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By Frank S. Collins and Alpheus B. Hervey.

With Six Plates.

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THE ALGAE OF BERMUDA.

By Frank S. Collins and Alpheus B. Hervey.

Bermuda consists of a little group of islands of not more than twenty square miles of dry land, lying in latitude 32° 14′–32° 23′ north and longitude 64° 38′–64° 53′ west, about 700 miles southeast of New York, and 600 miles east of the coast of South Carolina. They are some three or four hundred miles south and east of the Gulf Stream. This situation accounts for the very marked uniformity as well as the mildness of the climate of the islands.

All of Bermuda now above sea level consists of limestone, from a fine sand to hard crystalline rock. The lime comes from the various organisms inhabiting the water, in part animal but more largely vegetable;[1] many of these lime-producing algae are included in the following pages, but Lithothamnium and its allies, stony algae belonging to the Florideae, which furnish the larger part of the material, we have not been able to include here. The fine powder formed from the remains of these various organisms is carried by the wind and spread out over the ground. Rainwater dissolves a certain amount of it, which when the water dries up is deposited and acts as a cement. Crystallization goes on more or less within the masses after formation, and so some parts become much harder than others. Erosion from rain or from the sea is continually going on, and its action being greater in the softer than in the harder parts, we have a great variety of fantastic forms along the shore, and many caves underground.

It has long been supposed that there was a core of solid rock under the limestone, but only recently have any definite data been obtained in regard to it. Pirsson, 1914, gives the particulars in regard to a boring made in the hope, which was not fulfilled, of obtaining a supply of fresh water. The boring was in Southampton parish, about a mile west of Gibbs Hill Lighthouse, 135 feet above sea level. To 380 feet

1 For a summary of the results of investigations as to the parts taken in the formation of "coral" islands, by animal and vegetable organisms, see Howe, 1912.

below the surface it was the ordinary soft limestone; then to 695 feet, earthy, decomposed lava, in the lower part of the range with fragments of solid lava, sometimes waterworn; then to 1413 feet, the lowest point reached, solid lava. Considering these data in connection with our knowledge of the present under-water Bermuda, the slope from the present island to the ocean floor, the conclusion is reached that a great volcanic cone was formed, perhaps in the early Eocene, with its summit where the present island is, rising about 11,000 feet above the sea. The 718 feet above the bottom of the boring and an unknown distance below consist of the unchanged lava of the cone; the 315 feet layer above this was produced by the disintegration of the upper part of the cone; the foraminifera found in the 380 feet of limestone indicate that its formation, by the same processes that are now at work, began before the end of the Eocene; while the occurrence of the limestone 245 feet, and the decomposed lava 560 feet below sea level, indicate a long-continued subsidence.

At the present time there are no bodies of fresh water on the islands; rain water sinks almost immediately into the porous soil, which is also honeycombed by large and small caves and passages; brackish water can be obtained at sea level anywhere, but strictly fresh water nowhere. A curious instance of this permeability was told us by Mr. Reid Trott, owner of the aquarium known as the Devil's Hole; this is on the shore of Harrington Sound, distant a quarter of a mile, rather high ground, from the south shore; in a southerly storm the surf is very heavy on the south shore, and white from the fine lime of the beaches; within a day or two the water in the aquarium becomes milky. The only visible outlet of Harrington Sound is by the narrow passage at Flatts Bridge; but though the rise and fall of the tide in the Sound is only a few inches, it has been calculated that it represents a flow through unseen passages of much more than passes under the bridge. Devonshire Marsh forms a sort of bowl, with higher ground on all sides; surface drainage into this fills the ditches with practically pure fresh water after rains, but it soon disappears, and only a few species of fresh water algae are able to avail themselves of the short opportunity.[2]

A few species of "Fucus" are mentioned by Turner, Icones Fucorum, 1808–1819, but actually our knowledge of the algae of Bermuda

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2 A * is placed before the name of each fresh water or terrestrial species listed, including some Myxophyceae found here within range of tides, though not normally marine.

begins with the list published in the Canadian Naturalist by the Rev. Alexander F. Kemp (Kemp, 1857), who visited the islands in 1856 and collected somewhat extensively. Sixteen years later J. J. Rein, who had been a tutor in an English family at Bermuda, published two papers on the vegetation of the islands, one of them with a list of the algae (Rein, 1873). In 1881 Prof. W. G. Farlow made quite extensive collections, and some of the material obtained was distributed in the set of exsiccatae, Farlow, Anderson & Eaton, Algae Exsiccatae Boreali-Americanae. At a later visit, in 1900, Farlow collected additional species, a few of which were distributed in Collins, Holden & Setchell, Phycotheca Boreali-Americana, but otherwise no publication has been made of the material collected by him. The Challenger Expedition visited Bermuda, and the results are given in a preliminary paper (Dickie, 1874) and in a volume of the Results of the Challenger Expedition. In these are included the species listed by Kemp and Rein and those distributed by Farlow, with comparatively few additions. In the Journal of Botany George Murray published a Catalogue of West Indian marine algae (Murray, 1889), including in it the Bermuda lists above mentioned; noting that Bermuda did not belong to the West Indies, geographically or politically, but might be considered as having a similar flora. Setchell, 1912, is a paper calling attention to several species in the Farlow herbarium. Longer or shorter lists of algae occur in local publications, traveller's guides etc., but based on the papers above noted, and adding nothing to what is found in them. Occasional references to Bermuda occur in general works, but only as citations from the works mentioned, or referring to some specimen collected by Farlow.

Through the kindness of Mrs. Jane A. Sutherland, daughter of Mr. Kemp, we have been able to examine his collection, which still includes nearly all the species listed by him. Professor M. Möbius very kindly sent us for examination the Rein algae, now preserved in the collection of the Senckenbergischer Gesellschaft at Frankfurt a/m.; by the favor of Dr. D. Prain, Director of the Royal Botanic Gardens, Kew, we have examined specimens of the species added by the Challenger expedition; and Professor Farlow has given every facility for the study of his rich material, including beside his own collecting, specimens collected by G. Tucker in 1856 and Walter Faxon in 1882. In the collection of one of the writers is a considerable number of algae collected in 1890 by W. S. Wadsworth.[3] Miss Wilkinson of Ripleigh,

[3] A similar set is in the herbarium of the University of California.

Hamilton, has kindly allowed us to refer to an interesting collection she has made, and we are also much indebted to her for information as to stations of some of the rare species. In 1882 Miss Kate Peniston, now Mrs. Matthews, sent one of us some algae from the Harrington Sound region; comparatively few specimens, but including some of much interest. Several species from Bermuda are recorded by Dr. M. A. Howe in his papers in the Bulletin of the Torrey Botanical Club, and some of them have been distributed in the Phycotheca Boreali-Americana. An occasional specimen from some other collector will be noted in its appropriate place. Collections were made by ourselves in the years from 1911 to 1917, during which period one or the other of us has been in Bermuda rather more than half of the time, collecting in practically all parts of the islands and in all months except June. While future additions are of course to be expected, we think that the main characters of the algal flora are fairly settled, and the greater part of the species determined. A special effort has been made to distribute in the Phycotheca Boreali-Americana as full a representation as possible of Bermuda algae, and fascicles XXXVIII, XXXIX, XLI, XLII and XLIV consist entirely of specimens from the islands.[4] We have distributed in this way every species of which sufficient material was available.

A number of new species are described and figured in the following pages, and we have tried to give all details of value in regard to them. In case of other species, whenever we could add anything to previous knowledge of them, we have tried to do so, but no full descriptions have been given except for new species, varieties etc. Concise keys however, have been furnished, and we think will prove useful. We have been rather full in notes as to character of station, as this is something sadly lacking in many floras. Exact localities have been given, for the aid of future students, and the date of collecting is given by month, but it has not seemed necessary to give the year. No full synonymy is given, but pains have been taken to give for each species the proper name under the international rules; the original name, if published under another genus; and when possible reference to a good figure. Whenever specimens from Bermuda have been distributed in the Alg. Am.-Bor. Exsicc. or in the P. B.-A., reference is given by number. Other references are given in cases

[4] A set of these fascicles will be found at the Bermuda Agricultural Station, to whose Director, Mr. E. J. Wortley, we are indebted for many kindnesses during our visits to the islands.

where it seemed desirable, especially from distinctively American works, like Harvey, Nereis Boreali-Americana and Börgesen, The Marine Algae of the Danish West Indies. The latter is specially useful in connection with the present work, being a careful study of the marine flora of a small group of islands, of character not unlike Bermuda, though somewhat farther south. As Börgesen's work is still incomplete as this paper goes to press, full comparisons are not yet possible.

We had hoped to publish with the present paper somewhat full comparisons of the floras of Bermuda and other regions, but the list for the Danish West Indies, perhaps the most instructive, is not fully available. We have reluctantly had to omit from our list the families Rhizophyllidaceae, Squamariaceae and Corallinaceae; without careful study of the types any conclusions in these critical families would be uncertain, and in the present European conditions such study has not been practicable. In view of this we have made only a short statement, by classes, showing the percentage of the Bermuda species common to nine of the best known regions where a similarity might be expected. If later we are in position to take up the families now omitted, and a full account of the algae of the Danish West Indies is available, the proposed full comparison may be made. In the present comparison we have not included the Class Myxophyceae; first because the species of this class are largely cosmopolitan, second because in many regions where the other classes are fairly well known, the Myxophyceae have been little studied. We have considered a species as common to two regions, though represented by different forms or varieties in each; pelagic species, known only as washed ashore, have not been included.

Percentage of Bermuda algae represented in other floras.

	Chlorophyceae	Phaeophyceae	Rhodophyceae	Total
Great Britain	28	34	26	27
N. and NW. France	24	30	26	25
Bay of Biscay	11	20	25	18
Mediterranean	29	34	33	31
Canaries	19	28	23	21
New England	22	24	16	19
Florida	32	43	44	40
Jamaica	38	63	32	41
Barbados	33	41	32	33

The nine regions used in the above comparison are not equally well known; the affinity to an intensively studied region like Great Britain is somewhat overstated, that to a less thoroughly studied region, like the Canaries, understated; but some general indications may be obtained. Perhaps the most striking is the distinctness of the Bermuda flora, having only 41 per cent in common with Jamaica, and not so much in common with any of the others. Taking the three classes represented, there is only one in which more than half the species are common to another region, again Jamaica, which has 63 per cent of the Bermuda brown algae. Taking all the regions, the similarity is greatest in the brown algae, least in the green. The affinities of the Bermuda flora are evidently strongest with the Florida-West India region, next with the Mediterranean, and after that with more northern localities. New England has probably the least in common with Bermuda of all the regions compared, its slight numerical superiority over the Canaries being probably due to the less thorough exploration of the latter.

The following list of important stations, with indication of the characters of each, will, we think, be of use to future collectors; in a region where the coast line is so long in proportion to the surface area, many such stations must exist, but we think we have listed the more important ones.

In this list of stations we aim to conduct our readers around the whole island and point out the places where we have found certain forms of algae most common. Driven in on all sides by the winds one will find abundance of *Sargassum natans* "gulfweed" of which the farmers make so profitable use as a fertilizer. This grows in mid-ocean and is never found attached to the shores. Other species of the same genus are found growing all about the island along with other litoral plants. Many other forms such as *Ulva, Bryopsis, Caulerpa, Codium, Laurencia, Dictyota, Padina, Spyridia* etc. will be found almost everywhere, and so will not require special mention. We will start from Hamilton, going west to Fairyland and Grasmere; there we shall find shallow water and abundance of plants. Breaking into the land opposite Agar's Island is a large bay; as we first come to it on our left we shall find a large growth of mangrove trees among the roots of which in shallow water we will find abundance of the endemic *Halymenia bermudensis,* the loose, small form. Farther along in front of a cottage is rich collecting ground; another of the new plants, *Chondria curvilineata* occurs here, and very large masses of *Valonia macrophysa;* a larger form of the *Halymenia* was gathered in abundance in a little bay that comes up in front of the Grasmere Hotel. Beyond the hotel is a water called Mangrove Creek, lying between the hotel and Spanish Point, where good collecting may be had. At the extreme end of Spanish Point are two little bays, the larger of which is called Stovel Bay; this furnished good specimens of *Dudresnaya crassa* and Liagoras in the spring. It is well to make a careful search all about Spanish Point as far east as the Admiralty House. Beyond that as far as the Ducking Stool the shore is for the most part high and precipitous, and we did not find much to reward the climb down and up; but coming in a boat one finds a fairly rich flora, *Liagora* etc., at the base of the cliffs.

From the Ducking Stool to the Inlet of Harrington Sound most of the collecting was of the smaller forms, some of them microscopic. At one point, perhaps half a mile from the Inlet, was found at one time an abundance of *Coelarthrum Albertisii,* as it was also on the outer point of the Gibbet Islands. These two islands and the little beaches on either side, being near our place of abode, were carefully studied, and yielded from time to time several interesting things, among them the new *Lophosiphonia Saccorhiza,* growing on a *Codium; Halymenia Agardhii* and *Antithamnion cruciatum* var. *radicans* also occurred here. The Inlet of Harrington Sound is good collecting ground for several species; on the south side is plenty of *Ceramium nitens,* and on the wall of the Frascati Hotel may be found at all times a fine growth of *Callithamnion Halliae; Heterospora Vidovichii* also grew on this wall, and *Avrainvillea nigricans* grows buried in the mud in the lower part of the Inlet. Over on the north side in the shallow water one may find abundance of *Udotea* and *Penicillus.* Within the Sound near the bridge is always an abundance of *Wrangelia penicillata,* and always also *Griffithsia tenuis;* in Tucker's Bay at the west end of the Sound we first found *Neomeris annulata,* afterwards found at several other stations; farther to the north, in Major's Bay, were two or three species of *Bryopsis.* At the farther end of the Sound in a little cove near Walsingham House, called Dingle Bay, we found rich collecting; it is the best station for characteristic *Hypnea musciformis* and for *Champia parvula,* rare in Bermuda, and the only station for the new *Dasya spinuligera,* also the original station for *Nitophyllum Wilkinsoniae;* on the south side of the Sound we found our best growth of *Acetabularia crenulata* in a little pool near the chapel; the species is common in many other places, however; the shores of the Sound everywhere abound in species of *Bryopsis* and *Laurencia.*

About a mile north of Flatts Village we come to Shelly Bay, a fine beach; here in its season may be found the new *Chondria polyrhiza*, and at the north end of the Bay is a fine growth of *Udotea flabellum;* half a mile beyond Shelly Bay is Burchell Cove, well worth a visit; here we found splendid specimens of *Callithamnion Halliae.* Bailey's Bay, something over a mile beyond, is a good place for collecting; here we found some of our best specimens of *Eucheuma denticulatum.* In going on towards St. George's it would be worth while to take the old and now unused road about a quarter of a mile beyond Bailey's Bay, and follow along the shore to the old ferry, and then past Joyce's Caves to the Causeway. At the north end of the Causeway we come to Long Bird Island,[5] on the southeast side of which all the way to the Swing Bridge is good collecting, especially of *Helminthocladia Calvadosii* and *Castagnea.*

Beyond Swing Bridge the road winds with many a picturesque turn along the shores of Mullet Bay into St. George's; these waters ought to be fertile grounds for they are for the most part shallow and easily accessible. Once in St. George's we are in the immediate neighborhood of some of the best collecting grounds in Bermuda; going to the shore northwest of the city we first come to Tobacco Bay which is in fact two quite distinct bays near together; plenty of *Bryopsis* and *Liagora* here. A little farther along very near the old fort at St. Catherine's Point, where the shore makes a right angled turn to the east, is a little bay called Achilles Bay, where *Helminthocladia* may be found in abundance in its season. Following the shore for a mile to the east we pass several little coves which may be worth a visit; but just before we come to the place where the sewer from the hospital comes down, we come to Judy's Hole, so called in honor of a colored woman whose body was washed ashore here. Here we found splendid specimens of *Wrightiella Blodgettii* and *Naccaria corymbosa* floating in on the breakers. Farther along is Sylvester's Bay and beyond that Buildings Bay, so named from the fact that here Sir George Summers built the little ships in which he sailed away for Virginia. It is a little cove extending in behind an old fortification; there is a little beach at the head of the bay; comparatively few plants grow on the rocks along the shore or on the bottom, but among them is the

[5] This is the "Oblongarum Avium Insula" of the map in Jansen's atlas, Vol. III, 1646. This map, a copy of the original survey of 1622, is remarkably full and accurate; names of places have hardly changed at all, and the family names of many of the owners there given appear today everywhere in the islands. This accuracy and fullness is the more remarkable in contrast with the maps in the same volume, covering the mainland from Labrador to Florida; contours are vague and uncertain, and names strangely transposed.

"Staghorn" *Codium*, the very large form of *C. decorticatum*. But many things that come in there on the tide show that there are very fertile grounds outside; there is *Dudresnaya crassa, Trichogloea Herveyi, Naccaria corymbosa, Dasya pedicellata* and several other Dasyas, *Crouania attenuata*, Callithamnions, Liagoras etc.; there are probably more things to be found here than in any other like place in Bermuda. Just beyond this is Gates Bay, noted for abundance of *Crouania, Liagora* and *Laurencia*, for the most part epiphytic on *Sargassum*.

On the harbor side of St. George's may be found some good collecting; here by an old wharf at the eastern end of the city we found *Antithamnion cruciatum* and our only specimens of *Caulerpa verticillata*. Taking the ferry to St. David's and crossing over to the south side of the island near the lighthouse we come to a beach where we found a fine growth of *Gracilaria dichotomo-flabellata* and some small specimens of *Eucheuma Gelidium*. At the west end of the Causeway we find a new road leading around the shore to Walsingham House; there is good collecting all along here; first of all at the left, a growth of mangrove trees, on the amphibious roots of which is abundance of three species of *Bostrychia*, mingled with *Caloglossa Leprieurii* and *Catenella pinnata;* these plants grow on such roots, as well as on rocks covered only at high tide, in every part of the island. There are two little tide pools in the immediate vicinity of Moore's calabash tree in one of which are two or three species of *Caulerpa* and *Udotea flabellum;* in the other, smaller, one, partly under a big rock, the bottom is carpeted with delicate fronds of *Caulerpa sertularioides;* in the neighborhood of Walsingham House are several little coves rich in plants; one a hundred yards or so to the right of the driveway leading up to the main road always contains *Chrysymenia uvaria* in fine form; here also in 1915 we found a splendid growth of *Halymenia pseudofloresia*, and it is the only place in which we found more than a single frond or a fragment. Over on the shore of Castle Harbor in April we found a good collection of *Spyridia aculeata* var. *hypnoides*.

Following the southwest shore of Castle Harbor for a mile and a half we come to Tucker's Town, another fruitful locality; here in a little grotto, back of the concrete wharf, growing at all seasons are *Halymenia bermudensis* and *Galaxaura obtusata;* on the shore in front of the wharf where a small stream runs into the sea are quantities of *Gelidium pusillum* and around the point to the left a heavy growth of *Eucheuma denticulatum;* all about the wharf are fronds of *Ulva*, yards long. A boat can be taken from Tucker's Town to Cooper's Island, famous as a rich station; here in a single day in 1881 Farlow found *Dudresnaya caribaea, D. bermudensis, Calosiphonia verticillifera* and *Kallymenia perforata,* none of which except the second have been found in Bermuda since; we have made several visits to the island in the hope of finding them, but in vain, but each trip was rewarded by unexpected good things.

From Tucker's Town way along the South Shore to Ely's Harbor, a distance of some fifteen miles, the shore presents an alternation of long beaches and high precipitous rocks, with but here and there a bay where one can collect algae. The reef runs along parallel to the shore, from a quarter to a half a mile outside. There are two or three little bays in Southampton which we have not explored; but we have found that the flora of the west end of the island is not nearly as rich as that of the east end. On the south shore east of the meridian of Hamilton are a few bays that should be mentioned; these are in the neighborhood of Devil's Hole, viz., Pink Bay, Smith's Bay and Gravelly Bay; a reference to the text will show what plants have been collected in these localities; special attention is called only to the last of the three, Gravelly Bay. It is not more than a quarter of a mile across the island from Devil's Hole; it has proved a remarkably fertile place; it is the only station where we have found *Gracilaria horizontalis, Turbinaria tricostata* and *Dilophus guineensis,* though the latter was found by Farlow in Paget. The place is rich in several species of *Dictyota,* also in *Zonaria lobata* and *Dictyopteris Justii* in their seasons. Here also we first found *Trichogloea Herveyi,* and we have found it there every season since; a little cave near the bay has yielded a number of species, rarely found elsewhere.

About a mile farther along towards the west we come to what is known as Spanish Rock; here at the foot of a high precipice, *Colpomenia sinuosa* and *Hydroclathrus cancellatus* cover the rocks, and may be collected at low tide; another mile along in the same direction we come to Harris Bay, another good station; here several species of *Spyridia* and *Liagora* abound, also two species of *Sphacelaria, Wrightiella Blodgettii, Digenea simplex* and others; it is the only station for *Udotea conglutinata* and *Rosenvingia intricata.* Devonshire Bay just beyond we did not find very productive, but a mile and a half farther on is Hungry Bay, which will reward several visits at different seasons; Dictyotas and Dictyopteris abound here in summer, and in the tidal creek Howe collected *Acicularia Schenckii,* the only time it has been found in Bermuda; in this creek also is excellent *Ernodesmis verticillata. Geminella scalariformis* forma *marina* was found in a pool in the rocks on the west side of the bay.

Ely's Harbor and Mangrove Bay towards the west end of the group are noted for nothing in particular, but are by no means barren; in the former we found a better growth of *Porphyra atropurpurea* than elsewhere. Now crossing the land to the shore on the inside of the great hook that this end of the group makes, and going along to the neighborhood of Gibbs Hill light, we come to Jew's Bay and Heron Bay, in both of which good collecting may be had, especially in the latter, with its shallow still water and sunny exposure; we found it very fertile with several species of *Gracilaria, Laurencia, Spyridia, Chondria curvilineata* and other things. Coming back to Hamilton we may find something at Salt Kettle. The wall of the quay at Hamilton below low tide is well covered with algae, and a big timber float lying there yielded a rich harvest of *Polysiphonia foetidissima.* This brings us round to the point of beginning.

Class **MYXOPHYCEAE.**

Family CHROOCOCCACEAE.

Chroococcus Nägeli.

1. Cells 3–8 μ diam., 1. C. membraninus.
1. Cells 13–25 μ diam. 2. C. turgidus.

*1. C membraninus (Menegh.) Nägeli, 1849, p. 46; P. B.-A., No. 2151; *Pleurococcus membraninus* Meneghini, 1842, p. 34, Pl. IV, fig. 1. In brackish pool near race course, Aug.; in ditch in South Shore marshes, Sept., Collins. In the material from the locality first named the cells were dividing rapidly, and average smaller than in P. B.-A., No. 1201, about like Wittrock, Nordstedt & Lagerheim, No. 1538. Sometimes the division of the cells goes on so much faster than the separation of families that a mass resembling a *Microcystis* is formed.

2. C. turgidus (Kütz.) Nägeli, 1849, p. 46; *Protococcus turgidus* Kützing, 1845–49, p. 5, Pl. VI, fig. 1. In gelatinous masses in brackish pools, and in films on decaying algae near Flatts Bridge, April, Collins.

Synechocystis Sauvageau.

* S. aquatilis Sauvageau, 1892a, p. CXVI. On rocks near Hungry Bay, April; in cave, Agar's Island, Aug., Collins.

Synechococcus Nägeli.

* S. aeruginosus Nägeli, 1849, p. 56, Pl. I. E, fig. 1. Among other algae in brackish pool near race-course, Aug., Collins. Cells about 14 × 7 μ, which is rather small for this species.

Chroothece Hansgirg.

1. Cells seldom under 20 μ diam. 1. C. Richteriana.
1. Cells not over 3 μ diam. 2. C. cryptarum.

1. C. Richteriana forma marina Hansgirg, 1889, p. 5; P. B.-A., No. 702. Farlow; rather common on shaded stone work and on sides of caves, Collins.

2. C. CRYPTARUM Farlow in P. B.-A., No. 752; Forti, 1907, p. 30. Farlow; on walls and roofs of caves, often in company with *C. Richteriana*. *Gloeothece rupestris* often occurs in company with these two species, the whole forming a continuous stratum, generally one or two mm. thick, extending from just above low water mark to much above high water mark. Between tide marks it is a rich green and gelatinous, but beyond the range of tides it is yellowish or whitish and crumbly.

GLOEOCAPSA Kützing.

1. Cell without wall, 1.5–2 μ diam.; tegument yellow or brown. 1. G. fusco-lutea.
1. Cell without wall, over 2 μ diam.; tegument colorless or nearly so. 2.
   2. Colony amorphous, soft; cell without wall, 2–5 μ diam. 2. G. montana.
   2. Colony subspherical, firm; cell without wall, 4–6 μ diam. 3. G. atrata.

*1. G. FUSCO-LUTEA (Näg.) Kützing, 1849, p. 224; P. B.-A., No. 2153. *G. ambigua* var. *fusco-lutea* Nägeli, 1849, p. 50. On rocks, Hungry Bay, in company with *Synechocystis aquatilis*, April, Collins. The color of the tegument varies from dark brown to pale yellow.

*2. G. MONTANA Kützing, 1843, p. 173; 1845–49, p. 14, Pl. XIX, fig. 2. On wall of cave near Causeway, high up, April, Collins.

*3. G. ATRATA (Turp.) Kützing, 1843, p. 174, Pl. VI, fig. 1; *Globulina atrata* Turpin, 1830, Pl. V, fig. 6. On cliff, away from the sea, in company with *Scytonema* etc., Aug., Collins. The colonies are usually quite regularly spherical; they range from about 30 μ diam., containing only two cells, to above 140 μ diam., with hundreds of cells. The contents is bright green, somewhat granular; the surface inside the wall is usually thickly set with very short, bristle-like projections; bacterial?

GLOEOTHECE Nägeli.

1. Cell without tegument, about 2 μ wide. 1. G. confluens.
1. Cell without tegument, about 5 μ wide. 2. G. rupestris.

*1. G. CONFLUENS Nägeli, 1849, p. 58, Pl. I. G, fig. 1. On wall of shallow cave, by inland road, April, Collins.

*2. G. RUPESTRIS (Lyng.) Bornet in W. & N., No. 399, 1880; *Palmella rupestris* Lyngbye, 1819, p. 207, Pl. LXIX, fig. D; *G. membranacea* Bornet, 1892, p. 175. Common all about the islands in clefts of rocks, rock pools, roadsides, within reach of salt water or far from it. As noted by Bornet, 1892, p. 175, it varies much in the appearance of the stratum, from thick gelatinous masses to thin films, also in the development of the concentric walls; in a rock pool of fresh water, near the Old Ferry road, we collected a form quite without these walls, closely resembling *Aphanothece microscopica*, P. B.-A., No. 552; but it seems probable that it is merely a state of the present species corresponding to Bornet's section I, in which he includes *Microcystis microspora* Menegh. This form distributed as P. B.-A., No. 2154. Lyngbye's specific name, used by Bornet in 1880, is the oldest, and must supersede the name used by Bornet in 1892.

Entophysalis Kützing.

E. granulosa Kützing, 1843, p. 177, Pl. XVIII, fig. 5; Bornet & Thuret, 1876, Pl. I, figs. 4 & 5. On rocks, North Shore, Aug., Collins.

Microcystis Kützing.

*M. marginata (Menegh.) Kützing, 1845–49, p. 6, Pl. VIII; *Anacystis marginata* Meneghini, 1836, p. 6; 1842, p. 93, Pl. XIII, fig. 1. With other algae on wall of cave near Causeway, April, Collins.

Merismopedium Meyen.

1. Families 50–150 μ square.	1. M. glaucum.
1. Families 1–4 mm. square.	2. M. convolutum.

*1. M. glaucum (Ehrb.) Nägeli, 1849, p. 55, Pl. I. D, fig. 1; *Gonium glaucum* Ehrenberg, 1838, p. 56, Pl. III, fig. 5. Among other algae in pool by race course, Aug., Collins.

*2. M. convolutum Brébisson in Kützing, 1849, p. 472; 1855, p. 13, Pl. XXXVIII, fig. IX. Among various algae in Harrington Sound; in cave at Gravelly Bay, Jan., Hervey.

Oncobyrsa Agardh.

O. marina (Grun.) Rabenhorst, 1865, p. 68; *Hydrococcus marinus* Grunow, 1861, p. 420. On *Dictyopteris Justii*, Gravelly Bay, Aug., Collins; on *Sphacelaria*, Spanish Rock, March, Hervey.

Chlorogloea Wille.

C. tuberculosa (Hansg.) Wille, 1900, p. 5, Pl. I, figs. 1–6; *Palmella ? tuberculosa* Hansgirg, 1892, p. 240, Pl. VI, fig. 9. On *Bostrychia, Catenella* etc., in company with other minute Myxophyceae.

Family CHAMAESIPHONACEAE.

Pleurocapsa Thuret.

P. conferta (Kütz.) Setchell, 1912, p. 229; *Palmella conferta* Kützing, 1845, p. 149; 1845–1849, p. 12, Pl. XVI, fig. IV. On *Rhodochorton speluncarum,* in cave, Agar's Island, Aug.; on *Gelidium pusillum,* Harrington Sound, April, Collins.

Hyella Bornet & Flahault.

H. caespitosa Bornet & Flahault, 1888a, p. 162; 1889, p. CLXV, Pl. X, figs. 7–8, Pl. XI. In dead shells, in company with *Gomontia, Mastigocoleus* and *Plectonema,* but usually the least abundant of the four.

Dermocarpa Crouan.

1. Cells scattered.	1. D. solitaria.
1. Cells laterally united in pulvinate expansions.	2. D. prasina.

1. **D. solitaria** sp. nov.; P. B.-A., No. 2155. Cellula solitaria, clavata, circa 8 μ diam., supra discum basale paullo majus; superne uniformiter incrassata, vel interdum prope basin parvam expansionem annulatam ferente, usque ad apicem rotundatam, circa 20 μ diam.; longitudine ad 75 μ; ad maturitatem in duas cellulas divisa, superiore in gonidangium subsphaericum mutanda, gonidia pro more 8–12, 5–6 μ diam., continente; cellula inferiore obconica, supra plana vel concava, contentu laete aeruginoso; membrana crassa, sublamellosa.

Cell solitary, clavate, about 8 μ diam. above the slightly larger basal disk, increasing in diameter upwards uniformly, or sometimes with a slight ring-like expansion near the base, to the rounded apex, about 20 μ diam.; height up to 75 μ. At maturity dividing into two cells, the upper a subspherical gonidangium, containing gonidia, 5–6 μ diam., usually 8–12 in number; the lower cell obconical with flat or concave upper surface, contents bright blue-green; wall thick, somewhat lamellate.

On older parts of fronds of *Spermothamnion gorgoneum* and *Ceramothamnion Codii*, which grew on *Codium decorticatum*, in company with *Xenococcus Schousboei*, *Lyngbya Meneghiniana* and other small algae. The cells are always scattered, never forming cushion-like masses, as is the case with most species of *Dermocarpa*. The general appearance of the plant is not unlike that of some small species of *Codiolum*, except for the shade of color, and that the colorless stipe is shorter.

2. D. PRASINA (Reinsch) Bornet & Thuret, 1876, p. 75, Pl. XXVI; P. B.-A., No. 2051. *Sphaenosiphon prasinus* Reinsch, 1875, p. 73, Pl. XII. Not *D. prasina* P. B. A., No. 1, which is *D. Farlowii* Börgs. On *Catenella Opuntia* var. *pinnata* generally.

XENOCOCCUS Thuret.

X. SCHOUSBOEI Thuret in Bornet & Thuret, 1880, p. 74, Pl. XXVI, figs. 1–2; P. B.-A., No. 2052. On *Lyngbya confervoides*, in ditch back of Shelly Bay, Aug., Collins. Cells mostly separate and exactly spherical; but sometimes closely packed and compressed.

Var. PALLIDA Hansgirg, 1889, p. 5. On algae on roof of cave, Gravelly Bay, April, Collins. What may be a species of *Xenococcus* with minute cells was found on *Oedogonium* from Devonshire marshes, but could not be specifically identified.

FAMILY OSCILLATORIACEAE.

SPIRULINA Turpin.

1. Trichome rose-color. 1. S. rosea.
1. Trichome aeruginous. 2.
   2. Trichome less than 1 μ diam., spiral loose. 2. S. tenerrima.
   2. Trichome over 1 μ diam., spiral close. 3. S. subsalsa f. oceanica.

1. S. ROSEA Crouan ex Gomont, 1893, p. 273. Forming a pinkish film on *Amphiroa* between tide marks, North Shore, Sept., Collins.

*2. S. TENERRIMA Kützing ex Gomont, 1893, p. 272; Kützing, 1845–49, p. 25, Pl. XXXVII, fig. I; P. B.-A., No. 2054. Among other algae in a coating on rock between tide marks, North Shore, Sept., Collins.

3. S. SUBSALSA forma OCEANICA Gomont, 1893, p. 274; P. B.-A., No. 2053. Among other algae at various stations.

OSCILLATORIA Vaucher.

1. Filaments torulose.	2.
1. Filaments not torulose.	6.
2. Trichomes 18–36 μ diam., loosely spiral.	1. O. Bonnemaisonii.
2. Trichomes not spiral.	3.
3. Trichomes and stratum dull red.	2. O. miniata.
3. Trichomes and stratum not red.	4.
4. Limicolous; trichomes 17–29 μ diam.	3. O. margaritifera.
4. Trichomes 6–11 μ diam.	5.
5. Limicolous or saxicolous; black-olive.	4. O. nigro-viridis.
5. Epiphytic; aeruginous, light green or light brown.	5. O. Corallinae.
6. Trichomes not attenuate at tip.	7.
6. Trichomes attenuate at tip.	8.
7. Trichomes 4–10 μ diam.	6. O. tenuis.
7. Trichomes less than 3 μ diam.	7. O. amphibia.
8. Apical cell capitate.	8. O. amoena
8. Apical cell not capitate.	9.
9. Trichomes 3 μ diam. or more.	10.
9. Trichomes less than 3 μ diam.	11. O. longearticulata.
10. Distinctly marine.	9. O. laetevirens.
10. Plant of fresh water pools.	10. O. formosa.

1. O. BONNEMAISONII Crouan ex Gomont, 1893, p. 235, Pl. VI, figs. 17–18; P. B.-A., No. 2055. Forming floating masses in ditch in Pembroke Marsh, Aug., Collins.

2. O. MINIATA Hauck ex Gomont, 1893, p. 236; P. B.-A., No. 2156. Hungry Bay, April, May, Collins. Forming a deep red film on the bottom, also floating clots adhering to everything. The filaments are usually about 20 μ diam., but occasionally as high as 45 μ. The plant decays very quickly, and even when put on paper with a promptness ample for most Oscillatorias, the coloring matter stains the paper purple, and the filaments remain nearly colorless.

3. O. MARGARITIFERA Kützing ex Gomont, 1893, p. 236, Pl. VI, fig. 19. In brackish pool with other algae, April, Sept., Collins.

4. O. NIGRO-VIRIDIS Thwaites ex Gomont, 1893, p. 237, Pl. VI, fig. 20. On rocks wet by salt water, Jan., Farlow.

5. O. CORALLINAE Gomont, 1893, p. 238, Pl. VI, fig. 21. On *Codium tomentosum*, Cooper's Island, April, Collins.

*6. O. TENUIS Ag. var. TERGESTINA Rabenhorst ex Gomont, 1893, p. 241. Among other algae in a ditch in meadow by Shelly Bay, Aug., Collins.

*7. O. AMPHIBIA Gomont, 1893, p. 241, Pl. VII, figs. 4–5; P. B.-A., No. 1852. In brackish pool among other algae, April, Aug., Collins.

*8. O. AMOENA Gomont, 1893, p. 245, Pl. VII, fig. 9. Forming a thin coating on rock at Inlet, Aug., Collins.

*9. O. LAETEVIRENS Crouan ex Gomont, 1893, p. 246, Pl. VII, fig. 11. Among other algae, Tucker's Town, May, Collins.

*10. O. FORMOSA Bory ex Gomont, 1893, p. 250, Pl. VII, fig. 16. In a puddle of rain water in road, April, Collins.

11. O. LONGEARTICULATA Hansgirg ex Forti, 1907, p. 176. On *Codium*, near Causeway, April, Hervey. We have not seen an authentic specimen of this species, but our plant agrees with the original description, with no description in Gomont, and with none but this in Forti.

TRICHODESMIUM Ehrenberg.

T. THIEBAUTII Gomont, 1893, p. 217, Pl. VI, figs. 2–4; Wille, 1904, p. 57, Pl. I, figs. 17–22. Hamilton Harbor, Wille, l. c.[6]

PHORMIDIUM Kützing.

1. Trichomes strongly moniliform.	1. P. fragile.
1. Trichomes not moniliform.	2.
2. Stratum purple or pink.	2. P. luridum.
2. Stratum greenish or blackish.	3.
3. Trichomes 3 μ diam. or less.	3. P. valderianum.
3. Trichomes 4–12 μ diam.	4. P. Retzii.

1. P. FRAGILE Gomont, 1893, p. 183, Pl. IV, figs. 13–15. Among other algae in an incrustation in rock between tide marks, April, Collins.

*2. P. LURIDUM Gomont, 1893, p. 185, Pl. IV, figs. 17–18; P. B.-A.,

[6] *Catagnymene pelagica* Lemmermann var. *major* Wille, 1904, p. 51, pl. I, fig. 7, is reported by Tilden, 1910, p. 159, as occurring at Bermuda, but we are unable to obtain any confirmatory evidence. Wille, l. c., reports it from open sea, at several points. *Dermocarpa Leibleinii* (Reinsch) Bornet var. *pelagica* Wille, also appears in Tilden, 1910, p. 55, as from Bermuda, on authority of Wille, 1904, p. 50; but Wille's record is 39° 4′ N., Long. 57° 8′ W., "ungefahr in der Mitte zwischen den Bermuda-Inseln und New Foundland."

No. 2056. Forming a pinkish film over rocks between tide marks, North Shore, Aug., Collins.

*3. P. VALDERIANUM Gomont, 1893, p. 187, Pl. IV, fig. 20; P. B.-A., No. 2157. Among other algae in a blackish coating on rocks and on *Bostrychia*, Aug. In thick wrinkled sheets on brackish water, near old race course Dec. Collins.

*4. P. RETZII Gomont, 1893, p. 195, Pl. V, figs. 6–9; P. B.-A., No. 2057. Forming a light green, firm coating on rock between tide marks, North Shore, Sept., Collins.

LYNGBYA Agardh.

1. Filaments attached at the middle. 1. L. Meneghiniana.
1. Filaments attached at one end or free. 2.
  2. Trichomes over 5 μ diam., usually over 7 μ. 3.
  2. Trichomes 4 μ diam. or less, seldom over 3 μ. 5.
3. Trichomes 16–60 μ diam., dissepiments not granulate. 2. L. majuscula.
3. Dissepiments granulate. 4.
  4. Trichomes 9–25 μ diam., apex not attenuate nor capitate. 3. L. confervoides.
  4. Trichomes 5–12 μ diam., apex usually attenuate and capitate. 4. L. semiplena.
5. Trichomes 2.5–4 μ diam., straight or flexuous, not regularly spiral. 5. L. lutea.
5. Trichomes about 2 μ diam., more or less spiral. 6. L. Lagerheimii.

1. L. MENEGHINIANA Gomont, 1893, p. 145. Mangrove Creek, Farlow; on Codium, Cooper's Island, Collins; Gibbet Island, March, Hervey. The only representative here of the subgenus *Leibleinia*, the filaments bent hairpin-shape, attached in the middle, both ends free.

2. L. MAJUSCULA Harvey ex Gomont, 1893, p. 151, Pl. III, figs. 3–4; Harvey, 1858, p. 101, Pl. XLVII. A; P. B.-A., No. 2001. Rein; Moseley; Walsingham Grotto, March, Alden Fish pond, Dec., Hervey. Usually blackish green, occasionally reddish or violet.

