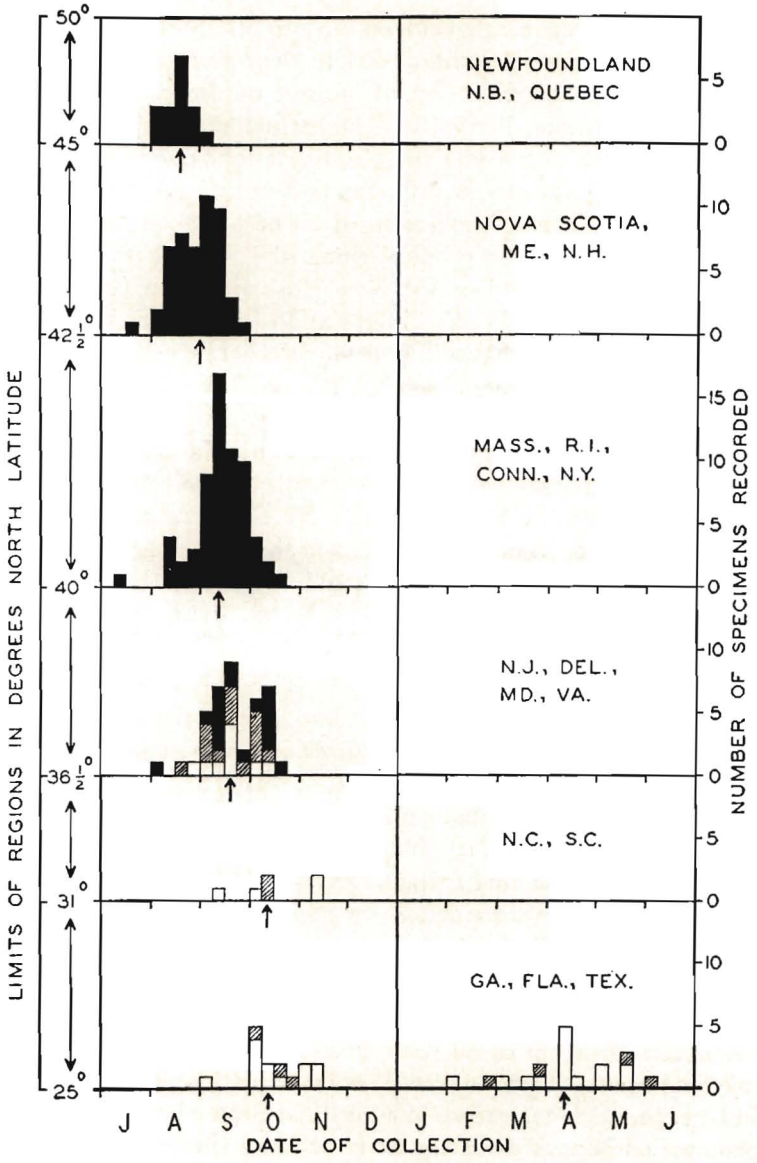

FIG. 1. Graphical representation of the collection dates of all the good flowering specimens of *S. sempervirens* and its southern variety in the Gray Herbarium, the United States National Herbarium, the Herbarium of the New York Botanical Garden, and in the private collections of Dr. W. S. Phillips and of the writer. The range has been split up by states into suitable sections, the north and south limits of which are given at the left. *S. sempervirens*—solid black; *S. sempervirens* var. *mexicana*—white; varietal determinations uncertain—cross-hatched.

may be answered by growing plants from various latitudes under the same environmental conditions.

TABLE 1.

Flowering dates of Solidago sempervirens L. and S. sempervirens L. var. mexicana (L.) Fernald at Rochester, N. Y. in 1940.

Place of Original Collection	Specimen	Anthesis of First Flowers	Plants in Full Bloom	Remarks
Ipswich, Mass.	a	Sept. 18	Oct. 3	See plate 1C.
Ocean City and Point Lookout, Md. ...	b, c	Oct. 4	Oct. 12	See plate 1F, G.
Ft. Myers, Fla.	d	Nov. 16	Nov. 26	See plate 1A, D. Plant brought into greenhouse on Oct. 16.

a Plants grown from seed obtained by cross pollinating two specimens of *S. sempervirens* collected on the sand dunes at Ipswich, Mass. in 1934.

b Plants of *S. sempervirens* var. *mexicana* transplanted from a sandy, vacant lot behind the beach at Ocean City, Md. in 1934.

c Plants of *S. sempervirens* var. *mexicana* grown from seed collected by Mr. O. M. Freeman from Point Lookout, Md. in 1934.

d Plants of *S. sempervirens* var. *mexicana* grown from seed collected by Mr. W. M. Buswell at Ft. Myers, Fla. in 1934.

In the course of a cytogenetic investigation of two species of goldenrods (Goodwin, 1937) casual mention was made of the fact that plants of *S. sempervirens* var. *mexicana* from Florida were physiologically distinct from plants of the same variety collected in Maryland. It was observed that the Florida material flowered at least a month later than the Maryland and grew almost twice as tall (8 to 10 ft.), when cultivated in the greenhouse at Cambridge, Mass. These observations have been confirmed over a period of five years. Table 1 gives the dates of anthesis of the first flowers and approximate dates of full bloom for plants from Ipswich, Mass., Ocean City and Point Lookout, Md., and Ft. Myers, Fla. under cultivation outdoors at Rochester, N. Y. in 1940. The dates are somewhat later than the median for these plants in their original habitats. The differences in flowering dates between specimens collected in these various localities show clearly, however, that these plants differ genetically from one another in their flowering behavior under the same environmental conditions.

The plants from Maryland (plate 1F, G) and Florida (plate 1A, D, E) both belong to the southern variety and are morphologically identical, with the exception that the Florida material in the north usually grows taller than the Maryland. This may be due at least in part to the longer growing period. Turesson (1930, 1931) reports similar differences in height in races of *Solidago virgaurea* and of other species. In addition, it should be noted that specimens from Florida probably cannot complete their re-

productive cycle outdoors at the latitude of Rochester. Plants from Miami, Florida (plate 1E), which were at exactly the same stage as the Ft. Myers material on October 16 and which were left outdoors, were killed by frost on October 21. This "lack of hardiness" of the southern material should be attributed to a delay in reproductive activity resulting in the presence of tender, actively-growing meristems at the time of the early frosts. Here is a case in which the northward extension of a southern, short-day strain would be limited by two climatic factors, photoperiod and early frost.

Successful crosses have been made between *S. sempervirens* from Ipswich, Mass. (plate 1C) and *S. sempervirens* var. *mexicana* from Ocean City, Md. (plate 1G). The progeny from such crosses (plate 1B) are very similar in appearance, height and flowering time to *S. sempervirens* from Ipswich. The number of these plants under observation has been too small to draw any conclusions as to the inheritance of flowering behavior but the results indicate that no serious genetic barriers occur between the species and its southern variety.

SUMMARY

An analysis of the flowering dates of *Solidago sempervirens* L. at various latitudes along the Atlantic Coast shows that this species flowers progressively later in the season as one passes from north to south. When plants from different portions of the range are grown at the same latitude under similar conditions these plants still flower at different times, those from the north flowering earlier than those from the south. This has been interpreted as evidence for the existence within the species of a graded series of strains genetically distinguished from one another by their physiological requirements for floral initiation.