3. L. CONFERVOIDES Agardh ex Gomont, 1893, p. 156, Pl. III, figs. 5–6; including forma *violacea* Collins, P. B.-A., No. 1853. Common in floating masses in quiet waters, as attached tufts in more exposed places, nearly everywhere. A brownish or yellowish green is the more usual color, but violet and reddish shades are not uncommon. These are in striking contrast to the normal color, but from our observations on the species of *Lyngbya* found at Bermuda, we are

of the opinion that there is no justification for keeping color forms distinct taxonomically. Both colors occur in nature, both in dried material; plants originally aeruginous may change to red, plants originally red fade to pale green. We have no suggestion to make as to the causes determining these changes, except the general principle in regard to filamentous Nostocaceae, that red forms generally occur where the plant is always under water, not left exposed at low tide.

4. L. SEMIPLENA J. G. Agardh ex Gomont, 1893, p. 158, Pl. III, figs. 7–11. Not uncommon among other small algae; rarely pure.

5. LYNGBYA LUTEA Gomont, 1893, p. 161, Pl. III, figs. 12 & 13. Among various small algae, not found pure; bright red form on *Codium*, Harris Bay, Dec., Hervey.

*6. L. LAGERHEIMII Gomont, 1893, p. 167, Pl. IV, figs. 6–7. On decaying *Sargassum*, near Shelly Bay, April, Collins.

SYMPLOCA Kützing.

1. Cells 1–2 diam. long, aeruginous.	1. S. muscorum.
1. Cells much shorter than their diam., violet.	2. S. violacea.

*1. S. MUSCORUM Gomont, 1893, p. 130, Pl. II, fig. 9. On rock by roadside, Aug., Collins.

2. S. VIOLACEA Hauck ex Forti, 1907, p. 311; Hauck, 1885, p. 507, fig. 224. On ground near margin of pool in woods by Walsingham, April, Collins. This appears to have been overlooked by Gomont in his monograph either as an accepted species or among "species inquirendae" or "species excludendae." Hauck's record is included by Forti in the Sylloge, and by the international rules, which fix Gomont's monograph as the point of departure for homeocysted filamentous Nostochineae, 1907 is the date of publication. The Bermuda plant agrees with Hauck's description and figure; the violet color and short cells distinguish it from all other marine species.

PLECTONEMA Thuret.

*P. NOSTOCORUM Bornet ex Gomont, 1893, p. 122, Pl. I, fig. 11. Common in gelatinous masses of algae of various kinds.

PORPHYROSIPHON Kützing.

*P. NOTARISII Kützing ex Gomont, 1893, p. 69, Pl. XII, figs. 1–2. On *Juniperus bermudiana*, Aug., Collins.

Microcoleus Desmazières.

1. Terrestrial. 3. M. vaginatus.
1. Marine. 2.
 2. Trichomes 2.5–6 μ diam. 1. M. chthonoplastes.
 2. Trichomes 1.5–2 μ diam. 2. M. tenerrimus.

1. M. chthonoplastes Thuret ex Gomont, 1893, p. 91, Pl. XIV, figs. 5–8; P. B.-A., No. 1854. Common among other small algae in incrustations on rocks, and on bottoms of shallow pools; occasionally nearly pure, as a thin, blackish coating; also in fresh water reservoir near Spanish Rock, Hervey.

2. M. tenerrimus Gomont, 1893, p. 93, Pl. XIV, figs. 9–11. Occasional filaments among *M. chthonoplastes*, less commonly among other small algae.

*3. M. vaginatus var. monticola Gomont, 1893, p. 94. On moist ground at roadside near Flatts Bridge, Dec., Hervey.

Hydrocoleum Kützing.

1. Trichomes 14–24 μ diam. 2.
1. Trichomes 8–14 μ diam., rarely to 16 μ; sheaths irregular, gelatinous, often quite diffluent. 2. H. lyngbyaceum.
 2. Color of mass of violet shade; sheaths cylindrical, distinct. 1. H. comoides.
 2. Color of mass dull green or yellowish; sheaths irregular, becoming shapeless and diffluent. 3. H. glutinosum.

1. H. comoides Gomont, 1893, p. 73, Pl. XII, figs. 3–5. Farlow, fide Gomont, l. c.; on rocks, Hungry Bay, April, Collins.

2. H. lyngbyaceum Kützing ex Gomont, 1893, p. 75, Pl. XII, figs. 8–10; P. B.-A., No. 2058. Farlow, fide Gomont, l. c.; occasional in pools, Collins. The latter resembling var. *rupestre* Gomont, l. c.

3. H. glutinosum Gomont, 1893, p. 77. Rocks east of Elbow Bay, Dec., Collins, forming a thin, tubercular coating on rocks between tides.

Schizothrix Kützing.

1. Among algae in pools; trichomes 2–3 μ diam. 1. S. vaginata.
1. On damp walls; trichomes 1–1.7 μ diam. 2. S. calcicola.

*1. S. vaginata Gomont, 1893, p. 40, Pl. VII, figs. 1–4. In a gelatinous mass with other algae, North Shore, Sept., Collins; Harrington Sound, Nov., Hervey.

*2. S. CALCICOLA Rabenhorst ex Gomont, 1893, p. 45, Pl. VIII, figs. 1–3; P. B.-A., No. 2158. On shaded wall of house near South Road, Dec., Collins.

FAMILY NOSTOCHACEAE.

ANABAENA Bory.

1. Spores ovoid, not contiguous to heterocysts.	1. A. variabilis.
1. Spores subcylindrical, contiguous to heterocysts.	2. A. torulosa.

*1. A. VARIABILIS Kützing ex Bornet & Flahault, 1888, p. 226, P. B.-A., No. 2059. *Sphaerozyga Thwaitesii* Harvey, 1846–51, Pl. CXIII. B. Brackish pool, April, Collins; in reservoir near Spanish Rock, Jan., Hervey. In the material from the latter station the filaments were sometimes straight, but oftener curved as in *A. flos-aquae* Bréb.; the spores were those of *A. variabilis.*

2. A. TORULOSA Lagerheim ex Bornet & Flahault, 1888, p. 236. Among other algae, North Shore, Aug., Collins.

Sterile filaments of an *Anabaena* or *Cylindrospermum* were found on ground wet by rain, near Flatts Bridge, Aug., Collins. The cells were about 4 μ diam., spherical, or just after division discoid.

HORMOTHAMNION Grunow.

H. convolutum sp. nov. Trichomatibus pallide aerugineis, interdum rubescentibus, parallelis, elongatis, 3–5 μ diam.; cellulis 1–4 diam. longis, cylindricis, nodis leviter constrictis; heterocystis ovoideis vel sphaericis, 8–10 μ diam.; sporis ?; fasciculis tenuibus, inter utriculis hospitis penetrantibus, curvatis.

Trichomes pale aerugineous, sometimes with a shade of red, parallel, long, 3–5 μ diam.; cells 1–4 diam. long, cylindrical, slightly constricted at the nodes; heterocysts ovoid to spherical, 8–10 μ diam.; spores ?; fascicles slender, winding among the utricles of the host. On *Codium tomentosum*, Cooper's Island, Aug. 29, 1913, F. S. Collins. Type in Collins herb., No. 7239.

More slender than the other species of the genus, the cells relatively longer. The cluster of filaments winds about among the utricles of the host, the continued growth of the two plants causing the endophyte to turn and twist very sharply.

NOSTOC Vaucher.

*N. COMMUNE Vaucher ex Bornet & Flahault, 1888, p. 203; P. B.-A., No. 1901; *N. ciniflonum* Bornet & Thuret, 1880, p. 102, Pl. XXVIII, fig. 13. Common everywhere, especially on sandy soil; thin brittle skins in dry weather, expanded thickish soft masses in wet weather. No spores seen. Native name, "Devil's Tobacco."

FAMILY SCYTONEMACEAE Kützing.

MICROCHAETE Thuret.

M. VITIENSIS Askenasy ex Bornet & Flahault, 1887, p. 85. Scattered filaments on *Wrangelia penicillata*, Harris Bay, Jan., Hervey.

SCYTONEMA Agardh.

1. Sheaths not lamellate.	2.
1. Sheaths lamellate.	3.
2. Trichomes 5–7 μ diam.	1. S. varium.
2. Trichomes 6–14 μ diam.	2. S. ocellatum.
3. Branches usually geminate, free and divergent.	4.
3. Branches frequently solitary, adherent at base.	5. S. crustaceum.
4. Filaments 15–21 μ diam.; sheath thin at apex.	3. S. figuratum.
4. Filaments 18–36 μ diam.; sheath thick throughout.	4. S. myochrous.

*1. S. VARIUM Kützing ex Bornet & Flahault, 1887, p. 97; Kützing, 1850–52, p. 6, Pl. XXIII, fig. II. High up on walls of a cave at Walsingham; shore of pool near Walsingham, April, Collins.

*2. S. OCELLATUM Lyngbye ex Bornet & Flahault, 1887, p. 95; P. B.-A., No. 711, on dunes, Paget, Farlow.

*3. S. FIGURATUM Agardh ex Bornet & Flahault, 1887, p. 101; *S. thermale* Kützing, 1850–52, p. 5, Pl. XVIII, fig. III. High up on wall of cave near Walsingham, April, Collins.

Bornet, 1889a, p. 155, shows that *Conferva mirabilis* Dillwyn, 1807, Pl. XCVI, is identical with *Scytonema figuratum* of Agardh, and of earlier date, and therefore changes the name to *S. mirabile* (Dillw.) Bornet. But as the starting point for nomenclature of the heterocysted Nostochaceae is definitely fixed at the Bornet & Flahault monograph, it appears as if the later name by Bornet cannot be substituted.

*4. S. MYOCHROUS Agardh ex Bornet & Flahault, 1887, p. 104; Kützing, 1850–52, p. 7, Pl. XXV, fig. III; P. B.-A., No. 1902. On perpendicular cliff, Paget, Aug., Collins; and common in company with *Calothrix* species etc. on rocks between tides. This species has a very wide distribution as a plant of rocks etc., dripping with fresh water, but in Bermuda it is commonly found with distinctly marine species, in mats on flat rocks in the litoral zone.

*5. S. CRUSTACEUM Agardh ex Bornet & Flahault, 1887, p. 106. On sand near Mangrove Creek, Hamilton, Jan., Farlow.

TOLYPOTHRIX Kützing.

*T. TENUIS Kützing ex Bornet & Flahault, 1887, p. 122; Kützing, 1850–52, p. 9, Pl. XXXI, fig. II. Among *Oedogonium*, in ditch in Devonshire Marsh, April, Collins.

HASSALLIA Berkeley.

*H. BYSSOIDEA Hassall ex Bornet & Flahault, 1887, p. 116. On bark of *Juniperus bermudiana*, rather common.

FAMILY STIGONEMACEAE Hassall.

MASTIGOCOLEUS Lagerheim.

M. TESTARUM Lagerheim ex Bornet & Flahault, 1887, p. 54; 1889, p. CLXII, Pl. X, fig. 4. In dead shells of mollusks, with *Gomontia* etc.

HAPALOSIPHON Nägeli.

*H. INTRICATUS W. & G. S. West, 1895, p. 271, Pl. XV, figs. 16–28; P. B.-A., No. 1855. In ditch in Devonshire Marsh, April, Dec., Collins.

STIGONEMA Agardh.

*S. INFORME Kützing ex Bornet & Flahault, 1887, p. 75; Kützing, 1850–1852, p. 15, Pl. XXXVIII, fig. 3. Feb., H. Kennedy in Farlow herbarium.

FISCHERELLA Gomont.

*F. AMBIGUA Gomont, 1895, p. 49, Pl. III. On stone wall, Jan., Farlow.

Family RIVULARIACEAE.

Calothrix Agardh.

1. Heterocysts basal only.	2.
1. Heterocysts basal and intercalary.	6.
2. Trichomes violet.	1. C. fusco-violacea.
2. Trichomes olivaceous or aerugineous.	3.
3. More or less endophytic.	3. C. parasitica.
3. Not endophytic.	4.
4. Filaments in stellate tufts on other algae.	6. C. confervicola.
4. Filaments not in stellate tufts; saxicolous.	5.
5. Trichomes olivaceous.	2. C. scopulorum.
5. Trichomes aerugineous.	4. C. aeruginea.
6. Filaments attached at the middle.	7. C. pilosa.
6. Filaments attached at one end.	7.
7. Filaments 9–10 μ diam.	4. C. aeruginea.
7. Filaments 12–40 μ diam.	5. C. crustacea.

1. C. FUSCO-VIOLACEA Crouan ex Bornet & Flahault, 1886, p. 352; P. B.-A., No. 2060. On *Enteromorpha, Ectocarpus* etc., rock pool, South Shore, Jan., Hervey.

2. C. SCOPULORUM Agardh ex Bornet & Flahault, 1886, p. 353; Bornet & Thuret, 1880, p. 159, Pl. XXXVIII; P. B.-A., No. 1856. On flat rocks between tides, Causeway, Shelly Bay, etc., common.

3. C. PARASITICA Thuret ex Bornet & Flahault, 1886, p. 357; Bornet & Thuret 1880, p. 157, Pl. XXXVII, figs. 7–10. In *Trichogloea Herveyi*, Cooper's Island, April, Collins; in gelatinous mass of various algae, in drip from Aquarium outlet, Aug., Collins. Occasionally found in various loose-tissued algae.

4. C. AERUGINEA Thuret ex Bornet & Flahault, 1886, p. 358; Bornet & Thuret, 1880, p. 157, Pl. XXXVII, figs. 1–6. On rocks, North Shore, mixed with *Schizothrix* etc., Nov., Hervey.

5. C. CRUSTACEA Thuret ex Bornet & Flahault, 1886, p. 359; Bornet & Thuret, 1876, p. 13, Pl. IV. Spanish Rock, April; on *Sargassum*, Gravelly Bay, Dec., Hervey.

6. C. CONFERVICOLA Agardh ex Bornet & Flahault, 1886, p. 349; Bornet & Thuret, 1876, p. 8, Pl. III. On *Cladophora crystallina*, Harrington Sound, Collins.

7. C. PILOSA Harvey ex Bornet & Flahault, 1886, p. 363; Harvey, 1858, p. 106, Pl. XLVIII. C. Common in shallow pools and on flat rocks between tides.

Dichothrix Zanardini.

1. On rocks; filaments 15–20 μ in branches of last order. 1. D. Baueriana.
1. Epiphytic; filaments 20–30 μ in branches of last order. 2. D. fucicola.

*1. D. Baueriana Bornet & Flahault, 1886, p. 376. On rocks between tides, North Shore, Oct., Nov., Hervey; Hamilton Harbor, Nov., Collins. Known heretofore only as a fresh water species, but the Bermuda plant is distinctly marine, though agreeing in characters with European and American specimens from fresh water stations.

2. D. fucicola Bornet & Flahault, 1886, p. 379; *Schizosiphon fucicola* Kützing, 1850–52, p. 18, Pl. LV, fig. II. On various algae forming a mat at the bottom of a pool, Gibbet Island, Hervey.

Polythrix Zanardini.

P. corymbosa Grunow ex Bornet & Flahault, 1886, p. 380; P. B.-A., No. 1903; *Microcoleus corymbosus* Harvey, 1858, p. 109, Pl. XLVIII. B. Common on rocks between tides in quiet water all around the islands.

Rivularia Roth.

R. polyotis Bornet & Flahault, 1886a, p. 360; P. B.-A., No. 1904; *R. hospita* Bornet & Thuret, 1880, p. 168, Pl. XLI. Rocks near high water, South Shore, Feb., April, Collins; grotto, Tucker's Town, Dec., Hervey.

Brachytrichia Zanardini.

B. maculans Gomont, 1901, p. 127, Pl. V, figs. 5–7; P. B.-A., No. 2159. Forming a thin film on roots etc. of mangroves between tides, in company with *Dichothrix* and *Calothrix* species, Fairyland, Dec., Collins.

Originally described from material collected in Siam, this species now makes its second appearance half way round the globe.

Family CRYPTOGLENACEAE.

Cryptoglena Ehrenberg.

C. americana B. M. Davis, 1894, p. 101, Pl. XI; P. B.-A., No. 1851. Among *Cladophora expansa* and other algae, in a brackish pool between Harrington Sound and the North Shore, April, Collins.

Class **CHLOROPHYCEAE**.

Family DESMIDIACEAE.

Closterium Nitzsch.

1. Apices subacute; median diam. 17–37 μ. 1. C. Leibleinii.
1. Apices obtuse; median diam. 33–50 μ. 2. C. moniliferum.

*1. C. Leibleinii Kützing ex Ralfs, 1848, p. 167, Pl. XXVIII, fig. 4; Wolle, 1884, p. 46, Pl. VII, figs. 13, 14, 20; G. S. West, 1904, p. 141, Pl. XVI, figs. 9–14; P. B.–A., No. 2061. In small quantity in an artificial reservoir for fresh water, near Spanish Rock, Dec., Hervey.

*2. C. moniliferum Ehrenberg ex Ralfs, 1848, p. 166, Pl. XXVIII, fig. 3; Wolle, 1884, p. 45, Pl. VII, fig. 15; G. S. West, 1904, p. 142, Pl. XVI, figs. 15–16; P. B.–A., No. 1961. Very abundant in an artificial reservoir for fresh water, near Spanish Rock, Dec., Hervey.

Cosmarium Corda.

1. Uniformly granulate; semi-cell ovate-pyramidal, 51–68 μ wide. 4. C. botrytis.
1. Smooth. 2.
   2. Semi-cell semicircular to semielliptic; 34–36 μ broad. 1. C. Cucumis.
   2. Semi-cell truncate-pyramidal, 19–30 μ broad. 2. C. granatum.
   2. Semi-cell trapezoidal to truncate-pyramidal; about 33 μ broad. 3. C. pseudonitidulum.

*1. C. Cucumis Corda ex Ralfs, 1848, p. 93, Pl. XV, fig. 2; G. S. West, 1905, p. 152, Pl. LIX, figs. 18–20; P. B.-A., No. 1858. Among *Sphagnum* in a ditch, Devonshire Marsh, April, Collins. Distributed as *C. subcucumis* Schmidle, but agreeing better with *C. Cucumis*.

*2. C. granatum Brébisson in Ralfs, 1848, p. 96, Pl. XXXII, fig. 6; Wolle, 1884, p. 60, Pl. L, fig. 13; G. S. West, 1905, p. 186, Pl. LXIII, figs. 1–3. Rather scanty, among *Oedogonium Itzigsohnii*, ditch in Devonshire Marsh, April, Collins.

*3. C. pseudonitidulum Nordstedt, 1873, p. 16, Pl. I, fig. 4; Wolle, 1884, p. 62, Pl. XVIII, fig. 19; G. S. West, 1905, p. 195, Pl. LXIII, fig. 26; P. B.-A., No. 2063. Among various algae in a ditch in South Shore marshes, Sept., Collins.

*4. C. BOTRYTIS Meneghini ex Ralfs, 1848, p. 99, Pl. XVI, fig. 1; Wolle, 1884, p. 74, Pl. XIII, fig. 5; G. S. West, 1911, p. 1, Pl. XCVI, figs. 1, 2, 5–15; P. B.-A., No. 2062. In artificial reservoir for fresh water near Spanish Rock, Dec., Hervey.

MESOTAENIUM Nägeli.

*M. ENDLICHERIANUM Nägeli, 1849, p. 109, Pl. VI. B; G. S. West, 1904, p. 56, Pl. IV, figs. 20–21; P. B.-A., No. 1857. Among other algae in a ditch, fresh water or nearly so, Devonshire Marsh, April, Collins.

FAMILY ZYGNEMACEAE.

SPIROGYRA Link.

S. SUBMARINA (Collins) Transeau, 1915, p. 25; *S. decimina* var. *submarina* Collins, 1909, p. 110; 1912, p. 72. Ditch in South Shore marshes, Sept., Collins. This was first described as a variety of *S. decimina,* which it considerably resembles, and it was known from three widely separated stations in New England. The Bermuda material emphasizes the differences from *S. decimina;* the long cells, up to 8 diam., and the considerably swollen fertile cells; the material from the Elizabeth Islands, Collins, 1912, p. 72, has cells as small as 21 μ diam.

FAMILY VOLVOCACEAE.

A *Chlamydomonas* was found in abundance in the water of an old tank, near Trott's Pond, Aug., Collins, but we have not been able to determine the species.

FAMILY TETRASPORACEAE.

TETRASPORA Link.

*T. LUBRICA (Roth) Agardh, 1824, p. 188; Collins, 1909, p. 139, fig. 26; *Ulva lubrica* Roth, 1806, p. 168. On dead leaves in ditch in Devonshire Marsh, Dec., Collins.

Family PROTOCOCCACEAE.

Protococcus Agardh.

*P. viridis Agardh, 1824, p. 13; *Pleurococcus vulgaris* Nägeli, 1849, p. 65, Pl. IV. E, fig. 2; Collins, 1909, p. 304, fig. 106. On shady side of trees, walls etc., all over the island; it occurs in similar stations in all temperate regions, and possibly also in tropical. Wille, 1913, p. 3, Pl. I, fig. 1, has pointed out the confusion that has long existed in regard to this species and *Pleurococcus vulgaris* Meneghini, and by examination of type specimens, cleared up the matter.

Chlorocystis Reinhard.

C. Cohnii (Wright) Reinhard, 1885, p. 4, Pl. I; Moore, 1900, p. 100, Pl. X; Collins, 1909, p. 148, fig. 35; *Chlorochytrium Cohnii* Wright, 1877, p. 367, Pl. IV–V. In *Ulva Lactuca*, Hungry Bay, April, Collins. Spores, apparently the smaller kind, had been formed in some of the cells.

Family SCENEDESMACEAE.

Oocystis Nägeli.

*O. Borgei Snow, 1903, p. 379, Pl. II, fig. VII; Collins, 1909, p. 160. Among *Oedogonium Itzigsohnii*, in ditch in Devonshire Marsh.

Scenedesmus Meyen.

*S. bijuga (Turp.) Wittrock, Nordstedt & Lagerheim, Alg. Exsicc., No. 1567; Collins, 1909, p. 168; *Achnanthes bijuga* Turpin, 1828, p. 310, Pl. XIII, fig. 4. Among *Rhizoclonium hieroglyphicum* in an artificial reservoir near Spanish Rock, Dec., Hervey.

Family ULOTHRICHACEAE.

Geminella Turpin.

G. scalariformis forma **marina** G. S. West in litt.; P. B.-A., No. 2002. Forming a floating gelatinous mass in an upper tide pool, at the entrance to Hungry Bay, April, Collins. The typical form of this species is a fresh water plant from Barbados, described and figured as *Hormospora scalariformis* by G. S. West, 1904a, p. 282, Pl. CCCCLXIV, figs. 6–7. In the Bermuda plant the cells are sometimes longer in proportion to the diameter, and the wall of the filament shows no differentiated portion about the individual cell. It is probable that *Hormotrichum bermudianum* Harvey is the same plant, but the specimens of the latter cannot be found. Rein, 1873, p. 153, gives this name as Harvey, sp. n. Dr. Möbius has kindly looked for it in the collection at Frankfort, and was unable to find it. Professor Dixon of the University of Dublin tells us that he cannot find it in the Harvey herbarium. The *nomen nudum* cannot of course stand against West's name, but it would be of interest to recover the material.

Stichococcus Nägeli.

*S. subtilis (Kütz.) Klercker, 1896, p. 103; Hazen, 1902, p. 162, Pl. XXI, figs. 10–13; Collins, 1909, p. 191; *Ulothrix subtilis* Kützing, 1845, p. 197. Among other algae, in a ditch in South Shore marshes, Aug., Collins. Straight filaments a few cells long, scattered among *Spirogyra, Rhizoclonium* etc.

Microspora Thuret.

1. Cells thick-walled, 20 μ or more diam. 1. M. Wittrockii.
1. Cells thin-walled, 11–14 μ diam. 2. M. Willeana.

*1. M. Wittrockii (Wille) Lagerheim, 1887, p. 417; Hazen, 1902, p. 172, Pl. XXIII, figs. 5–7; Collins, 1909, p. 193; P. B.-A., No. 2066; *Conferva Wittrockii* Wille, 1887, p. 461, Pl. XVII, figs. 35–41. Fresh water pool near Shark's Hole, Feb., Hervey.

*2. M. Willeana Lagerheim in De Toni, 1889, p. 228; Hazen, 1902, p. 175, Pl. XXIV, figs. 5–7; Collins, 1909, p. 194. Among *Oedogonium* etc. in ditch in Devonshire Marsh, April, Collins.

Family ULVACEAE.

Enteromorpha Link.

1. Cells not in longitudinal series except in the very youngest parts. 2.
1. Cells mostly in longitudinal series. 3.
   2. Cells 10–20 μ diam. 6. E. intestinalis.

2. Cells 5–7 μ diam.	2. E. minima.
3. Fronds simple or with a few proliferations.	4.
3. Fronds more or less branched.	5.
4. Fronds inflated and flexuous.	5. E. flexuosa.
4. Fronds compressed-filiform.	3. E. marginata.
5. Branches largely monosiphonous.	1. E. plumosa.
5. Branches not monosiphonous, except occasional proliferations.	4. E. prolifera.

1. E. PLUMOSA Kützing, 1843, p. 300, Pl. XX, fig. 1; Collins, 1909, p. 198; Börgesen, 1913, p. 7; P. B.-A., No. 2065; *E. Hopkirkii* Vickers, 1908, Pl. V. Rein, as *E. percursa;* North Shore, Jan., Gibbet Island, Feb., March, Devonshire Bay, Feb., Harris Bay, March, Hervey; Tucker's Town, Harrington Sound, Shelly Bay, April, Hungry Bay, May, Inlet, Aug., Collins. The most frequent species of the genus here and quite distinct from our other forms, by the rather large, longitudinally seriate cells, and the many branches of a few series or a single series of cells. Sometimes long, subsimple branches occur, of two series of cells, much resembling *E. percursa* (Ag.) J. Ag, with which a plant of this kind was identified by Rein. It is the *E. plumosa* of Börgesen, the *E. Hopkirkii* of Vickers, as shown by authentic specimens; whether the plants passing under these names in the North Atlantic are identical with this and with each other may be questioned. If there should prove to be two species, an examination of original specimens would be needed to decide what names to use.

2. E. MINIMA Nägeli in Kützing, 1849, p. 482; 1856, p. 16, Pl. XLIII, fig. 3; Collins, 1909, p. 201; P. B.-A., No. 2005. Grasmere, March, Hervey; on old fish car, Hungry Bay, April, in drip from outlet of aquarium, Agar's Island, Aug., Collins.

3. E. MARGINATA J. G. Agardh, 1842, p. 16; Kützing, 1856, p. 15, Pl. XLI, fig. 1; Collins, 1909, p. 202. On old *Sargassum*, below Flatts Bridge, May, Collins.

4. E. PROLIFERA (Fl. Dan.) J. G. Agardh, 1882, p. 129, Pl. IV, figs. 103–104; Collins, 1909, p. 202; *Ulva prolifera* Flora Danica, Vol. V, p. 5, Pl. DCCLXIII, 1782. Rein, as *E. compressa.* Rein's specimen is the only one of the species that we have seen from Bermuda, but it may be not uncommon. Little branched forms might easily be mistaken for *E. minima* or *E. flexuosa,* until examined microscopically.

5. E. FLEXUOSA (Wulf.) J. G. Agardh, 1882, p. 126; Collins, 1909, p. 203; P. B.-A., No. 2004; *Conferva flexuosa* Wulfen, 1803, p. 15. Miss Peniston; Harrington Sound, Feb., Dec., Devonshire Bay, Feb.,

Inlet, March, Hervey; Harrington Sound, April, Collins. In some specimens cells may be found as large as 20 μ square, but in other parts of the same individual they are of normal dimensions, little over 12 μ.

Forma **submarina** f. nov.; P. B.-A., No. 2161. Natans: frondibus inflatis, contortis.

Floating; fronds inflated, contorted. In extensive floating mats in brackish water, near old race course, Dec., Collins.

6. E. INTESTINALIS (L.) Grev. forma TENUIS Collins, 1903, p. 23; 1909, p. 205; P. B.-A., No. 2003. In brackish water, South Shore marshes, Aug., Collins. The thickness of the frond, 20–30 μ, is greater than that of the plant on which this form was founded. The latter grew in fresh water, remote from the sea; the present form, growing in brackish water, may be considered as intermediate between the form from fresh water and the typical species growing in the sea. A specimen in the Kemp herb., marked *Ulva linza,* seems to be typical *E. intestinalis,* but it is not in good enough condition for certainty.

MONOSTROMA Thuret.

1. Frond 25 μ thick or less, cells more or less in twos and fours. 1. M. latissimum.
1. Frond 30 μ thick or more; cells not in twos or fours. 2. M. orbiculatum.

1. M. LATISSIMUM (Kütz.) Wittrock, 1866, p. 33, Pl. I, fig. 4; Collins, 1909, p. 211; P. B.-A., No. 1859; *Ulva latissima* Kützing, 1856, p. 7, Pl. XIV. On mangroves just below Flatts Bridge; on *Salicornia,* Hungry Bay, April, Collins. This plant made its first appearance at Flatts Bridge about the middle of April, 1912, and grew rapidly. None was to be seen at the same station from July to September, 1913, nor elsewhere during those months.

2. M. ORBICULATUM Thuret, 1854, p. 388; Wittrock, 1866, p. 37, Pl. II, fig. 6; Collins, 1909, p. 212; Alg. Am.-Bor. Exsicc., No. 173. The material collected and distributed by Farlow is all that is recorded for Bermuda.

ULVA Linnaeus.

1. Frond divided into linear lobes. 2. U. fasciata.
1. Frond rounded or of irregular outline. 1. U. Lactuca.

1. U. LACTUCA L. var. LATISSIMA (L.) De Candolle, 1805, p. 9; Collins, 1909, p. 215. Rein; Moseley; April, June, Kemp, as *U.*

latissima; in high pool near Tucker's Town, April, Collins; in quiet waters elsewhere, but less common than var. *rigida.*

Var. RIGIDA (Ag.) Le Jolis, 1863, p. 38; Collins, 1909, p. 215; P. B.-A., No. 2064; *U. rigida* Agardh, 1822, p. 410. Rein; Kemp, as *U. Lactuca;* Tobacco Bay, Grasmere, March, Harrington Sound, July, Hervey; Inlet, Aug., Collins. Rather common both in sheltered and exposed places; sometimes quite near to *U. fasciata.*

2. U. FASCIATA Delile, 1813, p. 153, Pl. LVIII, fig. 5; Collins, 1909, p. 216. Miss Wilkinson; Harrington Sound, March, Hervey. Apparently not common; not easy to distinguish from forms of *U. Lactuca var. rigida,* but generally of darker color, especially near the margin of the linear, dentate or crenate lobes; the frond is thicker than in most forms of *U. Lactuca,* and the cells more elongate vertically.

PROTODERMA Kützing.

P. MARINUM Reinke, 1889, p. 81; Collins, 1909, p. 217. On pebbles, North Shore near Inlet, Aug., Collins. Probably common everywhere but inconspicuous.

FAMILY CYLINDROCAPSACEAE.

CYLINDROCAPSA Reinsch.

*C. INVOLUTA Reinsch, 1867, p. 66, Pl. VI, fig. 1; P. B.-A., No. 2067; *C. geminella* Wolle, 1887, p. 104, Pl. XCI, figs. 1–17; Collins, 1909, p. 222; *C. geminella* var. *minor* Hansgirg, 1886, p. 224, fig. 122; *Hormospora geminella,* Wolle, 1877, p. 140. In artificial reservoir near Spanish Rock, among *Rhizoclonium hieroglyphicum* etc., Feb., Hervey. In explanation of the synonymy just given, we must go into a little detail. The genus *Cylindrocapsa* and the species *C. involuta* were founded by Reinsch on vegetative characters only; the fructification was discovered by Cienkowski, described and well figured by him, 1876, p. 560, Pl. IX, figs. 50–65. Wolle, 1877, p. 140, described *Hormospora geminella,* vegetative characters only; in 1887, p. 104, *Cylindrocapsa geminella* with description of fructification. Pl. XCI, figs. 1–17 is supposed to represent the latter, but is not very instructive. No reference is made to *Hormospora geminella.* Hansgirg, 1886,[7] p. 223,

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[7] The date on the first title of the Prodromus is 1886; a second title, introducing a "Schlusswort" with separate paging, is dated 1888; under *C. geminella* there is a reference to the author's "Phyc. u. algol. Studien, 1887."

records for Bohemia "*C. geminella* Wolle (*Hormospora geminella* Wolle Bull. of the Tor. Bot. Club 1877)" and describes var. *minor.* The diameter of cells given for the typical *C. geminella*, 20–24 μ, does not agree with Wolle's figures, 16–21 μ for *Hormospora*, 14–16 μ for *Cylindrocapsa*, but are nearer *C. involuta* Reinsch, 23–30 μ. Hansgirg's var. *minor* is said to be 12–15 μ, diam., exceptionally 18–25 μ, in very young filaments 9–12 μ, which would certainly include Wolle's *C. geminella*. On comparing all the descriptions and figures, we can find no real distinction between *C. involuta*, *C. geminella* and *C. geminella* var. *minor;* and in the Bermuda material we can match practically every figure. We have therefore used the oldest name.

Family OEDOGONIACEAE.

Oedogonium Link.

1. Oogonium with a whorl of conical projections. 3. O. Itzigsohnii.
1. Oogonium without whorl of projections. 2.
   2. Filaments 14–20 μ diam. 1. O. Pringsheimii.
   2. Filaments seldom over 12 μ diam., usually in stellate clusters. 2. O. consociatum.

*1. O. Pringsheimii Cramer ex Hirn, 1900, p. 170, Pl. XXVII, fig. 155; Collins, 1909, p. 246; P. B.-A., No. 1861. In ditch in Devonshire Marsh, April, Collins.

*2. **O. consociatum** sp. nov. Plate I, figs. 1–4; P. B.-A., No. 2068. Diocum (?), macrandrium; oogonia solitaria, globosa vel depresso-globosa, operculata, rima mediana vel subsuperiore, angusta sed distincta; oospora globosa vel depresso-globosa, oogonium implente, membrana laevi; cellula basali depresso-globosa; cellulis vegetativis plus minusve distincte clavatis.

Dioecious (?), macrandrous; oogonia single, globose to depressed-globose, operculate, division median to superior, narrow but distinct; oospore globose to depressed globose, filling the oogonium, membrane smooth; basal cell depressed-globose; vegetative cells more or less distinctly clavate.

veg. cell, female,	6–12 (20) μ	diam.,	1–4 diam.	long.
oog.	28 μ	"	26–28 μ	"
oosp.	26 μ	"	24–26 μ	"

In an artificial fresh water reservoir near Spanish Rock, Jan., Hervey, Aug., Collins. Type in herb. Collins, No. 7812.

The basal cell is depressed-globose, 20–24 μ diam., 12–16 μ high; the first cell above is 6–8 μ diam., 2–3 diam. long; the filament may continue of the same diameter, or may increase up to 12 μ, the cells 1–2 diam. long; occasionally the diam. reaches 20 μ, the cells about one diam. long and moniliform; at any point a larger filament may suddenly change to the smaller diameter, a cell of 8–10 μ following a cell of 12–20 μ. Oogonia were not uncommon, but were very generally abortive; in the few instances where they seemed normal they were regularly globose, and contained a globose oospore, quite filling the oogonium, of orange yellow color. The division of the oogonium was median or slightly higher; no antheridia were seen.

The study being made from formalin material, the development of the zoospores could not be followed, but they must have been produced in immense numbers. Cells of *Pithophora kewensis* were seen, completely covered with zoospores which had affixed themselves, but still retained the spherical form, and were 16–24 μ diam.; the appearance was much like that of a filament of *Lyngbya* covered with *Xenococcus,* as shown in Bornet & Thuret, 1880, Pl. XXVI, fig. 1. The zoospores seemed to secrete some adhesive substance from the cell wall, forming a sort of collar underneath the cell, extending beyond the diameter of the cell, so as to be visible from above as well as from the side. Something similar is seen in *Chantransia collopoda* Rosenvinge, 1898, fig. 10, A. As the densely packed zoospores germinate, the host soon becomes indistinguishable, the sporelings forming a bristly mass, to the filaments of which more zoospores attach themselves, adhering to the young *Oedogonium* filaments in the same way as to the *Pithophora.* It seems probable, however, that often the zoospores adhere to each other in a larger or smaller rounded mass; when they germinate the radiating filaments form an echinate body, which is different from anything we find recorded for the genus, except the figures of *O. pachyandrium* in Wolle, 1887, Pl. LXXIII, figs. 38 and 39.

These figures though rude and in no way showing the evolution of the cluster, give a fair idea of the appearance. These masses often contain hundreds, probably thousands of spores, and before germination has much progressed, look like bits of fish roe. In the material of No. 7812 the *Pithophora* appeared to be fairly smothered by the *Oedogonium,* many of the cells dead; the greater part of the spores were attached to *Oedogonium* filaments or to each other; in No. 7368 material the *Oedogonium* was less abundant, and except a few loose clusters was all on the *Pithophora*, which was still uninjured; *Rhizoclonium hieroglyphicum* was much more common in this material than *Pithophora*, but was quite free from the *Oedogonium*. The nearest relative would seem to be *O. inversum* Wittr., which has capitate cells of approximately the same size, and a broadened basal cell, but has cells uniformly 12–14 μ diam., and up to 8 diam. long; rather larger oospores, with quite low division; the basal cell is attached by the flat lower surface, while in *O. consociatum* the lower surface is convex, resting in the ring by which it is affixed to the host.

*3. O. Itzigsohnii De Bary ex Hirn, 1900, p. 177, Pl. XXVIII, fig. 167; Collins, 1912, p. 86; P. B.-A., No. 1860. In ditch, Devonshire Marsh, April, Collins.

Sterile filaments of at least two other species have been found in collections from a roadside pool near Old Ferry Road, Aug., and from a ditch in South Shore marshes, Sept., Collins.

Family CHAETOPHORACEAE.

Diplochaete Collins.

D. solitaria Collins, 1901, p. 242; 1909, p. 278, fig. 99. Occasional individuals on *Laurencia* and other algae, never in any abundance.

Blastophysa Reinke.

B. rhizopus Reinke, 1889a, p. 27, Pl. XXIII; Börgesen, 1911, p. 151, fig. 13; 1913, p. 8, fig. 2; Collins, 1912, p. 99, fig. 12; P. B.-A., No. 1905. South Shore, Jan., Hervey; marsh near racecourse, Aug., Collins. At the South Shore in the basal layer of a growth of *Sphacelaria tribuloides;* at the marsh on *Ruppia maritima*, among other small algae; in *Ulva Lactuca*, Harrington Sound, Aug., Collins.

Phaeophila Hauck.

P. floridearum Hauck, 1876, p. 57; 1885, p. 464, fig. 200. Harris Bay, Jan., Hervey. This minute plant occurred among various other algae from a pool, the whole forming a thin, crisp, light green incrustation of about the consistency of some thin, encrusting sponge. It is probably not uncommon, but is easily overlooked, as it can be found only by microscopic examination. It has been found in small quantity in *Halymenia bermudensis,* Grasmere, March, Hervey.

ENDODERMA Lagerheim.

1. Cells mostly irregular.	1. E. viride.
1. Cells mostly cylindrical.	2. E. filiforme.

1. E. VIRIDE (Reinke) Lagerheim, 1883, p. 74; Collins, 1909, p. 279; P. B.-A., No. 2006; *Entocladia viridis* Reinke, 1879, p. 476, Pl. VI, In the cell wall of various algae, common.

2. **E. filiforme** sp. nov. Filamentis lateraliter vel dichotome ramosis, cellulis vegetativis cylindricis, prope apices circa 2 μ diam., longitudine diametrum pluries superante; inferne ad 6 μ diam., longitudine diametrum duplo superante, forma plus minusve irregulari; quavis cellula matura in sporangium mutata, circumscriptione circulari supra visa, 6–12 μ diam., depresso-hemisphaerica lateraliter visa, membrana crassa; prolongatione papilliformi per membranam plantae hopsitis protrusa, mox aperta ad exitum sporarum (?); sporis (?) 2 μ diam., in cellula paucis; setis, cellulae continuis, haud raro membranam hospitis penetrantibus, basi circa 4 μ diam., mox ad 2 μ attenuatis, neque bulbosis nec constrictis; chromatophora parietali, pyrenoideo unico, magno, munita.

Filaments branched laterally or dichotomously; vegetative cells cylindrical, near apex about 2 μ diam. and several diam. long, below up to 6 μ diam. and 2 diam long, more or less irregular; any cell of the older portion changing to a sporangium, circular in outline seen from above, 6–12 μ diam., depressed hemispherical in side view, with thick wall; a small papilla-like extension passing through the wall of the host, then opening to permit the exit of the spores (?); spores about 2 μ diam., few in a cell; bristles continuous with the cell also occasionally passing through the wall of the host, the base about 4 μ diam., quickly tapering to 2 μ, no constriction or bulb. In wall of *Lyngbya confervoides,* Bailey's Bay, Jan. 18, 1913, Hervey. Type in Collins herbarium, No. 7419a.

The older part is not unlike *E. viridis,* but the long, very slender, often quite straight filiform branches distinguish it from that as well as from other species; these branches seem usually to run lengthwise of the host, dividing mostly dichotomously; the older cells increase rapidly in width, and send off many branches at right angles, often in secund series, passing around the host; in older plants the branching may be quite dense, with no regularity discernible. The wall is very thin in the younger cells, but becomes quite thick in the older; the chromatophore is dense, and nearly or quite covers the wall. Bristles appear to be rare, and those we saw were short, evidently broken off. In the oldest parts of the plant, most of the cells had become sporangia, many of them had emptied, and only one was seen containing spores; these appeared spherical, but no details could be made out from the formalin material. The host has thick, distinctly laminate walls, and the Endoderma seems to push apart the laminae without difficulty; in one case two plants were seen, one outside the other, separated by one of the laminae of the host. In another case a plant was seen quite on the outside of the host wall; in this the cells were quite small and spherical; it seems probable that the lamina of the host under which they grew had peeled off, and the cells took the unusual form on release of the pressure.

Pringsheimia Reinke.

P. scutata Reinke, 1889a, p. 33, Pl. XXV; Collins, 1909, p. 288, fig. 95. On *Wurdemannia*, Gibbet Island, Aug., Collins; on *Ulva*, Harrington Sound, Aug., Collins.

Microthamnion Nägeli.

*M. Kuetzingianum Nägeli in Kützing, 1849, p. 352; Hazen, 1902, p. 191, Pl. XXVI, fig. 1; Pl. XXVII, figs. 2–4; Collins, 1909, p. 294. Among *Tetraspora lubrica*, on dead leaves in ditch in Devonshire Marsh, Dec., Collins.

Urococcus Kützing.

*U. insignis (Hass.) Kützing, 1849, p. 207; Wolle, 1887, p. 201, Pl. CXXIII, figs. 11–12; Collins, 1909, p. 306; P. B.-A., No. 1862; *Haematococcus insignis* Hassall, 1845, p. 324, Pl. LXXX, fig. 6. Among *Sphagnum* in Devonshire Marsh, April, Collins.

Gloiococcus A. Braun.

*G. mucosus A. Braun, 1851, p. 170; Collins, 1909, p. 310, fig. 122. Among *Oedogonium* etc., in ditch in Devonshire Marsh, April, Collins.

Family TRENTEPOHLIACEAE.

Trentepohlia Martius.

*T. aurea (L.) Martius, 1817, p. 351; Collins, 1909, p. 316; *Byssus aureus* Linnaeus, 1753, p. 1168. Common on shaded cliffs all over the islands, forming little orange-colored tufts of soft filaments, sometimes confluent and covering considerable spaces.

Family CLADOPHORACEAE.

Chaetomorpha Kützing.

1. Filaments under 100 μ diam.	2.
1. Filaments over 100 μ diam.	3.
2. Filaments attached, not over 25 μ diam.	1. C. minima.
2. Filaments not attached, 40–70 μ diam.	2. C. gracilis.
3. Filaments 500 μ diam. or more.	5. C. crassa.
3. Filaments 400 μ diam. or less.	4.
4. Light green; filaments 200–250 μ diam.	4. C. Linum.
4. Dark green; filaments 125–175 μ diam.	3. C. brachygona.

1. **C. mimima** sp. nov.; Plate I, figs. 5–7; P. B.-A., No. 2007. Filamentis disco affixis, cylindricis vel plus minusve clavatis, 10–20 μ diam., ad nodos interdum constrictis; cellulis 2–4 diam. longis, membrana crassa distincte laminata; zoosporis (?) in quavis cellula formatis, per foramine laterale liberatis.

Filaments attached by a disk, cylindrical or more or less clavate, 10–20 μ diam., nodes sometimes constricted; cells 2–4 diam. long, wall distinctly laminate; zoospores (?) formed in any cell, escaping by a lateral opening in the wall. On fronds of *Codium*, *Cladophora* etc.

The smallest species yet known in this genus; *C. californica* Collins, P. B.-A., No. 664 was the smallest heretofore known in the attached state, and its filaments average about twice the diameter of the present species; as regards length, the contrast is even more striking, as in *C. californica* the fronds reach a length of a decimeter, while in *C. minima* 5 mm. is the longest observed. It was first found growing on the rounded ends of the utricles of *Codium tomentosum*, sometimes singly, sometimes many individuals close together. Being quite imperceptible to the eye, it was noticed only in the examination of the *Codium* material preserved in formalin, so that nothing can be said as to the characters of the supposed zoospores; everything was however similar to the formation and emission of zoospores in the larger and better known species of *Chaetomorpha.* Emptied cells were common, sometimes every cell of a filament being fertile, even the basal cell; in one instance a filament consisted of a single cell, which had emptied itself through the small round lateral opening. In the form of the cells, thick laminate wall, dense chromatophore with many pyrenoids, the plant is a microscopic copy of forms like *C. Linum.* Rather curiously, it is the only attached form we find in the islands. The type is in the Collins herbarium.

2. C. GRACILIS Kützing, 1845, p. 203; 1853, p. 17, Pl. LII, fig. 1 P. B.-A., No. 2162. Hungry Bay, in dense masses, April, Collins.

3. C. BRACHYGONA Harvey, 1858, p. 87, Pl. XLVI. A; Collins, 1909, p. 325. Fish pond, Walsingham, Nov., Hervey, lying loose on the bottom of the pond.

4. C. LINUM (Fl. Dan.) Kützing, 1845, p. 204; *C. aerea* forma *Linum* Collins, 1909, p. 325; P. B.-A., No. 1863. *Conferva Linum* Flora Danica, Vol. V, p. 4, Pl. DCCLXXI, 1782; Harvey, 1846–51, Pl. CL. A; Moseley; Rein, as *C. geniculata;* Hungry Bay, Pool by Moore's calabash tree, April, Collins; Walsingham, Causeway, Nov., Tucker's Town, Dec., Hervey. Common and variable.

5. C. CRASSA (Ag.) Kützing, 1845, p. 204; 1853, p. 19, Pl. LIX, fig. 11; P. B.-A., No. 1864; *Conferva crassa* Agardh, 1824, p. 99. Kemp, as *Hormotrichum;* Pool near Walsingham, April, Lagoon near Fairyland, Aug., Collins. Not always easily distinguishable from *C. Linum;* study of the various forms in their natural condition if continued over a considerable time, might lead to considerable rearrangement.

RHIZOCLONIUM Kützing.

1. Cells rarely under 30 μ diam., wall thick, often lamellate. 2.
1. Cells rarely over 30 μ diam., usually 10–25 μ. 3.
  2. Filaments 50–100 μ diam., usually with frequent short branches. 4. R. Hookeri.
  2. Filaments 33–44 μ diam. branching from basal cell only. 5. R. crassipellitum.
3. In fresh or slightly brackish water. 2. R. hieroglyphicum.
3. In salt water. 4.
  4. Cells 20–25 μ diam. 3. R. riparium.
  4. Cells 10–15 μ diam. 1. R. Kerneri.

1. R. Kerneri Stockmayer, 1890, p. 582; Collins, 1909, p. 329. Forming a coating on mangroves, Hungry Bay, April, Collins.

*2. R. hieroglyphicum (Ag.) Kützing, 1845, p. 206; Collins, 1909, p. 329; P. B.-A., No. 2009; *Conferva hieroglyphica* Agardh, 1827, p. 636; Pool in rock by Old Ferry landing, Aug.; ditch in South Shore marshes, Sept., Collins; artificial reservoir near Spanish Rock, Feb., Hervey. Mostly the typical form, but with some var. *macromeres* Wittr.

3. R. riparium (Roth) Harvey, 1846–51, Pl. CCXXXVIII; Collins, 1909, p. 327; *Conferva riparia* Roth, 1806, p. 216; Hungry Bay, April, Collins; Causeway, Nov., Hervey. On mangroves and other objects between tide marks; apparently not very common; mostly the form known as var. *implexum* (Dillw.) Rosenvinge.

4. R. Hookeri Kützing, 1849, p. 383; 1853, p. 21, Pl. LXVII, fig. III; Collins, 1909, p. 330. Shore of Harrington Sound, April; Hungry Bay, May, Collins; Walsingham, Jan., Hervey. A rather coarse species, varying in diameter of filaments from 50 to 100 μ; the same filament is not infrequently double the diameter in one part that it is in another. The branches are mostly short, but have dense chromatophores the same as in the cells of the filament. Beside the localities given, it occurs on the walls of caves along high water mark, and on shaded sides of quarries, and even in reservoirs of quite fresh water.

5. R. crassipellitum W. & G. S. West, 1897, p. 35; Collins, 1909, p. 330. In small pools, Ely's harbor, April, Hervey.

Cladophora Kützing.

1. Fresh water.	19. C. fracta.
1. Marine.	2.
2. With distinction of prostrate and erect filaments.	16. C. Howei.
2. No distinct prostrate filaments.	3.
3. Forming a low matted expansion.	4.
3. Erect.	5.
4. Filaments 100–150 μ diam. throughout.	17. C. repens.
4. Filaments 70–100 μ diam. below, 60–80 μ above.	18. C. frascatii.
5. Main filaments 150 μ diam. and upwards.	6.
5. Main filaments seldom reaching 150 μ.	10.
6. Lower cells 10 diam. long or more.	14. C. catenifera.
6. Lower cells less than 10 diam. long.	7.
7. Diam. of filaments about the same throughout.	15. C. fuliginosa.
7. Terminal divisions markedly smaller than main axes.	8.

8. Ramuli clustered. 10. C. fascicularis.
8. Ramuli not clustered. 9.
9. Ultimate ramuli very short, often of a single cell; cells in ramuli ovoid, 1–2 diam. long. 8. C. brachyclona.
9. Ultimate ramuli not extremely short, cylindrical or nearly so. 13. C. utriculosa.
10. Cells generally with a sharp constriction near base. 3. C. constricta.
10. Cells without regular constrictions. 11.
11. Fronds floating except at earliest stages. 12.
11. Fronds always attached during active growth. 13.
12. Main filaments 30–60 μ diam. 4. C. crispula.
12. Main filaments, 100–150 μ diam. 7. C. expansa.
13. Main filaments distinctly angled or flexuous. 14.
13. Main filaments straight or nearly so. 15.
14. Pale yellow-green; cells 6–8 diam. long. 2. C. luteola.
14. Light to bright green; cells 2–6 diam. long. 6. C. flexuosa.
15. Main filaments 60 μ diam. or less. 1. C. delicatula.
15. Main filaments 80 μ diam. or more. 16.
16. Some branches decumbent, attaching by rhizoids. 5. C. corallicola.
16. No decumbent branches. 17.
17. Color pale, glossy, substance soft. 9. C. crystallina.
17. Color darker, substance crisp. 18.
18. Cells 3–5 diam. long; ramuli scattered. 11. C. piscinae.
18. Cells mostly 1–2 diam. long; ramuli closer and seriate. 12. C. rigidula.

1. C. DELICATULA Montagne, 1850, p. 302; Kützing, 1856, p. 1, Pl. I, fig. 2; Collins, 1909, p. 337; P. B.-A., No. 2070. Ely's Harbor, April, Hervey. Some of the plants were young and vigorous, reaching a length of 10 cm.; others were evidently old, the main branches with laminate walls up to 15 μ thick, and covered with minute epiphytes; new proliferous growth was very abundant, with delicate, thin walls, and generally like the younger plants.

2. C. LUTEOLA Harvey, 1858, p. 81; Collins, 1909, p. 338. Rein; Merriman in Farlow herb. We have not collected this species, and only these two records exist for Bermuda.

3. C. CONSTRICTA Collins, 1909a, p. 19, Pl. LXXVIII, figs. 4–5; 1909, p. 339. Hungry Bay, Feb., Hervey. Not over 3 cm. high, while the original material from Jamaica reached a height of 10 cm. The Bermuda plant occasionally sends out a very long, slender rhizoid from one of the lower cells; this has not been seen in the Jamaica material.

4. C. CRISPULA Vickers, 1905, p. 56; 1908, p. 19, Pl. XVI; Collins,

1909, p. 339; Börgesen, 1913, p. 24, fig. 15. P. B.-A., No. 2011. Harrington Sound, March, Hervey. To this species we have referred, with some doubt, a form found in floating masses, which agrees in size and length of cells, and in manner of branching, with *C. crispula*, but does not form contorted, rope-like strands. It seems to us that these may be a later development, and that our plant represents an earlier stage. Similar conditions are well known in species of *Rhizoclonium* and *Chaetomorpha*.

5. C. CORALLICOLA Börgesen, 1913, p. 21, figs. 11–12; P. B.-A., No. 2010. Tucker's Town, Dec., Hervey. Growing matted among old fronds of Bryopsis; the slender rhizoids characteristic of the species are well developed, and occasionally branch.

6. C. FLEXUOSA (Griff.) Harvey, 1846–51, Pl. CCCLIII; Collins, 1909, p. 339; *Conferva flexuosa* Griffiths in Wyatt, Alg. Danm., No. 227. Gibbet Island, June, Howe; North Shore, Tucker's Town, April, Inlet, Aug., Collins. A delicate plant but often reaching a length of 2 dm. Late in its season it becomes unattached and may be found in large floating masses, in Castle Harbor and similar places.

7. C. EXPANSA (Mert.) Kützing, 1853, p. 27, Pl. XCIX, fig. 1; Collins, 1909, p. 340; *Conferva expansa* Mertens in Jürgens, Algae Aquaticae, Dec. V. Brackish pool between North Shore and Harrington Sound, April, Collins. Forming loose floating masses, sometimes pure, sometimes in company with *Lyngbya* and *Enteromorpha*. In the latter case the algae form a felted stratum on the surface of the water so firm that the shore birds may be seen in large flocks, walking on it as if it were land, while they pick the small animals living among it. Whether this plant is the same as *C. heteronema* Kütz., as described by Börgesen, 1913, p. 25, may be a question. *C. flavescens* Harvey, 1846–51, Pl. CCXCVIII, Collins, 1909, p. 339, is certainly distinct, but we have not found it here; it seems to be a more northern form. Reinbold, 1893, p. 196, considers *Conferva expansa* of Jürgens Alg. Aquat. as distinct from *Cladophora fracta* forma *marina*, and refers for details to Farlow, 1881, p. 56; but the *C. fracta* forma *marina* of Farlow is a plant of much smaller filaments than the Hauck plant of the same name. We have found a plant in Harrington Sound, that could, without violence, pass for a slender form of *C. fracta* forma *marina* of Hauck, but it seems to us to fit equally well, if not better, in *C. expansa*, as we understand it.

8. C. BRACHYCLONA Montagne in Kützing, 1849, p. 394; 1853, p. 27, Pl. XCVI, fig. II; Collins, 1909, p. 344. A single specimen from Miss Peniston, without definite locality, is the only American

record for this Mediterranean plant. The specimen is well developed and characteristic.

9. C. CRYSTALLINA (Roth) Kützing, 1845, p. 213; 1854, p. 4, Pl. XIX, fig. II; Collins, 1909, p. 342; P. B.-A., No. 1865; *Conferva crystallina* Roth, 1797, p. 196. Rein, as *C. glaucescens;* Gravelly Bay, Feb., Dec., Hervey; Hungry Bay, April, North Shore, Harrington Sound, May, Collins. A handsome plant, soft and silky, growing on rocks on somewhat exposed shores, more commonly and luxuriantly in quiet water, where it sometimes becomes detached and continues growing in the floating state.

10. C. FASCICULARIS (Mert.) Kützing, 1843, p. 268; Vickers, 1905, p. 56; 1908, p. 18, Pl. XIII; Collins, 1909, p. 345; P. B.-A. No. 2163; *Conferva fascicularis* Mertens in Agardh, 1824, p. 114. Harrington Sound, Feb., Hervey. A quite variable species, common from Florida to South America, but found only once in Bermuda.

11. **C. piscinae** sp. nov. P. B.-A., No. 2165. Filamentis primariis 100 μ diam.; ramulis ultimis 50 μ; cellularum longitudine diametrum 3–5-plo superante; nodis haud constrictis; cellula terminali rotundata vel truncata, longitudine cellulas ceteras non superante; ramificatione inferne per dichotomias patentes, distantes, aequales, cellula dichotomias gerente plerumque sed non semper ceteris breviore; ramis superne ramulos distantes, patentes, ferentibus; colore laeteviridi; chromatophora laxe reticulata; substantia subcrispa, nec fragili.

Main filaments 100 μ diam.; ultimate ramuli 50 μ; length of cells 3–5 diam., nodes not constricted; terminal cell rounded or truncate, not longer than other cells; branching below by wide, equal, distant forkings, the cell bearing the forking usually but not always shorter than the others; above with distant patent ramuli; color light green; chromatophore a loose network; substance somewhat crisp but not fragile. In an old fishpool at Godet's Island, Nov. 30, 1915. Type in Collins herbarium, No. 8427.

The water in this pool is quite still, the tide having access only by small openings in the wall. The plant formed a loose mass, over one meter in diameter, the lower part caught on coral; the appearance was quite that of a loose *Spirogyra.* Though crisp to the touch, the fronds collapsed immediately on being taken from the water; the living plant is of a light green color, but this becomes dark in drying. There is some similarity in the characters above to those of the description of *C. Macallana* Harv., but that is a stouter and stiffer plant, with different habit. *C. patens* Kütz. has cells 4–8 diam. long, larger main filalents and smaller ramuli than *C. piscinae*. *C. crystallina*, the most nearly related Bermuda species, has larger main filaments, smaller and more closely set ramuli, longer cells, more fasciculate habit, softer substance, and does not become dark in drying.

12. **C. rigidula** sp. nov. Filamentis primariis circa 120 μ diam., secundi ordinis 100 μ, cellulis ultimis 80 μ; cellularum longitudine diametrum 1–2-plo superante; nodis haud constrictis; cellula terminali plerumque longiore, interdum ad 3 diam., rotundata vel subacuta; ramificatione prope basin per dichotomias patentes, primo approximatas, deinde distantes; ramis partis superioris frondis longis, rectis, ramulos gerentibus fere vel omnino sub angulo recto egredientes, distantes sparsosque inferne, in seriebus secundis prope apicem; colore viridi diluto obscuro; chromatophora subtiliter reticulata, pyrenoideos multos, minutos, nitidos monstrante; substantia firma crispaque.

Main filaments about 120 μ diam., secondary 100 μ, ultimate cells 80 μ; length of cells 1–2 diam., nodes not constricted; terminal cell usually longer, sometimes 3 diam., rounded or subacute; branching at base by broad forkings, at first frequent, later distant; branches in upper half of frond long, straight, with ramuli nearly or quite at right angles, distant and scattered below, near the tips in secund series; color rather dull light green; chromatophore a fine network with very many small bright pyrenoids; substance firm and crisp. In a stone tank above the bridge at Fairyland, Dec. 13, 1915. Type in Collins herbarium, No. 8513.

Though occurring in a station similar to that of *C. piscinae*, and in some points resembling the latter, it has seemed to us better to consider it a distinct species than to combine the two by too vague a description. *C. piscinae*, though crisp, promptly collapses when taken from the water, *C. rigidula* long keeps its shape and stiffness; the distinction is as marked as that between *Polysiphonia violacea* and *P. fastigiata*. In *C. piscinae* the cells are seldom under three or over five diam. long; in *C. rigidula* they are seldom over two diam., often only one diam. for a good part of the frond; the terminal cell is, however, often three diam. long. In both the ultimate ramuli are patent, often at a right angle; in *C. piscinae* they are scattered and usually distant, in C. rigidula closer and often in secund series. The differences can hardly be due to the station, as each grew in a stone tank, sea water going in and out with the tide, but with no active current, and no disturbance of the surface. On the other hand it has some resemblance to the plant from Harrington Sound which we distributed, P. B.-A., No. 2014, as *C. utriculosa*, but is still further removed from the typical Mediterranean form. In the latter the cells below are 6–8 diam. long, 2–4 diam. above, while in the present species only the terminal cell is usually over 2 diam. long. It seems to us safer to treat it as a new species than to put it in a species whose typical form, at least, is so distinct.

13. C. UTRICULOSA Kützing, 1843, p. 269; 1853, p. 26, Pl. XCIV, fig. I; Collins, 1909, p. 346; P. B.-A., No. 2014. Harrington Sound, Wadsworth, March; same station, Oct., Hervey. A common Mediterranean and West India species. Wadsworth's plants are rather more slender than the typical, but otherwise quite the same. The material collected by us in October formed loosely floating masses. evidently a later condition; all branching was wide; the dichotomies in the lower part about 120°, the ramuli, usually quite short, about 90°.

14. C. CATENIFERA Kützing, 1849, p. 390; 1853, p. 24, Pl. LXXXIII, fig. I; Collins, 1909, p. 347; P. B.-A., No. 2069. Kemp in herb., as *Cladophora* sp.?; Howe; Red Bay, St. David's Island, June, cave at Gravelly Bay, Feb., April, Dingle Bay, March, Hervey. The most striking of our species of the genus, with stout stem and main branches, very long cells, firm lustrous cell wall. Bermuda plants are 10–20 cm. high; at Jamaica it sometimes reaches a height of 50 cm. In February only very small plants were found.

15. C. FULIGINOSA Kützing, 1849, p. 415; Collins, 1909, p. 348; P. B.-A., No. 2012. Kemp, St. George's, unnamed specimen in herb.; Harris Bay, Jan., Apr., Gravelly Bay, Dec., Inlet, Dec., Hervey; Gravelly Bay, Aug., Collins. A coarse species, generally distributed and common; always infested with the fungus *Blodgettia Borneti* Wright. The combination of the two forms the *Blodgettia confervoides* Harvey, 1858, p. 48, Pl. XLV. C.

16. C. HOWEI Collins, 1909a, p. 18, Pl. LXXVIII, fig. 1; 1909, p. 349. Tide pools, Gibbet Island, June, 1900, Howe. The short, subsimple filaments arise from a dense mass of prostrate filaments, a character found in no other of our species. Gibbet Island is the type, and so far as known, the only, station for the species; so for the present it may be considered as endemic.

17. C. REPENS (J. Ag.) Harvey, 1846–51, Pl. CCXXXVI; P. B.-A., No. 2071. *Conferva repens* J. G. Agardh, 1842, p. 13; *Aegagropila repens* Kützing, 1854, p. 15, Pl. LXX, fig. II. Gravelly Bay, Jan., Feb., Hervey. A low, densely matted plant of dark color, not however, with prostrate and erect filaments clearly differentiated. The plant from California distributed under this name as P. B.-A., No. 727 has since proved to be *C. trichotoma* (Ag.) Kütz.; the present record is therefore the first for America.

18. C. **frascatii** sp. nov.; P. B.-A., No. 2164. Humilis, 1–2 cm. alta; ramificatione irregulari, inferne plerumque dichotoma, dichotomiis patentibus; superne partim conformi, sed etiam laterali, patente, saepe rectangulari; ramulis ultimis 1–3-cellularibus, prope vel omnino rectangularibus, saepe secundis latere exteriore rami recurvati; cellulis inferne 70–100 μ diam., 2–5 diam. longis, cylindricis; ramulorum 60–80 μ diam., 2–3 diam. longis, leviter inflatis, nodis constrictis; cellula terminali obtusa.

Low, 1–2 cm. high, branching irregular, below mostly dichotomous, with wide forkings; above partly similar, partly lateral, patent, often at a right angle; ultimate ramuli 1–3-celled, nearly or quite at right angles, often secund on the outer side of a recurved branch. Cells below 70–100 μ diam., 2–5 diam. long, cylindrical; in the ramuli 60–80 μ diam., 2–3 diam. long, somewhat swollen with constricted nodes; terminal cell obtuse. In matted tufts in tide pools near Frascati Hotel, Jan. 11, 1914, A. B. Hervey. Type in Collins herb.

Growing in similar places to C. repens, and forming similar matted tufts, but distinct by the smaller dimensions and the lateral, secund, submoniliform ramuli.

*19. C. FRACTA (Fl. Dan.) Kützing, 1843, p. 263; 1854, p. 10, Pl. L; Collins, 1909, p. 353; P. B.-A., No. 2013. *Conferva fracta* Flora Danica, Vol. V., Pl. DCCCCXLVI, 1782. Artificial Reservoir of fresh water near Spanish Rock, Dec., Hervey. Some of the material is in a vigorously growing state; some in a hibernating state, cells with thick walls, dense contents, few branches.

CLADOPHOROPSIS Börgesen.

C. MEMBRANACEA (Ag.) Börgesen, 1905, p. 288, figs. 8–13; 1913, p. 47, fig. 33; Collins, 1909, p. 362; P. B.-A., No. 1866; *Conferva membranacea* Agardh, 1824, p. 120. North Shore, Jan., Tucker's Town, March, Harris Bay, Shelly Bay, April, Hervey; Inlet, May, Hungry Bay, July, Collins. A very common species, forming cushions on rocks, and on and under mangroves; in still pools it is sometimes also in floating masses.

PITHOPHORA Wittrock.

*P. KEWENSIS Wittrock, 1877, p. 52, Pl. I, fig. 8; Pl. II, figs. 1–12; Pl. III, figs. 1–9; Pl. IV, figs. 2–11; Pl. V, figs. 9–10; Collins, 1912, p. 98; P. B.-A., No. 2072. With *Rhizoclonium* etc. in reservoir of fresh water near Spanish Rock, Dec., Hervey.

Anadyomene Lamouroux.

A. stellata (Wulf.) Agardh, 1822, p. 400; Vickers, 1908, p. 21, Pl. XXI; P. B.-A., No. 1906; *A. flabellata* Harvey, 1858, p. 49, Pl. XLIV. A; Alg. Am.-Bor. Exsicc., No. 172; *Ulva stellata* Wulfen in Jacquin, 1786, p. 351. Common in shallow water everywhere about the islands, and dredged down to 18 m.; in quiet places as large, thin fronds, in exposed places masses of short, irregular, densely packed fronds. Apparently equally common at all times of the year. Aug. 11, 1913, in the cave at Agar's Island, young plants were found growing on the rocks between tides, forming a continuous coating, the individual plants not over 1 mm. high. In some individuals the lamina was beginning to form, but most of the plants resembled young *Cladophora,* except that the branching was in one plane. There was a distinct filiform stipe, attached at the base by slender coralloid projections.

Dictyosphaeria Decaisne.

D. favulosa (Ag.) Decaisne, 1842, p. 32; Börgesen, 1913, p. 33, figs. 20–22; Collins, 1909, p. 367, fig. 137; P. B.-A., No. 2015; *Valonia favulosa* Agardh, 1822, p. 432. Harrington Sound, Farlow; South Shore, Jan., Feb., Hervey; Hungry Bay, Tucker's Town, April, Reef, Ely's Harbor, Aug., Collins. Grows both in sheltered and in exposed stations, perhaps more generally in the latter.

Family GOMONTIACEAE.

Gomontia Bornet & Flahault.

G. polyrhiza (Lagerheim) Bornet & Flahault, 1888a, p. 164; 1889, p. CLVIII, Pl. VI–VII; Collins, 1909, p. 370, fig. 135; *Codiolum polyrhizum* Lagerheim, 1885, p. 22. Common in dead shells of mollusks along the shore, giving them a more or less deep grass-green color.

Family VALONIACEAE.

Valonia Ginnani.

1. Fronds bullate, unbranched.	1. V. ventricosa.
1. Fronds branched.	2.
2. Branches in whorls.	4. V. pachynema.

2. Branches not whorled. 3.
3. Cells spherical, ovoid or pyriform. 2. V. macrophysa.
3. Cells cylindrical to clavate. 3. V. utricularis.

1. V. VENTRICOSA J. G. Agardh, 1886, p. 96; Vickers, 1905, p. 56; 1908, p. 21, Pl. XXIII. A; Collins, 1909, p. 373; Börgesen, 1913, p. 27, fig. 16. July, Kemp; Gravelly Bay, Aug., Collins. At Gravelly Bay this plant was washed ashore; the plants were 1–3 cm. diam., smooth and glassy, spherical or slightly ovoid. Murray states that it is sometimes as large as a hen's egg.

2. V. MACROPHYSA Kützing, 1843, p. 307; 1856, p. 30, Pl. LXXXVII, fig. III; P. B.-A., No. 1867; *V. utricularis* Alg. Am.-Bor. Exsicc., No. 171, not of Agardh. Harrington Sound, Walsingham, Jan., Tucker's Town, Dec., Hervey; pool near Moore's calabash tree, Ducking Stool, April, Ely's Harbor, July, Gravelly Bay, Gibbet Island, Aug., Fairyland, Nov., Collins. Grows usually in dense masses sometimes as large as a man's head; the individual plants are only loosely attached, and are easily separable; under water it usually shows a very brilliant iridescence. The turgor in the living cell is considerable; when the cell is punctured by a dissecting needle, it sends out a fine stream which may reach a distance of a meter or more.

3. V. UTRICULARIS (Roth) Agardh, 1822, p. 431; Collins, 1909, p. 373; *Conferva utricularis* Roth, 1797, p. 160, Pl. I, fig. 1. Dredged in 18 meters, Hamilton Harbor, Dec., Collins.

Forma CRUSTACEA Kuckuck, 1907, p. 180; Börgesen, 1913, p. 30, figs. 17–18; P. B.-A., No. 2074. The typical *V. utricularis* is rather loosely branched, but in forma *crustacea* the cells form a dense mass, and might be mistaken for one of the solid-fronded species of *Dictyosphaeria,* but under the microscope it is easily distinguished by the different manner of attachment of the cells. It has some resemblance to *V. macrophysa,* but the cells are smaller, closely adherent and more elongate. It appears to be a form of shallow water, forming dense masses, as well in the quiet water at Grasmere as on the reefs, always awash, at Ely's Harbor.

4. V. PACHYNEMA (Martens) Weber, 1913, p. 61; *V. confervoides*[8] Harvey, Alg. Ceylon, No. 73; J. G. Agardh, 1886, p. 100; Collins, 1909, p. 373; *Bryopsis pachynema* Martens, 1866, p. 24, Pl. IV, fig. 2. Miss Wilkinson.

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8 Mme. Weber calls attention to the fact that *Valonia confervoides* was *nomen nudum* until 1886; hence *V. pachynema* has priority.

Ernodesmis Börgesen.

E. verticillata (Kütz.) Börgesen, 1912, p. 259, figs. 10–12; 1913, p. 66, figs. 51–54. P. B.-A., No. 1907; *Valonia verticillata* Kützing, 1849, p. 508; Collins, 1909, p. 373. Kemp, April, St. George's, unnamed specimen in herb.; Castle Harbor, Farlow; Harrington Sound, 3–10 dm., June, Howe; cave by Gravelly Bay, April, tidal stream, Hungry Bay, July, Collins. Generally grows in dense masses of crisp fronds, but easily separable.

Siphonocladus Schmitz.

1. Primary cell long, erect; substance soft.	1. S. tropicus.
1. Primary cell short; substance firm.	2. S. rigidus.

1. S. tropicus (Crouan) J. G. Agardh, 1886, p. 105; Börgesen, 1913, p. 61, figs. 44–51; Collins, 1909, p. 374; Vickers, 1908, p. 20, Pl. XVIII; *Apjohnia tropica* Crouan in Mazé & Schramm, 1870–77, p. 105. Harris Bay, in pools, a few individuals only, Feb., Hervey.

2. S. rigidus Howe, 1905, p. 244, Pl. XII, fig. 1; Pl. XIV; Collins, 1909, p. 374, fig. 139; P. B.-A., No. 2169. On flat rock at low water mark, Agar's Island, Dec., Collins.

Petrosiphon Howe.

P. adhaerens Howe, 1905, p. 248, Pl. XV; Collins, 1909, p. 375; P. B.-A., No. 2073. Forming a closely attached crust in pools at Harris Bay, March, Hervey.

Struvea Sonder.

S. ramosa Dickie, 1874a, p. 316; Murray & Boodle, 1888, p. 280, Pl. XVI, fig. 3; Collins, 1909, p. 377. This species was described from specimens collected by Moseley with the Challenger Expedition; there is no record of it since, either here or elsewhere.

Family DASYCLADACEAE.

Acetabularia Lamouroux.

A. crenulata Lamouroux, 1816, p. 249; Harvey, 1858, p. 40, Pl. XLII. A; Collins, 1909, p. 378, fig. 131; P. B.-A., No. 1908. St. George's, Kemp; Achilles Bay, June, Harrington Sound, Oct., Hervey; Fairyland, July, Harrington Sound, Aug., Collins. Common, at least during summer and autumn, on rocks and pebbles in shallow water, also brought up by dredge from about 5 meters off Spanish Point. Ripe aplanospores were found in plants from Fairyland, distributed as P. B.-A., No. 1908. At this station it covers the bottom in patches many meters square, just below the low water level.

Acicularia d'Archiac.

A. Schenckii (Möb.) Solms, 1895, p. 33, Pl. III, figs. 4, 9, 11, 12, 14, 15; Collins, 1909, p. 380; *Acetabularia Schenckii* Möbius, 1889, p. 318, Pl. X, figs. 8–12. Hungry Bay, in the tidal stream under the mangroves, June, Howe. Resembling *Acetabularia crenulata*, but with disk usually smaller, stipe shorter and stouter. It probably occurs in other stations, but has been overlooked on account of its resemblance to the more common plant.

Neomeris Lamouroux.

N. annulata Dickie, 1874, p. 198; Howe, 1909, p. 87, Pl. I, fig. 2; Collins, 1909, p. 382, fig. 143; P. B.-A., No. 1909; Börgesen, 1913, p. 71, figs. 55–57; *N. Kelleri* Vickers, 1908, p. 28, Pl. XLVI. In shallow water on rock and especially on small stones, and dredged in 18 meters. Faxon; Miss Wilkinson; White Island, June, Howe; Ely's Harbor, July, Harrington Sound, Aug., Collins; Harrington Sound, Oct., Nov., Hervey. Probably to be found in quiet shallow water everywhere in the islands; other species of *Neomeris*, equally common in the West Indies, have not been noticed here.

Dasycladus Agardh.

D. clavaeformis (Roth) Agardh, 1828, p. 16; Collins, 1909, p. 383; P. B.-A., No. 1868; *Conferva clavaeformis* Roth, 1806, p. 315. Cooper's

Island, April, Collins; Pink Bay, Spanish Point, March, Hervey. In habit much like *Batophora Oerstedi var. occidentalis,* but growing in more sheltered places.

Batophora J. G. Agardh.

B. Oerstedi J. G. Agardh. 1854, p. 108; Collins, 1909, p. 383, fig. 145; Börgesen, 1913, p. 73, fig. 58; P. B.-A., No. 1910. Fairyland, July, with ripe aplanospores, Collins.

Var. occidentalis (Harv.) Howe, 1905a, p. 579; Collins, 1909, p. 384; P. B.-A., No. 2016; *Dasycladus occidentalis* Harvey, 1858, p. 38, Pl. XLI. B. Rein; Spanish Point, June, Howe; Shelly Bay. Dec., Hervey. A condensed form, growing in more exposed localities.

Family CODIACEAE.

Codium Stackhouse.

1. Prostrate.	1. C. intertextum.
1. Erect.	2.
2. All divisions contracted at base, enlarging upwards.	4. C. isthmocladum.
2. No distinct contractions at base of divisions.	3.
3. Peripheral utricles 100–150 μ diam., exceptionally 200 μ.	2. C. tomentosum.
3. Peripheral utricles rarely under 300 μ.	3. C. decorticatum.

1. **C. intertextum** sp. nov.; P. B.-A., 2018. Fronde prostrata, tereti vel complanata, saxo arcte adhaerente, apicibus autem vulgo liberis; ramis brevibus, irregularibus, stratum subcontinuum formantibus, strato interiore siphonum dense implicatorum strato corticali cincto, utriculorum longorum, cylindricorum vel subclavatorum, apicibus truncatis, subrotundatisve, diam. 70–90 μ; colore atroviridi; substantia subfirma, nec maxime gelatinosa.

Frond prostrate, subterete or flattened, closely adherent to the rock, but with tips usually free; with short, irregular branches, forming an almost continuous coating. Interior layer of densely packed, slender tubes, surrounded by a cortical layer of long, cylindrical or somewhat clavate utricles, with truncate or somewhat rounded ends, 70–90 μ diam. Color dark green, substance rather firm, not specially gelatinous. Forming a continuous belt a few dm. wide on upright or sloping rocks, at low water mark; Harrington Sound, Castle Harbor, etc.

In habit somewhat resembling *C. adhaerens and C. difforme*, but the frond in these is continuous, with margin entire or lobed; in *C. intertextum* the frond is narrow and branching, the branches being so densely set as to make an almost continuous coating, one branch often over another. The utricles are of much the same size and shape as in *C. adhaerens*, but the structure of the latter is dorsiventral, the utricles on the upper side only, the lower, adherent surface consisting of the slender tubes, which in *C. intertextum* form a central layer, surrounded on all sides by the utricles, rarely the middle part of the under surface without the utricles. *C. repens* Crouan, also a prostrate species, has utricles even larger than *C. tomentosum*, of the order of size of *C. decorticatum;* its branching is not as dense as that of *C. intertextum*, being more like that of *C. tomentosum*, but without the erect habit. The utricles vary somewhat in shape and size, as in all species of the genus, but the long, slender shape, the end either sharply truncate or slightly capitate, is distinct from the shape in all other American species except *C. adhaerens.* Type 7070 in Collins herbarium, from Tucker's Town, April 25, 1912. Also from Ely's Harbor, July, Gibbet Island, Sept., Collins; Gravelly Bay, Dec., Hervey. All records of *C. adhaerens* for Bermuda probably belong here.

2. C. TOMENTOSUM (Huds.) Stackhouse, 1795, p. 21, Pl. VII; Harvey, 1846–51, Pl. XCIII; Collins, 1909, p. 388; P. B.-A., No. 1869; *Conferva tomentosa* Hudson, 1762, p. 480. Tucker, No. 4, 1856; Tucker's Town, Farlow; Kemp in herb; Moseley; Buildings Bay, Harrington Sound, Shelly Bay, March, Hervey; Hungry Bay, April, Ely's Harbor, Aug., Collins. Rather common about the islands; sporangia found in May.