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PLATE 1. Strains of *Solidago sempervirens* L. all photographed on October 9, 1940 at Rochester, N. Y. A. and D.—*S. sempervirens* var. *mexicana* from Ft. Myers, Fla., in early bud. B.—A cross between *S. sempervirens* ♀ from Ipswich, Mass., and *S. sempervirens* var. *mexicana* ♂ from Ocean City, Md. past full bloom. C.—*S. sempervirens* from Ipswich, Mass., past full bloom. E.—*S. sempervirens* var. *mexicana* from Miami, Fla., in early bud. F.—*S. sempervirens* var. *mexicana* from Point Lookout, Md., nearly in full bloom. G.—*S. sempervirens* var. *mexicana* from Ocean City, Md., nearly in full bloom.


A
B
C
D
E
F
G

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A RESPIRATORY STUDY OF BARLEY GRAIN AND SEEDLINGS[1]

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INTRODUCTION

Though many papers have appeared on the respiration of seeds and seedlings practically no information is available on the nature of the oxidases catalyzing this respiration. Nor has any attention been paid to the problem of whether the oxidases functional in embryos and early seedlings are of the same nature as those functional in the older plant. Allen and Goddard (1938) observed that the respiration of mature wheat leaves is not inhibited by sodium azide or HCN though they had some unpublished observations which indicated that the respiration of immature leaves was inhibited by these poisons. Further, Ross (1938) has shown that the respiration of wheat seeds is partially inhibited by HCN. Marsh and Goddard (1939a) had shown that a large fraction of the respiration of mature carrot roots and immature leaves was inhibited by HCN, NaN_3, and CO with light reversal, while the respiration of mature carrot leaves was not so inhibited. In view of the results of Warburg (1928) and of Keilin (1929, 1936), Marsh and Goddard interpreted their results to mean that the respiration of carrot roots and immature leaves is catalyzed by cytochrome oxidase while the respiration of mature leaves is mediated by some other oxidase. It seemed worth while to investigate more carefully this shift from one oxidase system to another in the course of differentiation of the seedling.

This paper will present results obtained with barley by the use of respiratory inhibitors (HCN, NaN_3, and CO) on intact grain, isolated embryos, endosperm, young seedlings, and on roots and leaves at two stages of development. These results indicate a qualitative differentiation of respiratory mechanisms accompanying morphological differentiation of the shoot. Also, results will be presented indicating the existence of aerobic fermentation in the early stages of germination and the existence of a Pasteur mechanism in grain, embryos, and seedlings. Though much data exists in the literature on the growth of the respiratory rate with germination, we felt it necessary to present some similar data as an introduction to the experiments mentioned above.

[1] Received for publication March 12, 1941.

[2] This work was carried out during the tenure of the Emma J. Cole Fellowship in Botany of the University of Michigan.

The literature on the respiration of seeds is vast and no attempt to review it will be presented here. The reader is referred to Stiles and Leach (1932, 1933) and Stiles (1935). The pertinent newer papers will be referred to in the discussion of our results.

MATERIALS AND METHODS

The grain used was *Hordeum vulgare* strain alpha, obtained from the College of Agriculture, Cornell University. The grain was stored in a desiccator over saturated $CaCl_2.2H_2O$ and solid crystals of $CaCl_2.2H_2O$. This mixture maintains a relative humidity of 32 per cent in the gas phase. Grain that has been stored in this manner reaches, in a few days, a constant moisture content, in this case of 8.32 ± 0.24 per cent. This method of storage was adopted after it was found that air dry grain soaked in water for 12 hours gave variable respiratory results. This variation was markedly reduced by the storage method given above.

The broken and discolored grain was discarded. The grains were individually weighed and only those between the limits 40 to 50 mg. were used. When individual seedlings were run, they were from grains which weighed between 44 to 46 mg. The grain was soaked in water for 12 hours, unless otherwise stated. If not used immediately after 12 hours in water it was transferred to moist filter paper in Petri dishes. For the experiments with "stripped seeds" the lemma, palea, ovary wall, and seed coat were removed as completely as possible, and the grain was always stripped just before use.

The usual procedure was to use 5 or 10 grains, embryos, or endosperm in each respirometer vessel. All vessels were set up duplicate. Except where noted, in the experiments with grains, embryos or endosperms, the bottom of the respirometer vessels were lined with No. 40 Whatman filter paper and moistened with 0.1 ml. of dilute Shive's solution. (KH_2PO_4 0.490 gm./1 ; $Ca(NO_3)/2.4H_2O$, 0.254 gm./1 ; $MgSO_4.7\ H_2O$, 0.739 gm./1 ; $FePO_4$ 0.00088 gm./1). Dry grain was placed in the vessels with 0.6 ml. of Shive's solution, and leaves and roots in 2.0 ml. of Shive's solution, and with roots 2 per cent sucrose were included in the solution. The Fenn (1928) micro-respirometers used had a sensitivity of 0.6 $mm.^3$ per mm. of scale deflection. The bath temperature was either 22° or 25°C. ± 0.01 and is indicated for each experiment. All results are expressed as values of dry gas at 0° C. and 760 mm. Hg. In O_2 consumption measurements CO_2 was absorbed by 5 per cent KOH in the insets. The aerobic CO_2 was determined by Warburg's (See Dixon, 1934) two-vessel direct method. Anaerobic CO_2 was measured in an atmosphere of tank nitrogen freed of oxygen by passage over freshly reduced hot copper. CO was generated by H_2SO_4 dehydration of formic acid, washed through KOH,

and mixed with O_2 in burette bottles. Krebs (1936) KCN/KOH mixtures were used in the insets in the HCN experiments.

The apparatus was shaken 120 times a minute through an arc whose chord is 2.5 cm. This was sufficient to prevent gas diffusion from the atmosphere into liquid being a limiting factor, except where grain was submerged in 2.0 ml. of liquid. No data are reported where gas diffusion to suspending liquid is limiting.

In the cyanide and azide experiments the grains, seed parts, or seedlings were soaked for ½ hour in the poison and then transferred to the respirometer vessels, in which the filter paper was moistened with the same concentration of poison solution. The KCN solutions were neutralized and made to volume in Shive's solution.

The respiration of green tissues and seedlings was measured in a photographic dark room, with a very weak light used only during the period of reading of the apparatus. For light reversal of CO inhibition 100 watt lamps 10–12 cm. from the bottom of the vessels were used.

EXPERIMENTAL RESULTS

Germination and Respiratory Metabolism. Prior to a study of the nature of the oxidases catalyzing respiration, some experiments were undertaken to determine the growth of the respiration with time. Though these results duplicate, in part, some results in the literature, features of our experiments are worth reporting. Further, it is impossible to determine the percentage inhibition by respiratory poisons if gas diffusion is limiting the respiratory rate. Therefore, we examined the relations between oxygen diffusion and respiratory rate.

All results are expressed as $mm._3$ of dry gas at 0° C. and 760 mm. of Hg. Results given as dry weight are calculated on a basis of the weight of grain of 8.32 per cent moisture, and are therefore not strictly dry weight. The dry weight of soaked grain and seedlings is the dry weight, as above, of the grain and not of the seedlings. Wet weights are weights of grain or seedlings that had imbibed water.

One frequently sees the statement that air dry seeds do not respire. White (1909) has reported that several dry seeds have no respiration. However, a careful reading of her paper indicates that she would not have detected the low rates which occur. Some preliminary experiments showed two difficulties in determining the respiration of dry barley grain by the mannometric technique. First, absorption of water from the KOH of the insets causes the seeds to swell and the volume changes interfere with the mannometer readings. Second, preformed CO_2 is released when the tension of atmospheric CO_2 is reduced to zero. Though both effects are small, they are larger than the gas consumption measured. These difficulties may be overcome by the technique outlined below.

Barley grain was equilibrated for several days over $CaCl_2.2H_2O$ as outlined above. After the moisture content was constant the grain was transferred to a second desiccator over a solution containing 80 gm. KOH to 100 ml. of solution. This solution has the same vapor pressure as the Ca Cl_2 mixture. After 48 hours the grain had lost all preformed CO_2. To each of the two respirometer vessels were transferred 4.40 gm. of this grain, and to the inset and control vessel was added KOH from the desiccator. Control respirometers were set up in a similar fashion but without grain. After an equilibration period of 4 hours with the vessels closed, readings were commenced and continued for 48 hours. The experimental vessels showed a low oxygen consumption of 0.044 and 0.024 mm.^{3} O_2/gm. dry wt./hr. for the first 24 hour period and 0.048 and 0.027 for the second 24 hour period. These values are below the dependable limit of the apparatus. The control respirometers showed a negative drift (positive pressure) of 0.03 cm./hr.; if such a drift occurred in the experimental vessels, the O_2 consumption would be 0.027 mm.^{3}/hr. too low. The average value, corrected for control drift, is 0.062 mm.^{3}/gm. dry wt./hr. or 0.0028 mm.^{3} O_2/seed/hr. No great reliance may be placed on this figure, but we may reasonably accept 0.1 mm.^{3}/gm. dry wt./hr. as the upper limit of the oxygen consumption of this barley grain of 8.32 per cent moisture.

TABLE 1.

Oxygen consumption or CO_2 production of dry seeds.

Material	Gas measured and units	mm.^{3}/gm. dry wt./hr	mm.^{3}/ seed/hr.	Reference
Barley 8.32% H_2O 25°C.	O_2	0.062	0.0028	This paper
Barley 10–11% H_2O ?°C.	CO_2 0.33–1.5 mg./kgm./24 hr.	0.007–0.031	....	Kolkwitz (1901)
Barley dry seed 22°C.	CO_2 0.43 mg./80 grain/3 hr.	....	0.912	James and James (1940)
Wheat 12.5% H_2O 25°C.	CO_2 0.45 mg./100 gm./24 hr.	0.095	....	Bailey and Gurjar (1918)
Oat 14.31% H_2O 25°C.	O_2	0.31	....	Bakke and Noecker (1933)
Oat 9.16% H_2O ?°C.	CO_2 59 mg./kgm./5 day	0.25	....	Quann (1904)

Reference to table 1 will show the results obtained in comparison with those obtained by several other investigators. The divergence of results, with one exception, is not greater than is to be expected, considering the different conditions, materials, and methods. The value of James and

James is completely out of line, and is due to the fact that their value was not measured, but determined by extrapolation from the rate six hours after addition of water. Reference to figure 1 of this paper shows that this extrapolation is unjustified and may lead to a value more than 100 times too high!

When dry grain was allowed to imbide water in the respirometer a marked increase in respiratory rate occured with time, as is shown in table 2 and figure 1. For the experiments of more than 12 hours duration the grain was soaked in water for 12 hours at 25° C. and then transferred to moist filter paper in Petri dishes and maintained at 25° C, until just before the measurements were made. On seedlings of 24 hours or older, single seedlings were used in each vessel and the data in figure 1 represent averages of 4 seedlings for O_2 consumption and 4 similar seedlings for CO_2 production.

An inspection of figure 1 shows three clearly marked phases of respiration. An initial rapid increase in rate of O_2 consumption from 0–3 hours; a second phase of lower and variable acceleration from 3–12 hours, and a third phase beginning at 12–14 hours and continuing until 72 hours. The initial phase, and very likely the second phase, is associated largely with the imbibition of water. At 22° C. 1.0 gm. of dry grain imbibed 217 mgs. H_2O during the first 3 hours and 93, 53, and 30 mgs. of water in successive 3 hour periods. Though little data exist in the literature which shows the respiratory rate of seeds during the early hours of soaking, there are considerable data on the relation between increase of respiratory rate with increasing moisture. Particular attention may be called to the papers of Bailey and Gurjar (1918) and Bailey (1921). Recently, Shirk and Appleman (1940) have shown that when dry wheat grain imbibes water there is a rapid increase in freezable water and respiratory rate. If the grain is removed from the water and allowed to stand for several hours, there is a decrease in freezable water and respiratory rate, while the total water content remains practically constant. Their results indicate a striking correlation between freezable (free) water content and respiratory rate. The third phase, beginning at 12–14 hours is probably associated with the marked morphological development. At 12–14 hours the coleorhiza ruptures the seed coats. This rupture of the seed coats and the increase in surface probably mean a much increased oxygen diffusion. No particular significance should be attached to the linear curve from 12–72 hours in figure 1, the line is arbitrarily drawn.

If the data in figure 1 for O_2 consumption or CO_2 production are plotted as log rate against time, the curve is linear from 24–60 hours in agreement with the results of James and James (1940). During the first 2 hours the curve is so steep that extrapolation to zero time is unwarranted. The three phases recognized by James and James may be seen