3. C. DECORTICATUM (Woodw.) Howe, 1911, p. 494; P. B.-A., No. 2017; *C. elongatum* Vickers, 1908, p. 22, Pl. XXVII; Collins, 1909, p. 388; *Ulva decorticata* Woodward, 1797, p. 55. Faxon; Miss Peniston; Harrington Sound, April, Aug., St. David's Island, April, Cooper's Island, Gibbet Island, Aug., Collins. Very variable in habit and size, but usually less densely branched than *C. tomentosum*, the branches often quite virgate; usually compressed more or less at or below the axils. But there are often cases when the two species are indistinguishable by external characters; the size of the utricles must then determine; in *C. tomentosum* 100–150 μ diam. rarely to 200 μ; in *C. decorticatum* 300–400 μ diam. rarely to 200 μ. There has

been some question as to whether the distinction between these two species should be based on the size of the utricles, or on the presence or absence of compression; the matter is fully discussed by Bornet, 1892, p. 216. We have adopted the former plan. It must be kept in mind that in actively growing plants or parts of plants, small and immature utricles occur among those of normal size. *C. decorticatum* sometimes grows to a large size; one plant which we found growing below low water mark in Harrington Sound was nearly a meter long and over 10 cm. wide in the expanded part; it was the largest alga we have seen in Bermuda, except possibly some *Sargassum*. It is unfortunate that the rather appropriate name of *elongatum* should have to be replaced by the quite inappropriate *decorticatum*, but as shown by Howe, it seems inevitable.

Var. **clavatum** var. nov. Fronde habitu formam cylindricam *C. decorticati* approximante, sed substantiae firmioris, vix gelatinosa, colore laete viridi; utriculis forma multo variantibus; aliis cylindricis vel leviter clavatis, 80 × 480 μ; aliis 500 μ longis, sursum dilatatis ad caput subsphaericum 145 μ diam.; aliorum inflatione terminali ad 200 μ diam., a parte subcylindrica minus distincta; aliis obcampanulatis, 650 μ longis, 350 μ diam., apice spatio brevi paullo latioribus; aliis turbinatis, 640 μ longis, apice 470 μ diam.; inter omnes, formis intermediis.

Habit that of a rather densely branched cylindrical *C. decorticatum*, but of quite firm substance, hardly gelatinous, color light green. Utricles very variable in form; some cyclindrical or slightly clavate, 80 × 480 μ; some 500 μ long, increasing in size upward to 112 μ, then with a subspherical head 145 μ diam.; in others the capitate swelling up to 200 μ diam., but less sharply marked off from the subcyclindrical part, 120 μ diam.; others inverted bell-shape, 650 μ long, 350 μ diam., somewhat wider for a short space at the truncate top; others turbinate, 640 μ long, 470 μ wide at top; with all intermediate gradations.

The largest utricle observed was 980 μ long, 480 μ diam. The plant is so firm in texture that it does not collapse when taken from the water; but when dried it is thin and papery. Sporangia ovoid, largest at the middle, obtuse at each end; sporangia apparently not mature, 160 × 64 μ, 275 × 105 μ, 280 × 100 μ; mature sporangia, packed with spherical spores about 12 μ diam., 190 × 100 μ, 240 × 120 μ. Type specimen, from stone wall at Inlet, by Frascati Hotel, Dec. 20, 1912, Hervey, No. 7322 in Collins herb. Also at Devonshire Bay, Gravelly Bay, Feb., Causeway, March, Hervey.

4. C. ISTHMOCLADUM Vickers, 1905, p. 57; 1908, p. 23, Pl. XXVIII; Collins, 1909, p. 388. Shelly and Gravelly Bays, March, Hervey. Probably not uncommon, resembling a condensed form of *C. tomentosum*, but with the divisions more or less contracted at the base, gradually increasing in diameter to the next forking. The utricles are larger than in *C. tomentosum*, approaching the size in *C. decorticatum*.

AVRAINVILLEA Decaisne.

1. Filaments distinctly moniliform.	1. A. nigricans.
1. Filaments nearly or quite cylindrical.	2. A. longicaulis.

1. A. NIGRICANS Decaisne, 1842, p. 96; Howe, 1907, p. 508, Pl. XXVIII, figs. 8–25; Collins, 1909, p. 390. Walsingham, Feb., Harris Bay, April, Hervey; Inlet, Cooper's Island, Aug., Collins. Very variable, from small, delicate plants to coarse, heavy and unsightly ones.

Var. FULVA Howe in P. B.-A., No. 1480; Collins, 1909, p. 390; P. B.-A., No. 2171. Stouter, coarser, with less difference between stipe and flabellum; color more yellowish than in the type.

2. A. LONGICAULIS (Kütz.) Murray & Boodle, 1889, p. 70, as to name only; Collins, 1909, p. 391; P. B.-A., No. 2170; *Rhipilia longicaulis* Kützing, 1858, p. 13, Pl. XXVIII, fig. 2. Walsingham, Feb., Mangrove Bay, Feb., Harrington Sound, Nov., Inlet, Dec., Hervey; Fairyland, Dec., Collins. Growing in company with *A. nigricans*, from which it is frequently indistinguishable, except that the filaments of the latter show distinctly moniliform on microscopic examination, while those of *A. longicaulis* are nearly or quite cylindrical. The name is a somewhat unfortunate result of following the rules of botanical nomenclature; the authors of the binomial used it for a different plant, *A. nigricans*. *Rhipilia longicaulis*, from which it derives its specific name, is according to the type specimen the present species, while the description and figure given by Kützing belong better to a third species, *A. sordida* Murray & Boodle. The arguments in favor of the name used here are found in Howe, 1907, p. 509; those in favor of preferring *A. Mazei* Murray & Boodle in Gepp, 1911, p. 27; a later summation will be found in Howe, 1911, p. 133.

PENICILLUS Lamarck.

1. Surface of stipe smooth.	1. P. capitatus.
1. Surface of stipe rough.	2. P. pyriformis.

1. P. CAPITATUS Lamarck, 1813, p. 299; Harvey, 1858, p. 45, Pl. XLIII. B; Collins, 1909, p. 392; P. B.-A., No. 1911. Kemp, specimen in herb.; Rein; Moseley; Wadsworth, No. 75; Tucker's Town, Farlow; Hungry Bay, June, Howe; Gravelly Bay, March, Mangrove Bay, Feb., Harris Bay, Oct., Nov., Inlet, Dec., Hervey; Cooper's Island, April, Jew's Bay, July, Ely's Harbor, Inlet, Hungry Bay, Aug., Collins. Common practically everywhere in shallow water and dredged down to 10 m.

Forma ELONGATUS (Dcne.) Gepp, 1911, p. 83, figs. 166–167; P. B.-A., No. 1912; *P. elongatus* Decaisne, 1842, p. 97 (reprint). Jew's Bay, July, Harrington Sound, Mangrove Lake, Aug., Collins. A form with long stipe, pyriform head, filaments stouter than in the typical form, in company with which it grows, the two shading into each other.

Forma LAXUS Börgesen, 1913, p. 98, fig. 80. Walsingham, Feb., Hervey. A form with long and slender stipe, head more or less irregular in form, filaments loose and slender. In the specimens which we identify with this form the branching of the stipe is not unusual, each division having a head of the normal shape for this form.

2. P. PYRIFORMIS Gepp, 1905, p. 1, Pl. CCCCLXVIII, fig. 1; Collins, 1909, p. 393; P. B.-A., No. 2075. June, Howe; Feb., Farlow; Harris Bay, Jan., Oct., Dec., Inlet, Dec., Hervey. Often growing with *P. capitatus,* but less common.

UDOTEA Lamouroux.

1. Whole flabellum with a stony coating. 2. U. flabellum.
1. Flabellum flexible, individual filaments encrusted. 1. U. conglutinata.

1. U. CONGLUTINATA (Soland.) Lamouroux, 1816, p. 312; Howe, 1909, p. 96, Pl. II, Pl. VIII, figs. 1–13; Collins, 1909, p. 395; P. B.-A., No. 1913; *Corallina conglutinata* Solander in Ellis & Solander, 1786, p. 125, Pl. XXV, fig. 7. Rein; Kemp; South Beach by Paget, Feb., Farlow; Harris Bay, Jan., Feb., March, Nov., Hervey. In tide pools, a small form only; dredged in 10 meters by the Challenger Expedition.

2. U. FLABELLUM (Ell. & Sol.) Howe, 1904, p. 94; Gepp, 1911, p. 131, Pl. III, figs. 26–28; Collins, 1909, p. 395; P. B.-A., No. 1914; *Corallina flabellum* Ellis & Solander, 1786, p. 124, Pl. XXIV. Rein; Kemp; Tucker, No. 23; Walsingham, Farlow; many stations, Hervey,

Collins. Grows practically everywhere in shallow water, varying much in size, texture, outline, etc. Some forms are rounded and entire, wider than broad; some plane, others folded longitudinally; some cuneate and much divided, some consisting of a few linear laciniae from the top of the stipe, the laciniae up to 3 dm. long and less than 1 cm. wide. All pass gradually into each other, so that varietal or form names are useless.

HALIMEDA Lamouroux.

1. All segments except those bearing branches cylindrical.	4. H. Monile.
1. Most segments ovoid or flattened, not cylindrical.	2.
2. Segments distinctly ribbed.	3. H. tridens.
2. Segments indistinctly or not at all ribbed.	3.
3. Segments strongly calcified, firm, thick.	2. H. simulans.
3. Segments lightly calcified, flexible, thin.	1. H. Tuna.

1. H. TUNA (Ell. & Sol.) Lamouroux, 1812, p. 186; Collins, 1909, p. 400; P. B.-A., No. 1918; *Corallina Tuna* Ellis & Solander, 1786, p. 111, Pl. XX, fig. e. Kemp; Moseley; Walsingham, Farlow; Howe; Harrington Sound, Jan., Inlet, Dec., Harris Bay, Dec., Hervey; cave, Agar's Island, Aug., Hamilton Harbor, dredged in 5 meters. Dec., Collins. Not uncommon, but less frequent than *H. tridens* and *H. Monile*. Our *H. Tuna* seems all to belong to forma *typica* Barton, 1901, p. 13, Pl. I, fig. 1.

2. H. SIMULANS Howe, 1907, p. 503, Pl. XXIX; Collins, 1909, p. 401; P. B.-A., No. 1916. Tucker's Town, Dec., Hervey. Found only in this one locality and in small quantity. Its segments have the outline of those of *H. Tuna*, but are thicker and more calcified.

3. H. TRIDENS (Ell. & Sol.) Lamouroux, 1812, p. 186; Harvey, 1858, p. 24, Pl. XLIV. C; Collins, 1909, p. 398; P. B.-A., No. 1917; *Corallina tridens* Ellis & Solander, 1786, p. 109, Pl. 20, fig. a. Rein; Moseley, as *H. incrassata;* Walsingham, Farlow; many stations, Collins and Hervey, dredged down to 18 meters. Common nearly everywhere and very variable. Of the various varieties and forms to which names have been given, we have

Forma TYPICA (Barton) Collins, 1909, p. 398; *H. incrassata* forma *typica* Barton, 1901, p. 27, Pl. IV, fig. 39. A stout, stony form, with lower joints short, more or less adherent, upper joints three-ribbed or three-lobed.

Forma TRIPARTITA (Barton) Collins, 1909, p. 399; *H. incrassata* forma *tripartita* Barton, 1901, p. 27, Pl. IV, fig. 43. A more slender form, less branched, the lower joints longer, the upper joints ending in three cylindrical lobes.

Forma GRACILIS Börgesen, 1913, p. 111, fig. 89. Joints small, subcircular in outline, not strongly calcified.

These forms all pass into each other. Börgesen considers *H. Monile* and *H. simulans* also as forms of this species, and it may be that he is right as to the former, but the differences between these two, and the three forms that we consider to belong to *H. tridens*, are greater than the differences among the latter. Gepp and Börgesen prefer the name *H. incrassata* to *H. tridens;* the case for the former is stated by Börgesen, 1911, p. 136, that for *H. tridens* by Howe, 1907, p. 501.

4. H. MONILE (Ell. & Sol.) Lamouroux, 1812, p. 186; Collins, 1909, p. 399; P. B.-A., No. 1915; *H. incrassata* forma *monilis* Barton, 1901, p. 27, Pl. IV, fig. 40; *Corallina monilis* Ellis & Solander, 1786, p. 110, Pl. XX, fig. c. Inlet, Jan., Oct., Dec., Bailey's Bay, Jan., Walsingham, Nov., Tucker's Town, Dec., Hervey; Hungry Bay, April, Collins. Rather common; the forms recognized by Börgesen both occur here.

Forma ROBUSTA Börgesen, 1913, p. 113, fig. 90. Densely branched, the upper joints cylindrical, the lower tripartite and sometimes resembling the upper joints of *H. tridens* forma *tripartita.*

Forma CYLINDRICA Börgesen, 1913, p. 113, fig. 91. Less branched, the joints nearly all cylindrical.

FAMILY BRYOPSIDACEAE.

BRYOPSIS Lamouroux.

1. Ramuli distichous. 2. B. pennata.
1. Ramuli not distichous. 2.
  2. Main branches virgate, with very slender ramuli. 3. B. Duchassaingii.
  2. Outline pyramidal, branching of several orders, no sharp distinction between branches and ramuli. 1. B. hypnoides.

1. B. HYPNOIDES Lamouroux, 1809, p. 333; 1809b, p. 135, Pl. I, fig. 2, a & b; Collins, 1909, p. 403. Harrington Sound, Jan., Feb., April, Walsingham, March, Hervey; Kemp, May, as *B. plumosa*, in part; cave by Gravelly Bay, April, Collins.

Forma PROLONGATA J. G. Agardh, 1886, p. 28; P. B.-A., No. 1870; *B. hypnoides* Harvey, 1846–51, Pl. CXIX. Harrington Sound, May, Dec., Collins; Old Ferry, April, Hervey.

2. B. DUCHASSAINGII J. G. Agardh, 1854, p. 107; Collins, 1909,

p. 403; *Trichosolen antillarum* Montagne, 1860, p. 171, Pl. XI. C. Kemp; Harrington Sound, March, Hervey.

Var. **filicina** var. nov. Frondis circumscriptione late vel anguste lanceolata; axi primario non diviso; axibus secundariis approximatis, aequidistantibus, saepe oppositis, a basi ramulis tenuissimis aequilongis dense obsitis.

Outline of frond broadly to narrowly lanceolate; main axis not divided; secondary axes closely and uniformly set, often opposite, densely beset from the base with very fine ramuli of equal length. Near Flatts bridge, Feb., Hervey. Type in Collins herb.

The habit of this variety is strikingly different from that of typical *B. Duchassaingii*, and the very regular pinnate branching makes it a beautiful object; but in a genus where there is so much variation within each species, it is hardly safe to consider this a distinct species.

3. B. PENNATA Lamouroux, 1809, p. 133; 1809b, p. 134, Pl. III, fig. 1; Collins, 1909, p. 405; P. B.-A., No. 1871. Rein, as *B. plumosa;* Kemp, as *B. plumosa,* in part, *B. hypnoides,* in part. In Collins, 1909, *B. pennata, B. Leprieurii* and *B. Harveyana* were kept distinct, chiefly on the judgment of Miss Vickers, who was familiar with them at Barbados. Since then we have examined some 200 specimens of *Bryopsis* of Miss Vickers' collecting, and some hundreds of specimens from Bermuda, and we have come to the conclusion that while typical examples of these three are quite distinct, intermediate forms are more common, and specific distinction is impracticable. So far we agree with Börgesen, 1911, p. 145, and 1913, p. 117, but we cannot agree with him in placing them all under *B. plumosa* (Huds.) Ag. The normal form of *B. pennata* seems to be a long, simple rachis, with short, distichous ramuli of uniform length, giving a linear outline to the frond. In *B. plumosa* the rachis bears lateral branches, increasing in length from the apex to the base, so as to give a triangular outline, usually broadly triangular, to the frond. Each of the branches has a similar triangular outline. There is much variation in luxuriance of branching, but in examining a considerable series of *B. plumosa* from northern Europe and America, to the Mediterranean on one side, to North Carolina on the other, we have seen nothing like the linear form. Among the abundant material from Barbados and Bermuda we have found no plants with repeated triangular outline of the frond and its divisions. We recognize the same varieties as Börgesen, but place them under *B. pennata,* the oldest name for the distinctly linear forms. The species and its varieties are to be found almost everywhere in the islands, but one must expect more intermediate than typical forms; moreover old plants become denuded, and present many puzzles.

Var. **secunda** (Harv.) comb. nov.; *B. plumosa* var. *secunda* Harvey, 1858, p. 31, Pl. XLV. A, figs. 1–3; *B. Harveyana* Collins, 1909, p. 405. This variety shows a certain dorsiventral arrangement, the ramuli on both edges of the rachis curving towards each other on one side.

Var. **Leprieurii** (Kütz.) comb. nov.; *B. Leprieurii* Kützing, 1849, p. 490; 1856, p. 27, Pl. LXXV, fig. 2; Collins, 1909, p. 404. In this variety the ramuli are in short secund series, separated by short vacant spaces.

Family DERBESIACEAE.

Derbesia Solier.

1. Filaments 100–600 μ diam. 3. D. Lamourouxii.
1. Filaments less than 100 μ diam. 2.
   2. Filaments 40–50 μ diam., dichotomously branched. 1. D. vaucheriaeformis.
   2. Filaments 50–70 μ diam., simple or with short lateral branches. 2. D. marina.

1. D. vaucheriaeformis (Harv.) J. G. Agardh, 1886, p. 34; Collins, 1909, p. 406; *D. tenuissima* Farlow, 1881, p. 60, Pl. IV, fig. 4; *Chlorodesmis vaucheriaeformis* Harvey, 1858, p. 30, Pl. XL. D. On *Dictyopteris Justii*, Gravelly Bay, Aug., Collins. With sporangia.

2. D. marina (Lyng.) Kjellman, 1883, p. 16; Collins, 1909, p. 407; *Vaucheria marina* Lyngbye, 1819, p. 79, Pl. XXII. On *Acanthophora spicifera*, Hungry Bay, May, Collins. With sporangia.

3. D. Lamourouxii (J. Ag.) Solier, 1847, p. 162, Pl. IX, figs. 18–30; Collins, 1909, p. 407; P. B.-A., No. 2168; *Bryopsis Balbisiana* var. *Lamourouxii* J. G. Agardh, 1842, p. 18. Castle Harbor, near landing at Tucker's Town, March, Hervey. The fronds are much stouter than in the two other species of the genus, sometimes simple, sometimes with a few irregular tufts of ramuli. Old and denuded plants of *Bryopsis* have some resemblance to it, but always show the scars of fallen ramuli.

Family CAULERPACEAE.

Caulerpa Lamouroux.

1. Stolon and fronds filiform, without distinct ramuli. 1. C. fastigiata.
1. Stolon and fronds different in character. 2.
   2. Fronds very slender, ramuli whorled, near the summit. 3.
   2. Fronds stouter, ramuli not in distinct whorls. 4.

3. Fronds not over 1 cm. high, stolon and base of frond hairy. 2. C. pusilla.
3. Fronds to 5 cm. high, hairs wanting or few. 3. C. verticillata.
4. Fronds flat or with ramuli in one plane. 5.
4. Ramuli not in one plane. 8.
5. Frond flat, entire or with proliferations. 4. C. prolifera.
5. Frond pinnate. 6.
6. Pinnules flat. 5. C. crassifolia.
6. Pinnules cylindrical or compressed. 7.
7. Pinnules narrowed at base and tapering to tip. 6. C. taxifolia.
7. Pinnules at base somewhat larger than at the curved and mucronate tip. 7. C. sertularioides.
8. Ramuli peltate. 8. C. peltata.
8. Ramuli not peltate. 9.
9. Ramuli varying from long-clavate to spherical-pedicellate. 9. C. racemosa.
9. Ramuli short, of various form, the lowest always rostriform. 10. C. cupressoides.

1. C. FASTIGIATA Montagne, 1838, p. 19, Pl. II, fig. 3; Collins, 1909, p. 411. Dingle Bay, March, Hervey; Hungry Bay, April, Collins. Fine, Vaucheria-like tufts or mats on mangroves and other objects near low water mark. The Hungry Bay material seems to be the floating form known as var. *confervoides* Crouan.

2. C. PUSILLA (Kütz.) J. G. Agardh, 1872, p. 6; Weber, 1898, p. 266, Pl. XX, fig. 6; Vickers, 1908, p. 25, Pl. XXXVIII; Collins, 1909, p. 412; P. B.-A., No. 2019. *Stephanocoelium pusillum* Kützing, 1847, p. 54. Tide pool, Harris Bay, Oct., Nov., Hervey. The branching stolon creeps over the loose sand etc., on the bottom of the pool, forming with other small algae a thin but firm turf, which has to be forcibly torn apart to show the character of the plant. The ramuli are in two or three whorls; in the Bermuda plants these whorls are more closely set than in the forms figured by Mme. Weber and Miss Vickers, and can often be distinguished only by dissection.

3. C. VERTICILLATA J. G. Agardh, 1848, p. 6; Weber, 1898, p. 267, Pl. XX, figs. 7–10; Collins, 1909, p. 412; Börgesen, 1907, p. 355, figs. 1–3; 1913, p. 121, figs. 95, 96. St. George's, April, Hervey.

4. C. PROLIFERA (Forsk.) Lamouroux, 1809, p. 332; Weber, 1898, p. 278, Pl. XXII, fig. 1; Collins, 1909, p. 413; P. B.-A., No. 1872; *Fucus proliferus* Forskäl, 1775, p. 163. Rein; Kemp; Walsingham, Farlow; Walsingham, April, Hervey; Pool by Moore's calabash tree, April, Somerset Bridge, July, Ely's reef, July, Collins. Typical form, passing into

Forma OBOVATA J. G. Agardh, 1872, p. 11; Börgesen, 1907, p. 359, fig. 4; 1913, p. 127, fig. 100; Collins, 1909, p. 413; with broad, little proliferous fronds.

Forma ZOSTERIFOLIA Börgesen, 1907, p. 359, fig. 6; 1913, p. 127, fig. 101; Collins, 1909, p. 413; with narrow, proliferous fronds; Fairyland, Dec., Collins.

5. C. CRASSIFOLIA (Ag.) J. G. Agardh, 1872, p. 13. Typical *C. crassifolia* has not been found here; forma *laxior* is common, and is apparently a well marked endemic form, not having been reported elsewhere; forma *mexicana* is the common form of Florida and the West Indies, and though not rare in Bermuda is less common than forma *laxior.*

Forma LAXIOR (Weber) Collins, 1909, p. 413; P. B.-A., No. 1919; *C. pinnata* forma *laxior* Weber, 1898, p. 291; *C. crassifolia* var. *mexicana* Alg. Am. Bor. Exsicc., No. 170. Walsingham, April, Hervey; Hungry Bay, Tuckertown, Gravelly Bay, Pool by Moore's calabash tree, Cliff pool, April, Harrington Sound, May, Collins.

Forma MEXICANA (Sond.) J. G. Agardh, 1872, p. 13; Collins, 1909, p. 413; *C. mexicana* Sonder in Kützing, 1849, p. 496; Harvey, 1858, p. 16, Pl. XXXVII. A; Gibbet Island, Bailey's Bay, Jan., Hervey.

The form from Cliff Pool deserves special notice; Cliff Pool is a name we have used for a small but deep pool, near the SW. corner of Harrington Sound, between Tucker's Bay and Green Bay. It has a steep cliff on the side towards the sea; on the other side it is near the Sound, but separated from it by land considerably above its level. It evidently has underground connection with the Sound, the water rising and falling somewhat with the tide. On the surface of this pool, in April and May, 1912, was a floating mass of algae, chiefly *C. crassifolia, C. racemosa* and *C. sertularioides.* The stolons floated on the surface, the fronds extending beside them, the tapering rhizoids hanging straight down, sometimes reaching a length of 2 dm., reminding one of the roots of a *Lemna* or *Spirodela,* on a larger scale. Börgesen, 1907, p. 344, classifies the Caulerpas under three types. (1) The epiphytic or mud-collecting Cauperpas. (2) The sand and mud Caulerpas. (3) Rock and coral-reef Caulerpas. These three types are represented in Bermuda, and we can now add a fourth, the floating Caulerpas. Evidently this form can occur only at a station with considerable depth of water, not reached by surf, sheltered from winds, and with no current. Specimens collected here in May have been distributed as P. B.-A., Nos. 1873 and 2021. The station was revisited in August, 1913, but only a few bleached individuals were found; apparently the plants could not endure the intense heat of the midsummer sun.

6. C. TAXIFOLIA (Vahl) Agardh, 1822, p. 435; Weber, 1898, p. 292; Börgesen, 1907, p. 363, figs. 9–10; 1913, p. 131, figs. 104–105; Collins, 1909, p. 414; *Fucus taxifolius* Vahl, 1802, p. 36. Farlow; Walsingham, a single plant, Hervey. Apparently rare, but may have been mistaken for the commoner *C. crassifolia* or *C. sertularioides*, from both of which it can be distinguished by the opposite, sickle-shaped, narrow pinnules, with contracted base.

7. C. SERTULARIOIDES (Gmel.) Howe, 1905a, p. 576; Collins, 1909, p. 414; *Fucus sertularioides* Gmelin, 1768, p. 151, Pl. XV, fig. 4.

Forma LONGISETA (J. Ag.) Svedelius, 1906, p. 114, fig. 10; Collins, 1909, p. 415; P. B.-A., No. 1873; *C. plumaris* forma *longiseta* Weber, 1898, p. 295. Harrington Sound, Oct., Hervey; Cliff Pool, April, Collins.

Forma BREVIPES (J. Ag.) Svedelius, 1906, p. 114, fig. 7; Collins, 1909, p. 415; *C. plumaris* forma *brevipes* Weber, 1898, p. 294. Walsingham, March, Hervey; Ely's Harbor, July, Collins.

8. C. PELTATA (Turn.) Lamouroux, 1809, p. 332; 1809c, p. 145, Pl. III, fig. 2; Weber, 1898, p. 373, Pl. XXXI, figs. 9–11; Collins, 1909, p. 421; *Fucus chemnitzia* var. *peltatus* Turner, 1819, p. 8, Pl. CC. Faxon, a single quite typical specimen; Bethel's Island, Dec., Collins.

9. C. RACEMOSA (Forsk.) J. G. Agardh, 1872, p. 35; Weber, 1898, p. 357, Pl. XXXI, figs. 5–8; XXXII, figs. 1–7; Collins, 1909, p. 419; *Fucus racemosus* Forskäl, 1775, p. 191. A very variable species, with no acknowledged typical form, apart from the many forms and varieties into which it has been divided. It is uncertain to which of these should be referred the *C. clavifera* of Rein and Moseley.

Var. CLAVIFERA (Turn.) Weber, 1898, p. 361: Vickers, 1908, p. 28, Pl. XLV; Collins, 1909, p. 420; *Fucus clavifer* Turner, 1808, Pl. LXXVII. Harrington Sound, March, Wadsworth, No. 71; Hamilton, Farlow; these are the only records of the typical form of this variety, but forms between this and vars. *uvifera* and *laetevirens* are not uncommon.

Var. UVIFERA (Turn.) J. G. Agardh, 1872, p. 35; Weber, 1898, p. 363, Pl. XXXIII, figs. 6–7; Collins, 1909, p. 420; P. B.-A., No. 2022. *Fucus uvifer* Turner, 1819, Pl. CCXXX; Gravelly Bay, Feb., Hervey.

Var. OCCIDENTALIS (J. Ag.) Börgesen, 1907, p. 379, figs. 28–29; 1913, p. 152, fig. 124; Collins, 1909, p. 420; P. B.-A., No. 2021. *C. chemnitzia* var. *occidentalis* J. G. Agardh, 1872, p. 37; Walsingham, Jan., March, Tucker's Town, Feb., Dec., Hervey; Cliff Pool, Hungry Bay, April, Hamilton Harbor, dredged down to 18 meters, Dec., Collins. Agrees well with Börgesen's description and figures, and with the plant distributed as W. N. & L., No. 1586. The Cliff Pool plants have mostly more distant ramuli, but some individuals are quite typical. At Hungry Bay a form was found in which the ramuli were produced on one side of the frond only; not secund in the usual sense, as they were not in a single series, but were placed, apparently irregularly, on one semi-cylinder of the axis, the other being naked.

Var. LAETEVIRENS (Mont.) Weber, 1898, p. 366, Pl. XXXIII, figs. 8, 16–22; Börgesen, 1907, p. 386, fig. 30; 1913, p. 154, fig. 125; Collins, 1909, p. 420; P. B.-A., No. 2020. *C. laetevirens* Montagne, 1842, p. 16. Kemp, in herb.; Wadsworth, No. 70; Walsingham, March, Hervey; Tucker's Town, April, Cooper's Island, Aug., Collins.

10. C. CUPRESSOIDES (Vahl) Agardh, 1822, p. 441; Weber, 1898, p. 323; Collins, 1909, p. 416; *Fucus cupressoides* Vahl, 1802, p. 29. A species containing many forms, all intergrading, once held to be distinct species.

Var. TYPICA Weber, 1898, p. 326; Börgesen, 1907, p. 368, figs. 14–16; 1913, p. 137, figs. 109–111. South Beach, Paget, Farlow.

Var. MAMILLOSA (Mont.) Weber, 1898, p. 332, Pl. XXXVIII, figs. 2–7; Collins, 1909, p. 417; Alg. Am.-Bor. Exsicc., No. 96; P. B.-A., No. 1920; *Caulerpa mamillosa* Montagne, 1842, p. 13. Outer reef, Ely's Harbor, July, Somerset Bridge, July, Gravelly Bay, Aug., Collins. At Gravelly Bay it grew exposed to the waves, the stolon adhering firmly to the rock and covered with sand, so that only the short fronds were visible, often only the tips.

Var. ERICIFOLIA (Turn.) Weber, 1898, p. 335; Collins, 1909, p. 417; *Fucus ericifolius* Turner, 1808, p. 124, Pl. LVI, "found at Bermuda Islands, Herb. Banks." Kemp, in herb. as *C. ericifolia;* Gravelly Bay, Aug., Collins. A few plants at Gravelly Bay, among var. *mamillosa,* distinguished by the cylindrical ramuli.

C. Ashmeadii Harvey, is recorded in Collins, 1909, p. 414, as occurring at Bermuda. We have not been able to confirm this record, and as we have not ourselves found this species, we do not include it in the present work.

FAMILY VAUCHERIACEAE.

VAUCHERIA DC.

*V. SPHAEROSPORA Nordstedt, 1878, p. 177, Pl. II, figs. 7–8; Collins, 1909, p. 429. In "Millbrook" Dec., Collins, with oogonia and antheridia. This species has been found in Greenland, Denmark, Sweden and Great Britain, and also in Uruguay. The Bermuda plant is dioecious, agreeing in that respect with the South American form; in Europe the species is monoecious. Another *Vaucheria* was found at Hungry Bay, Collins, but being sterile could not be specifically determined.

Dichotomosiphon Ernst.

D. pusillus Collins, 1909, p. 431; P. B.-A., No. 2023. Bailey's Bay, Jan., Harrington Sound, March, Inlet, March, Hervey; Shelly Bay, Hungry Bay, April, Collins. Apparently common, forming dark green or almost black mats on rocks, Udotea etc., or loose floating felts. At Bailey's Bay it was found with filaments 50 μ diam.; the normal diam. does not exceed 30 μ. In the material from Harrington Sound, the contents of the filaments is often divided into sections, approximately as long as their diameter, separated by a narrow transparent space in a plane at right angles with the axis of the filament. This may be preliminary to the formation of spores of some sort, but no more advanced stage was seen.

Family CHARACEAE.

Chara Agardh.

*C. gymnopus var. Berteroi A. Braun, 1882, p. 195. Pembroke Marshes, Jan., Farlow. The specimen in the Farlow herbarium was characterized by Nordstedt, in litt., as "forma tenuior" which we understand to be merely descriptive, not a name.

Class **PHAEOPHYCEAE.**

Family ECTOCARPACEAE.

Pylaiella Bory.

P. fulvescens (Schousboe) Bornet, 1889, p. 5, Pl. I; P. B.-A., No. 2076; *Conferva fulvescens* Schousboe ms ex Bornet. On sand-covered rocks by lighthouse, St. David's Island, May, 1913, Hervey. The plant agrees fully with Bornet's figure as to form and dimension of horizontal filaments and sporangia; the erect filaments are in part simple, as figured by Bornet, in part like those figured by Sauvageau, 1896a, fig. 1, being recurved near the tips, and bearing numerous longer or shorter branches, mostly on the outer side of the curve. The unilocular sporangia are rare, but well developed. *P. Hooperi*, Barbados, Miss Vickers, seems hardly distinct. In comparing the description of *P. fulvescens* by Bornet with that of *Pylaiella* sp. (*Ectocarpus Hooperi* Crouan) on the following page, the chief distinctive character of the latter would seem to be the Rhizoclonium-like ramuli near the base; such ramuli were occasionally seen in the Bermuda plant, but were not at all abundant.

Ectocarpus Lyngbye.

1. Lower part of frond endophytic. 2.
1. Not endophytic. 3.
   2. Only slightly endophytic, in Dictyopteris Justii; largely free; plurilocular sporangia cylindrical. 8. E. luteolus.
   2. Mostly endophytic, in Halymenia; plurilocular sporangia ovoid. 9. E. parasiticus.
3. Erect filaments arising from prostrate, branching filaments. 4.
3. No distinct prostrate filaments. 5.
   4. Erect filaments with plurilocular sporangia near base, no other branching. 7. E. elachistaeformis.
   4. Erect filaments freely branched, bearing sporangia throughout. 9.
5. Plurilocular sporangia seriate on upper side of branches, near base. 6.
5. Plurilocular sporangia variously placed, not seriate. 8.
   6. Plurilocular sporangia cylindrical. 3. E. Mitchellae.
   6. Plurilocular sporangia ovoid to conical. 7.

7. Branching irregular, branches patent. 4. E. coniferus.
7. Branches subsecund, ramuli long, pectinate. 5. E. Sandrianus.
8. Plurilocular sporangia fusiform, unilocular unknown. 1. E. confervoides.
8. Plurilocular sporangia short-conical, unilocular ovoid or subspherical. 2. E. siliculosus forma arctus.
9. Plurilocular sporangia variable, always blunt or truncate. 6. E. Duchassaingianus.
9. Plurilocular sporangia acute. 10. E. Rallsiae.

1. E. CONFERVOIDES (Roth) Le Jolis, 1863, p. 75; Kuckuck, 1891, p. 19, fig. 3; *Ceramium confervoides* Roth, 1797, p. 151. Floating, Gibbet Island, March, Hervey. Somewhat variable, but mostly of the typical form.

2. E. SILICULOSUS (Dillw.) Lyng. forma ARCTUS (Kütz.) Kuckuck, 1891, p. 18; P. B.-A., No. 1922; *Ectocarpus arctus* Kützing, 1843, p. 289; *Corticularia arcta* Kützing, 1855, p. 23, Pl. LXXX, fig. II. On sand covered rocks, below low water mark, Gibbet Island, March, Harris Bay, April, Hervey; floating, Tucker's Town, April, Harrington Sound, May, Collins. *E. acanthoides* Vickers, Barbados, No. 95, seems to be the same plant. We have not found in Bermuda the typical form of *E. siliculosus*, which is common on both sides of the North Atlantic.

3. E. MITCHELLAE Harvey, 1852, p. 142, Pl. XII. G; P. B.-A., No. 1921; *E. virescens* Thuret in Sauvageau, 1896, p. 18 of reprint. Harris Bay, Heron Bay, Jan., St. David's Island, Feb., Harrington Sound, Shelly Bay, March, Hervey; Shelly Bay, Harrington Sound, Cooper's Island, April, Collins. A common species, growing on corals, larger algae, aquatic phanerogams, and on submerged twigs of live Tamarisk. Plurilocular fruit apparently always abundant, megasporangia and meiosporangia in about equal numbers. The former have not been recorded for the Atlantic coast of North America, where the species is common, but were found in California, and distributed as P. B.-A., No. 671. When growing on any hard substance, rhizoidal growth is usually insignificant; on *Castagnea, Helminthocladia* etc., the rhizoids are strongly developed, penetrating well into the tissue of the host.

4. E. CONIFERUS Börgesen, 1914, p. 164, figs. 131–132. Shelly Bay, April. Hervey, among *E. Mitchellae*. This species was quite recently described from the Danish West Indies, and its occurrence at Bermuda is of interest, indicating that it may be found at other stations in the Atlantic.

5. E. Sandrianus Zanardini, 1843, p. 41; 1865, p. 143, Pl. LXXIV. B; *E. elegans* Thuret in Le Jolis, 1863, p. 77, Pl. II, fig. 1–2; not of Menegh. Shelly Bay, Jan., St. David's Island, Feb., Hervey; with plurilocular sporangia. In both cases mixed with other species of *Ectocarpus;* this mixture of species of *Ectocarpus* is quite common and sometimes perplexing. It is the rule rather than the exception.

6. E. Duchassaingianus Grunow, 1867, p. 45, Pl. IV, fig. 1; Vickers, 1905, p. 59; 1908, Pl. XXVII; Börgesen, 1914, p. 159, figs. 127–128; P. B.-A., No. 2077. Major's Bay, March, Hervey. On sticks and twigs, outlet of aquarium, Agar's Island, Aug., Collins. The Major's Bay plant agrees with Börgesen's description and figures, and with a specimen of Miss Vickers, Barbados, No. 89. The plant from the aquarium outlet differs in the absence of hairs, and in the greater variability of form of the plurilocular sporangia. These are often exactly like Börgesen's figures, but in other instances the cylindrical or clavate body of the sporangium has a shortly acuminate or subulate apex; the same occurs in Miss Vickers specimen. Unilocular sporangia were not seen. The cells were all very densely packed, and it was only in the youngest that the irregularly rounded disks of the chromatophores could be seen. Though there were no hairs, the branches often ended in a long simple filament, 10–14 μ diam., with longer cells than in the rest of the plant, but all were well supplied with chromatophores. The sporangia were sometimes sessile, oftener on a short pedicel, occasionally terminating a branch, as shown in Börgesen's fig. 128e. The cell bearing a sporangium was usually distinctly shorter than the adjacent cells, as in *E. indicus* Sonder, as noted by Mme. Weber, 1913, p. 129, fig. 34. We are inclined to agree with Börgesen that *E. Duchassiangus* may be merely a form of *E. indicus,* but for the present it seems better to retain the former name. The station where this plant occurred is a peculiar one; the salt water outlet of the aquarium is well up in the rock at the shore of the island; the water runs down into the sea, stalks of grass and other objects reached by it being covered by a dense coating of various kinds of algae, *Enteromorpha* predominating, but also other Chlorophyceae and several Myxophyceae; the variations of this material from the type may be due in some way to the exceptional conditions.

7. E. elachistaeformis Heydrich, 1892, p. 470, Pl. XXV, fig. 14; Börgesen, 1914, p. 174, fig. 137. On *Codium decorticatum,* Cooper's Island, Aug., on *Galaxaura squalida* & *Helminthodadia Calvadosii,* St. David's Island, April, Collins. The form reported by Börgesen

differs somewhat from the typical, but not enough to raise any question as to identity. Our form comes nearer to the type from New Guinea. The only marked difference is in the basal portion of the plant growing on *Codium*. When growing on *Sargassum* it formed a more or less definite basal layer, from which short rhizoids issued, entering the host. On the *Codium* there is no definite basal layer, but a compact bundle of irregular rhizoidal filaments, narrower than the assimilating filaments, with few chromatophores, and cells up to 10 diam. long. The lower ends of these rhizoids separate more or less, and spread among the utricles of the host. This difference is explainable by the difference in structure of the hosts. On the *Galaxaura* the rhizoids are less conspicuous. Plurilocular sporangia, similar to those figured by Heydrich, were abundant.

8. E. LUTEOLUS Sauvageau, 1892, p. 25, Pl. II, figs. 14–19. On *Dictyopteris Justii*, South Shore, Aug., Collins. The lower part of the frond inhabits the tissue of the host; the upper part forms a fine down on the surface.

9. E. PARASITICUS Sauvageau, 1892, p. 28, Pl. III, figs. 20–23; *Streblonema parasiticum* (Sauv.) De Toni, 1895, p. 575. In *Halymenia pseudofloresia*, Jan., Hervey. Mostly endophytic; the plants from Maine, distributed as P. B.-A., No. 1337, were chiefly external, the difference being probably due to the firmer tissue of the host in the latter case, *Cystoclonium purpurascens*.

10. E. RALLSIAE Vickers, 1905, p. 59; 1908, Pl. XXXII; Börgesen, 1914, p. 169, fig. 133; P. B.-A., No. 2172. On *Helminthocladia calvadosii*, Old Ferry, April, Hervey. The main filaments are occasionally stouter than in the Barbados and St. Thomas material, up to 40 μ diam., but usually not over 30 μ, in lesser divisions down to 20 μ, in hairs to 10 μ. There is a system of descending filaments, irregular and twisted, but otherwise like the erect filaments, extending for quite a distance in the tissues of the host; plurilocular sporangia agree in form, dimensions and position with Börgesen's figure.

STREBLONEMA Derbès & Solier.

S. SPHAERICUM Derbès & Solier in Castagne, 1851, p. 100; Sauvageau, 1897, p. 18, figs. 2–3 (of reprint); Kuckuck, 1899, p. 28, figs. 6–7. In *Castagnea Zosterae*, Cooper's Island, April, Collins. With uni- and plurilocular sporangia; generally in company with *Myriotrichia*, which it much resembles.

Ascocyclus Magnus.

A. orbicularis (J. Ag.) Magnus, 1874, p. 73; P. B.-A., No. 1878; *Myrionema orbiculare* J. G. Agardh, 1848, p. 48. On marine phanerogams in shallow water, Cooper's Island, April, Collins. Probably elsewhere, but easily overlooked.

Family SPHACELARIACEAE.

Sphacelaria Lyngbye.

1. Propagula with broad body. 2.
1. Propagula slender, branching. 3.
  2. Filaments mostly 30–40 μ diam.; lateral cell of propagulum not divided. 3. S. tribuloides.
  2. Filaments mostly 55–75 μ diam.; lateral cell of propagulum divided into two. 4. S. novae-hollandiae.
3. Propagulum with three rays from summit of pedicel. 2. S. fusca.
3. Propagulum with two rays from summit of pedicel. 1. S. furcigera.

1. S. furcigera Kützing, 1855, p. 27, Pl. CX; Sauvageau, 1901,[9] p. 145, fig. 35. On small spider crab, Hungry Bay, July, on floating *Turbinaria*, Dec., Collins; with propagula.

2. S. fusca (Huds.) Agardh, 1828, p. 28; Sauvageau, 1902, p. 206, fig. 43; *Conferva fusca* Hudson, 1798, p. 602. Spanish Rock, April, Hervey, with propagula.

3. S. tribuloides Meneghini, 1840, p. 2; Sauvageau, 1901, p. 123, figs. 28–29; P. B.-A., No. 1923. Not uncommon in shallow rock pools and on various submerged substances. In pools, South Shore, Farlow; Harris Bay, Feb., March, Dec., Gravelly Bay, Jan., Hervey; on *Galaxaura*, St. David's, April, Collins. Found once on twigs of Tamarisk that drooped into the water of Harrington Sound. Propagula common; no sporangia seen.

4. S. novae-hollandiae Sonder, 1845, p. 50; Sauvageau, 1901, p. 137, fig. 33. In small quantity, among *S. tribuloides*, Spanish Rock,

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9 In references to this work, the page given is that of the completed and separate issue; the date, however, is that of the original publication in the Journal de Botanique.

Harris Bay, March, Hervey. The species is a native of Australia, but has been found at Martinique and at Barbados; in both these places it was in company with *S. tribuloides,* as at Bermuda. It is a stouter plant than the latter, and the technical difference, though not striking, seems to be constant.

Family ENCOELIACEAE.

Colpomenia Derbès & Solier.

C. sinuosa (Roth) Derbès & Solier, 1856, p. 11, Pl. XXII, figs. 18–20; Börgesen, 1914, p. 176, fig. 138; P. B.-A., No. 2024; *Ulva sinuosa* Roth, 1806, p. 327, Pl. XII, fig. 2. Rein; Moseley; Kemp, as *Asperococcus sinuosus;* Gibbet Island, Tucker's Town, Gravelly Bay, Harrington Sound, Feb., Hungry Bay, April, Hervey. Very common from Feb. to April, disappearing entirely in July and August, and at least the first part of September. On exposed shores it forms a nearly continuous coating, firmly adherent to the rock; in quiet water, such as the tidal stream at Hungry Bay, it takes the form of subspherical vesicles, up to 20 cm. diam.

Hydroclathrus Bory.

H. cancellatus Bory, 1825, p. 419; Vickers, 1908, Pl. XXIII; Börgesen, 1914, p. 177, fig. 139; P. B.-A., No. 2078. Spanish Rock, March, April, Hervey. Apparently not common.

Scytosiphon Agardh.

S. Lomentaria (Lyng.) J. G. Agardh, 1848, p. 126; P. B.-A., No. 2079; *Chorda Lomentaria* Lyngbye, 1819, p. 74, Pl. XVIII. E. Inlet, Feb., Dec., Bailey's Bay, Jan., Mangrove Bay, Feb., Hervey. Appears to be a plant of winter and early spring, varying in different years as to date of appearance, in some years not appearing at all at a station where it was plenty the year before. It is a rapid grower, and disappears soon after maturity.

Rosenvingia Börgesen.

R. intricata (J. Ag.) Börgesen, 1914, p. 182; P. B.-A., No. 2173; *Asperococcus intricatus* J. G. Agardh, 1847, p. 7; *Striaria intricata* Vickers, 1905, p. 59; 1908, p. 41, Pl. XXIV. Harris Bay, Feb., Hervey, with plurilocular sporangia.

Family MYRIOTRICHIACEAE.

Myriotrichia Harvey.

M. repens Hauck, 1879, p. 22; Kuckuck, 1899, p. 21, Pl. III (of reprint); P. B.-A., No. 2025; *Dichosporangium repens* Hauck, 1885, p. 339, fig. 141. In fronds of *Castagnea Zosterae,* Cooper's Island, April, Collins. The creeping filaments bear abundant unilocular sporangia; the erect filaments bear each a terminal cluster of plurilocular sporangia; no unilocular sporangia were seen on the erect filaments. *Streblonema sphaericum,* with both kinds of sporangia, accompanies the *Myriotrichia.* As pointed out by Kuckuck, it is practically impossible to distinguish the two species when both bear only unilocular sporangia, as is often the case; the presence of erect filaments in *Myriotrichia* and their absence in *Streblonema* is the only distinguishing character.

Family MESOGLOIACEAE.

Castagnea Derbès & Solier.

C. Zosterae (Mohr) Thuret, fide Börgesen, 1914, p. 184, figs. 144–145; *Castagnea mediterranea* P. B.-A., No. 1879. Kemp, as *Mesogloia vermicularis, M. Griffithsiana* and *M. Chordariae;* Castle Harbor, Bailey's Bay, March, Wadsworth; Shelly Bay, Jan., Castle Harbor, Feb., Hervey; Cooper's Island, April, Collins. As this plant seems to be the same as that from the Danish West Indies, we provisionally give the same name used by Börgesen. It was distributed by us as *C. mediterranea* (Kütz.) Bornet, but is not *Cladosiphon mediterraneus* Kützing, as shown by comparison with an authentic specimen of the latter, for which we are indebted to the kindness of

Dr. M. A. Howe. It is certainly not *C. Zosterae* Farlow, 1881, p. 86, Alg. Am.-Bor. Exsicc., No. 162, but resembles *C. virescens* Farlow, 1881, p. 85, *Eudesme virescens* P. B.-A., No. 33, which is the same as *Mesogloia virescens* Carmichael in Wyatt, Alg. Danm., No. 49. Though some writers speak of *C. virescens* as having a solid axis, *C. Zosterae* as hollow, for instance Bornet, 1892, p. 236, the statement is true of the former only in the earlier stages. "A section of the frond of a well-developed *C. virescens* shows a circle of roundish cells around a central cavity"; Farlow, l. c. The description and figure of *C. Zosterae* Börgesen, agree with the Bermuda plant.

In New England and northern Europe there are two species of *Castagnea,* which are well distinguished by Farlow as *C. virescens* and *C. Zosterae;* the former resembles the Bermuda plant; the latter, quite distinct, is the *Myriocladia Zosterae* Crouan, Alg. Mar. Finistère, No. 49, and the *Castagnea Zosterae* of Le Jolis, 1863, p. 85, fide spec. authent.; but it may be open to question whether it is the *Mesogloia virescens* var. *zostericola* Harvey, 1846–1851, Pl. LXXXII, of which Harvey says "only differs in being of smaller size, with less compound ramification; there is no microscopic character to distinguish it." And in the Nereis Bor.-Am., part 1, 1852, p. 127, where he recognizes two species as distinct, he questions the identity of his *Mesogloia Zosterae* with the species of Lyngbye and Areschoug. His plate X. B, *M. virescens,* is drawn from a specimen from Sand Key, Florida, to which we will refer later; we do not think it is the *M. virescens* of New England and northern Europe. Plate X. A, *M. Zosterae,* is incorrect and misleading, as pointed out by Farlow. If it should prove that *Rivularia Zosterae* Mohr, 1810, p. 367, was identical with *Mesogloia virescens* Carmichael, *Castagnea Zosterae* would be the proper name for the spring plant of New England and northern Europe, and a new name would be needed for the smaller summer plant now known by that name. As to the identity of *C. virescens* of New England and northern Europe with the Bermuda plant, we are not now prepared to point out distinctive characters. But the southern plant is usually stouter, less branched, and with a firmer gelatine. For the purpose of comparison we have examined a large number of specimens of *Castagnea* (or *Mesogloia*) *virescens* of northern Europe and New England, including specimens from Mrs. Griffiths, Mrs. Wyatt, Greville, Harvey, Le Jolis etc.; with very few exceptions they bore unilocular sporangia; none had plurilocular. Of *Castagnea* (or *Myriocladia*) *Zosterae* we have examined a considerable number, including specimens from Le Jolis and Crouan, and the No. 162 of Farlow, Anderson

& Eaton; with one exception, sterile, all had plurilocular sporangia, none unilocular. Of the Bermuda plant we have examined many specimens of different ages and from different stations; with the exception of a very few, very young or very old individuals, sterile, all bear both uni- and plurilocular sporangia on the same individual. To add to the confusion, the plant from Florida, distributed as *C. mediterranea,* P. B.-A., No. 481, when compared with the Bermuda plant now seems to be distinct both from that and from *Cladosiphon mediterraneus* Kütz. The peripheral filaments seem to be not so much laterally attached to the external longitudinal filaments as continuations of them or their branches; the basal cell, up to 25 μ diam., followed by several similar colorless cells rapidly diminishing to about 12 μ diam.; above this begins the peripheral filament proper, with colored cells about 7–9 μ diam.; this is several times dichotomous, the cells, except the few lower ones, spherical, increasing in size up to 15 μ, sometimes to 20 μ diam., the filaments strongly incurved; unilocular sporangia, 70–80 $\times$ 55–60 μ in the lower forkings. The frond does not exceed 10 cm. in height, and has few branches. Harvey's figure of *Mesogloia virescens,* 1852, Pl. X. B, was drawn from a plant from Sand Key, Florida, and we have examined two specimens collected by Harvey at that place at that time; they agree with P. B.-A., No. 481, except that they have no fruit. In Harvey's plate fig. 4 represents quite well the upper part of a peripheral filament of this plant, but is quite different from a filament of *C. virescens.* We have found only one European specimen agreeing with P. B.-A., No. 481; this is "No. 572, Société dauphinoise, 1882, *Cladosiphon mediterraneus* Kütz. (Vidit Bornet, 1882) Portofino (Ligurie orientale) sur les feuilles de *Posidonia Caulini.* Dr. A. Piccone, Mai, 1876." This specimen was received by one of us from Dr. Piccone. Sauvageau, 1897, p. 46, discusses *Castagnea,* assuming correctly enough that if *Castagnea* is maintained, *Cladosiphon* Kützing should be divided between *Castagnea, Nemacystus* etc. But the name *Cladosiphon* clearly antedates *Castagnea,* and under the international rules should be retained for *C. mediterraneus* and its congeners. *Eudesme* J. G. Agardh seems to have no claim to distinctness from *Cladosiphon.* We refrain from making any new combinations, in the hope that Kuckuck's work on the Phaeophyceae may soon appear, and bring order out of the present chaos.

Family STILOPHORACEAE.

Stilophora J. G. Agardh.

S. rhizodes (Ehrh.) J. G. Agardh, var. adriatica (Ag.) J. G. Agardh, 1848, p. 85; *Sporochnus adriaticus* Agardh, 1827, p. 646; 1828–35, Pl. XXX. Harrington Sound, April, Hervey, with plurilocular sporangia. More slender and delicate than the typical *S. rhizodes,* which is of a more northern range.

Family SPOROCHNACEAE.

Sporochnus Agardh.

S. Bolleanus Montagne in Kützing, 1859, p. 33, Pl. LXXXI, fig. II; P. B.-A., No. 2174. Dredged in 22 meters on coral rocks in June, Kemp, as *S. pedunculatus;* handsome plants with assimilative filaments well developed, Castle Island, Miss Wilkinson; a similar plant, Miss Peniston, no data; Gravelly Bay, old plants with mature fruit, washed ashore, Aug., Collins; dredged near Challenger Reef, in 60 meters, Aug., 1903, Bermuda Biological Station.

Family TILOPTERIDACEAE.

Heterospora Kuckuck.

H. Vidovichii (Meneg.) Kuckuck, 1895, p. 318, Pl. IV, figs. 1–20; *Haplospora Vidovichii* Bornet, 1891, p. 363, Pl. VIII, figs. 1–5; P. B.-A., No. 2026; *Ectocarpus Vidovichii* Meneghini in Kützing, 1845, p. 233; *E. crinitus* Hauck, 1885, p. 330, not of Carmichael. Forming rather dense tufts, up to 4 dm. long, on wall of inlet by the Frascati Hotel, March, Hervey, with monosporangia. The occurrence here of a representative of the family Tilopteridaceae is of much interest; barely half a dozen species are known, and all but this one inhabit the colder waters of the Atlantic. *H. Vidovichii* inhabits the Mediterranean, and this is its first recorded occurrence elsewhere.

Family FUCACEAE.

Ascophyllum Stackhouse.

A. nodosum (L.) Le Jolis, 1863, p. 96; *Fucus nodosus* Linnaeus, 1763, p. 1628; Harvey, 1846–51, Pl. CLVIII. Wadsworth, in Farlow herb.; Inlet, Jan., May, Gravelly Bay, Feb., Shelly Bay, March, Hervey; Gravelly Bay, April, Shelly Bay, Bethel's Island, Dec., Collins. This species is not uncommonly found among the floating algae left by the tide but it has never been found attached, and as it is a conspicuous plant, it is not likely that it has been overlooked. It is common on the American coast from New Jersey to the arctic regions, but rarely reaches to low water mark, and does not grow in places exposed to the full force of the waves. There is no reason to suppose that it grows here in deep water, or on the outer reefs awash with the waves, the only class of localities not well explored. Prof. Sauvageau, to whom we are much indebted for information as to its habits in Europe, writes us "Jamais je n'ai vu l'*Ascophyllum* dans les stations franchement exposées au choc des vagues, mais toujours dans les stations plus ou moins abritées, par exemple dans les anses rocheuses, dans les petits ports, sur les rochers qui émergent parmi la vase. C'est une plante de mi-marée." As regards the general question of brown algae washed ashore in places on the Bay of Biscay, where they do not grow, he says, "En résumé, l'*Ascophyllum*, rejeté, arrive en très bon état, fructifié ou non, selon la saison, mais on ne peut dire s'il a flotté très longtemps, puisqu'il vit sur les rochers à une trentaine de kilometres de là. *L'Himanthalia* est dans le même cas. Mais le *Cystoseira concatenata* et le *Sargassum vulgare* viennent surement de très loin, et cependant leurs organes reproducteurs sont aptes à la fecondation. Les algues brunes, normalment fixées, se conservent très bien à l'état flottant, beaucoup mieux qu'on le croit generalment. Donc, à mon avis, il n'est nullement nécessaire que l'*Ascophyllum* croisse aux Bermudes pour que vous l'y trouvez rejeté; il peut y arriver en très bon état, et même capable de produire des fécondations et des germinations, bien qu'il provienne d'un pays lointain et qu'il ait flotté longtemps." It seems to us quite unlikely that the plants found at Bermuda could have come from the American coast across the Gulf Stream. The chances are certainly greater for its European origin, and there is good reason to suppose that it forms a portion, a relatively small portion, to be sure, of the living and floating brown algae of the North Atlantic, which have given a certain district of it the name of the "Sargasso Sea." Bouvier, 1907, p. 35, says "Ça et la, parmi les Sargasses, on rencontre quelques fragments de Fucus nodosus, arrachées certainement aux rivages des Canaries, de Madère ou des Açores." To be sure, Sauvageau, 1907, p. 1084, points out that the *Fucus* (*Ascophyllum*) has never been reported growing at the Canaries, Madeira or the Azores; but Bouvier's erroneous assumption does not invalidate his record of the occurrence of the plant as described. Börgesen, 1914a, p. 14, note, says "Professor Gran has most kindly communicated me that *Ascophyllum* was found in the northern part of the Sargasso Sea, and rather abundant." We think it may be concluded that *Ascophyllum*, the original derivation unknown, continues to live in a floating state among the *Sargassum* of the North Atlantic in active vegetation, and at least occasionally fruiting.

Fucus Linnaeus.

F. vesiculosus Linnaeus, 1763, p. 1636. A single battered but unmistakable fragment was found washed ashore, Hervey.

Turbinaria Lamouroux.

T. tricostata Barton, 1891, p. 218, Pl. LIV, fig. 3; P. B.-A., No. 1877. Gravelly Bay, Jan., Feb., March, April, Aug., Oct., Nov., Dec., Hervey; Hungry Bay, July, Collins. Except a few plants from near the entrance of Hungry Bay, the only locality we have observed is at Gravelly Bay, where it grows abundantly in pools at low water mark and sometimes higher up. *T. trialata* Kütz., the common species of the West Indies, we have not found, and though the two species have much in common, we have found no plants that would raise any doubt as to their distinctness. Quite young plants were found in August; in these neither alae nor costae had yet been formed. The mature plants, in December and January, are from 10 to 15 cm. high; the root is rather slender, much branched, 2–4 cm. long; as the plants grow close together, the roots are intermixed, but so loosely that individual plants can be separated without difficulty.

SARGASSUM Agardh.

The Sargassa abound everywhere in warmer water; there have been very many species described, and new ones are continually added to the list; undoubtedly there have been many cases where observers from distant regions have described the same species independently and in good faith; ultimately one of the names must give way to the other. On the other hand more conservative botanists have used the name of a well-known species for a form found at a station distant from the home of the species, and sooner or later the later named form will have to be segregated. Whether mistakes made by too radical or by too conservative treatment are more harmful, will probably remain an open question in botanical as in other matters. In our treatment of the Bermuda species, we find in some of them more or less noticeable differences from the species of the same name elsewhere, and we have given an account of the characters of each of the species we recognize, and have drawn these characters from Bermuda specimens, not from descriptions of others.

Key to the Species of Sargassum.

1. Always floating, without fruit or basal attachment. 2.
1. Attached, fruiting. 3.
  2. Slender throughout, the leaves very narrow, with aculeate teeth. 1. S. natans.
  2. Stouter; leaves lanceolate with triangular teeth. 2. S. fluitans.
3. Stem densely muriculate or with short proliferations. 4.
3. Stem not muriculate, or only slightly and occasionally so. 5.
  4. Leaves ovate or broadly lanceolate. 4. S. lendigerum.
  4. Leaves narrowly linear, simple or 1-several times forked. 3. S. linifolium.
5. Fructification long, slender, filiform, loosely branched. 6. S. Filipendula var. Montagnei.
5. Fructification not so slender or elongate. 6.
  6. Receptacles with dentate wings. 8. S. platycarpum var. bermudense.
  6. Receptacles wingless. 7.
7. Individual receptacles on slender pedicels. 3. S. linifolium.
7. Receptacles fertile throughout. 8.
  8. Receptacles forming a dense glomerule. 7. S. Hystrix.
  8. Receptacles repeatedly forked, branches separate. 5. S. vulgare.

1. S. NATANS (L.) J. Meyen, 1838, p. 185; Börgesen, 1914, p. 7; P. B.-A., No. 2180; *S. bacciferum* Agardh, 1821, p. 6; Harvey, 1852,

p. 54; *Fucus natans* Linnaeus, 1753, p. 1160; *Fucus bacciferus* Turner, 1808, p. 105, Pl. XLVII. Stem long, slender, smooth, with more or less distant similar branches; leaves long, slender, linear, with many sharp teeth, cryptostomata wanting or inconspicuous; vesicles numerous, on long slender pedicels, and usually with a filiform prolongation; fructification unknown; unattached, floating near the surface of the sea, forming loose floating patches, or strips in the line of the direction of the wind; in quiet water the tips of the leaves project above the water, like bristles; drifting ashore at all times, and in case of storms in immense quantities, and used as a fertilizer. It inhabits a large area in the North Atlantic, within a boundary formed by the Gulf Stream and its subsidiaries, reaching the coast of Europe, turning south and then west to its origin in the Gulf of Mexico. It has an active vegetative growth, the lower part of the stem decaying, increasing the number of individuals by fragmentation. It has never been found attached nor in fruit, and though in all probability originally derived from an attached form, it now appears to be so changed by its mode of life that it is unlikely that the attached species from which it was derived will ever be certainly determined.[10]

In several instances there have been reports of finding this species in fruit, but in each case when examined there are circumstances leading to the conclusion that the plant observed belonged to some other species.

2. S. FLUITANS Börgesen, 1914a, p. 222; P. B.-A., No. 2177; *S. Hystrix* var. *fluitans* Börgesen, 1914, p. 11, fig. 8. Stem rather stout, mostly smooth, occasionally with a few spines, much branched; leaves lanceolate to ovate-lanceolate, thickish, cryptostomata present but not conspicuous, teeth short and triangular; vesicles spherical, about 5 mm. diam., short-pedicelled, usually without prolongations; fructification unknown. Floating with *S. natans*, but less abundant; propagated by fragmentation only. It may be derived from *S. Hystrix* J. Ag., but if so the derivation is remote and the differentiation considerable. Both *S. natans* and *S. fluitans* are lighter in color than the attached species.

3. S. LINIFOLIUM (Turn.) Agardh, 1848, p. 18; P. B.-A., No. 2179; *Fucus linifolius* Turner, 1811, p. 64, Pl. CLXVIII. On rocks above and below Flatts bridge and at other points in Harrington Sound and in Hamilton Harbor, Hervey, Collins. From a common base but without any general trunk arise several axes with more or less frequent

10 For fuller discussion of floating Sargassum, see Collins, 1917.

branches, elongate, virgate, bearing leaves, fructification, and short branches; stems slender, terete, densely muriculate with short simple or forked papillae, which are occasionally more scattered on the older parts; leaves thickly set at the tips of the main branches and along short lateral branches, linear and attenuate to both ends, 1–2 mm. wide, up to 5 cm. long, simple or forked, margin irregularly dentate with small distant teeth, in young leaves larger and more frequent; midrib not specially conspicuous; cryptostomata rather large, a single series each side of the midrib, rather irregularly spaced; vesicles 3–6 mm. diam., smooth, or sometimes with cryptostomata, subspherical on a filiform pedicel of uniform diameter, or pyriform on a pedicel enlarged above; pedicel smooth, length one and one half to three times the diameter of the vesicle, usually unarmed, occasionally with a small mucro, rarely with a short filiform prolongation. Rachis of fructification usually short, sterile and filiform, or fertile and torulose, bearing several alternate, torulose, fertile branches, with subacute tip, one half to one cm. long; fructification mostly on the lower part of short branches of the second order with leaves about them on the branches.

The above description refers to the attached plant of quiet waters, but individuals more slender than the typical form can be found, in which the stem is almost entirely smooth and the rachis of fructification quite elongate. As with other species of *Sargassum*, individuals are to be found among the masses of *S. natans* floating after storms, and these show a certain resemblance to the latter, but their condition shows indications of their not persisting.

4. S. LENDIGERUM (L.) Agardh, 1820, p. 9; P. B.-A., No. 2178; *Fucus lendigerus* Linnaeus, 1763, p. 1628; Turner, 1808, p. 107, Pl. XLVIII. South shore, various points, Jan., Feb., Apr., Dec., Hervey; Little Agar's Island, Nov., Collins. Common on exposed rocks in shallow water all around the islands. A stout torulose trunk, 1–3 cm. high, divides into several main axes, often unbranched, occasionally rather freely branching; axes and branches terete, usually thickly set with short, simple or forked proliferations, rarely over 1 mm. long; leaves ovate or broadly lanceolate, margin irregularly undulate or slightly dentate; occasionally forked, usually much crisped, midrib distinct, cryptostomata small, scattered; vesicles spherical, smooth, usually about 3 mm. diam., occasionally 5 mm., on filiform pedicels usually shorter than the diameter of the vesicle, rarely with short tips. Fructification of filiform branching receptacles, the main rachis usually distinct, stouter than the radial branches, which may reach a length of 2 cm. in the looser forms, but usually do not reach a length of 1 cm.;

branching more or less dense, when dense often apparently dichotomous, tips acute; sometimes fertile throughout, sometimes rachis or even branches sterile. Fructification mostly on the upper part of the axes, often occupying these to the exclusion of leaves and vesicles, but also sometimes on short branches on the lower part of the axes. Specially a plant of exposed shores.

5. S. VULGARE Agardh var. FOLIOSISSIMUM (Lamour.) J. G. Agardh, 1889, p. 108; *Fucus foliosissimus* Lamouroux, 1813, p. 36, Pl. VII, fig. 1. Cooper's Island, April, Hervey. From a very short trunk arise several main axes, mostly smooth, sometimes slightly muriculate, bearing more or less numerous similar branches; leaves lanceolate to oblong, the margins finely and closely dentate; midrib distinct, cryptostomata abundant and without definite order on the younger leaves, often obsolete on the older and thicker leaves; vesicles spherical, 3–5 mm. diam., without prolongation, on a pedicel equal to the diameter or longer; receptacles axillary, branching, fertile throughout, verrucose, shorter than the leaves.

At Spanish Point, March, Hervey, was found a form probably belonging here, but without fruit; the leaves are narrower and nearly entire; it may be *S. vulgare*, typical; *S. vulgare* varies much in the size and form of the leaves.

6. S. FILIPENDULA Ag., var. **Montagnei** (Bailey) comb. nov.; *S. Montagnei* Bailey in Harvey, 1852, p. 58, Pl. I. A; *S. vulgare* var. *Montagnei* Farlow, 1881, p. 103; *S. Filipendula* forma *subedentata* J. G. Agardh, 1889, p. 120. Kemp; near Wistowe, floating, Aug., Collins. Stem long, slender, filiform, smooth except for a few minute, scattered papillae on the younger parts, loosely branched; leaves linear, usually 3–6 mm. wide, up to 15 cm. long, often one or more times forked, the divisions sometimes equal and symmetrical, oftener subpinnate and alternate; leaves tapering gradually or abruptly to the subacute tip; midrib distinct throughout leaves and their divisions; cryptostomata few, small, scattered, rarely showing a linear arrangement; margin even or slightly undulate or indistinctly dentate; vesicles spherical to subpyriform, 2–3 mm. diam., tipped generally with a mucro, often with a leaf; pedicel in length one and one half to three times the diameter of the vesicle, sometimes filiform, often compressed, or with midrib and margin. Rachis of fructification filiform, smooth, sterile, elongate, bearing rather distant lateral branches at first with sterile base, later fertile throughout, sometimes with a second series of similar branches, all branches at right angles, of uniform diameter, torulose; ultimate divisions up to 3 cm. long.

Generally characterized by the slenderness and delicacy of all the parts; typical *S. Filipendula*, stouter and shorter, with broader and more dentate leaves and more condensed fructification, has not been found here.

7. S. Hystrix J. G. Agardh, 1847, p. 7; 1889, p. 91, Pl. VI. Stem terete, smooth; leaves thickish, lanceolate or ovate-lanceolate, entire or obscurely dentate, 3–6 cm. long, 4–8 mm. wide, midrib rather indistinct, no cryptostomata; vesicles spherical, up to 7 mm. diam., pedicel short, sometimes imperceptible; fructification in dense glomerules of short, verrucose branches; receptacles, vesicles and leaves densely packed along the little branched axis. Harris Bay, Dec., attached, Hervey; washed ashore on Agar's and Bethel's Islands after a storm, Dec., Collins. Apparently recently torn from its attachment.

While our plant appears to agree in all other respects with *S. Hystrix*, the receptacles, though quite verrucose, show no spines or teeth. We should hardly have ventured to give it this name, but for what is said by Reinbold in Weber, 1913, as to sexual dimorphism in *Sargassum*, with presence or absence of spines on the receptacles according to sex. We suspect that another instance of dimorphism may be found in *S. platycarpum* Montagne and *S. vulgare* Agardh, at least the plant distributed under the latter name as P. B.-A., No. 178. We have seen a large number of plants from Florida, some with smooth, some with spiny receptacles, otherwise indistinguishable.

8. S. platycarpum Montagne var. bermudense Grunow, 1915, p. 389. We have not seen this, and include it only on the authority of Grunow.

Family DICTYOTACEAE.

Spatoglossum Kützing.

S. Schroederi (Mert.) J. G. Agardh, 1880, p. 113, in part; 1894, p. 38; P. B.-A., No. 2027; *S. Areschougii* Vickers. 1905, p. 58; 1908, part II, p. 38, Pl. XI; *Ulva Schroederi* Mertens in Martius, 1826, p. 21; 1827, Pl. II, fig. 3; *Taonia Schroederi* Farlow in Alg. Am.-Bor. Exsicc., No. 159. Gravelly Bay, Feb., March, Hervey; Gravelly Bay, April, Aug., Cooper's Island, Aug., Collins. Observed only at these two stations, and apparently not common. In the water it shows a brilliant iridescence. Tetraspores, much like those of *Dictyota*, were found on a few plants; there does not seem to have been any previous record of them. Tufts of hairs were common; the cells in a definite rectangular region divide, four cells from an original cortical cell, and each of these cells grows out into a hair; the hairs are contracted at base, lower cells about as long as their diameter, moniliform, with rich contents; upper cells 5–6 diam. long, cylindrical, nearly empty. It does not seem to us that the distinction made by J. G. Agardh between *S. Schroederi* and *S. Areschougii* can be maintained. Bermuda specimens show the forms of frond and characters of dentation characteristic of both species, as well as intermediate gradations.

Zonaria Draparnaud.

1. Frond rounded, little divided; mostly dorsiventral and prostrate. 1. Z. variegata.
1. Frond erect, with many deep and narrow divisions. 2. Z. lobata.

1. Z. variegata (Lamour.) Mertens in Martius, 1826, p. 21; 1827, p. 6, Pl. II, fig. 2; Vickers, 1905, p. 58; 1908, Pl. VI. B; Börgesen, 1914, p. 197, figs. 151–152; *Dictyota variegata* Lamouroux, 1813, p. 57, Pl. V, figs. 7–9. Kemp, including some specimens marked *Z. lobata;* Wadsworth, No. 6; Moseley, from shallow water down to 31 fathoms; Hamilton Harbor, Agar's Cave, Jan., Walsingham, Feb., Farlow; Gravelly Bay, Jan., Harrington Sound, Feb., Harris Bay, Jan., Nov.; Inlet, Dec., Hervey; Ely's Harbor, Aug., Collins. Common nearly everywhere. It is sometimes found with one side of the lamina quite firmly attached; sometimes the frond is quite free, with little difference between the two sides; these differences do not seem to depend on the depth of water. Dickie, 1874, p. 311, notes that the plants dredged in 31 fathoms were mostly bluish green in color.

2. Z. lobata Agardh, 1824, p. 265; Harvey, 1852, p. 105, Pl. VII. C; Vickers, 1905, p. 58; 1908, Pl. VI; Börgesen, 1914, p. 199; P. B.-A., No. 1876. Kemp; Tucker, No. 5; South Beach, near Paget, Farlow; Wadsworth, No. 11; Inlet, Jan., Dec., Gravelly Bay, Feb., March, Dec., Hervey; Gravelly Bay, July, Aug., Ely's Harbor, Hungry Bay, July, Cooper's Island, Aug., Collins. Young plants are common in Dec.; by the last of Jan. good sized plants are common, and the plants continue in good condition till May; after that, only old, battered fronds are to be found. It is common in quiet water as well as on exposed shores. The best locality we observed was at Gravelly Bay, where it grew in great tufts in pools and on rocks at low water mark. The color varies from light to dark brown, the substance from

thin and membranaceous to coarse and leathery; the dark, zonate lines are distinct in the thin, light colored form, imperceptible on the old, coarse and dark fronds. It differs much in the extent of division of the fronds, from broad-cuneate and little parted, to fronds consisting of innumerable narrow divisions, sometimes broad below, narrow above, always more or less cuneate with apex truncate. Under water it shows a very brilliant iridescence of peacock blue and green.

Padina Adanson.

1. Epidermis persistent as an indusium over the spores. 2.
1. No indusium; spore band in middle of each second zone between bands of hairs. 4. P. gymnospora.
 2. Frond dark and thickish, not much calcified; in middle part 2–3 cells thick; bands of spores alternating with bands of hairs. 3. P. variegata.
 2. Lighter colored and thinner; distinctly calcified. 3.
3. Band of spores above each second band of hairs; frond normally 2 cells thick. 1. P. sanctae-crucis.
3. One band of spores above and one below each second band of hairs; frond normally 3 cells thick. 2. P. Pavonia.

1. P. sanctae-crucis Börgesen, 1914, p. 201, figs. 153–154; P. B.-A., No. 2082. Harris Bay, Jan., Nov., Hervey; Shelly Bay, April, Jew's Bay, Ely's Harbor, Hungry Bay, July, Gravelly Bay, Aug., Collins. A rather thin, delicate species, growing mostly in shallow, quiet water. The color is usually a quite light yellowish brown on the upper side, the under side being usually covered with a continuous but quite thin calcareous coating, white or bluish in color. The dried plant is papyraceous and brittle. Only tetrasporic fruit has been found, which was on plants collected in July and August. The indusium consists of the epidermis, which is pushed up by the spores as they grow, and finally ruptured; being very thin and transparent it is not always easy to make out, but it often happens that when it is pushed away from the frond, it retains the markings outlining the layer of cells beneath; in such case a fine network corresponding to the cells can be seen with the microscope by careful focusing, on a level with the top of the spores. This form of indusium has been noted in *Zonaria variegata* by Sauvageau, 1905, p. 11 (of reprint.)

2. P. Pavonia (L.) Gaillon, 1828, p. 371; Harvey, 1846–51, Pl. XCI; P. B.-A., No. 2081; *Fucus pavonius* Linnaeus, 1763, p. 1630.

Gates Bay, March, Gibbet Island, April, Hervey. In the Bermuda material identified with this species the frond is smaller throughout and generally more delicate than in *P. variegata,* averaging much the size and consistency of *P. sanctae-crucis,* and with a similar calcareous coating. Tetrasporic fruit was well developed on the material from both stations noted above. Sterile plants resembling the two species just mentioned abound in warm shallow water, but can be distinguished only by sectioning and counting the layers of cells. In *P. Pavonia* the sexual plant, which we have not found here, is monoecious; in *P. variegata* it is dioecious, in both it is rare. While all American forms of *Padina* were formerly placed under *P. Pavonia,* this seems to be the first occurrence of the species on this side of the Atlantic. The material from Florida distributed as *P. Pavonia,* P. B.-A., No. 1442a, and that distributed as *P. Durvillaei,* P. B.-A., No. 580b, should be referred to *P. variegata;* 1442b to *P. gymnospora.* The plant distributed as *P. Durvillaei,* 580a, closely resembles *P. gymnospora,* but in the specimens now accessible the frond is uniformly two cells thick, which would bring it under *P. australis* Hauck; but Mme. Weber, 1913, p. 180, suggests that the latter may be only a form of *P. gymnospora.* The true *P. Durvillaei* Mont., appears to be found only in the Pacific.

3. P. VARIEGATA (Lamour.) Hauck, 1887, p. 42; P. B.-A., No. 2083; Börgesen, 1914, p. 205, figs. 157–161; *Dictyota variegata* Lamouroux, 1809, p. 331. Kemp, May, June, July, as *P. Pavonia;* Shelly Bay, Harris Bay, Jan., Gibbet Island, Jan., Nov., Dec., Hervey; Inlet, July, Aug., Collins. Very variable in form, from orbicular and undivided up to 15 cm. diam., to fronds split into innumerable strips, or with many rounded proliferations; in texture from thin and papery to thick and tough. It is however always darker than the two preceding species, and with less conspicuous calcification, and it is more than two cells in thickness, except at the growing edge, and may be six layers in the older parts. Tetrasporic fruit is rather common, oogonia infrequent; antheridia are known in this species, but we have not found them here.

4. P. GYMNOSPORA (Kütz.) Vickers, 1905, p. 58; 1908, Pl. VII; Börgesen, 1914, p. 202, figs. 155–156; *Zonaria gymnospora* Kützing, 1859, p. 29, Pl. LXXI, fig. 11. Farlow, 1881, without exact station. Observed once only, but in good condition and fruit. Characterized among our species by the absence of indusium, the frond with one layer of small cells and one layer of large in cross section, the larger cells sometimes dividing so as to give a section of three cells; the spore bands in the center of every second space between hair bands.

Dictyopteris Lamouroux.

1. Frond thick, wide, Fucus-like. 2. D. Justii.
1. Frond thin, delicate. 2.
  2. Diagonal veins from midrib to margin. 3. D. plagiogramma.
  2. No lateral veins. 1. D. delicatula.

1. D. delicatula Lamouroux, 1809, p. 332, Pl. VI, fig. 2 B; Vickers, 1905, p. 58; 1908, part 2, Pl. III; Börgesen, 1914, p. 216, fig. 166; P. B.-A., No. 1924. Castle Harbor, Jan., Farlow; Cave, Gravelly Bay, Oct., Harris Bay, Heron Bay, Dec., Hervey. Not uncommon, but mostly small plants, not over 10 cm. high.

2. D. Justii Lamouroux, 1809, p. 330, Pl. VI, fig. 2 A; Vickers, 1905, p. 58; 1908, part 2, Pl. V; P. B.-A., No. 1925. Rein, as *Haly-seris polypodioides;* Mosely, dredged in 31 fathoms; Wadsworth, March, No. 9; St. David's Island, April, Kemp, as *Fucus ceranoides;* Faxon; Gravelly Bay, Jan., Feb., Oct., Dec., Hervey; Gravelly Bay, April, July, Aug., Tucker's Town, April, Outer Reef, Ely's Harbor, Hungry Bay, July, Cooper's Island, Aug., Collins. Occasionally found growing just below low water mark, but mostly floating, coming from deeper water. Old and battered plants came in abundantly in August; only young plants were found in February. It may grow to a length of 40 cm. Most reports of species of *Fucus* from Florida and the West Indies are based on large specimens of this species. Tetra-spores were found in abundance on plants collected in August; they occur on both sides of the frond, the sori originally circular, about 1 mm. diam., or elongate, about 1 mm. wide. They increase in size, often become confluent, forming irregular patches, more than 1 cm. across. The sporangia are broadly pyriform, about 45 μ high, 25–35 μ diam. seen from above, and closely packed.

3. D. plagiogramma (Mont.) Vickers, 1905, p. 58; 1908, part 2, Pl. IV; *Haliseris plagiogramma* Montagne, 1837, p. 356. Kemp, May, as *Haliseris polypodioides;* this single specimen, large and in fine condition, is the only Bermuda record.

Dictyota Lamouroux.

1. Margin with small sharp teeth. 3. D. ciliata.
1. Margin even or uneven, without teeth. 2.
  2. Frond rather broad, with more or less distinct rachis, bearing alternate divisions; tips not tapering, either blunt or with two points. 8. D. dentata.