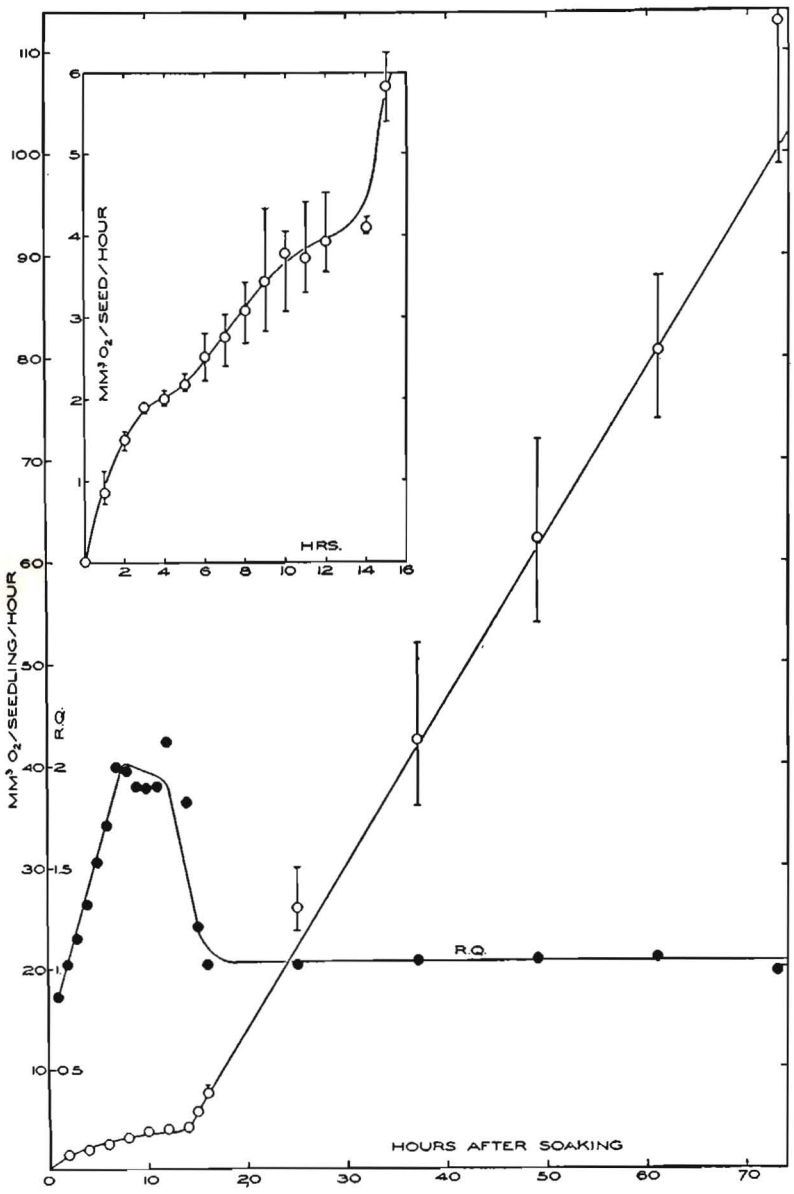

FIGURE 1. Open circles represent the rate of oxygen consumption per seed or seedling at 25° C. in relation to the number of hours after the first addition of water. Each point represents the average of 4 separate experimental vessels and the vertical lines represent the maximum deviation from the mean. The enclosed graph shows the first 12 hours on enlarged scale. Closed circles show the corresponding R.Q.

in our data, if put on a semi-log plot, except that we have insufficient points to establish the phase from 12–24 hours. However, between 0–12 hours our data splits into 3 phases, of dubious validity, except the much greater acceleration from 0–3 hours than 3–12 hours.

Since the rate of liberation of CO_2 increased more rapidly than the rate of O_2 consumption the respiratory quotient (R.Q.=CO_2/O_2) rose above unity (figure 1, tables 2 and 3) and between 12–16 hours returned to unity or slightly below. The decrease in R.Q. corresponded with the rupture of the seed coat and the emergence of the coleorhiza. The marked oscillations of R.Q. obtained by James and James (1940) were not found in our data, including several experiments at 22° C. not reported here.

TABLE 2.

Relation between time of soaking of barley seeds and gaseous metabolism.. Ten dry seeds placed in 0.6 ml. H_2O in respirameter vessels unless otherwise noted. Each figure is the average of 2 vessels run simultaneously.

Hours After Soaking	mm.[3] gas/gm. dry wt./hr. 25°C						
	O_2	Aerobic CO_2	R. Q.	Anaerobic CO_2	Meyerhof Quotient	Anaerobic CO_2	M.Q.
			Seeds started Dry				
1	22.1	16.4	0.74	13.9	0.63	...	...
2	34.4	36.4	1.06	24.0	0.64	...	...
3	40.4	47.8	1.18	31.8	0.60	...	...
4	45.7	61.7	1.35	38.4	0.49	...	...
5	49.7	74.3	1.48	46.1	0.42	...	...
						Seeds soaked [1] 6 hrs. in air	
6	57.8	100	1.70	51.0	0.17		
7	61.5	127	2.06	56.5	...	96.0	0.50
8	68.8	143	2.08	60.9	...	104	0.44
9	72.7	147	2.02	63.6	...	115	0.56
10	89.0	157	1.71	64.5	...	122	0.61
11	82.0	143	1.79	81.0	0.24	125	0.90
12	87.0	146	1.68	82.5	0.26	139	0.92
			Seeds soaked 12 hrs. in air [2]				
14	91.3	166	1.80	105	0.67	...	...
15	130	156	1.15	115	0.68	...	...
16	173	176	1.02	104	0.58	...	...
26	395[3]	390	0.99	231	0.59	...	...

[1] Run at the same time as the seeds started dry left hand columns. In this and the following tables seed was used for grain.

[2] 0.1 ml. of H_2O + filter paper in each vessel.

[3] Seeds from first run above removed, placed on moist filter paper and ½ of the seeds (5) returned to the respirometers at 25 hrs. and measurements continued.

The high R.Q. during early phases of germination has been found by several other authors, including James and James (1940) for barley, Fernandes (1923) and Frietinger (1927) for *Pisum sativum,* and *Genevois* (1927) for *Lathyrus.* That the high R.Q. is associated with a limita-

tion of oxygen diffusion has been pointed out before. That the high R.Q. was really due to a limitation of oxygen diffusion is seen from the data in table 3. Increasing the oxygen tension caused a marked stimulation of the oxygen consumption of whole grain and a fall of the R.Q., but the R.Q. was still above unity. Removal of grain coats caused a greater stimulation of oxygen consumption with the R.Q. distinctly below unity. That this respiration was sufficient to suppress all fermentation is apparent. "Stripped seeds" in 100 per cent O_2 had a higher rate of O_2 consumption than "stripped seeds" in air; however, this increase was not associated with an additional lowering of the R. Q.

TABLE 3.

The effect of oxygen diffusion on the respiration of seeds.

Hours After Soaking	mm.³/gm. dry wt/hr. 25° C. Whole seeds air O_2	air R.Q.	100% O_2 O_2	100% O_2 R.Q.	Stripped seeds air O_2	air R.Q.	100% O_2 O_2	100% O_2 R.Q.
7	52	2.08	131	0.98	171	0.79	274	0.66
8	61	2.02	168	1.08	209	0.67	345	0.59
9	94	1.63	200	1.17	271	0.75	416	0.72
10	144	1.36	220	1.26	303	0.78	458	0.75
11	190	1.31	268	1.20	371	0.82	495	0.78
12	216	1.17	309	1.09	384	0.80	580	0.81
13	252	1.06	342	1.06	447	0.83	617	0.84
14	279	1.06	385	1.03	470	0.83	670	0.88

The high R.Q. is best interpreted as due to aerobic fermentation. Aerobic fermentation is found, normally, only when the rate of respiration is insufficient to fully inhibit the fermentation mechanism. The inhibition of fermentation by oxygen is known as the Pasteur effect. Warburg (1926) and Meyerhof (1925) have interpreted the oxygen effect as an inhibition of fermentation by respiration. (See Turner, 1937; Dixon, 1937; and Burk, 1938, 1939; for reviews of the Pasteur effect.) Meyerhof (1925) has given a convenient expression for evaluating the Pasteur effect; this expression is now known as the Meyerhof Quotient.

$$\text{M.Q.} = \frac{\text{mols of } CO_2 \text{ of fermentation in } N_2 - \text{mols of } CO_2 \text{ fermentation in air}}{\text{mols of } O_2 \text{ consumed in respiration}}$$

The CO_2 of fermentation in air is zero when the R.Q. is equal to or less than 1.0; when the R.Q. is greater than 1.0 aerobic fermentation is assumed. The CO_2 of aerobic fermentation=total CO_2 minus respiratory CO_2, assuming respiratory CO_2=O_2. When the M.Q. is equal to or less than $\frac{1}{3}$, no Pasteur effect need be assumed, for respiration is rapid enough to oxidize the products of fermentation. When the M.Q. is greater than $\frac{1}{3}$ a Pasteur effect is demonstrated, if the fermentation equation is:

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

since the rate of respiration is not great enough to remove the products of fermentation, and the only way to account for the decreased CO_2 of fermentation is an aerobic inhibition (though it may be partial) of fermentation.