2. Frond dichotomously branched, with or without lateral proliferations. 3.
3. Frond usually rather broad, very regularly dichotomous, axils usually wide, tips rounded, proliferations on old plants only. 1. D. dichotoma.
3. Not with above combination. 4.
4. Frond very narrow, almost filiform throughout. 5.
4. Frond of varying width, not appearing filiform throughout. 6.
5. Regularly dichotomous, few or no proliferations except in very old plants. 2. D. linearis.
5. Dichotomous in younger parts, elsewhere with many proliferations, often much entangled. 6. D. divaricata.
6. Fronds narrow, dichotomous, few or no proliferations. 7.
6. Fronds broad or narrow, divisions of dichotomies often unequal, sometimes appearing subpinnate, proliferations frequent. 5. D. Bartayresii.
7. Dichotomies distant, regular, divisions equal. 3. D. indica.
7. Dichotomies close, some divisions long, some short, patent, acute. 4. D. cervicornis.

1. D. DICHOTOMA (Huds.) Lamouroux, 1809, p. 331; Harvey, 1846–51, Pl. CIII; P. B.-A., No. 2175; *Ulva dichotoma* Hudson, 1798, p. 476. Rein; Hamilton, Kemp; up to 31 fathom depth, Moseley; Tucker, No. 11; Cave near Ducking Stool, Farlow; Faxon; Buildings Bay, Inlet, Dec., Hervey. This species, the common one of Europe and the most widely distributed of the genus, seems to be rather uncommon in Bermuda; we have found it of only moderate size, not at all like the large plants from North Carolina distributed as P. B.-A., No. CXX. Antheridia have once been observed, but no other form of fruit. There is little indication of rhizoidal filaments in the Bermuda plants.

2. D. LINEARIS (Ag.) Greville, 1830, p. XLIII; Kützing, 1859, p. 9, Pl. XXI, fig. II; P. B.-A., No. 2031; *Zonaria linearis* Agardh, 1820, p. 134. Jew's Bay, July, Collins. In loose floating masses, antheridia fairly frequent, no other fruit observed. The frond is very narrow, seldom over 1 mm.; the forkings are rather distant, axils narrow. The lower part of the frond was old and dry, but showed no proliferations; no rhizoidal filaments were seen.

3. D. INDICA Sonder in Kützing, 1859, p. 8, Pl. XVII, fig. 1; Vickers, 1905, p. 59; 1908, part 2, Pl. XVIII; P. B.-A., No. 2030. Kemp, as *D. fasciola*, in part; Ely's Harbor, Aug., Collins. Our plants agree with the narrower form distributed by Miss Vickers under No. 78; the width of the frond from 1–2 mm. remaining practically the same throughout in each individual. The divisions are quite

regularly dichotomous throughout, the axils rather wide and rounded, the divisions immediately incurving and often becoming parallel, the apices rounded. Antheridia of the usual form were found on these plants; also, on the same plants, scattered or in twos, tetrasporangia; none of these were found showing the regular division into fours, but in many the contents had divided into many small squarish cells, the sporangium enlarging to two or three times its former dimensions, and developing a point of growth at the tip. This closely parallels the development in *D. dichotoma,* described and figured by Reinke, 1878, p. 8, Pl. I, figs. 31–35. The occurrence on the same frond with antheridia is, however, noteworthy. We hardly see how *D. volubilis* Vickers, Algues de la Barbade, No. 78a, can be distinguished from the present species, apart from the spiral twisting of the frond. A plant in the Kemp herbarium, marked *D. fasciola,* is intermediate between *D. indica* and *D. volubilis* of the Algues de la Barbade.

4. D. CERVICORNIS Kützing, 1859, p. 11, Pl. XXIV, fig. II; *D. fasciola* Harvey, 1852, p. 108, Pl. VIII. B., not of Lamouroux. Rein, as *D. fasciola.* The true *D. fasciola* has slender fronds, regularly but not very closely dichotomous, the divisions all developing equally and ending at nearly the same level. In *D. cervicornis* one division is frequently short, acute and erect, giving quite a different habit, which is well characterized by the specific name.

5. D. BARTAYRESII[11] Lamouroux, 1809, p. 331; *D. Bartayresiana,* Harvey, 1852, p. 110, Pl. VIII. C.; P. B.-A., No. 1874. Kemp, as *D. fasciola,* in part; in shallow water, Moseley; St. David's Island, from half tide down, April, Shelly Bay, May, Gravelly Bay, Hungry Bay, July, Cooper's Island, Aug., Collins; Gibbet Island, Jan., Oct., Dec., Hervey. This seems to be the species of *Dictyota* occurring most frequently in Bermuda. It is quite variable, and narrow forms certainly show similarity to *D. divaricata.* On comparing the accounts given of the species by different authors, and the specimens from different localities distributed under this name, one is led to suspect that more than one species is really in question. As originally described, stress was laid on the acute apices, but later authors include forms with distinctly blunt apices. Both forms occur among the Bermuda material we have studied. It is probable that all species of the genus

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11 This species is generally known as *D. Bartayresiana,* but in the original publication by Lamouroux the specific name is *Bartayresii.* Few authors refer to this rare and neglected paper, almost all starting from a later publication of the same year, 1809a, p. 43, in which the author, without stating any reason, substitutes the name *Bartayresiana.*

are subject to much variation with age and environment, and much study of living plants is needed before we can get a clear idea of specific lines. What we consider as the normal form of the species in Bermuda closely resembles No. 72 of Miss Vickers Algues de la Barbade; in this some apices are acute, some rounded, on the same individual. The branching seems intermediate between *D. dichotoma* and *D. dentata,* with a suggestion of lateral branching not found in the former, but not the distinctive character as in the latter. Antheridia were common in material collected at all seasons; tetraspores occurred occasionally on the same individual with antheridia, in July and August. No rhizoidal filaments were seen. Mme. Weber, 1913, p. 182, states that the type of *D. Bartayresii* cannot be found; she speaks of Harvey's figure as excellent, and we have taken it for our standard.

6. D. DIVARICATA Lamouroux, 1809, p. 331, not of Kützing, 1859, p. 10, Pl. XXIII, fig. 1; *D. acutiloba* Kützing, 1859, p. 13, Pl. XXIX, fig. 1, not of J. Ag. Inlet, Gravelly Bay, Dec., Hervey. Fronds as narrow as in *D. linearis,* but the dichotomous habit, distinct in young growing branches, is quite obscured in the older parts by the abundant, mostly short, proliferous branches. By these the fronds are often so densely matted that it is not easy to disentangle any individual plant. Antheridia are abundant in this material, but no other form of fruit was observed. The fronds seem to attach themselves by interlaced proliferous branches, with a few short, monosiphonous rhizoidal filaments close to the tip.

7. D. CILIATA J. G. Agardh,[12] 1841, p. 5; Harvey, 1852, p. 110, Pl. VIII. A.; *D. crenulata* P. B.-A., No. 1875, an J. Ag. ?. Rein; Kemp, May, June; South Shore near Paget, Feb., Castle Harbor, Feb., Farlow; Gravelly Bay, Jan., Feb., Harris Bay, Dec., Hervey; Causeway, April, Shelly Bay, May, Hungry Bay, July, Collins. There is considerable variation in the material which we now include under *D. ciliata,* but after a re-examination of the form that we distributed as *D. crenulata,* we do not feel justified in keeping it distinct. It seems to us also that *D. crenulata* from Barbados, Vickers, No. 75,

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[12] The first use of the combination *Dictyota ciliata* is by Lamouroux, 1809, p. 331, where a synonym is given, *Fucus pseudociliatus* Lamouroux, 1805, p. 41; a description is given of the latter and figure, Pl. XXX, fig. 2; the locality is the Mediterranean. It is now generally acknowledged to be *Taonia atomaria* (Good. & Woodw.) J. Ag. Being a name proposed for a plant recognized by Lamouroux as already named, *Dictyota ciliata* Lamouroux never had any standing, and cannot interfere with the subsequent *D. ciliata* J. Ag.

of which we have examined several specimens, belongs under *D. ciliata.* Agardh, 1848, p. 94, says of *D. crenulata* "margine tenui dentibus brevissimis late triangularibus initio fere serrato, demum dentato aut crenato." Harvey, 1852, says "The margin is undulated, and closely eroso-denticulate, or jagged with unequal, deltoid or subulate, tooth-like processes." In the Bermuda plants the margin is quite even, and the teeth are of uniform size and never very closely set. We have, however, seen a specimen of *D. crenulata* from the Suhr herbarium "West Indien," that fully agrees with Agardh's and Harvey's descriptions. In the Bermuda material of this species confervoid rhizoidal filaments arise from the lower part of the main axis of the frond, often forming a dense, continuous mass for several cm.; proliferations are few and insignificant. Antheridia and oogonia were found on specimens collected in February, tetrasporangia on specimens collected in July.

8. D. DENTATA Lamouroux, 1809, p. 331; Kützing, 1859, p. 15, Pl. XXXV, fig. I; *D. Mertensii* (Mart.) Kützing, 1859, p. 15, Pl. XXXVI, fig. I; *Ulva Mertensii* Martius, 1826, p. 21; 1827, Pl. I; P. B.-A., No. 1926; *D. Brongniartii* J. G. Agardh, 1841, p. 5; Kützing, 1859, p. 15, Pl. XXXV, fig. II; *D. subdentata* Kützing, 1859, p. 14, Pl. XXXIII, fig. II. Kemp, as *D. crenulata,* in part; Gravelly Bay, Jan., Hervey, Aug., Collins; Hungry Bay, July, Collins. J. G. Agardh, 1880, p. 98, gives *D. Mertensii* as a synonym of *D. Brongniartii,* mentioning *D. subdentata* without expressing an opinion as to whether it should be referred to *D. dentata* or *D. Brongniartii;* later, 1894, p. 70, he recognizes *D. dentata, D. Mertensii* and *D. Brongniartii* as distinct species. Hauck, 1888, p. 466, unites all four under the oldest name, *D. dentata,* as it seems to us rightly. The distinctive characters are found in the greater or less distinctness of the axis and branches, and in the character of the terminal segments. In the abundant material we found in Bermuda, there were individuals with the primary axis narrower and firmer than the lateral segments, and others, apparently mostly younger individuals, in which all was uniformly membranaceous. Typical *D. dentata* has segments ending in acute, spinous tips; typical *D. Mertensii* has segments short-cuneate, with truncate or emarginate tips. It is not uncommon to find both these types on the same individual. In comparing the vegetative structure of *D. dentata* with that of *D. dichotoma,* as described by Reinke, 1878, several points are to be noted. The main axis is thick, and somewhat flattened, but can hardly be described as a "rundtrieb." In old plants, there grow from this, for a distance of

three or four cm. from the base, descending, terete, branching filaments, of an average diam. of one half mm., forming a loose felt. A cross section shows a densely cellular structure, the cells much smaller than in the median layer of the frond, the superficial cells much like those of the frond. From the superficial cells issue, not continuously but in groups, monosiphonous filaments, 20–25 μ diam., the cells 2–4 diam. long, nodes somewhat constricted; these filaments are mostly simple, occasionally with short branches; when a filament reaches the substratum the terminal cell forms a coralloid expansion as an organ of attachment. Other species of *Dictyota, D. ciliata* for instance, are attached by rhizoidal filaments of a similar character, but arising directly from the frond; *D. dentata* is the only Bermuda species in which they arise from descending cellular branches. In older plants prolifications are common from the surface of the frond, sometimes papillose to clavate, sometimes flattened with rounded outline. None were observed over 1 mm. in length; the papillose-clavate form seemed to be of a similar character to the descending filaments developed near the base. Antheridia were common in material collected in Jan., July and Aug.; no other fruit was observed.

DILOPHUS J. G. Agardh.

D. GUINEENSIS (Kütz.) J. G. Agardh, 1880, p. 108; Vickers, 1905, p. 59; 1908, part 2, p. 37, Pl. IX; Börgesen, 1914, p. 214, figs. 164–165; P. B.-A., No. 2080; *Spatoglossum guineense* Kützing, 1843, p. 339; 1859, Pl. XLVI, fig. I. South Shore near Paget, Farlow; Gravelly Bay, March, Hervey.

Class **RHODOPHYCEAE.**

Family BANGIACEAE.

Bangia Lyngbye.

B. fuscopurpurea (Dillw.) Lyngbye, 1819, p. 83, Pl. XXIV. C; P. B.-A., No. 2084; *Conferva fuscopurpurea* Dillwyn, 1809, p. 54, Pl. XCII. On exposed rock, North Shore near Shelly Bay, April, Fairyland, Dec., Collins; in tufts on wall by Palmetto Vale, Harrington Sound, March, Hervey. In the North Shore and Fairyland stations there were scattered filaments only, imperceptible except on microscopic examination. At the Sound station the tufts were several cm. long. In all cases it was a slender form, mostly monosiphonous, rarely over four cells to a segment.

Porphyra Agardh.

P. atropurpurea (Olivi) De Toni, 1897, p. 17; P. B.-A., No. 2085; *P. leucosticta* P. B.-A., No. 1927; *Ulva atropurpurea* Olivi, 1791, p. 153, Pl. I–III. Kemp, May, as *P. laciniata*; "Spitall Lake Ferry" May, Kemp, unnamed specimen in herb.; on mangroves below Flatts Bridge, April, May, Collins; Ely's Harbor, May, Hervey. At Flatts Bridge the *Porphyra* began to be visible about April 20, 1912, growing on mangroves in company with *Monostroma latissimum;* both minute when first observed, but growing rapidly up to May 3, when we left Bermuda. When next at this place, from July to Sept., 1913, the *Porphyra* was not to be found. The Ely's Harbor plant is of moderate size, up to 6 cm. long; the specimens in the Kemp herbarium reach 10 cm. in length. *P. vulgaris* of Moseley is undoubtedly this species.

Erythrotrichia Areschoug.

E. carnea (Dillw.) J. G. Agardh, 1882, p. 15, Pl. I, figs. 8–10; P. B.-A., No. 2032; *E. ceramicola* Farlow, 1881, p. 113; *Conferva carnea* Dillwyn, 1809, p. 54, Pl. LXXXIV. Common on various algae, Jan., Feb., Hervey; April, May, July, Aug., Nov., Dec., Collins; on submerged tamarisk branches, Harrington Sound, May, Collins.

ERYTHROCLADIA Rosenvinge.

E. SUBINTEGRA Rosenvinge, 1909, p. 73, figs. 13–14; Börgesen, 1915, p. 7, figs. 3–4; P. B.-A., No. 2086. On *Bryopsis pennata*, Tucker's Town, April; on *Caulerpa crassifolia*, Hungry Bay, May, Collins; on *Cladophora catenifera*, Gravelly Bay, Feb., Hervey. Probably common, but perceptible only on microscopic examination when it appears in the form of minute orbicular disks, of closely set radiating filaments, dichotomously branched, united laterally except at the edge, closely adherent to the host. At Gibbet Island it grew in company with *Pringsheimia scutata*, the fronds of which have much the same structure; their bright green color contrasts strongly with the red of the *Erythrocladia*.

GONIOTRICHUM Kützing.

1. Filaments one or at most two cells wide. 1. G. elegans.
2. Main filaments many cells wide. 2. G. Humphreyi.

1. G. ELEGANS (Chauv.) Le Jolis, 1863, p. 103; Rosenvinge, 1909, p. 75, fig. 15; Börgesen, 1915, p. 4, fig. 2. *Bangia elegans* Chauvin, 1842, p. 33. On many species of algae, especially on *Codium* and its epiphytes, very frequently met with as isolated individuals, rarely in large quantity. The filaments are often simple; when branched, the branching approaches lateral rather then dichotomous; the cells are 10–15 μ diam., spherical or slightly compressed or elongate; they are smallest at the base of the filament, largest near the apex, while the filament is largest at the base, up to 25 μ, tapering slightly towards the apex. Lateral division of cells by an oblique wall is not uncommon. It is quite distinct from the duplication by displacement described by Rosenvinge, 1909, p. 75, and seems to be a normal process.

2. G. HUMPHREYI Collins, 1901, p. 251; P. B.-A., No. 421; *Bangiopsis subsimplex* Börgesen, 1915, p. 10, figs. 5 and 6, not *Compsopogon subsimplex* Mont. Among other algae, *Ectocarpus Mitchellae*, *Calothrix fusco-violacea*, *Enteromorpha* species, etc., forming a dense growth on the bottom of a rock pool near Gravelly Bay, Jan., Hervey. The fronds are more freely branched than in the material from Jamaica, but the main stems are not as stout; otherwise they are identical.

Family HELMINTHOCLADIACEAE.

Acrochaetium Nägeli.

A conservative course has been followed by us in regard to the plants belonging to this genus. No such richness of new forms has been found here as by Börgesen in the Danish West Indies, but we cannot claim to have made as thorough a study as he has, and it is very unlikely that all the Bermuda forms have been discovered and listed. We include under *Acrochaetium* the marine species formerly passing under *Chantransia,* many of which have recently been juggled back and forth, only too often.

1. Original spore remaining manifest at base of filament.	2.
1. Original spore not distinguishable.	5.
2. Basal cell with descending endophytic and erect free filaments.	3.
2. No descending endophytic filaments.	4.
3. Cells 8–10 μ diam., 4–5 diam. long.	3. A. corymbiferum.
3. Cells 12–14 μ diam., 2–3 diam. long.	4. A. barbadense.
4. Cells short, subspherical.	2. A. crassipes.
4. Cells long, cylindrical.	1. A. Dufourii.
5. Frond arising from a disk.	8. A. Thuretii.
5. Frond not arising from a disk.	6.
6. Horizontal filaments on surface of host.	7.
6. Horizontal filaments endophytic only.	9. A. Hypnae.
7. Horizontal filaments producing endophytic branches.	7. A. Nemalionis.
7. Horizontal filaments without endophytic branches.	8.
8. Erect filaments 6–12 μ diam.	6. A. Sagraeanum.
8. Erect filaments 4–5 μ diam.	5. A. leptonema.

1. A. Dufourii Collins, P. B.-A., No. 1594; *Chantransia Dufourii* Collins, 1911, p. 187; P. B.-A., No. 2087. On *Dictyota ciliata,* Hungry Bay, Dec., Hervey. Forming a dense fringe on the edge of the host. The basal cell (original spore) remains distinct, attached to the host by a circular disk, of diameter larger than that of the cell. This development is of the same character as that in *Chantransia collopoda* Rosenvinge, 1909, p. 81, but on a smaller scale; it is found also in another Bermuda species, *A. crassipes.*

2. A. crassipes Börgesen, 1915, p. 20, fig. 11; *Chantransia crassipes* Börgesen, 1909, p. 1, fig. 1; P. B.-A., No. 2033. On *Ceramium clavulatum* and *Polysiphonia ferulacea,* St. David's Island, Feb., and on *Callithamnion Hookeri,* Gravelly Bay, April, Hervey.

3. **A. corymbiferum** (Thuret) comb. nov.; *Chantransia corymbifera* Thuret in Le Jolis, 1863, p. 107; Bornet & Thuret, 1876, Pl. V, fig. 3; P. B.-A., No. 1880. On *Dudresnaya crassa*, Salt Kettle, Feb., Spanish Point, March, Buildings Bay, April, Hervey; Shelly Bay, May, Collins. In Europe and California this species occurs on *Helminthocladia calvadosii;* although the latter is common in Bermuda, the *Acrochaetium* has not been observed on it, but seems to occur generally on the *Dudresnaya.* Its filaments have some resemblance to those of the host, and the resemblance might puzzle one unfamiliar with both. But usually antheridia or cystocarps can be found.

4. A. BARBADENSE (Vickers) Börgesen, 1915, p. 45; *Chantransia barbadensis,* Vickers, 1905, p. 60. On *Liagora elongata,* Buildings Bay, March, Hervey. This plant resembles *A. corymbiferum,* but is kept distinct by Bornet, 1904, p. XX, as well as by Miss Vickers, the distinctive characters being the stouter and shorter cells, and the less developed basal portion. We have compared our plant with an authentic specimen from Miss Vickers, also on *Liagora elongata,* and find them to agree, except that while in the Bermuda plant most of the filaments are composed of cells agreeing in dimensions with Miss Vickers plant and description, in others the dimensions approach those of *A. corymbiferum.* It is possible that future observations may show that the difference is not specific.

5. A. LEPTONEMA (Rosenv.) Börgesen, 1915, p. 31; *Chantransia leptonema* Rosenvinge, 1909, p. 118, figs. 47–48. On *Dictyopteris Justii,* Gravelly Bay, Aug., Collins. Our smallest species of the genus.

6. A. SAGRAEANUM Bornet, 1904, p. XXI; P. B.-A., No. 2181; *Cladophora Sagraeana* Montagne, 1838, p. 459. On *Zonaria lobata,* Gravelly Bay, Aug., Collins; On *Dictyopteris Justii,* Buildings Bay, July, Hervey. The Buildings Bay plant almost entirely covers the *Dictyopteris* with a dense coating, the individual plants up to 5 mm. high, main filaments about 12 μ diam., branches seldom under 7 μ. These dimensions are greater than those given by Bornet in his description, but as all other characters agree, it must be considered a luxuriant form of this species. Monospores, 18–22 $\times$ 8–10 μ were observed, on unicellular pedicels in a series on the inner side of a branch near the base. On other individuals were observed tetraspores, not before known for the species. They were arranged similarly to the monospores, but were larger and relatively broader, 28–34 $\times$ 17–27 μ. The division is in the form indicated by Rosenvinge, 1909, p. 85, as characteristic of the genus, cruciate with the first division horizontal;

sometimes the division proceeds no farther, but usually a vertical division occurs in one of the halves, often in both, but in the latter case the divisions of the two are seldom in the same plane.

7. A. Nemalionis (De Not.) Börgesen, 1915, p. 55; *Chantransia Nemalionis* Rosenvinge, 1909, p. 126, figs. 53–54; *Callithamnion Nemalionis* De Notaris in Erb. Critt. Ital., No. 952. Harrington Sound, April, Collins, growing on Tamarisk branches which had bent down until submerged. As in *A. Sagraeanum* the erect filaments arise from a plexus of irregular horizontal filaments, but in *A. Nemalionis* the latter emit descending filaments which penetrate the host. In the Bermuda plant these are less developed than in the European plant growing on *Nemalion,* probably on account of the more resisting character of the substratum of Tamarisk, as compared with *Nemalion.*

8. **A. Thuretii** (Bornet) comb. nov.; *Chantransia Thuretii* Kylin, 1907, p. 119, fig. 28; *C. efflorescens* forma *Thuretii* Bornet, 1904, p. XVI. On *Codium decorticatum,* Cooper's Island, Aug., Collins. With monospores.

9. A. Hypneae Börgesen, 1915, p. 51, fig. 54; *Chantransia Hypneae* Börgesen, 1909, p. 2, fig. 2. On *Ceramium clavulatum,* in company with *A. crassipes,* St. David's Island, Feb., Hervey. With monospores.

Trichogloea Kützing.

T. Herveyi Setchell ms.; P. B.-A., No. 2034. In tide pools, Gravelly Bay, March, April, Hervey; from low water mark to two meters depth, near Cooper's Island, April, May, Collins. Extremely gelatinous, not calcified. Appearing in March, but not found after midsummer.

Helminthocladia J. G. Agardh.

H. calvadosii (Lamour.) Setchell in P. B.-A., No. 2035; *Dumontia calvadosii* Lamouroux in Duby, 1830, p. 941; *Nemalion purpureum* Harvey, 1846–51, Pl. CLXI; *Helminthocladia purpurea* J. G. Agardh, 1851, p. 414. Bailey's Bay, Feb., Castle Harbor, March, Wadsworth; Dingle Bay, March, North Shore, April, Old Ferry Road, April, Hervey; Tucker's Town, St. David's Island, Long Bird Island, April, Collins. Specimens in Kemp herbarium, marked *Helminthora divaricata* and *Helminthocladia divaricata* both belong here. On stones from half tide down, not uncommon in quiet water; antheridia and cystocarps in April. Prof. Setchell has called our attention to Lamouroux's name which considerably antedates the Harveyan name in general use.

LIAGORA Lamouroux.

1. Not calcified. 4. L. pectinata.
1. Calcified. 2.
   2. Very soft and gelatinous. 3. L. pulverulenta.
   2. Firmer. 3.
3. Calcareous coating continuous and smooth. 1. L. valida.
3. Calcareous coating loose, penetrated by assimilative filaments. 2. L. elongata.

1. L. VALIDA Harvey, 1853, p. 138, Pl. XXXI. A; Börgesen, 1915, p. 70, figs. 71–75; P. B.-A., No. 1929. Rein; Kemp; St. David's Island, Feb., April, Buildings Bay, April, Hervey; Cooper's Island, April, Aug., Collins. The most common of the Bermuda species of *Liagora,* and generally easily recognized by the continuous calcareous coating and firm, little gelatinous consistency. It occurs in its best condition just below low water mark, but may extend up nearly to high water mark. In many places it forms a continuous zone between tide marks, the individual plants short and stunted, mostly chalky white. When growing in more favorable conditions a pinkish shade shows through the coating more or less.

2. L. ELONGATA Zanardini, 1851, p. 35; 1858, p. 274, Pl. VI, fig. 1; Börgesen, 1915, p. 67, figs. 67–70; P. B.-A., No. 2088; *L. corymbosa* J. G. Agardh, 1896, p. 104. Kemp, July, unnamed specimen in herb.; Miss Wilkinson; Gates Bay, Buildings Bay, March, St. David's Island, May, Hervey; Cooper's Island, Aug., Collins. Cystocarps in March. Not as variable as other species of the genus, and usually recognized easily by the light purple-brown color, the light and loose calcification, and the long, rather distantly dichotomous fronds, of nearly uniform diameter. *L. corymbosa,* according to J. G. Agardh, 1896, p. 104, "Hab. ad littora Floridae et insulas Bermudas." Specimens agreeing fairly well with Agardh's description were collected at Castle Harbor by Wadsworth, March, 1890; at Tobacco Bay, March 11, 1914, Hervey; but it is impossible to separate them from *L. elongata.* As to characters derived from internal structure used by Agardh in his treatment of the genus, l. c., we have not been able to apply them, as we find them inconstant. He divides *Liagora* into two subgenera, *Euliagora* and *Goralia,* the former with an inner layer

of longitudinal filaments, subdistant, large and small intermixed, the outer usually small, the fascicles of the cortical layer free from each other except as united by the general gelatinous coating. In *Goralia* the larger filaments of the inner layer are densely packed, the smaller being on the surface only, the fascicles of the cortical layer adherent and confluent. *L. pulverulenta* is placed in *Euliagora, L. valida* in *Goralia;* but in both species as they occur in Bermuda we have found large central filaments branching and producing smaller filaments, with no definite position in the central strand; generally the cortical fascicles are borne on the smaller filaments of the central strand, but not infrequently on the larger ones. The density of the cortical fascicles and their mutual adhesion or freedom seem to depend largely on age or activity of growth; they often vary much in the same individual.

3. L. PULVERULENTA Agardh, 1822, p. 396; Börgesen, 1915, p. 80, figs. 87–92; P. B.-A., No. 1928. Miss Peniston; Castle Harbor, Harrington Sound, Cooper's Island, March, Wadsworth; St. David's Island, Feb., May, Tobacco Bay, March, Hervey; Cooper's Island, Shelly Bay, April, Collins. Very soft and gelatinous, collapsing into a shapeless jelly when taken from the water, but not difficult to arrange in natural form on paper if dried without pressure or with very slight pressure.

L. pectinata sp. nov. Fronde submolli, ecalcarea, rubro-purpurea, ad 20 cm. alta; ramis primariis inferne nudis vel ramulis paucis brevibus munitis, superne ramos gerentibus frequentes breves, alternantes vel secundatos, ramulos similes gerentes; ramis et ramulis omnibus, primariis exceptis, plus minusve sinuosis et curvatis, ultimis patentibus, in- vel recurvatis, saepe pectinato-secundatis; apicibus abrupte acutis. Strato axili, circa 150 μ diam., filamentis dense compactis; cellulis circa 20 μ diam., 4–8 diam. longis; fasciculis filamentorum assimilatorium 600–800 μ longis, densis, aequilongis, superficiem aequalem continuam frondis formantibus; filamentis repetite dichotomis, cellulis inferioribus 5–7 μ diam., 5–8 diam. longis, subcyclindricis; superioribus brevioribus, crassioribus, ovoideis; terminalibus 8–10 μ diam., 2–3 diam. longis, interdum pilos breves, circa 4 μ diam., ferentibus. Fructificatione ignota.

Frond rather soft, without incrustation, dull red-purple, up to 20 cm. high; main branches naked below or with a few short ramuli, above with numerous alternate or secund branches, bearing similar ramuli, all but the main branches more or less sinuous and curved, the lesser divisions patent, in- or recurved, often pectinately secund; all tapering suddenly to an acute point. Central strand about 150 μ diam., of closely packed filaments, cells about 20 μ diam., 4–8 diam. long; fascicles of assimilative filaments 600–800 μ long, dense, even-topped, making a continuous smooth surface to the frond; filaments many times dichotomous, lower cells 5–7 μ diam., 5–8 diam. long, subcylindrical; upper cells shorter, stouter, more ovoid; end cells 8–10 μ diam., 2–3 diam. long, occasionally with a short hair, about 4 μ diam. Fructification unknown. Cooper's Island, April, Hervey.

The peripheral filaments do not arise directly from the cells of the central strand; at the summit of one of these cells a short conical or ovoid cell is formed, from which radiate the basal filaments of several peripheral fascicles; these filaments are usually straight and unbranched for 200–400 μ, then dichotomous. The substance is softer than in *L. valida,* not as soft as in *L. pulverulenta.* The reference to the genus *Liagora* is from the structural characters; we have found no fruit. As is well known, the amount of calcification varies much in the different species, but there is only one species recorded practically free from lime, *L. dubia* (Bory) Bornet in De Toni, 1905, p. 1628; *Cladostephus dubius* Bory, 1832, p. 331, Pl. XXXVIIbis, fig. 6. Little is known of this species beyond Bory's plate and description, but it seems to be quite distinct from the present species.

Family CHAETANGIACEAE.

Scinaia Bivona.

S. complanata (Collins) Cotton, 1907, p. 260; Setchell, 1914, p. 100, Pl. XI, figs. 19–22; *S. furcellata* var. *complanata* Collins, P. B.-A., No. 836; 1906, p. 110. Farlow. A single specimen in the Farlow herbarium is the only representative of the species and genus that we have seen from Bermuda; as the segregation of the forms till recently included under *S. furcellata* has only just been made, it is impossible to locate the *S. furcellata* recorded by Moseley, "a single specimen dredged."

Galaxaura Lamouroux.

Representatives of this genus are common all around the islands, but the distinguishing of species is very difficult. We note below five species in regard to which we feel some confidence, but we have many collections that cannot be placed under any of them, and to which we do not venture to give names. Kjellman, 1900, gives full descriptions of many species founded by him on material in Scandinavian herbaria, but without descriptions of older species, and with little indication of the distinguishing characteristics between the latter and his new species. Howe, 1917, shows that in one case what Kjellman considers as two sections of the genus are really sexual and asexual forms of the same species. Beside the five species listed below, we can only say that we have also forms resembling *G. fasciculata* Kjellm., *G. ramulosa* Kjellm., and *G. fruticulosa* Kjellm. Moseley reports *G. rugosa* and *G. lapidescens*, from both of which species, as formerly understood, Kjellman segregated new species. Rein reports *G. fastigiata*, but we have not been able to see a specimen.

G. FLAGELLIFORMIS Kjellman, 1900, p. 47, Pl. III, figs. 2–11; Pl. XX, fig. 16; Börgesen, 1916, p. 93, figs. 99–101. Castle Island, Feb., Hervey.

G. SQUALIDA Kjellman, 1900, p. 55, Pl. VI, figs. 1–12; Pl. XX, fig. 9; Börgesen, 1916, p. 102, figs. 108–111; P. B.-A., No. 1882. Harris Bay and other points on the South Shore, at all seasons. In pools from half tide to low water, in dense tufts or often a much branched individual plant, about 10 cm. high, varying much in smoothness, firmness, and in density of branching; a favorite host for many species of small algae.

G. CYLINDRICA (Ell. & Sol.) Lamouroux, 1821, p. 22, Pl. XXII, fig. 4; Kjellman, 1900, p. 64, Pl. VIII, figs. 34–42; Pl. XX, fig. 53; Börgesen, 1916, p. 106; *Corallina cylindrica* Ellis & Solander, 1786, p. 114, Pl. XXII, fig. 4. Miss Wilkinson, a single specimen, without exact locality.

G. MARGINATA (Ell. & Sol.) Lamouroux, 1816, p. 264; Kjellman, 1900, p. 77, Pl. XX, fig. 44; Börgesen, 1916, p. 106, figs. 115–117; *Corallina marginata* Ellis & Solander, 1786, p. 115, Pl. XX, fig. 6; *Brachycladia marginata* P. B.-A., No. 1930. Near low water mark, Gravelly Bay, Jan., Hervey; at and below low water mark, Cooper's Island, Aug., Collins.

G. OBTUSATA (Ell. & Sol.) Lamouroux, 1816, p. 262; Kjellman, 1900, p. 88; P. B.-A., No. 1881; *Corallina obtusata* Ellis & Solander, 1876, p. 113, Pl. XXII, fig. 2. Faxon; Tucker's Town, Feb., Dec.; Walsingham, April, Hervey. Varies much in amount of calcification, which sometimes is entirely lacking. Usually there is not a gradual diminution of the amount of calcification, often the lower part of a frond is thickly calcified, this part sharply marked off from the upper part, quite uncalcified.

Family GELIDIACEAE.

Wrangelia Agardh.

W. penicillata Agardh, 1828, p. 138; Harvey, 1853, p. 143, Pl. XXXIV. B; Börgesen, 1916, p. 120, figs. 131–132; P. B-A., No. 1883. Rein; Kemp; Merriman, No. 5; Harris Bay, Jan., Castle Harbor, March, Tucker's Town, May, Harrington Sound near Flatts Bridge, Dec., Hervey; Shelly Bay, washed ashore, Hungry Bay, Nov., young plants only; dredged in 18 m. Nov., Collins. Abundant and luxuriant near Flatts Bridge from Dec. to Feb., seldom seen during the summer months.

Naccaria Endlicher.

N. corymbosa J. G. Agardh, 1899, p. 109; P. B.-A., No. 2036. Cooper's Island, Feb., Farlow; Buildings Bay, April, Hervey. Bornet, 1892, p. 266, incidentally refers to Farlow's specimens as *N. Wigghii;* comparison with the type specimen of *N. corymbosa* from Key West, in Agardh's herbarium, shows that the Bermuda plant is the same. Whether the differences between the American and the European plant are specific may require further study.

Gelidium Lamouroux.

1. Basal layer well developed; erect shoots seldom over 2 cm. high. 4. G. pusillum.
1. Basal layer scanty or wanting; erect shoots 5–50 cm. high. 2.
  2. Frond compressed or flat throughout, pinnate. 1. G. corneum.
  2. Frond terete, at least in the lower part. 3.
3. Fruit in ovate terminal expansions. 2. G. crinale.
3. Fruit in terminal expansions of irregular form, the edges dentate or ciliate. 3. G. spathulatum.

1. G. corneum (Huds.) Lamouroux, 1813, p. 41; *Fucus corneus* Hudson, 1798, p. 585; Turner, 1819, p. 146, Pl. CCLVII, fig. a. Kemp, June, July. Two specimens in the Kemp herbarium resemble ordinary European forms; one is marked "var. k, *abnorme* Harvey" but is hardly like the figure in Turner for that variety. We have not ourselves found anything we should refer to this species.

2. G. crinale (Turn.) Lamouroux, 1825, p. 191; P. B.-A., No.

2089; *Fucus crinalis* Turner, 1819, p. 4, Pl. CXCVIII. North Village, Dingle Bay, Jan., Hervey. A slender, irregularly branching form; the erect filaments are more flattened than in the common northern forms, and the branching is scanty, but there seems to be no better place for it than here.

3. G. SPATHULATUM (Kütz.) Bornet, 1892, p. 268; *G. crinale* var. *spathulatum* Hauck, 1885, p. 193, fig. 84; *Acrocarpus spathulatus* Kützing, 1868, p. 13, Pl. XXXVI, d–g. Harrington Sound, Feb., Hervey. Resembles *G. crinale*, but the upright fronds are terete except at the summit, where they are suddenly flattened; in the fruiting specimens numerous short branches arise here, making a tubercular mass, but always showing a distinct flattening.

4. G. PUSILLUM (Stack.) Le Jolis, 1863, p. 139; P. B.-A., No. 2182; *Fucus pusillus* Stackhouse, 1795, p. 16, Pl. VI. North Shore, Jan., Nov., Tucker's Town, Feb., Hervey; above and below Flatts Bridge, April, May, Aug., Collins. Tetraspores in March, April, Nov. Very common on pebbles, shells and flat rock bottom in shallow quiet water all about the islands, forming a dense mat, usually not over one cm. in thickness, the creeping basal part and the lower part of the upright growth terete, the upper part flat. As we understand this species, it includes *G. pulvinatum* (Kütz.) Thuret, and *G. repens* Kütz. Forms corresponding to Kützing's plates of both of these, as well as to typical *G. pusillum*, are found in Bermuda material, with all intermediate forms.

Var. CONCHICOLA Piccone & Grunow in Piccone, 1884, p. 316, P. B.-A., No. 2183, is a reduced form, common on small shells in shallow water; the upright fronds seldom reach 5 mm. high; they are mostly flat for their entire length, and only sparingly branched. But the same form occurs also on stones, and every intermediate can be found up to plants with erect fronds, 2 cm. high. Forms which we refer to *G. pusillum* occasionally occur in which the terete stipe expands into a flat frond, up to 5 cm. long and 3–5 mm. wide. This is very different in appearance from the usual form, but it intergrades so that it and var. *conchicola* must be regarded as extreme forms of a very variable species.

WURDEMANNIA Harvey.

W. SETACEA Harvey, 1853, p. 246; P. B.-A., No. 1887. A very common plant in quiet shallow water, all about the islands and dredged down to 18 m. It is quite variable in size, amount of ramification etc. It often forms dense mats, attached to the substratum by frequent rhizoids; at other times only the bases of the filaments are attached, the upper part forming loose tufts. Cystocarps and antheridia are unknown, tetraspores seldom occur, but were found in plants collected at Smith's Bay, Nov., Hervey. Short much branched forms might be mistaken for *Gelidium,* but on sectioning, the absence of the fine descending rhizoidal filaments of the internal layer is a sufficient distinction. *Gelidiopsis gracilis* Vickers, Algues de la Barbade, No. 126, seems to be this species; we have compared her specimen with an authentic specimen of *W. setacea* from the Harvey herbarium, and both with Bermuda material, and can find no differences.

Family GIGARTINACEAE.

Gigartina Stackhouse.

G. aciculars (Wulf.) Lamouroux, 1813, p. 48; Harvey, 1846–51, Pl. CIV; P. B.-A., No. 1884; *Fucus acicularis* Wulfen, 1803, p. 63. Kemp, June, as *G. Teedii;* Burchell's Cove, Feb., Gravelly Bay, April, Tucker's Town, March, May, Dec., Hervey; pool near Moore's calabash tree, April, Collins. Forming a somewhat matted coating on floors of caves or on bottoms of pools.

Kallymenia J. G. Agardh.

K. perforata J. G. Agardh, 1871, p. 9; 1876, p. 219. Washed ashore, Cooper's Island, Feb., Farlow. There is much variability as to the amount of perforation; some fronds 6–7 cm. diam. are quite imperforate, while others, no larger, are little more than a network.

Family RHODOPHYLLIDACEAE.

Catenella Greville.

C. Opuntia (Good. & Woodw.) Grev. var. pinnata (Harv.) J. G. Agardh, 1876, p. 588; Alg. Am.-Bor. Exsicc., No. 149; P. B.-A., No. 1885; *C. pinnata* Harvey, 1853, p. 201, Pl. XXIX. B. Common between tide marks in quiet waters all about the islands, on ground, rocks and mangroves, usually in company with *Caloglossa Leprieurii*, species of *Bostrychia*, *Cladophoropsis membranacea* and the like. Cystocarps were found on plants collected near Flatts Bridge in August, Collins. The pinnate branching is usually quite manifest, but occasionally plants are found where it is not at all conspicuous; these are quite close to the typical *C. Opuntia* of Europe.