Assuming the equation of alcoholic fermentation to hold for barley, the data in table 2 clearly demonstrates a Pasteur mechanism in barley grain. The fall of the M.Q. with time, which appears in table 2, is open to three interpretations: (1) The Pasteur mechanism has failed. (2) The end products of fermentation in the anaerobic experiments have partially inhibited the fermentation. (3) The development of enzyme mechanisms including the fermentation mechanism, is slower in nitrogen than in air. That the first interpretation is not correct is shown by the data in the two right hand columns of table 2. This grain, started at the same time as those in the left hand columns was soaked for 6 hours in air, and then made anaerobic. The fermentation rate in nitrogen was higher than that continuously in nitrogen and the M.Q. was greater than $\frac{1}{3}$ showing the Pasteur mechanism was in operation. No decision can be made between the two later interpretations on the basis of data at hand.

These experiments not only show the rapid rise of oxygen consumption during germination, an increase of 200–300 times during the first hour, but also demonstrate that during the early phases of germination in air fermentation plays an important role. If the fermentation is of the alcohol type, when the R.Q.=2.0, three fourths of the sugar metabolized is fermented and one fourth is respired. Further, it should be pointed out that if respiration was measured only by CO_2 liberation, as is common in plant physiology, during the early phases of germination an error in determining respiratory gas exchange of 100 per cent would occur, or in case of carbohydrate oxidized, an error of 400 per cent!

The Respiration of Embryo and Endosperm.—There is no tissue connection between the embryo and the endosperm of barley. In soaked seeds from which the lemma, palea, and seed coats have been removed, the embryo may be lifted off without apparent damage. Brown and Morris (1890) showed that such embryos may be grown to mature plants. When 5 or 10 such embryos were placed in our respirometers a good uptake of O_2 occurred and though the embryos have but 1/10 the weight of the whole grain they conusmed half as much O_2. The data are shown in tables 4 and 5 and similar data for the isolated endosperms of the same grain. It may readily be seen that the O_2 consumption per unit weight is about 10 times as great in the embryos as in the endosperm. That little injury has resulted is probable since the sum of O_2 uptake of embryo and endosperm equals that of the intact grain. In our experiments of short duration we found no effect of 2 per cent sucrose on the respiratory rate of the embryos.

TABLE 4.

Comparison of the respiration of embryo, endosperm and seeds at 22° C.

Hours After Soaking	mm.^{3}O$_2$/hr.[1] embryo	endosperm	Σ embryo endosperm	whole stripped seed	mm.^{3}O$_2$/gm. wet wt./hr. embryo	endosperm	Σ embryo endosperm	whole stripped seeds
15	3.20	3.90	7.10	6.21	715	76.5	127	113
16	4.08	3.66	7.74	7.43	910	71.8	139	135
17	4.82	4.12	8.94	7.55	1075	81.0	160	137
18	5.52	4.42	9.94	8.54	1230	86.8	178	155
wet wt.[2] in mgs.	4.58	51.0	55.6	55.0				

[1] Values given per unit calculated from average of 2 vessels each containing 5 embryos, endosperms, or seeds.
[2] Average weight from 10 used above.

Recalculating the data of James and James (1940) to the units we use, they find that 12 hour embryos with sucrose form 4.13 mm.^{3} CO_2/embryo/hr. while we find for 15 hour embryos an O_2 consumption of 3.2–4.4 mm.^{3}/embryo/hr. These rates are in good agreement with those obtained by Stoward (1908). No direct comparison of the values obtained here can be made with those obtained by Barnell (1937) on isolated barley endosperm and embryos, because of differences of age.

One striking difference between the respiration of embryo and endosperm is in the R.Q. as may be seen in table 4. The R.Q. of the embryo is that expected for the metabolism of carbohydrates, while the very low endosperm value is below that of the complete combustion of fats. Such low values may be due to incomplete oxidation as in succulent plants (1932) or due to the conversion of fats to carbohydrates. Murlin and co-workers (1933) have shown that the low R.Q. of *Ricinus* seeds is due to a conversion of fat to carbohydrate. James and James (1940) have shown that barley grains contain about two per cent of fat. It is possible that the low R.Q. of barley endosperm is due to the conversion of fat to carbohydrate. James and James have found a low R.Q. of barley embryos in contrast to our findings. No explanation for this discrepancy is apparent. However, Stoward (1908) found an R.Q. for isolated barley embryos of 0.98 at 19° C. and 1.09 at 25° C.

Marsh and Goddard (1939b) have shown that 10^{-3}M NaN_3 and HCN poison the oxygen consumption but not the anaerobic fermentation of carrot root. When such poisons are added to a tissue in air whose respiration is cyanide sensitive and potentially able to ferment, the O_2 consumption may be expected to fall, while the CO_2 production may decrease less, not at all, or may even increase. This is in fact the easiest way to demonstrate the Pasteur effect, for on poisoning with cyanide or azide the R.Q. should rise markedly. James and Hora (1940) failed to demonstrate a

TABLE 5.

The effect of azide and cyanide on the respiration of seeds, embryos and endosperm.

Hours After Soaking	mm.³ O_2/hr. 10 embryos	10 endosperm	10 stripped seeds	mm.³ CO_2/hr. 10 embryos	10 endosperm	10 stripped seeds	R.Q. embryos	endosperm
			Controls for NaN_3					
15	44.4	51.5	95.1	46.2	15.8	...	1.04	0.31
16	59.2	52.0	110.8	59.2	16.5	...	1.00	0.32
17	69.0	55.0	126.0	69.4	23.9	...	1.01	0.44
			In 10^{-3} M NaN_3					
15	9.6(78)[1]	7.4(86)	23.8(75)	59.5	40.0	...	6.2	5.9
16	9.9(84)	8.1(84)	22.6(80)	52.9	36.8	...	5.3	4.5
17	9.6(86)	8.5(85)	22.3(82)	47.3	33.8	...	4.9	4.0
			Controls for HCN					
15	30.9	28.1	...					
16	40.6	29.2	94.5					
17	45.4	29.2	117.4					
			In 10^{-3} M HCN					
15	5.6(82)	6.1(79)	...					
16	4.6(89)	5.7(80)	10.0(88)					
17	5.3(88)	6.0(80)	11.8(90)					

[1] Figures in brackets indicate per cent inhibition.

Pasteur effect in barley embryos with M/250 HCN though they were able to demonstrate it in seedlings. Using NaN_3 we have been able to demonstrate clearly a Pasteur effect in barley embryos, endosperm, and seedlings. See the rise in R.Q. and the failure to markedly inhibit CO_2 production in tables 4 and 6.