Meristotheca J. G. Agardh.

M. Duchassaingii J. G. Agardh, 1871, p. 36; 1879, Pl. XXXI, figs. 1–3. A single specimen among other algae collected March 4, 1911, Hervey, without exact locality. Evidently not common in Bermuda, as this one specimen, about 2 cm. high, is all that is recorded. It grows to a considerable size along the coast from Florida to North Carolina, specimens from Beaufort, N. C., reaching a length of 4 dm. It is usually very rough with short, stiff proliferations on the surface and margin, but occasionally it occurs quite smooth, when it is not so easily recognized. The difference is not one of maturity, as large smooth plants are found as often as small ones.

Eucheuma J. G. Agardh.

1. Fronds flattened.	1. E. Gelidium.
1. Fronds stout, subterete, very spinous.	2. E. denticulatum.

1. E. Gelidium J. G. Agardh, 1851, p. 627; 1876, p. 602; P. B.-A., No. 2184; *Sphaerococcus Gelidium* Kützing, 1869, Pl. XX. St. David's Island, Feb., Hervey, a few small plants only; South Shore, April, Collins.

2. **E. denticulatum** (Burm. f.) comb. nov.; *E. spinosum* J. G. Agardh, 1847, p. 16; *E. isiforme* Harvey, 1853, p. 118, Pl. XXIV; P. B.-A., No. 1886; *Fucus denticulatus* N. L. Burman, 1768, p. 28; *F. spinosus* Linnaeus, 1771, p. 313; Turner, 1808, Pl. XVIII. Rein; Moseley; April, May, June, Kemp; March, Wadsworth; Tucker, No. 14; Castle Harbor, Jan., Farlow; Bailey's Bay, Mrs. Hastings in Farlow herb.; Bailey's Bay, Jan., Gibbet Island, Jan., Cooper's Island, April, Devonshire Bay, Harris Bay, Dec., Hervey; Gravelly Bay, Tucker's Town, April, Aug., Collins. As may be inferred from the list of stations and collectors, this plant is plentiful and attractive. The living plant is of a dull red, and if prepared without exposure to

sun or air, the color darkens, sometimes becoming nearly black. But if the plant has grown where it is exposed to the full sunshine or if it has been exposed long to the air, the red becomes lighter and clearer, and later takes on a yellow shade. Exposure to the air for several days, if not in full sunshine, gives handsome color without disintegrating or decomposing the plant, if quite fresh when collected. It occurs in all sizes from 5 to 50 cm. high, and varies much in diameter of frond, frequency and regularity of branches, and especially as to the frequency, position and form of the conical or spinous ramuli. In the typical form these ramuli are arranged in whorls, distinctly separated, but forms occur, especially in old and large individuals, in which this whorled arrangement is hardly perceptible. The same differences occur in this species as found on the Florida coast, where it is common. At some stations in Bermuda a form occurs which we have not seen elsewhere; the frond is not over 10 cm. high, is relatively slender, but is so densely and so repeatedly branched that no trace of regularity is seen. This form was collected by Wadsworth in 1890, and has been found by us each year we have collected here. The American plant was described by Agardh, 1822, p. 271, as *Sphaerococcus isiformis;* J. G. Agardh, 1847, p. 16, proposed the new genus *Eucheuma,* including this and other species of *Sphaerococcus,* and the name has been continued since that time. Comparing the original description of *Sphaerococcus isiformis* with the species following, *S. spinosus,* the only distinctions of importance are, first that the former is described as "cartilagineo-gelatinosa" the latter as "gelatinoso-cartilaginea"; second, the former "papillulis ramorum verticillatis," the latter "papillulis solitariis, vel binis ternisve." The question of the distinctness of the two species was raised by Sonder, 1871, p. 60; under *E. spinosum* he notes that he found it with long, naked branches, also beset with papillae, either scattered or whorled. This alga is sold as an article of food in eastern countries, and most of the specimens that had then reached Europe were coarse forms obtained in the markets. J. G. Agardh, 1876, p. 601, referring to Sonder's criticism, says "Quae potissimum conveniunt, *E. spinosum* atque *E. isiforme,* stadio fructifero omnino diversae obvenerunt." But we find on *E. isiforme* fruit of the character attributed by him to *E. spinosum,* as well as that attributed to *E. isiforme.* Later, 1892, p. 12, in a revision of the genus, he uses vegetative characters, giving as the reason that the cystocarps were unknown to him on many of the species. Under *E. spinosum* he says "Icon Turneri tab. 18 pro suo tempore egregia." *E. isiforme* he considers as represented by Harvey's plate, 1853, Pl. XXIV, and the specimens distributed as Alg. Am.-Bor. Exsicc., No. 12. Turner's plate of *Fucus spinosus* was drawn from the specimen in the Linnean herbarium, and represents the type of the species. It has papillae partly whorled, partly scattered; there would be no trouble in matching it from Bermuda material, while Harvey's plate is quite typical of the ordinary, well developed plant. We think we are justified in discontinuing the name *E. isiforme.* But on referring to the original description of *Fucus spinosus,* Linnaeus, 1771, p. 313, we find that he gives as synonym "*F. denticulatus* Burm. prodr. 28".[13] Referring to that page we find the description "Caule compresso ramoso ramis dentato-geniculatis ramulosis subdichotomis." This, with the reference by Linnaeus, necessitates the new binomial we have used.

We have examined specimens from the Cape of Good Hope, Singapore and the Sunda Islands, quite indistinguishable from the American plant.

Family SPHAEROCOCCACEAE.

Gelidiopsis Schmitz.

G. rigida (Vahl) Weber, 1904, p. 9; P. B.-A., No. 2090; *Gelidium rigidum* var. *radicans* Alg. Am.-Bor. Exsicc., No. 142; *Fucus rigidus* Vahl, 1802, p. 46. Forms dense mats at and below low water mark, generally coarse and unattractive.

Gracilaria Greville.

1. Fronds stout, prostrate, attached to the substratum. 8. G. horizontalis.
1. Frond erect. 2.
   2. Frond plane. 3.
   2. Frond terete or compressed. 4.
3. Frond membranaceous, dichotomous, axils wide and rounded, apices obtuse. 7. G. dichotomo-flabellata.
3. Frond cartilaginous, axils acute, divisions tapering, acute. 6. G. multipartita.
   4. Branches long, filiform, slender. 1. G. confervoides.
   4. Branches not filiform. 5.

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13 There is an error in the paging of this work; the pages run 1–28, then 25, 26, 27, 28, and thereafter correctly; the present reference is to the second p. 28.

5. Frond coarse, stout, branches mostly short and blunt. 5. G. Wrightii.
5. Frond less stout; many short, acute branches. 6.
6. Branching corymbose; short acute branches near summit. 4. G. damaecornis.
6. Short acute branches throughout. 7.
7. Frond pyramidal, branchlets dense, erect. 2. G. ferox.
7. Frond irregular, delicate, branches scattered, patent. 3. G. divaricata.

1. G. CONFERVOIDES (L.) Greville, 1830, p. 121; Harvey, 1846–51, Pl. LXV; *Fucus confervoides* Linnaeus, 1763, p. 1629. Kemp, a single plant of typical character; another specimen, marked *G. compressa,* is probably also *G. confervoides.*

2. G. FEROX J. G. Agardh, 1851, p. 592; 1876, p. 414; P. B.-A., No. 1932. Faxon; In shallow water, Moseley; Kemp; Rein, as *G. armata;* Dingle Bay, Inlet, Heron Bay, Jan., Grasmere, March, Hervey; Grasmere, Aug., Collins. Several species of the general appearance of *G. ferox* have been described, and it is by no means easy to separate them. There is a good deal of variety in the Bermuda forms we have included under this name, but they seem to agree in the terete but apparently distichously branched frond, with short acute branches, subsecundly placed. We have found it quite common in warm shallow water, such as the lagoons near Grasmere and Fairyland.

3. G. DIVARICATA Harvey, 1853, p. 109. Mrs. S. A. Boggs; Bailey's Bay, Feb., Wadsworth; reported by Kemp, but no specimen found in his herbarium. The two specimens we have seen agree well with Harvey's description, and there seems no other place for them. The habit is much like that of *Ochtodes filiformis* J. Ag., and the latter species, from Jamaica, was erroneously distributed as *G. divaricata* in P. B.-A., No. 789. The *Ochtodes* has an articulated filamentous axis which is not found in *Gracilaria.*

4. G. DAMAECORNIS J. G. Agardh, 1851, p. 597; 1876, p. 415. In shallow water, Grasmere, Aug., Collins; Miss Wilkinson. As we understand this species, it is stouter than *G. ferox,* drying very hard and firm; the branching is more regularly dichotomous, the ramuli short and subulate, near the ends of the branches. We have found it once only, when it grew among *G. ferox,* but could be distinguished from the latter by its appearance, even as seen from the boat.

5. G. WRIGHTII (Turn.) J. G. Agardh, 1851, p. 599; *Fucus Wrightii* Turner, 1811, Pl. CXLVIII; including *G. Poitei* J. G. Agardh, 1851, p. 596 and *G. cornea* J. G. Agardh, 1851, p. 598. Castle Harbor, Feb., Farlow; Elbow Bay, Dec., Collins. We have carefully examined

a large amount of material from the Florida-West India region, including specimens determined by J. G. Agardh, and can find no line of demarcation between the three species mentioned. *Fucus Poitei* Lamouroux, 1805, Pl. XXX, figs. 2–3, antedates *F. Wrightii*, but now proves to be a *Laurencia*, and the next oldest name is Turner's which we adopt. It includes most of the coarse, fleshy or cartilaginous Gracilarias of the warmer Atlantic; probably always terete when alive, but often appearing compressed in herbarium material. It is not common at Bermuda.

6. G. MULTIPARTITA (Clem.) Harvey, 1846–51, Pl. XV; *Fucus multipartitus* Clementi, 1804, p. 311. Kemp, July, two specimens in herb.; Building's Bay, Feb., one small frond, Hervey.

7. G. DICHOTOMO-FLABELLATA Crouan in Mazé & Schramm, 1870–77, p. 218. Mrs. Boggs, 1895; St. David's Island, Feb., May, South Shore, April, Hervey; tetraspores in May. This species varies considerably in color and texture, from thin membranaceous and clear red to subcartilaginous and brownish. In the former case the shape and subdivision of the frond are indicated by the specific name; in the latter the division is more irregular. The Bermuda plant as a rule has a thinner frond and narrower segments than the Florida material distributed as P. B.-A., No. 334. We were at first inclined to identify this plant with *G. Textorii* (Suringar) Hariot, 1891, p. 223, *Sphaerococcus Textorii* Suringar, 1870, p. 36, Pl. XXIII, and a specimen from Province Boshu, Japan, for which we are indebted to the kindness of Dr. K. Yendo, has much resemblance to the Bermuda plant. But the plant figured by Okamura, 1901, p. 65, Pl. XXIII, and distributed in his Algae Japonicae Exsiccatae No. 13, differs considerably, having a habit more like the common little divided forms of *Rhodymenia palmata*. Our plant agrees with Crouan's species, as represented by an authentic specimen in the Museum d'Histoire Naturelle, at Paris, and it has seemed to us better on the whole to retain for the present Crouan's name, under which the plant had already been distributed in P. B.-A. J. G. Agardh, 1889, p. 25, refers to *G. dichotomo-flabellata* as a possible synonym of *Chrysymenia halymenioides* Harvey, mentioning *Chrysymenia dichotomo-flabellata* Crouan as perhaps the same; the latter has been distributed as P. B.-A., No. 385; it is probable that it is, as suggested by J. G. Agardh, a form of *Chrysymenia halymenioides*, but the plant distributed as P. B.-A., Nos. 334 & 1931 is certainly a *Gracilaria*. The following short diagnosis, in connection with the material distributed as P. B.-A., Nos. 334, 1931, will probably give a sufficient idea of the species.

Gracilaria dichotomo-flabellata Crouan in Mazé & Schramm, Algues de la Guadeloupe, p. 218, without description. A disco parvo, stipite brevi subtereti vel compresso, mox in frondem planam regulariter dichotomam abeunte, segmentis linearibus 5 mm. ad 2 cm. latis, apicibus obtusis vel truncatis; axillis latis, rotundatis; substantia membranacea, juniore tenuiore, adultiore crassiore et firmiore; colore laete- vel fusco-rubro; tetrasporangiis sparsis; cystocarpiis magnis, ad superficiem utrinque sparsis.

8. **G. horizontalis** sp. nov. Fronde a disco centrali irregulari horizontaliter expansa, ramis quoquoversum exeuntibus, subteretis, crassis, ramos ferentibus densissimos, minime attenuatos; cellulis interioribus magnis, corticem versus minoribus, cortice submonostromatico, cellularum minutarum coloratarum. Fructificatione ignota.

Frond expanding horizontally from a central irregular disk, emitting on all sides very densely set branches, tapering very little; interior cells large, becoming smaller towards the submonostromatic cortex, which is formed of small colored cells. Fructification unknown.

The habit is unique in the genus; the plant seems to creep over the bottom of the pool in which it grows, much in the same way as do the haptera of a *Laminaria;* the tips of the branches, or short projections on the margins or lower surface, adhering to the substratum quite firmly. If a young but vigorous frond of *Laminaria* were cut off at the base of the stipe, just at the level of the upper haptera, the remaining basal part would give a good idea of the appearance of this species. Plants growing together are almost inextricably entangled, and even when a plant is not in contact with others, it is difficult to detach it. The substance is tough and cartilaginous, the color of the more or less wrinkled surface is dull yellowish brown, but the lower part, not exposed to the light, is of the clear purplish red found in other species of Gracilaria. It was found in rock pools at low water mark at Gravelly Bay, Aug. 27, 1913, Collins. Type in Collins herb., No. 7818. Since found at the same station in Feb. and April, at Harris Bay, April, Hervey.

Hypnea Lamouroux.

1. Branches long, virgate, often with hooked tips. 1. H. musciformis.
1. Branches not virgate, no hooked tips. 2.
   2. Forming a low, dense, matted expansion. 3. H. spinella.
   2. Erect fronds from a matted base, slender, with patent ramuli. 2. H. cervicornis.

1. H. MUSCIFORMIS (Wulf.) Lamouroux, 1813, p. 43; Hauck, 1885, p. 188, fig. 81; P. B.-A., No. 2185; *Fucus musciformis* Wulfen in Jacquin, 1789, p. 154, Pl. XIV, fig. 3. Rein; Kemp; Miss Peniston; Dingle Bay, Bailey's Bay, Jan., St. David's Island, Feb., Grasmere, March, Buildings Bay, Heron Bay, April, Hervey; Hungry Bay, April, Cooper's Island, Aug., Collins. Generally distributed; the well developed plants with long, virgate branches, beset with short ramuli, and with tips hooked, are not to be mistaken for anything else, but young and stunted forms are hard to distinguish from other species of the genus.

Wulfen's type was from Trieste, where he found the plant growing on crabs for sale in the fish market. His plate is excellent, and shows a slender form with filiform ramuli, often with constricted bases. We have seen similar plants from the Mediterranean and the Adriatic, and on the American shore from Cape Cod to Florida and the West Indies. A form different in appearance has been distributed by Bornet, collected at Biarritz; it is stouter, the ramuli shorter and more patent, and mostly with distinctly wider base, in dried specimens often like rose thorns; hooked tips are very rare in this form, common in the other. This form we have seen from various parts of the Atlantic coast of France, and on the American coast from Beaufort, N. C., to Florida and the West Indies. The two extreme forms are distinct in appearance, though less characteristic forms can be found. Sterile plants can be found in both, but as far as we have observed, cystocarpic plants usually have all the ramuli of the thorn-like type, always some ramuli of this form; while tetrasporic plants have the filiform ramuli with base ultimately constricted. The appearance of the two types is so different that in Agardh's treatment of the genus, 1851, p. 441, the former would come under Sect. I, Virgatae, " ramulis adultioribus basi constrictis," the other, p. 446, Sect. Spinuligerae, "ramulis subulatis, a basi latiore acuminatis." Both forms occur in Bermuda.

2. H. CERVICORNIS J. G. Agardh, 1851, p. 451; 1876, p. 564. Miss Peniston; Old Ferry, April, Hervey. This lacks the hooked apices of *H. musciformis,* and is a more slender and more densely branched plant; but the line between the two species is by no means clear.

3. H. SPINELLA (Ag.) J. G. Agardh, 1847, p. 14; *Sphaerococcus spinellus* Agardh, 1822, p. 323. Cave by Gravelly Bay, Apr., Hervey. Forming a dense, inextricable mat on rocks, usually 1–2 cm. thick.

There is probably no genus of red algae of this region the species of which are so poorly defined, and the plants so little characteristic, as

Hypnea. Well developed plants of *H. musciformis* are easily recognized, but practically everything else is vague and doubtful, and our determinations of other species are only tentative. In regard to the smaller forms, it seems as if no two authors used the same name for the same plant, and even the best authors are often inconsistent with themselves. For instance, J. G. Agardh, 1876, p. 564, under *H. cervicornis,* refers to *H. spinella* Kützing, 1868, Pl. XXVI, as a synonym; under *H. spinella* (Ag.) J. Ag., on the next page, he refers to the same plate. We have collections of *Hypnea* from several stations to which we do not feel willing to give specific names. *H. cornuta* reported by Moseley proves to be *Chondria polyrhiza* Collins & Hervey.

Family RHODYMENIACEAE.

Cordylecladia J. G. Agardh.

C. rigens (Ag.) comb. nov.; P. B.-A., No. 2186; *C.? irregularis* Harvey, 1853, p. 156; *Sphaerococcus rigens* Agardh, 1822, p. 332; *Chylocladia rigens* J. G. Agardh, 1851, p. 362. In dense matted tufts between tide marks, Harrington Sound, Feb., Farlow; Fairyland, Dec., Collins. Comparison with authentic specimen of *Chylocladia rigens* shows the identity with Harvey's species, and the fructification, see Collins, 1901, p. 255, is that of *Cordylecladia.*

Chrysymenia J. G. Agardh.

1. Frond with solid terete stipe and vesicular ramuli.	2.
1. Frond without solid stipe.	3.
2. Branches long, virgate, with spherical or ovoid ramuli.	4. C. uvaria.
2. Branches short, stout, with larger, pyriform ramuli.	5. C. pyriformis.
3. Frond tubular, branches proliferous with constricted base.	3. C. Enteromorpha.
3. Frond compressed, dichotomous or irregularly cleft.	4.
4. Frond slender, divisions linear.	2. C. halymenioides.
4. Frond broader, divisions lanceolate or ovate.	1. C. Agardhii.

1. C. Agardhii Harvey, 1853, p. 189, Pl. XXX. A. Cooper's Island, Feb., Farlow; shallow water, Moseley. Apparently rare, as

neither of us has found it. In Kemp's list mention is made of *Chylocladia rosea.* No specimen with that name is to be found in his herbarium; the species is northern in its range, and not likely to occur here; some forms of *Chrysymenia Agardhii* have habitual resemblance to *Chylocladia,* and may have been the basis for this record.

2. C. HALYMENIOIDES Harvey, 1853, p. 188, Pl. XX. A. One very small plant, Moseley.

3. C. ENTEROMORPHA Harvey, 1853, p. 187. Dredged in 60 meters on Challenger Bank, Aug., 1903, Berm. Biol. Sta.

4. C. UVARIA (L.) J. G. Agardh, 1842, p. 106; Harvey, 1853, p. 191, Pl. XX. B; P. B.-A., No. 1933; *Fucus uvarius* Linnaeus, 1767, p. 714. Rein; Kemp; Moseley; Faxon; Walsingham, Jan., March, Hervey, April, Collins. Appears to grow chiefly in sheltered places among rocks, and may be more common than would appear from the single locality in which we have found it.

5. C. PYRIFORMIS Börgesen, 1910, p. 187, figs. 8–9. A single, well-developed plant, on the perpendicular wall of a "chasm" near Tucker's Town, below low water mark, April, Collins.

COELARTHRUM Börgesen.

C. ALBERTISII (Piccone) Börgesen, 1910, p. 189, figs. 11–12; P. B.-A., No. 2091; *Chylocladia Albertisii* Piccone, 1884a, p. 37, figs. 3–5. Attached to Corallines, Ducking Stool, Jan., Farlow; floating off Cooper's Island, Feb., Farlow; Miss Wilkinson; Shore of Gibbet Island, Jan., Feb., North Shore, March, washed ashore, Buildings Bay, Feb., Hervey; dredged in 18 m., Nov., Collins. This species was founded on a single specimen collected at the Canaries, 1882; a single specimen with the ms. name *Chrysymenia Lomentaria* Crouan is in the Thuret herbarium at Paris; it was dredged once, in about 30 meters, in March, in the Danish West Indies; these are the only records outside of Bermuda. In January and February small plants are found among the roots of *Sargassum,* seldom over 1 cm. high; the larger plants are found washed ashore, probably from deep water. These plants were packed together in crisp masses, with rounded surfaces, like the masses of *Valonia macrophysa,* but on a smaller scale. No fruit was found on the specimens of our collecting, but there were cystocarps on those collected by Farlow in February, tetraspores on those collected by Börgesen in March; both are figured by Börgesen.

Lomentaria Gaillon.

L. uncinata Meneghini in Zanardini, 1840, p. 21; Farlow, 1881, p. 154. Miss Wilkinson; Walsingham, Jan., Hervey. Rather small plants.

Var. filiformis (Harv.) Farlow, 1881, p. 155; *Chylocladia Baileyana* var. *filiformis* Harvey, 1853, p. 185, Pl. XX. C, fig. 2. Very small plants among *Polysiphonia macrocarpa*, on mangroves, Hungry Bay, May, Collins.

Champia Desvaux.

C. parvula (Ag.) Harvey, 1853, p. 76; P. B.-A., No. 1934; *Chondria parvula* Agardh, 1824, p. 207; *Chylocladia parvula* Harvey, 1846–51, Pl. CCX. Gibbet Island, Jan., Heron Bay, April, Hervey; Gibbet Island, Sept., Fairyland, Dec., Collins. On *Sargassum*, *Coelarthrum* and other algae; mostly with tetraspores; small plants, seldom over 3 cm. high.

Family DELESSERIACEAE.

Nitophyllum Greville.

N. Wilkinsoniae sp. nov.; P. B.-A., No. 2037. Frondes usque ad 10 cm. altae, dense di- polychotomae, divisionibus linearibus cuneatisve, latitudine centimetrum raro superantibus; marginibus dentes minutas ciliiformes plus minusve approximatas ferentibus; venis nullis; fronde monostromatica, juniore 15 μ crassa, adultiore usque ad 60 μ; cellulis in superficiem visis irregulariter polygonis, 30–80 μ diam.; in sectione transversali junioribus elongatis, adultioribus subquadratis. Tetrasporangiis tripartitis, ad 60 μ diam., soris rotundatis vel elongatis per totam frondem sparsis, utrinque prominulis; cystocarpiis ignotis; substantia tenuissima; fronde viva, colore malvacea; emersa cito in aurantiacam mutata; siccata rosea. Plate I, fig. 8, Plate II, fig. 9, Plate V, figs. 32–33.

Fronds up to 10 cm. high, densely tufted, di- polychotomously divided, divisions linear or cuneate, seldom over one cm. wide, margin more or less densely set with small ciliform teeth; no veins; monostromatic, 15 μ thick in the younger part, up to 60 μ in older parts; cells regularly polygonal in superficial view, 30–80 μ diam., in cross section, elongate in younger, squarish in older parts. Tetraspores tripartite, up to 60 μ diam., densely packed in small roundish or oval sori, generally distributed over the frond, slightly projecting on both surfaces; cystocarps unknown. W. Faxon; Miss Wilkinson; Harrington Sound, Ducking Stool, Feb., Farlow; Dingle Bay, April, caves at Tucker's Town, May, Collins. On rocks below low water mark; forming dense masses, crisp when first taken from the water, but soon softening into a shapeless mass. The branching is so dense and the substance so tender that it is difficult to disentangle individual plants. When growing the color is mauve, on exposure changing almost instantaneously to orange; when mounted on paper lake or rosy red. In habit like *N. marginatum* Harvey, Ceylon Algae No. 26, but that species lacks the ciliiform teeth, and has somewhat smaller cells but larger tetraspores, which are in less dense sori, and tend to form a confluent marginal band. A specimen of *N. venulosum* Zan., from Trieste, leg. Hauck, also resembles *N. Wilkinsoniae,* but has more slender segments, less densely branched and tufted, and distinct though microscopic veins.

Hypoglossum Kützing.

H. hypoglossoides (Stack.) comb. nov.; *H. Woodwardi* Kützing, 1843, p. 444, Pl. LXV, fig. 1; *Delesseria Hypoglossum* Harvey, 1846–51, Pl. II; *Fucus hypoglossoides* Stackhouse, 1795, p. 76, Pl. XIII. Jan., 1912, a single specimen, without exact locality, Hervey. The rather unfortunate combination we now use for the first time, appears to be required by the international rules.

Caloglossa J. G. Agardh.

C. Leprieurii (Mont.) J. G. Agardh, 1876, p. 499; P. B.-A., No. 2038; *Delesseria Leprieurii* Montagne, 1840a, p. 196, Pl. V, fig. 1; Harvey, 1853, p. 98, Pl. XXII. C. Among other algae on mangroves and other objects between tide marks, less commonly pure or nearly so. Farlow; Burchell's Cove, Feb., Ely's Harbor, Dingle Bay, April, Hervey; Hungry Bay, May, Collins. Tetraspores in April. The Bermuda material corresponds to *C. mnioides* J. G. Agardh, 1876, p. 500,[14] the segments being ovate, sometimes quite broadly so, and the

[14] Later, 1898, p. 235, J. G. Agardh intimates that most of the described species of the genus may be only forms, depending on locality. This appears to be his latest expression of opinion on the subject.

cells in the membrane narrowly rectangular, in quite distinct series to the margin. Compared with the very narrow form from brackish water at West Point, New York, the distinctness of species seems justified, but intermediate forms occur, some from Florida having as wide segments as the Bermuda plant, but with polygonal or rhomboidal cells in indistinct series. The variation can hardly be due to climate, as a specimen of Miss Vickers, Algues de la Barbade, No. 144, has fronds as narrow as in the plant of Long Island Sound and Hudson River.

Taenioma J. G. Agardh.

T. perpusillum J. G. Agardh, 1863, p. 1257; *T. macrourum* Thuret in Bornet & Thuret, 1876, p. 69, Pl. XXV; P. B. -A., No. 1935; *Polysiphonia perpusilla* J. G. Agardh, 1847, p. 16. In a gelatinous mass among small algae, Gibbet Island, April, Hervey. Tetraspores were common in this material; a single mature cystocarp was found, but unfortunately was lost before notes and figures could be made.

Family BONNEMAISONIACEAE.

Asparagopsis Montagne.

A. taxiformis (Delile) comb. nov.; *A. Delilei* Montagne, 1840, p. XIV; *Dasya Delilei* Montagne, 1840, p. 166, Pl. VIII, fig. 6; *Fucus taxiformis* Delile, 1813, p. 151, Pl. LVII, fig. 2. Merriman; Cooper's Island, Feb., Farlow. Apparently rare, as we have not met with it, nor have we found it in any other collections than as above. As Montagne refers to *Fucus taxiformis* Delile, but changes the specific name to do more honor to the author, the original name must be restored according to the international rules.

Family RHODOMELACEAE.

Laurencia Lamouroux.

1. Ultimate ramuli short, often tubercle-like. 2.
1. Ultimate ramuli longer. 3.
   2. Ultimate ramuli distant, simple. 2. L. Poitei.
   2. Ultimate ramuli densely set, mostly lobed. 3. L. papillosa.

3. Frond decumbent, rooting, densely matted. 1. L. perforata.
3. Frond erect. 4.
4. Outline of frond and of main divisions narrowly pyramidal. 5.
4. Outline broader. 6.
5. Slender, 3 or 4 cm. high. 5. L. obtusa var. gelatinosa.
5. Stout, 1–2 dm. high. 6. L. paniculata.
6. Branching mostly opposite or whorled. 5. L. obtusa.
6. Branching subdichotomous, corymbose. 4. L. cervicornis.

1. L. PERFORATA Montagne, 1860, p. 155; Kützing, 1865, p. 18, Pl. XLIX, figs. c–g; P. B.-A., No. 1889. Bailey's Bay, Jan., Harris Bay, Jan., Nov., Gravelly Bay, Oct., Hervey; Tucker's Town, May, South Shore, Aug., Collins. This species occurs not uncommonly in caves and potholes, where it forms dense matted masses, the filaments adhering to the rock and to each other by numerous holdfasts. The surface of the mass sometimes has an iridescence of remarkable brilliancy, chiefly in metallic blues and greens. The iridescence is on the upper surface only, and persists for a short time after the plant is taken from the water.

2. L. POITEI (Lamour.) M. A. Howe, 1905, p. 583; *L. tuberculosa* J. G. Agardh, 1852, p. 760; P. B.-A., No. 1937. *L. gemmifera* Harvey, 1853, p. 72, Pl. XVIII. B.; *Fucus Poitei* Lamouroux, 1805, p. 63, Pl. XXXI, figs. 2–3. Harrington Sound, Farlow; Cooper's Island, a slender form, Wadsworth; Heron Bay, April, Hervey; Fairyland, July, Collins. In warm shallow water, where it forms loose-lying masses in warm weather. *L. tuberculosa* has been described by J. G. Agardh as "fronde compressa distiche decomposito-pinnata," but it may well be that the compression and distichous branching in Agardh's plant are due to the manner of preparation; the Bermuda plant has no such characters.

3. L. PAPILLOSA (Forsk.) Greville, 1830, p. LII; P. B.-A., No. 1936; *Fucus papillosus* Forskäl, 1775, p. 190. Castle Harbor, Farlow; Harris Bay, Jan., Heron Bay, April, Hervey; Jew's Bay, July, Cooper's Island, Harrington Sound, Aug., Collins. Quite common and usually easily recognizable.

4. L. CERVICORNIS Harvey, 1853, p. 73, Pl. XVIII. C; P. B.-A., No. 2187. Wadsworth, No. 19; Miss Wilkinson; Cooper's Island, April, Aug.; dredged in 4 m., Dec., Collins; Buildings Bay, April, St. David's Island, May, Hervey. This species appears to be little known to European botanists; De Toni, 1903, p. 781, gives it as a synonym under *L. implicata*, but it is certainly not the *L. implicata* of Harvey, 1853, p. 72, Pl. XVIII. D., fide authentic specimens. *L.*

cervicornis has a frond of rounded outline, branching subdichotomous, distant below, increasingly close upward; all branches, long or short, are of about the same diameter, about that of the main axis of a frond of *L. obtusa,* medium size. Proliferous ramuli, very short, may be abundant or nearly or quite wanting. It is found in rather sheltered stations, the color a somewhat deep and translucent red in the living plant, growing darker in the mounted specimen. It usually adheres fairly well to paper.

5. L. OBTUSA (Huds.) Lamouroux, 1813, p. 42; Harvey, 1846–51, Pl. CXLVIII; P. B.-A., No. 2092; *Fucus obtusus* Hudson, 1798, p. 586. A very common and variable species, occurring nearly everywhere in quiet water, and often in somewhat exposed places, and dredged to a depth of 18 m. The genus *Laurencia* is very puzzling; though typical forms can be found of all the species, intermediate forms are equally common, and it is very difficult to draw any sharp lines. Of what may be considered the typical form of *L. obtusa* there are two varieties, differing sharply in color, but not otherwise; one is reddish or yellowish brown, lighter where exposed to sunshine, darker below; the other a light, glaucous blue-green. They grow in similar stations; often, as in the lower part of Harrington Sound, both are found together, but as separate individuals or tufts; we have seen no intermediate forms under these conditions.[15] Beside the typical form, two varieties may be noted.

Var. GRACILIS Kützing, 1865, p. 20, Pl. LIV, figs. c and d; *L. dasyphylla* Kemp, in herb. A delicate, soft and slender form.

Var. GELATINOSA (Desf.) J. G. Agardh, 1852, p. 751; P. B.-A., No. 1888; *Fucus gelatinosus* Desfontaines, 1798, p. 427. Mrs. Hastings; Spanish Rock, Jan., Gravelly Bay, March, Dec., Hervey. Tetraspores in Jan. A low and slender form of exposed rocky shores; in spite of its name it is firmer and less adherent to paper than *L. obtusa,* typical. In connection with *L. obtusa* we have found forms near to *L. setacea* Kützing, 1848, p. 854; *L. intricata* Kützing, 1865, Pl. LXI, figs. a-c,[16] but they shade into the typical *L. obtusa* so plainly, and in no

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15 It is of interest to note that practically the same forms occur at Naples; see Falkenberg, 1901, p. 247. "Um Neapel, wo die Pflanze das ganze Jahr hindurch zu den gemeinsten Formen gehört, kommt sie in zwei Varietäten vor, welche, im übrigen gleich, durch ihre Färbung sich wesentlich unterscheiden, die eine ist gelbrothlich, die andere grünlich. Beide Formen treten gesondert in unregelmässig durch einander gewirrten Rasen an den gleichen Standorten auf."

16 *L. intricata* Lamouroux, 1813, p. 43, Pl. IX, figs. 8–9, is nomen nudum, hence Kützing's name of 1848 has priority.

case are they quite typical *L. setacea,* that it seems best to consider them merely forms of the common and variable *L. obtusa.* A specimen in the Farlow herbarium, collected by G. Tucker, No. 10, is near *L. implicata* J. G. Agardh, 1852, p. 745, and a similar form was found on the outer reef, Ely's Harbor, July, Collins, and this also we have considered as a local form of *L. obtusa.* This form is found rather commonly when dredging.

6. L. PANICULATA (Ag.) J. G. Agardh, 1852, p. 755; *Chondria obtusa* var. *paniculata* Agardh, 1822, p. 343. Faxon; Dingle Bay, Jan., Buildings Bay, Mangrove Bay, Feb., Hervey. Connected by intermediate forms with *L. obtusa,* but in its typical form quite distinct by the firmer, little adhesive substance, the narrowly pyramidal form of the frond and of its principal divisions, the main axis distinctly projecting.

CHONDRIA Agardh.

1. Rhizoids frequent; tetraspores in specialized branches. 4. C. polyrhiza.
1. No rhizoids except at extreme base; tetraspores in normal branches. 2.
   2. Ends of pericentral cells showing as a wavy line across the frond. 1. C. curvilineata.
   2. Pericentral cells not showing externally. 3.
3. Ramuli acute or subacute. 3. C. atropurpurea.
3. Ramuli blunt or truncate. 2. C. dasyphylla.

1. **C. curvilineata** sp. nov.; P. B.-A., No. 2039. Fronde tenui, axibus principalibus diametro $\frac{1}{2}$ mm. raro superantibus, ramos paullo minores paucos pluresve alternantes ferentibus, ordinum duorum, raro plures, cylindricos vel ad basin et apicem paullo contractos; puncto vegetationis ad fundo foveae apicalis, folia brevia ferente; foliis similibus secundum ramos sparsis; segmentis diam. duplo longioribus; cellulis corticalibus diam. duplo longioribus; apicibus cellularum centralium per corticem manifestis ut lineis curvis, latere convexo apicem versus; cystocarpiis sessilibus; substantia submolli; colore rubro obscuro. Plate II, figs. 10–11.

Frond slender, main axes seldom reaching $\frac{1}{2}$ mm. diam., with more or less numerous alternate branches of two orders, seldom more, of only slightly less diam., cylindrical or slightly contracted at base and apex; growing point at bottom of an apical pit, with a tuft of short leaves, similar leaves occurring also at scattered points on branches; segments about 2 diam. long; cortical cells about twice as long as broad; swollen apices of pericentral cells showing through the cortication as rounded lines, the convex side towards the apex of the branch; cystocarps sessile on the branches; no other organ of fructification observed; color dull red; substance rather soft. Type specimen in Collins herbarium, No. 7509, Heron Bay, April 19, 1913, Hervey; also at St. David's Island, Feb., near Wistowe, Dec., Hervey.

This plant belongs to the subgenus *Coelochondria* Falkenberg, but is distinct from all but one of the species of the subgenus by the peculiar transformation of the upper ends of the pericentral cells, which show even under a slight magnification as curved lines, two or three showing in the width of the branch. This same character is found in *C. succulenta* (J. Ag.) Falkenberg, 1901, Pl. XXII, figs. 22–23, an Australian species, but that is a large and fleshy plant. In some specimens of *C. curvilineata* this character is less conspicuous than in others, but it is always quite distinct at the base of a branch, where the cortication is thin.

2. C. DASYPHYLLA (Woodw.) Agardh, 1822, p. 350; *Fucus dasyphyllus* Woodward, 1794, p. 239, Pl. XXIII, figs. 1–3; *Laurencia dasyphylla* Harvey, 1846–51, Pl. CLII. St. David's Island, May, Hervey. A single plant, well developed and typical.

3. C. ATROPURPUREA Harvey, 1853, p. 22, Pl. XVIII. E. Heron Bay, March, Hervey. A single, quite typical plant.

4. **C. polyrhiza**, sp. nov.; P. B.-A., No. 2040. Fronde tenui, axi principali diametrum ½ mm. raro attinente, ramos paullo minores paucos pluresve alternantes ferente, ramulis secundi vel tertii ordinis minoribus brevioribusque, ad basin plus minusve contractis, prope apices conicos foliis brevibus deciduis armatis; ramis ordinum omnium plus minusve flexuosis; cellulis corticalibus linearibus, longitudine latitudinem 3–4-plo superante; tetrasporis in ramulis ultimis, partis fertilis margine subdentato, apice breviacuto; basi a parte inferiori sterili ramuli evidenter distincto, parte fertili diametro partem sterilem duplo superante; segmentis per corticem tantum in parte extrema juvenili manifestis; rhizoideis brevibus unicellularibus in fasciculis densis ex partibus omnibus frondis exeuntibus; substantia subfirma; colore rubro pallido. Plate II, fig. 12.

Frond slender, main axis seldom reaching ½ mm. diam., with more or less numerous, alternate patent branches of slightly less size, with one or two orders of smaller and shorter branches with more or less contracted bases, and with tufts of short, fugacious leaves near the tapering apices; branches of all orders more or less flexuous; cortical cells linear, 3–4 times as long as wide; tetraspores in ultimate ramuli, the fertile portion showing a subdentate outline, the apex short-pointed, the base sharply distinct from the lower sterile part of the ramulus, which is usually about half the diam. of the fertile part; segments of pericentral cells showing indistinctly through the cortication in the youngest portions only; dense fascicles of short, unicellular rhizoids issuing from all portions of the plant; color pale red; substance rather firm. Type in Collins herbarium, No. 8007, Shelly Bay, Jan. 10, 1913, Hervey; also at North Shore near Wistowe, Jan., Feb., Hervey; dredged in 18 meters, Dec., Collins.

The cylindrical fronds and the absence of apical pits place this plant in the subgenus *Euchondria* Falk.; the abundant rhizoids are of the same type as in the genus *Herpochondria,* but there is neither the dorsiventral structure nor the lateral adherence of the latter. The rhizoids may occur in short cylindrical fascicles, or may form a dense mass along the frond for a distance equal to several diameters; they may occur on branches of any order, even on the stichidia with mature tetraspores.

ACANTHOPHORA Lamouroux.

A. SPICIFERA (Vahl) Börgesen, 1910, p. 204, figs. 18–19; P. B.-A., No. 1938; *A. Thierii* Harvey, 1853, p. 17, Pl. XIV. A; *Fucus spiciferus* Vahl, 1802, p. 44. Aug., Kemp; Rein; Tucker, No. 13; Walsingham, Farlow; common in quiet waters generally, Jan., March, Oct., Hervey; April, May, July, Aug., Collins. In July and August lying loose on the bottom, but continuing to grow. On submerged tips of live Tamarisk branches, Harrington Sound, Aug., Collins.