Nature of the Oxidases.—Since the classical work of Warburg (1928, 1930), the inhibition of respiration by HCN and by CO with light reversal of the CO inhibition has been interpreted as a strong indication that the respiration is mediated by an iron porphyrin enzyme known as the phaeohemin oxidase. Keilin (1936) has shown that NaN_3 also inhibits this enzyme and has renamed (1938) the enzyme cytochrome oxidase. That other oxidases occur is well recognized. Polyphenol oxidases have been isolated by Kubowitz (1937, 1938) and Keilin and Mann (1938) and are copper proteins, inhibited by HCN and CO but the later inhibition is not reversed by light. Cyanide resistant respiration is widespread, particularly in the shoots of higher plants. The oxidases catalyzing this respiration are unknown, though on insufficient evidence this respiration is frequently ascribed to the flavine enzymes.

The experiments of Marsh and Goddard (1939) show that a shift in oxidases occurs during the development of carrot leaves. Similar experiments were undertaken with barley. The effect of cyanide and azide

on barley seeds, embryos and endosperms is shown in table 5. It is observed that 80 to 90 per cent of the respiration is inhibited by 10^{-3} M HCN or NaN_3. The CO_2 production is not so inhibited and may even increase. It must be emphasized that if oxygen diffusion is limiting the rate of O_2 uptake, smaller inhibitions will be obtained, since the cyanide resistant respiration in barley seeds appears from our experiments to be less sensitive to O_2 pressure than the cyanide sensitive respiration. (See also DuBuy and Olson, 1940.)

TABLE 6.

Inhibition of respiration of embryos and endosperm by carbon monoxide and light reversal of the inhibition. Embryos and endosperm from grain soaked 12 hours.

Gas Mixture	mm.^{3} O_2/embryo or endosperm/hr. Dark	Light	25° C. Dark
Embryos			
95% CO/5% O_2	1.53	4.32	1.39
	1.46	4.96	1.52
95% N_2/5% O_2	5.08	6.10	58.4
	6.64	7.32	8.80
Endosperm			
95% CO/5% O_2	1.10	3.40	1.21
	1.30	3.54	...
95% N_2/5% O_2	3.08	4.04	3.66
	2.38	3.48	3.80

TABLE 7.

The effect of sodium azide on the gaseous metabolism of seedlings.

Hours After Soaking	Control O_2	Control CO_2	Control R.Q.	mm.^{3}/gm. dry wt./hr. 1.0x10^{-3} M NaN_3 O_2	25° C. 1.0x10^{-3} M NaN_3 CO_2	1.0x10^{-3} M NaN_3 R.Q.
28	545	495	0.91	...	...	...
30	...	...	...	201 (63) [1]	558	2.62
51	740	700	0.95	...	...	...
54	...	...	...	261 (65)	585	2.22
77	788	788	1.00	...	...	...
78	...	...	...	360 (54)	708	1.97

[1] Figures in brackets indicate percentage inhibition calculated on the O_2 consumption of the period immediately preceding.

That the enzyme system inhibited by HCN and NaN_3 is probably cytochrome oxidase is made clearer from the results with CO reported in table 6. It is apparent that the O_2 uptake is inhibited by CO and that this inhibition is light sensitive. We have further observed that barley embryos are strongly and rapidly stained by the Nadi reagent (0.01 M α napthol + 0.01 M dimethylparaphenylenediamine), but not in the presence of HCN. Brown and Goddard (1941) have recently prepared ac-

tive enzyme extracts from wheat embryos which catalyze the oxidation of hydroquinone only in the presence of cytochrome c. Therefore, there is a strong probability that a large fraction of the respiration of the barley embryo and endosperm is mediated by cytochrome oxidase.

When barley seedlings were poisoned with NaN_3 a respiratory inhibition was obtained which was smaller than that found in seeds. (table 7.) It seemed worth while to determine, separately, the effect of cytochrome oxidase inhibitors on roots and leaves. Table 8 shows that the respiration of primary roots from 4 day old seedlings was strongly inhibited. Adventious roots (14–20 days old) from 25 day old plants raised in Shive's mineral solution were also used. The inhibition is smaller than in the young roots but still appreciable. For leaf material, the first leaf from 7 day old and 14 day old seedlings was used. As may be seen from table 8 the younger leaf has a large fraction (70 per cent) of its respiration inhibited by NaN_3 while in the mature leaf (14 days) a stimulation rather than an inhibition was obtained. This stimulation was surprising, since though previous experience in this laboratory had often indicated that HCN may cause respiratory stimulation, this is the first time stimulation has been obtained with NaN_3

TABLE 8.

Respiratory inhibition of sodium azide on roots and leaves.

Material	mm.³ O_2/gm. wet wt./hr. 25° C. Control	NaN_3 10^{-4}M	% inhibition	NaN_3 10^{-3}	% inhibition
Primary Roots from 7 day seedlings	1275	410	68	162	87
Adventitious Roots [1] from 25 day plants	755	...	..	238	66
First Leaf from 7 day seedlings	539	324	40	185	66
" "	584	315	51	191	70
First Leaf from 14 day seedlings ...	216	...	..	364	–70

[1] Plants raised in liquid culture, roots 14–20 days old.

James and Hora (1940) have found that 0.005 M HCN inhibits the respiration of 10 day old barley leaves about 66 per cent. With 13 day old leaves inhibitions were found at 0.01 M and 0.02 M but the inhibitions at the two later concentrations were not shown to be reversible. In fact, results obtained with such high cyanide concentrations, and particularly with experiments of long duration, are of no value as an indication of the nature of the oxidases involved.

Considerable difficulty was obtained in demonstrating carbon monoxide inhibition of the respiration of the first leaf from 7 day plants. In three out of four separate experiments at 25° C. with 95 per cent CO + 5

per cent O_2 the rate in CO was slightly less than in the N_2+O_2 controls. The difference was hardly greater than the experimental error. In the fourth experiment significantly higher rates were obtained in CO than in the N_2+O_2 controls. One of the difficulties is that in immature barley leaves the respiratory rate is markedly lower in 5 per cent oxygen than in air. A second difficulty is the decreasing rate with time. Experiments were then run at 15° C. and at 10° C. with the results shown in table 9. Two vessels were run throughout with the gas space containing air. Two others had N_2+O_2 for the first period and then $CO+O_2$ for the second period. While in two other vessels the experiment was started in $CO+O_2$ and shifted for the second period to N_2+O_2. The results are not as clean-cut as could be desired, but they do indicate a respiratory inhibition due to CO. Light reversal was not attempted because of the difficulty imposed by photosynthesis.

TABLE 9.

The inhibition of respiration of the first leaf tissue from 7 day seedlings by carbon monoxide. Gas mixtures 95% CO/5% O_2 *and* 95% N_2/5% O_2.

Gas Mixture	Period 0–2 hrs.	Period 2–4 hrs.	% Change 0–2 hrs. to 2–4 hrs.
	15° C.		
Air	180	155	—13.9
N_2/O_2	141.5	...	
	141.0	...	
CO/O_2	...	108	—23.6
	...	108.3	
CO/O_2	83.3	...	
	95.0	...	
N_2/O_2	...	105.5	+25
	...	119.0	
	10° C.		
Air	129.5	110.4	—16.3
	124.7	103.0	
N_2/O_2	120.6	...	
	126.5	...	
CO/O_2	...	64.8	—47.8
	...	63.9	
CO/O_2	110.0	...	
	104.0	...	
N_2/O_2	...	100.3	—8.5
	...	95.5	

DISCUSSION

The results presented in this paper show that dry barley grain has an extremely low respiration of the order of magnitude of 0.05–0.10 mm.^{3}/gm./hr. During the first hour after the addition of water, to such grain, the respiratory rate increases 200 to 300 times. A rapid acceleration con-

tinues during the first twelve hours after addition of water, but at a lower rate than during the first hour. Between 12–14 hours after addition of water the rate of increase rises and the acceleration remains practically constant until the seedlings are 60 hours old.

During the first few hours the rate of increase of CO_2 production rises more rapidly than the increase in oxygen consumption and the R.Q. becomes high (about 2). This high R.Q. is almost certainly due to aerobic fermentation. A Pasteur mechanism has been demonstrated in the grain, and the aerobic fermentation is due to a limitation of the respiratory rate by oxygen diffusion. The frequent practice of plant physiologists of evaluating respiration only in terms of CO_2 production should be avoided when dealing with germinating seeds or other structures where aerobic fermentation may occur. It is to be particularly emphasized that measurements of CO_2 production may frequently fail to show marked inhibitions of respiration by poisons like HCN, NaN_3 or CO. In the case of the endosperm, if the respiratory effect of NaN_3 was calculated on the basis of CO_2 production, a stimulation of 153 per cent would have been demonstrated (due to fermentation), while on an O_2 basis, an inhibition of 86 per cent was found.

Nearly 90 per cent of the respiration of the intact seed, embryo, or endosperm is mediated by an enzyme sensitive to HCN, NaN_3 and CO, with light reversal of the CO inhibition. It is probable that the enzyme is cytochrome oxidase. As the embryo differentiates and grows into a seedling the fraction of the respiration catalyzed by an azide sensitive enzyme decreases. This is largely due to the disappearance of an active cytochrome oxidase from the developing shoot and to some decrease in the percentage of the root respiration mediated by cytochrome oxidase.

At least in barley, the cytochrome oxidase system appears to be the embryonic respiratory oxidase, while in mature leaf tissue some unidentified azide resistant oxidase develops. However, during the early stages of germination (0–18 hours) there is a marked increase in the azide sensitive respiration, and it is only in the later stages that the decrease pointed out above occurs. It is interesting to note that the roots retain the "embryonic" oxidase system even in maturity while it is lost in the leaves. There appears to be a differentiation of enzyme systems in development accompanying the differentiation of tissues and organs.

SUMMARY

The respiration of dry barley grain is of the order of 0.1 $mm.^3$ O_2/gm./hr. Within the first hour of soaking such grain, the respiratory rate increases 200 to 300 times. The rate continues to increase for the next 72 hours, but the rate of increase is less than during the first hour. Dur-

ing the first 12 hours of germination the rate of oxygen diffusion limits the rate of oxygen consumption with a resulting aerobic fermentation. A Pasteur effect may be demonstrated in embryos, endosperm, and seedlings.

The respiration of the embryo accounts for about one half of the total grain respiration. Its rate per unit weight is about ten fold that of the endosperm.

The respiration of the grain, embryo, and endosperm is inhibited by HCN, NaN_3, and CO, with light reversal of the CO inhibition. This is interpreted as respiration catalyzed by cytochrome oxidase. The respiration of young and mature root and young leaf tissue is mediated largely by cytochrome oxidase, while no evidence of the function of this oxidase is found in mature leaves. An apparent differentiation of oxidase mechanisms occurs in the development of the shoot.

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NEWS AND NOTES

THE PROCEEDINGS

Volume 7 was completed with the paper of Stewart and Merrell. This number constitutes the first number of volume 8. With the new volume some minor changes have been made in typography and some changes in publication policy. It is the intention of the publication committee to have each volume consist of six numbers and to publish approximately three numbers each year. There has been added a new section, known as *News and Notes* to record the activities of the Academy and its members. This section will be reprinted and distributed to all members of the Academy. Members having information for the *News and Notes* are requested to submit the information to the Secretary or to the Section Recorders.

D. R. G.

THE NEW LIBRARIAN

The Council of the Academy takes pleasure in announcing the election of John Richmond Russell as Librarian to the Academy. Mr. Russell came to Rochester on April 1, 1940 as Librarian to the University. A graduate of the University of Chicago he was later a graduate student at the University of Michigan. After four years at the New York Public Library, Mr. Russell studied in Europe on a General Education Board Fellowship. From 1935–1940 he was Chief, Division of Cataloging at the National Archives, Washington.

Mr. Russell is much interested in the Academy and is taking an active part in the editorial work of its Publications. The Academy is fortunate to have him for its Librarian.

D. R. G.

GENERAL MEETINGS

October 24, 1940.—Mr. Robert Simpson, of the Department of Geology, University of Rochester, gave an address on *Mountains and Men.* He reviewed the distribution of mountain masses in the various continents, showed their effects as natural boundaries and discussed the limitations which they impose on the inhabitants of the various areas. His conclusion was that the peoples of mountainous areas should not compete with the plains, but should exploit the advantages of their areas for recreation, hydroelectric power and specialized manufacturing.

November 11, 1940.—Dr. William C. Senning, of the New York State Conservation Department gave an address on *Conservation and Research in the Bureau of Fisheries.* Dr. Senning outlined the progress which has been made in an inventory of the fish inhabiting the rivers and lakes of New York State. He described some of the problems faced in Conservation work and outlined the plans for the future. An office of the State Conservation Department, known as the West Central District has been established at the Prince Street Campus of the University of Rochester, with Dr. Senning in charge.

November 22, 1940.—A joint meeting with the Optical Society. Mr. Russel W. Porter of the California Institute of Technology gave a lecture on *The Building of the Two Hundred Inch Telescope of Mt. Palomar.*

December 9, 1940.—Mr. Earl Hilfiker of the Rochester Museum of Arts and Sciences presented an illustrated lecture on *Life at the Beaver Ponds.*

January 13, 1941 with the Research Section, see below.

January 23, 1941.—Joint meeting with the Optical Society and the Astronomy Club. Address by Dr. Lawrence M. Gould, second in command of the First Byrd Antarctic

Expedition. The Academy was fortunate to have had Dr. Gould and greatly enjoyed his fine lecture and movies.

February 24, 1941.—Joint meeting with the Rochester Section, American Chemical Society. Dr. Cyril J. Stand of Eastman Kodak Co. presented an illustrated lecture on a recent trip to Hawaii.

March 24, 1941.—Dr. Edwin Jelley of the Eastman Kodak Research Laboratory addressed the Academy on the subject *Color Phenomena of Crystals.* His lecture was illustrated with Kodachrome slides showing, in particular, the effect of polarized light on various crystals.

April 28, 1941.—Meeting sponsored by the Botanical Section.

M. N. S.

BOTANICAL SECTION

The Botanical Section of the Rochester Academy of Science meets the first and third Monday nights of every month at the Eastman Building on the Prince Street campus of the University of Rochester from 8–9:30 P. M. In addition, occasional meetings are held in the Herbarium Rooms at the River Campus of the University. At this meeting the members study herbarium specimens upon any subject they are especially interested in.

The following program for the year 1940–41 has been or will be followed.

During September, October and November 1940 the study period was confined largely to the *Gramineae* and *Compositae.* In September *Solidago*—Goldenrods—were gathered, analyzed and identified, together with autumn grasses. In October and November Asters were studied and identified. A number of the more difficult *Solidago* and Asters were collected by several members and sent to well recognized authorities in these difficult genera. These aided us in reclassifying some specimens.

The Section is responsible for collecting and mounting specimens for the Burroughs-Audubon Nature Club for its herbarium at its Conservation Station at Railroad Mills and some of these were identified.

The December program was appropriate to the season and the Section studied *Lycopodiaceae* (Club Moss Family) from the Academy Herbarium augmented by specimens from the herbaria of individual members. These, with local conifers, made two interesting programs.

January, February, March and April have been devoted to a study of winter characteristics of trees using Brown's *Trees of Northeastern United States;* studies were made of the genus *Panicum* of the *Gramineae* family and of some of the *Juncaceae* (Rush family). Different members of the Section who are especially interested in these plants have acted as leaders.

During the last four months of the year, May, June, July, and August fresh specimens, perhaps species new to the area or old species from new stations, will be brought in for critical analysis and identification.

On April 13, 1941, the sixtieth anniversary of the founding of the Botanical Section occurred. The members celebrated this date with a field trip. These field trips are held during the summer season either in small groups or by the entire section.

The regular Academy meeting on April 28, 1941, will also note this sixteenth anniversary in its program. We expect to have as our speaker Dr. Josiah L. Lowe of the New York State College of Forestry who will talk on *Lichens* illustrated by Kodachrome slides.

G. A. B. C.

MINERALOGY SECTION

The Mineralogy Section of the Rochester Academy of Science meets once each month, from October through May inclusive, on the second Thursday of each month. The indoor meetings are held at Ward's Natural Science Establishment. In addition to the indoor meetings, several field trips are taken each year for the purpose of collecting specimens of minerals, rocks, and fossils, and to study the geology of the region visited.

The indoor meetings of the 1940–41 season have consisted of the following:

October 10.—Members exhibited specimens collected during the past summer, and told of their collecting experiences.

November 14.—Mr. Everett G. Beine and Mr. Charles E. Francis talked on the *Minerals Used in the Chemical Industries.*

December 12.—Mr. John Dowe, Jr., lectured on the *Varieties of Quartz.*

January 9.—Mr. Charles W. Foster demonstrated and explained fluorescence.

February 13.—Mr. Edwin G. Foster spoke on the *Strategic Minerals.*

March 13.—Miss Alice S. Richardson told of her experiences in the collecting of mineral specimens in Vermont, New Hampshire, and Maine.

April 10.—Mr. Walter H. Wright reported on *The Minerals of North Carolina.*

May 8.—Miss Marguerite Smith will lecture on *The Minerals of Monroe County.*

Field Trips

June 22–23, 1940.—A two-day trip was taken to St. Lawrence and Lewis Counties. The Carbola Chemical Company talc mine near Natural Bridge was visited. Specimens of talc, serpentine, pyrite, chlorite, etc., were collected. A marble quarry near Gouverneur was visited. From here good crystals of tourmaline and calcite were collected. The lead mines near Rossie and the Loomis talc mine near Fowler were also visited.

Other field trips included the LeRoy limestone quarries, the region around Alfred, Deep Run, and Niagara Falls. The latter trip was at the invitation of and in conjunction with the Buffalo Society of Natural History.

The Section has in progress a permanent record of mineral localities of Monroe County. This work is being carried on under the direction of Mr. Edwin G. Foster. A map, mounted and donated by Mr. Foster, has recorded on it the mineral localities. The geology is expertly done on the map by Miss Marguerite Smith.

Officers of the Mineral Section—1941

Robert C. Vance	Chairman
David E. Jensen	Recorder
George R. Costich	Treasurer
Edwin G. Foster	Chairman of the Committee for Recording Mineral Localities of Monroe County
John Dowe, Jr.	Chairman of Field Trip Committee

R. C. V.

RESEARCH SECTION

This is a new section of the Academy which has been meeting regularly since January of this year. It had its inception in a report to the Council by a special Committee consisting of Dr. S. C. Bishop and W. S. Cornwell. The Council ap-

pointed a larger committee consisting of Dr. D. L. Gamble (Chairman), W. S. Cornwell (Secretary), and Professors Bishop and Fairbanks. Later Drs. Goddard and Roudabush were added. As a result of the report of this committee the new Section was formed.

The purpose of the Research Section is to provide for monthly meetings for the professional Scientists of the Rochester area, for the presentation of original research, and to aid in the publication of the *Proceedings*. It is particularly hoped that it shall provide a common meeting ground for the industrial, academic, and medical scientists. All persons interested should apply to the Recorder of the Section.

The dues of the Section are $3.00 a year in addition to the regular Academy dues of $2.00. All of the section dues are used for publication of the *Proceedings*.

Meetings are held the first Tuesday of each month from October through May at the Dewey Building, River Campus. All members of the Academy and their guests are welcome to the meetings of this Section.

The following meetings have been held:

November 26, 1940.—Organizational meeting.

January 13, 1941.—Mr. Karl Schmidt, Field Museum of Natural History, Chicago, on the subject: *Desert and Highland in Peru.*

February 4, 1941.—Drs. S. C. Bishop and R. H. Goodwin of the University of Rochester, *What Is a Species?*

March 4, 1941.—Mr. William A. Ritchie of the Rochester Museum of Arts and Sciences gave an illustrated lecture entitled *The Recent Excavation of an Ancient Site on Frontenac Island.*

April 1, 1941.—Drs. R. L. Roudabush, O. R. McCoy, F. S. Bond, and E. P. Offutt participated in a *Symposium on Malaria.*

W. S. C.

MILTON S. BAXTER

The Academy, and particularly the Botanical Section, lost one of its most valued members in the death of Milton S. Baxter on October 15, 1938. Mr. Baxter had been a member of the Academy for a great many years, was leader of the Botanical Section and Curator of the Academy Herbarium. He was widely known for his extensive botanical collections. A forthcoming issue of these Proceedings will carry a biographical article on Mr. Baxter.

DONALD BEAN GILCHRIST

The Academy regrets to announce the death of its former Librarian, Donald Bean Gilchrist on August 4, 1939 at Meredith, New Hampshire. Donald Gilchrist was born at Franklin, New Hampshire in 1896. Mr. Gilchrist came to Rochester as Librarian of the University of Rochester in 1919, a position which he held until his death. From 1931 till his death he was also Librarian to the Academy. Mr. Gilchrist was a graduate of Dartmouth College (A.B. 1913) and of the New York State Library School (B.L.S. 1915). Mr. Gilchrist served in the New York State Library and University of Minnesota Library before coming to Rochester.

Mr. Gilchrist was widely known among American librarians, particularly for his work in their associations and for his numerous articles in professional journals.

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