FALKENBERGIA Schmitz.

F. HILLEBRANDI (Born.) Falkenberg, 1901, p. 689; Börgesen, 1910, p. 199, fig. 17; P. B.-A., No. 2043; *Polysiphonia Hillebrandi* Bornet in Ardissone, 1883, p. 376. Growing in matted tufts on various algae; Miss Peniston; cave by Ducking Stool, April, cave, Gravelly Bay, Aug., Dec., Gibbet Island, Aug., Bethel's Island, Dec., Collins; Harrington Sound, Oct., Nov., Dec., cave, Gravelly Bay, Dec., Hervey. In the plants collected at Gravelly Bay in December, were found tetraspores, which have not before been recorded for the species; they are tripartitely divided, and formed from one of the pericentral cells of a ramulus, quite as in *Polysiphonia,* but occurred singly, not in series.

Polysiphonia Greville.

1. Pericentral cells 4. 2.
1. Pericentral cells more than 4. 4.
 2. Forming low, dense, more or less even-topped tufts or mats. 2. P. macrocarpa.
 2. Taller, more open in growth. 3.
3. Segments seldom over 1 diam. long; tetraspores in densely forking, divaricate ramuli. 4. P. ferulacea.
3. Segments in main axis usually over 1 diam. long; tetraspores near tips of normal branches. 1. P. havanensis.
 4. Pericentral cells 8–13; soft and dense. 3. P. foetidissima.
 4. Pericentral cells 20–24 in main axis; firmer. 5. P. opaca.

1. P. havanensis Montagne forma mucosa J. G. Agardh, 1863, p. 960; P. B.-A., No. 1941; *P. havanensis* Harvey, 1853, p. 34. Spanish Rock, April, floating by Causeway, Oct., Inlet, Oct., St. George's Bay, Dec., Hervey. On *Penicillus, Halimeda, Sargassum* etc.; cystocarps in April. Fairyland, Dec., Collins. The fine soft filaments and rich red-brown color are characteristic of this form; the segments vary from one to four diam. long in the same plant. The cystocarps are globose below, broadly urceolate above. The leaves are long and much branched; normal branches are formed in their axils.

2. P. macrocarpa Harvey in Mackay, 1836, part 2, p. 206; P. B.-A., No. 2093; *P. pulvinata* Harvey, 1846–51, Pl. CII. B, not of J. Ag. On mangroves, with *Dichotomosiphon pusillus* etc., Hungry Bay, May, Collins. Forming a close and rather dense coating. The filaments resemble *P. subtilissima* Mont., but are more slender, and the habit is quite different. An account of the distinction between this plant and the original *P. pulvinata* (Roth) J. Ag. will be found in Bornet, 1892, p. 306. Our plant is more slender than the European but otherwise the same.

3. P. foetidissima Cocks in Bornet, 1892, p. 314; British Seaweeds, No. 29; P. B.-A., No. 1890. On timbers by sea wall at Hamilton, Jan., on stones on beach at St. George's, April, Hervey; cystocarps and tetraspores in Jan. An apparently little known species, but quite well marked. The filaments have 8–10, rarely to 13 pericentral cells, are creeping at the base, then erect, much branched, reaching a height of 15 cm. The substance is soft, the color deep purplish red. It decays promptly when taken from the water, and then thoroughly justifies its specific name.

4. P. FERULACEA Suhr in J. G. Agardh, 1863, p. 980; P. B.-A., No. 1940; *P. breviarticulata* Harvey, 1853, p. 36, Pl. XVI. B, not of J. Ag. Rein, as *P. nigrescens* in part; Moseley, as *P. subtilissima;* Spanish Point, Harrington Sound, Jan., Gravelly Bay, Feb., April, Tucker's Town, Feb., Dec., Hervey. A rather common and generally distributed species. Harvey's figure represents the plant quite accurately, except as to the quadrangular section of the filaments, which was probably due to the use of dried material; the Bermuda material shows the usual circular section. Rhizoids are well developed on the lower, prostrate part, arising each from a pericentral cell, often one from each segment. Where the creeping filament is near to a firm substratum, the rhizoids are short and stout; where there is no such stratum near, the rhizoids may be much elongated, up to 3 mm. long, becoming very slender. In the actively growing tips, the segments may have a length of only one fifth their diameter; in older parts the segments may be slightly longer than their diameter; the usual length is about one half a diam. Leaves are abundant, branches being produced from their axils.

At Heron Bay we found a plant agreeing quite closely with *P. fracta* Harvey, 1853, p. 38, and with an authentic specimen in the Farlow herbarium; it seems to us, however, to be only an old and battered form of *P. ferulacea*. Authentic specimens of the latter, in the Farlow herbarium, confirm this view.

5. P. OPACA (Ag.) Zanardini, 1842, p. 165; P. B.-A., No. 1891; *Hutchinsia opaca* Agardh, 1824, p. 148. Kemp, as *P. fibrillosa;* Rein, as *P. nigrescens*, in part; On rocks, Heron Bay, Jan., March, Ely's Harbor, April, Hervey; in grotto, Tucker's Town, April, Fairyland, Dec., Collins. We have included under this name all the many-tubed Polysiphonias that we have found in Bermuda. Some specimens agree well with the European form, others, specially those from Fairyland, considerably resemble *P. simulans* Harvey, but we have not been able to draw any line between these and the more typical forms. Tetraspores were found in April. Branches arise in the axils of the leaves.

DIGENEA Agardh.

D. SIMPLEX (Wulfen) Agardh, 1822, p. 389; Harvey, 1853, p. 29, Pl. XIII. D; P. B.-A., No. 1939; *Conferva simplex* Wulfen, 1803, p. 7. Castle Harbor, Farlow; Gravelly Bay, Feb., Mangrove Bay, Feb., Harris Bay, April, Dec., Hervey; St. David's Island, April, Collins. Fairly common at various places, but plants usually small compared with ordinary forms of Florida and the Mediterranean.

WRIGHTIELLA Schmitz.

1. Main axes virgate, except in the older parts beset with short, subequal ramuli. 1. W. Blodgettii.
1. Branches of successive orders diminishing in size; ramuli of varying length. 2. W. Tumanowiczi.

1. W. BLODGETTII (Harv.) Schmitz, 1893, p. 222; P. B.-A., No. 1942; *Alsidium Blodgettii* Harvey, 1853, p. 16, Pl. XV. B. Kemp, specimen in herb. as *Dasya mucronata,* also unnamed specimen; Shelly Bay, Feb., Harris Bay, Walsingham, April, Hervey; in pot-hole, Gravelly Bay, April, Bethel's Island, Dec., Collins; tetraspores in Jan. and April.

2. W. TUMANOWICZI (Gatty) Schmitz, 1893, p. 222; P. B.-A., No. 2095. *Dasya Tumanowiczi* Gatty in Harvey, 1853, p. 64. Moseley; Buildings Bay, April, with cystocarps, Hervey. In this collecting a single plant was found, dense and bushy and over 7 dm. high; over 30 good mounted specimens were made from it, but it was throughout more slender than much smaller individuals of *W. Blodgettii.* In appearance the two species are quite different, the stout spinous branches of the latter are quite visible to the naked eye, and set all over the plant; in *W. Tumanowiczi* they are hardly visible without a lens. Technically, it is hard to find distinguishing characters; tetraspores and cystocarps are quite alike, and as suggested by Falkenberg, 1901, p. 559, they are certainly closely related.

MURRAYELLA Schmitz.

M. PERICLADOS (Ag.) Schmitz, 1893, p. 227; P. B.-A., No. 2096; *Hutchinsia periclados* Agardh, 1828, p. 101; *Bostrychia Tuomeyi* Harvey, 1853, p. 58, Pl. XIV. E. Among *Bostrychia* species, on mangroves and rocks, Tucker's Town, Hungry Bay etc., Common as scattered individuals among other species, rarely pure or constituting the greater part of the growth.

HERPOSIPHONIA Nägeli.

1. Branches recurved. 3. H. pecten-veneris.
1. Branches straight. 2.
   2. Determinate branches about the same size as the axis. 1. H. secunda.
   2. Determinate branches about half the size of the axis. 2. H. tenella.

1. H. SECUNDA (Ag.) Falkenberg, 1901, p. 307, Pl. III, figs. 10–12; P. B.-A., No. 2041; *Hutchinsia secunda* Agardh, 1824, p. 149; *Polysiphonia pecten-veneris* Var. β Harvey, 1853, p. 46, Pl. XVI. D. On reef, Ely's Harbor, Aug., Collins. In this material the erect branches are often abortive, and the regularity of position of branches characteristic of the species is obscured.

2. H. TENELLA (Ag.) Nägeli, 1846, Pl. VII, fig. 2; P. B.-A., No. 1943; *Hutchinsia tenella* Agardh, 1828, p. 105. On rocks, corallines and other algae, Harrington Sound, Bailey's Bay, Gibbet Island, Jan., Smith's Bay, Feb., Nov., Harris Bay, April, Tucker's Town, Dec., Hervey.

3. H. PECTEN-VENERIS (Harv.) Falkenberg, 1901, p. 315; *Polysiphonia pecten-veneris* Harvey, 1853, p. 46, Pl. XVI. C. Among *Gelidiopsis,* Harris Bay, April, Hervey. A delicate and attractive species; the graceful recurving of the branches easily distinguishes it.

LOPHOSIPHONIA Falkenberg.

1. Pericentral cells 10–16. 3. L. obscura.
1. Pericentral cells 4. 2.
   2. Basal filament attached to substratum by filiform rhizoids, with or without disks. 1. L. bermudensis.
   2. Basal filaments penetrating the host by rhizoids much inflated below. 2. L. Saccorhiza.

1. **L. bermudensis** sp. nov.; Cellulis pericentralibus 4, interdum 5 aut 6; filamentis prostratis 100–110 μ diam., cellulis 1–2 diam. longis; filamentis erectis numerosis, ad 60 segmentis longis, 60–80 μ diam. a basi ad prope apicem; cellulis 1½–2 diam. longis, interdum solummodo ½ diam.; ramis plus minusve ramosis, aliquando densissime; ramis brevibus. Antheridiis conicocylindricis, 160–200 μ × 40–50 μ, ad apicibus ramorum aggregatis; cystocarpiis subglobosis, lateraliter sessilibus, vel ad pedicellum perbreve, circa 250 μ diam.; tetrasporangiis circa 80 μ diam., 2–5 in seriem rectilineam, in ramulis subincrassatis, saepe curvis. Plate III, figs. 18–21.

Pericentral cells 4, occasionally 5 or 6; prostrate filaments 100–110 μ diam., cells 1–2 diam. long; erect filaments numerous, up to 60 cells long, 60–80 μ diam. from base to near apex, cells 1½–2 diam. long, occasionally only ½ diam.; more or less branched, sometimes quite densely, branches short. Antheridia conical-cylindric, 160–200 × 40–50 μ, clustered at apices of branches; cystocarps subglobose, sessile or lateral on very short pedicels, about 250 μ diam.; tetrasporangia about 80 μ diam., 2–5 in a straight series, in somewhat swollen, often curved ramuli. Rhizoids filiform, varying in size but usually slender, attached to the substratum by a terminal disk. Type in Collins herbarium. Gravelly Bay, Feb., Hervey, Fairyland, Cave at Agar's Island, Aug., and dredged in 6 m., Collins. A rather delicate plant, usually on *Sargassum* or *Zonaria,* but also on limpet shells. The variation in number of pericentral cells is something exceptional in a plant of normally four. The increased number does not seem to be limited to any part of the plant, but may occur in horizontal or erect filaments, younger or older. It has some resemblance to *L. subadunca* (Kütz.) Falk., but that has uniformly six pericentral cells.

2. **L. Saccorhiza** sp. nov.; P. B.-A., No. 2042. Cellulis pericentralibus 4; filamentis prostratis 50–70 μ diam., segmentis 1–2 diam. longis; filamentis erectis numerosis, ad 2 mm. longis, 25–45 μ diam., ad basin abrupte, apicem versus longissime attenuatis, prope apicem folia bene evoluta sed fugacissima gerentibus; segmentis 2–3 diam. longis, ad apicem diametro brevioribus; filamento prostrato ad plantem hospitem rhizoideis numerosis affixo a parte inferiore filamenti ortis, primo cylindraceis vel ortu complanatis axis filamenti sensu, mox in saccos ovoideos expansis, ad 800 μ longis, 160 μ diam., inter utriculos plantae hospitis penetrantes. Tetrasporangiis uniseriatis in parte superiore filamenti erecti sitis, diametrum filamenti ad duplo superantibus; cystocarpiis subsphaericis, circa 100 μ diam., apicibus ramorum proximis, segmentis proxime inferioribus saepe ramulos breves solitarios vel paucos gerentibus. Antheridiis foliorum evolutione ortis, conico-ovoideis. Colore roseo; substantia molli. Plate II, figs. 13–14, Plate III, figs.15–17.

Pericentral cells 4; prostrate filaments 50–70 μ diam., segments 1–2 diam. long, erect filaments numerous, up to 2 mm. long, 25–45 μ diam., contracted abruptly at base, gradually towards apex, segments 2–3 diam. long, at growing tip shorter than the diam.; well developed but very fugacious leaves formed on the upper part; prostrate filaments attached to the host by numerous rhizoids issuing from the lower pericentral cells of the prostrate filament, one or more from a segment, at first cylindrical in section, or flattened in a line with the axis of the filament, below expanding into an ovoid sac, up to 800 μ long, 160 μ wide, penetrating between the utricles of the host. Tetrasporangia in a single series in the upper part of a filament, up to twice the diameter of the filament. Cystocarps subspherical, about 100 μ diam., near end of erect filament, one or more short branches issuing from the segments next below. Antheridia developed from leaves, conical-ovoid. Color rosy red; substance soft.

From the few 4-tubed species of *Lophosiphonia* this is distinguished by branching characters, but specially by the great development of the rhizoids, which show a remarkable adaptation to its habitat, the fronds of *Codium*. The rhizoids take the shape of utricles, of much the same shape and size as those of the host, but in reversed position. At first a relatively slender cell, cylindrical, or occasionally flattened in a line with the axis of the filament, as soon as the rhizoid has penetrated between the stouter parts of the *Codium* utricles it expands, and wedges itself in tightly among the latter. As seen under the microscope, there is a striking contrast between the rosy color of one set of utricles, and the green of the other. Type in Collins herbarium, No. 7456, Gibbet Island, March, 1913, Hervey; also from Gibbet Island, Jan., Smith's Bay, March, Hervey; Tucker's Town, April, Cave near Ducking Stool, Hungry Bay, May, Collins.

3. L. OBSCURA (Ag.) Falkenberg, 1901, p. 500; P. B.-A., No. 1892; *Hutchinsia obscura* Agardh, 1828, p. 108; *Polysiphonia obscura* Harvey, 1846–51, Pl. CII. A. Moseley, as *Polysiphonia exilis;* Smith's Bay, Spanish Rock, Jan., Gibbet Island, March, Harrington Sound, Dec., Hervey; North and South Shores, April, May, July, Aug., Collins. Common everywhere on rocks between tide marks, and in caves, where in well sheltered places it reaches even above ordinary tides. It varies considerably in size and in luxuriance of branching, but is not likely to be mistaken for any other species. Young plants bear long hairs (leaves) in dense branching tufts.

BOSTRYCHIA Montagne.

1. Main axis ecorticate.	1. B. rivularis.
1. Main axis corticate.	2.
2. Long monosiphonous ramuli present.	2. B. tenella.
2. Only a few terminal segments monosiphonous.	3.
3. Tips of branches incurved; rather coarse.	4. B. Montagnei.
3. Branches straight; slender.	3. B. sertularia.

1. B. RIVULARIS Harvey, 1853, p. 57, Pl. XIV. D. Walsingham, April, Hervey. This species, the only one occurring as far north as New England, has been found only once in Bermuda, and then in a quite small form, not over 2 cm. high. It was sparingly scattered among *B. Montagnei.*

2. B. TENELLA (Vahl) J. G. Agardh, 1863, p. 869; P. B.-A., No. 1894; Alg. Amer.-Bor. Exsicc., No. 137, as *B. calamistrata; Fucus tenellus* Vahl, 1802, p. 45. Common on roofs and walls of caves, flat rocks, under mangroves, etc., at all seasons; tetraspores in Nov. The most common species of the genus; the species of *Bostrychia* usually grow intermixed with each other, and with *Caloglossa* and *Catenella;* it is exceptional to find any one species pure, while the combination of two or more, in varying proportions, is to be found everywhere in the stations noted for this species. *B. tenella* is quite variable, and the extreme forms seem quite distinct. Forma *tenuior* J. G. Agardh, 1863, p. 869; *B. calamistrata* Harvey, 1853, p. 56, Pl. XIV. C, and forma *densa* J. G. Agardh, 1863, p. 869; *Rhodomela calamistrata* Montagne, 1846, p. 36, Pl. IV, fig. 1, both occur, often in the same collecting, connected by intermediate forms.

3. B. SERTULARIA Montagne, 1859, p. 176; P. B.-A., No. 2094; Alg. Am.-Bor. Exsicc., No. 138. Grotto, Tucker's Town, Dec., Hervey; Gravelly Bay, April, Collins. The tetraspores of this species, of which there seems to have been no record, were found in material from the cave at Gravelly Bay, and are also in material distributed by Farlow, in Alg. Am.-Bor. Exsicc. A stichidium is formed in the limited branch of a main axis, usually occupying only a small part of its length, in the majority of cases below the middle, the unchanged branch extending both above and below the stichidium, bearing both above and below ramuli of normal construction; this appears to be an exception to the usual formation in this genus. *B. sertularia* has been considered by some as a synonym of *B. tenella,* e. g., De Toni, 1903, p. 1162, but the two seem quite distinct. *B. tenella* is a plant of softer substance, with long monosiphonous ramuli, and long-lanceolate or linear-lanceolate stichidia; *B. sertularia* is firmer, only a few of the extreme segments of a ramulus being monosiphonous; the branching is strictly distichous, and the stichidium occupies the middle part of the otherwise unchanged ramulus of the penultimate or ultimate order.

4. B. MONTAGNEI Harvey, 1853, p. 55, Pl. XIV. B; P. B.-A., No. 1893; Alg. Am.-Bor. Exsicc., No. 136. H. Kennedy, Feb. in Farlow herb.; July, Kemp, as *B. scorpioides;* Hungry Bay, April, May, Collins; Causeway, Nov., with cystocarps, Hervey. The largest and coarsest species. The cystocarps are large, depressed-globose, and terminal on rather long ultimate ramuli.

Dasya Agardh.

1. Divisions few, subsimple, ramelli very dense at tips. 1. D. ocellata.
1. More branched; ramelli less dense at tips. 2.
  2. Ramelli all unbranched or forkings narrow. 3.
  2. Ramelli divaricately or squarrosely branched, at least near base. 5.
3. Ramelli deciduous, leaving short, acute, spinous branches. 3. D. spinuligera.
3. Ramelli more persistent; no spinous branches. 4.
  4. Ramelli very slender, short-celled, generally distributed on all but the oldest parts. 2. D. pedicellata.
  4. Ramelli larger, longer-celled, in more or less distinct whorls. 4. D. punicea.
5. Ramelli stout near their base, diminishing at each forking, very slender at apex. 6.
5. Ramelli nearly uniform in size throughout. 5. D. arbuscula.
  6. Ramelli forming a very dense coating, especially near tips of branches. 6. D. ramosissima.
  6. Ramelli in minute, subcorymbose clusters, not denser near apices. 7. D. corymbifera.

1. D. ocellata (Grat.) Harvey in Hooker, 1833, p. 335; 1846–51, Pl. XL; *Ceramium ocellatum* Grateloup, 1807, p. 34. Cooper's Island, Feb., Farlow; on *Sargassum*, Gibbet Island, Jan., Gravelly Bay, Feb., Hervey; tetraspores in Jan.

2. D. pedicellata Agardh, 1824, p. 211; *D. elegans* Harvey, 1853, p. 60; Kützing, 1864, p. 21, Pl. LIX. Kemp, as *D. pediculata;* Merriman; Miss Peniston; Miss Wilkinson; Shelly Bay, April, Collins; Buildings Bay, March, Hervey. The common *Dasya* of the Atlantic coast from Cape Cod to Florida, but evidently not common here. Though the name *D. elegans* has been long familiar, it will have to be given up for *D. pedicellata*, the priority of which is unquestionable.

3. **D. spinuligera** sp. nov.; P. B.-A., No. 2188. Cellulis pericentralibus 5, corticatis, cortice glabro, continuo, cellularum minorum, elongatarum; ramis paucis, elongatis, ramulos breves, patentes, acutos, gerentibus; apice ramuli junioris fasciculum densum ramellorum ferente, adultioris nudo; ramellis densissimis, deciduis, monosiphoniis, dichotomis, rectis nec divaricatis, cellulis 2–3 diam. longis, superne 1 diam. modo, diametro ubique aequali; stichidiis conicis vel cylindro-conicis, prope basin fasciculi ramellorum ortis; tetrasporangiis 2–4 in verticillo; frondis substantia firma; colore rubro obscuro. Plate IV, figs. 24–25.

Pericentral cells 5, corticate, cortex smooth, even, of small elongate cells; with few elongate branches, bearing patent, acute ramuli, the younger with a dense fascicle of ramelli at the tip, the older naked; ramelli very dense, deciduous, monosiphonous, dichotomous, straight, not divaricate; cells 2–3 diam. long, above only 1 diam.; diameter the same throughout; stichidia conical or cyclindric-conical, arising near the base of a fascicle of ramuli; tetrasporangia 2–4 in a whorl. Substance of the frond firm; color dark red. Type in Collins herbarium, No. 7243; collected at Shelly Bay, May 4, 1912, Collins. When ramelli are abundant, this plant somewhat resembles *D. punicea*, but the ramelli show no tendency to a verticillate arrangement, and fall off more easily. The surface of the frond after the ramelli have fallen is smooth and even, not knotted and irregular as in *D. punicea;* the cells are small and regular, not large and irregular as in that species.

4. D. PUNICEA Meneghini in Zanardini, 1842, p. 171; 1865, Pl. LII. Dingle Bay, March, Hervey; Bethel's Island, Dec., Collins; both with tetraspores. In habit somewhat resembling *D. pedicellata*, but the ramelli are larger, of longer cells, and with a distinct tendency to issue in whorls.

5. D. ARBUSCULA (Dillw.) Agardh, 1828, p. 121; Harvey, 1846–51, Pl. CCXXIV; P. B.-A., No. 1944; *Conferva arbuscula* Dillwyn, 1809, Pl. G. Shelly Bay, Jan., Smith's Bay, March, Harris Bay, April, Hervey; Hungry Bay, April, in dense floating masses and attached to mangroves, Collins.

6. D. RAMOSISSIMA Harvey, 1853, p. 61; Kützing, 1864, Pl. LXIX, figs. d–e; P. B.-A., No. 1945. On vertical rock between tides, Pink Beach, Jan., Feb., Smith's Bay, March, Gibbet Island, Dec., Hervey. In habit not unlike *D. corymbifera*, but the divisions of the ramelli are incurved.

7. D. CORYMBIFERA J. G. Agardh, 1841, p. 31; *D. venusta* Harvey, 1846–51, Pl. CCXXV; *D. arbuscula* P. B.-A., No. 1097b, not 1097a; *D. arbuscula* forma *subarticulata* P. B.-A., No. 493. Washed ashore from deep water, Buildings Bay, Feb., Hervey; dredged in 4 m., Nov., Collins. Sometimes confused with *D. arbuscula* which it resembles in habit; both have a dense coating of divaricately branching ramelli, but in *D. corymbifera* the tips of the ramelli are much more slender than their bases.

HETEROSIPHONIA Montagne.

H. WURDEMANNI (Bailey) Falkenberg, 1901, p. 638, Pl. XVI, fig. 11; P. B.-A., No. 2097; *Dasya Wurdemanni* Bailey in Harvey, 1853, p. 64, Pl. XV. C. Cooper's Island, Feb., Farlow; Harrington Sound, Jan., March, Gibbet Island, Dec., Hervey; Hungry Bay, April, Cooper's Island, Aug., Little Agar's Island, Nov., Collins. On *Gelidium* and other algae, but most frequently on *Sargassum;* a careful search would probably discover it in any lot of old *Sargassum*, but it is seldom found in large quantity.

Family CERAMIACEAE.

Spermothamnion Areschoug.

1. Cells 5–20 diam. long; tetraspores usually in corymbose clusters. 3. S. macromeres.
1. Cells 2–7 diam. long; tetraspores solitary. 2.
  2. Filaments 15–20 μ diam. 1. S. investiens.
  2. Filaments 40–50 μ diam. 2. S. gorgoneum.

1. S. investiens (Crouan) Vickers, 1905, p. 64; *Callithamnion investiens* Crouan in Mazé & Schramm, 1870–1877, p. 141. On *Galaxaura squalida*, Gravelly Bay, April, St. David's Island, April, Collins; Harris Bay, Dec., Hervey. The dimensions of the Bermuda plant agree with those given by Miss Vickers for the Barbados plant; Börgesen, 1909, p. 17, fig. 10, describes and figures var. *cidaricola* from the Danish West Indies; the dimensions are considerably larger than in the typical form, but the habit and the tetraspores are the same as in the Bermuda plant.

2. S. gorgoneum (Mont.) Bornet in Vickers, 1905, p. 64; *Callithmanion gorgoneum* Montagne, 1857, p. 289. Common on fronds of species of *Codium*. Tetraspores with tripartite division were found in Bermuda material, borne on an upcurved pedicel.

3. **S. macromeres** sp. nov.; P. B.-A., No. 2044. Filamentis prostratis circa 65 μ diam., cellulis 3–5 diam. longis, rhizoideis magnum discum terminalem ferentibus, affixis; filamentis erectis 5–8 mm. longis, basi circa 50 μ diam., sensim diminutis, in ramis ultimis circa 30 μ; cellulis 5–20 diam. longis, cylindricis vel leviter clavatis, cellulis ramiferis valide clavatis; ramificatione distante, apparenter dichotoma, axi ramoque subaequalibus, minime divergentibus; tetrasporangiis in ramo laterali evolutis, ramum vegetativum referente, vel in ramis brevibus oppositis; ramis tetrasporangiferis raro simplicibus, vulgo di- trichotome ad cellulam quamque repetite divisis, cellulis brevibus, clavatis; tetrasporangiis terminalibus, tripartitis, 50–55 μ diam., globosis vel paullo elongatis, membrana crassa; antheridio

latere interiore rami evoluto, loco rami vegetativi, ovoideo-cylindrico, 125–130 × 50–60 μ; cystocarpio cellula brevi clavata suffulto, loco rami vegetativi evoluta.

Prostrate filaments about 65 μ diam., cells 3–5 diam. long, attached by rhizoids with a large terminal disk; erect filaments 5–8 mm. long, about 50 μ diam. at base, gradually diminishing to about 30 μ in ultimate divisions, cells 5–20 diam. long, cylindrical or somewhat clavate, branch-bearing cells strongly clavate; branching usually distant, apparently dichotomous, the axis and branch nearly equal in size and diverging very slightly; tetrasporangia produced on a short branch arising like a vegetative branch, or on two short branches opposite on the axis; tetrasporic branches rarely simple, usually di- or trichotomously divided, the divisions each of a short, clavate cell; tetraspores borne on the ultimate divisions, tripartite, 50–55 μ diam., globose or slightly elongate, with wide pellucid wall; antheridium on the inner side of a branch, occupying the place of a vegetative branch, ovoid-cylindrical, 125–150 × 50–60 μ; cystocarp borne on a short, clavate cell, taking the place of a vegetative branch. Type in Collins herbarium, Smith's Bay, Jan. 18, 1913, Hervey. Also at the same place, Feb., March, Nov., Dec., Hervey.

The extremely long cells in this species, 20 diameters long being not uncommon, distinguish it from other species of the genus. The erect filaments are usually very sparingly branched, though in the upper half there may sometimes be a branch from every cell; in other cases the erect filament branches only two or three times in its whole length; the branch is hardly distinguishable from the axis, either by size or direction. The tetrasporangium may be terminal on a relatively short cell, 2–3 diam. long, arising from the axis; or this cell may divide one to several times, in the latter case twenty to thirty tetrasporangia being borne at the apices of the divisions, forming a dense, corymb-like cluster. The antheridia appear sessile, as they take the place of normal branches on the inner side of a secondary axis, the unmodified cells of which are shorter than the normal, though not as short as in the tetrasporic clusters; occasionally both branches of a forking are transformed into antheridia. Cystocarps are formed in the same position as antheridia, but the lower cell of the transformed branch remains unchanged. Antheridia were plentiful in material collected in January, tetraspores at all seasons; cystocarps were found in January material only, scarce and somewhat immature. The prostrate filaments are affixed by numerous short, stout rhizoids with much expanded terminal disks; occasionally a more slender rhizoid is produced by the lowest cell of an erect filament. The plant grew on the top of sand-covered rocks, covered at high tide; the coral sand sifted in among the alga, forming a dense fibrous mass.

Ceramothamnion Richards.

C. Codii Richards, 1901, p. 264, Pl. XXI; P. B.-A., No. 1899; Plate III, fig. 22; plate IV, fig. 23. Common on *Codium tomentosum* and other species of *Codium* all about the islands, at all times of the year, almost always in abundant fruit. It was once found on *Laurencia cervicornis*. A few notes can be added to the quite full description of Richards. He observed only a single ripe tetrasporangium at a node; we have found not uncommonly two, rarely three, in one instance four, of apparently equal age, side by side; branches occasionally occur independently of the polyspores; we have found organs quite agreeing with his figures of the latter, but also similar organs, larger, up to 160 μ diam., spherical, containing up to 45 spores, and in appearance quite indistinguishable from cystocarps of *Ceramium*.[17] Against the identification of these organs as cystocarps must be reckoned our failure to discover anything like procarps, and the question must be left open. The rhizoids offer some interesting peculiarities, doubtless due to adaptation to their position, between the closely-packed utricles of the host; at first terete, they soon become flattened, and often two or more unite laterally, in a membranous expansion, which may be as much as 10 cells wide. In one case three rhizoids from one individual united with two from another to form one membrane. The cross walls in these rhizoidal membranes are often much oblique, and the arrangement of the cells reminds one somewhat of that in the leaf of a moss. See Figures 22 and 23. The material from which this species was described was collected in Bermuda in 1898 and 1899; the only other record of its occurrence is at Barbados, Vickers, 1905, p. 65.

Griffithsia Agardh.

1. Vegetative cells cylindrical throughout.	1. G. tenuis.
1. Lower cells subcylindrical, upper ovoid.	2. G. Schousboei.
1. All cells subspherical.	3. G. monilis.

17 Schiller, 1913, has made extensive observations on organs of this character in genera allied to *Ceramothamnion*, and he reports that in every case they were accompanied by tetraspores of normal character on the same individual. This is not the case with this species.

1. G. TENUIS Agardh, 1828, p. 131; P. B.-A., No. 1895; Plate VI, figs. 38–39; *G. thyrsigera* Askenasy, 1888, p. 36, Pl. IX, figs. 1 & 4; Vickers, 1905, p. 64; *Callithamnion tenue*, Harvey, 1858, p. 130. Inlet, above and below Flatts Bridge, Jan., Feb., March, April, Dec., Heron Bay, Jan., Hervey. Common at these stations in late winter and early spring; cystocarps, antheridia and tetraspores all produced from January to March. The similarity between *Griffithsia tenuis* Ag. and *Callithamnion thyrsigera* Thwaites has been noticed more than once. Harvey, 1858, p. 130, kept up the distinction with some doubt. Grunow, 1874, p. 8, considers the latter merely a robust form of the former. Harvey had compared the plant from Beesley's Point, New Jersey, with an authentic Mediterranean specimen; we have compared with a Beesley's Point specimen of the original collecting specimens from Atlantic City, N. J. (S. R. Morse), Nantucket (L. L. Dame), Falmouth, Massachusetts (Collins), and *G. thyrsigera*, Vickers, Algues de la Barbade, No. 182. All agree in essential details with each other, and with the figures and text of Askenasy. The Bermuda material seems to be more luxuriant, especially the tetrasporic; it is not uncommon to find 15 tetrasporangia in a whorl, five whorls of tetrasporangia, mature or nearly mature, and two whorls of immature, at once on an axis. Antheridia are borne on a pedicel of one to three cells; Askenasy reports one-celled pedicels only. The cystocarps were unknown until found on our Bermuda material; they are characteristic of *Griffithsia*, and the generic position of the species may now be regarded settled. Rhizoids were frequent on the older plants, of the usual form, unicellular, longer or shorter as required to reach the substratum, where an expanded disk was formed. They have thicker walls than the filament cells, and contain nearly as deeply colored chromatophores.

2. G. SCHOUSBOEI Montagne in Webb, 1839, p. 11, Pl. X. Washed ashore, St. George's, Feb., sand covered rock, Pink Bay, March, Hervey. Agrees with the European plant in vegetative characters, but in the absence of fruit the identification is only provisional.

3. G. MONILIS Harvey, 1855, p. 559; in Hooker & Harvey, 1855–1860, p. 332, Pl. CXCV. B. In cave, Gravelly Bay, Dec., Jan., March, on sand-covered rocks, Smith's Bay, March, Hervey; Bethel's Island, Dec., Collins. Tetraspores in Jan. *G. monilis* is an Australian species, and its occurrence here is of interest. Agardh calls attention to its similarity to *G. Schousboei*, but while what we take for that species occurs in Bermuda, it has most of the cells cylindrical, a few ovoid, while in *G. monilis* the cells are strictly globose, or a little elongated or depressed.

CALLITHAMNION Lyngbye.

1. Branching distichous, pinnate. 2.
1. Branching radial or dichotomous. 3.
   2. Little cortication, cells long, ultimate ramuli long, slender. 4. C. roseum.
   2. Much cortication, cells short, pinnae decompound, ultimate ramuli, short, stout. 5. C. Hookeri.
3. Branching alternate throughout. 1. C. byssoideum.
3. Branching at least in part dichotomous. 4.
   4. Ultimate divisions long, slender. 6. C. cordatum.
   4. Ultimate divisions shorter and stouter. 5.
5. Alternate branching usually confined to axis and branches of first order, otherwise dichotomous. 3. C. Halliae.
5. Only smaller divisions dichotomous; distance very short between forkings. 2. C. corymbosum.

1. C. BYSSOIDEUM Arnott var. JAMAICENSE Collins, 1901, p. 258; P. B.-A., No. 2045. Gravelly Bay, Jan., Feb., March, Oct., Hervey; April, Aug., Collins. Growing in dense patches, not over 3 cm. high, just below low water mark, in a small cave. In the water it shows a peculiar bluish iridescence, like the bloom on a plum.

2. C. CORYMBOSUM (Eng. Bot.) Lyngbye, 1819, p. 125, Pl. XXXVIII. C.; Harvey, 1846–51, Pl. CCLXXII; *Conferva corymbosa* Eng. Bot., 1811, Pl. MMCCCLII. Washed ashore, Cooper's Island, Feb., Farlow; on *Wrightiella Blodgettii,* Harris Bay, April, Collins. In both cases with abundant tetraspores.

3. C. HALLIAE Collins in P. B.-A., No. 698; 1906, p. 111; P. B.-A., No. 1896. Outlet of Harrington Sound, Jan., Feb., March., Hervey, large and handsome plants; tetraspores in Jan., no other fruit; Burchell's Cove, Feb., large rich purple patches on bottom in shallow water, Hervey; shore of Agar's Island, Dec., Collins.

4. C. ROSEUM (Roth) Harvey in Hooker, 1833, p. 341; Harvey, 1846–51, Pl. CCXXX; *Ceramium roseum* Roth, 1798, p. 46. On *Codium,* near Causeway, Feb., Hervey, with tetraspores. The plants are attached to the *Codium* by a dense mass of slender filaments with red protoplasts, penetrating deeply the tissue of the host. They are continuations of the descending growths from the bases of the branches, which cover the lower part of the axis, as a cortex.

5. C. HOOKERI (Dillw.) Agardh, 1828, p. 178; Harvey, 1846–51, Pl. CCLXXIX; P. B.-A., No. 2046; *Conferva Hookeri* Dillwyn, 1809, Pl. CVI. Kemp, as *C. spongiosum.* Pink Beach, Jan., Feb.,

March, Gravelly Bay, Feb., March, April, Hervey. At Pink Beach this plant grew buried in fine sand, on an exposed rock; at Gravelly Bay in the cave with *C. byssoideum* var. *jamaicense,* not as large nor as well fruiting as at Pink Beach. At that station it bore tetraspores along the upper edge of the ramuli, as figured by Harvey; antheridia in rounded tufts at the same points; cystocarps large, spherical to ovoid, on opposite sides of a branch; the three on separate individuals. Paraspores were often found at the ends of the ramuli, ovoid, of varying size, up to $50 \times 35\ \mu$ including the rather thick wall. Tetraspores were occasionally found on the individuals producing the paraspores, but no other organ of fructification. We saw no seriate paraspores, such as are found in *Seirospora Griffithsiana* Harv., but sometimes two were side by side, touching each other, at the end of an ordinary cell. Kylin, 1907, p. 152, figures and describes paraspores of *C. Hookeri,* but of quite a different type; they take each the place of a tetrasporangium, dividing to produce an indefinite number of spores, "polyspores" of most authors. De Toni, 1903, p. 1317, describes *C. Hookeri* with tetraspores and cystocarps, and vegetative characters quite as above, and adds "Cautissime haec a *Seirospora? Gaillonii,* quacum characteribus plurimis congruit, dignoscatur." The latter species is described by him, p. 1352, by vegetative characters and tetraspores only. There is practically no distinction as regards these characters between the descriptions of the two species. The final note under *S. Gaillonii* is "Seirosporae et cystocarpia (sec. Crouan) presentia." De Toni includes under *Seirospora,* with or without a ?, a number of species which do not seem to us to belong to that genus, and without any statement of his reasons for so assigning them; among them *Callithamnion byssoideum,* with var. *jamaicense* and three other varieties.

C. CORDATUM Börgesen, 1909, p. 10, figs. 5–6; P. B.-A., No. 2189. Washed ashore, Buildings Bay, Feb., Hervey. Abundant, but entirely sterile, so that the determination must remain doubtful, although the vegetative characters agree with Börgesen's description and figures.

GYMNOTHAMNION J. G. Agardh.

Plumaria Schmitz, not Stackhouse. The genus *Plumaria* was founded by Stackhouse, 1809, p. 58, *P. pectinata* type, with synonym *Fucus plumosus* Linnaeus. C. A. Agardh, apparently not knowing of this publication, proposed, 1817, p. XIX, the genus *Ptilota,* founded on the same *Fucus plumosus* L.; Agardh's genus has been generally accepted, and many recent species have been included in it. Ruprecht, however, 1856, p. 335, calls attention to the priority of Stackhouse's name, and makes the combination *Plumaria asplenioides,* and also uses the *P. pectinata* of Stackhouse. Otto Kunze, 1891, p. 911, takes the same position, and makes new combinations for 16 species of Ptilota, some of which, however, are unnecessary, as the species had already been properly transferred to *Euptilota* Kütz. Schmitz, 1889, p. 450, retains *Ptilota* for most of the species, including Stackhouse's type for *Plumaria,* but revivies *Plumaria* for *Ptilota elegans,* Bonnemaison, a species unknown to Stackhouse; and in 1896, p. 7, transfers to *Plumaria, Ptilota Schousboei* Bornet in Bornet & Thuret, 1876, p. 34, *Callithamnion elegans* Schousboei in Agardh, 1828, p. 162. Under the international rules of nomenclature, and probably under any rule, the name *Plumaria* must be retained for Stackhouse's type, *P. plumosa* and its congeners; *Ptilota* founded on the same species, has no standing, and the only name we find available for the species placed under *Plumaria* by Schmitz is *Gymnothamnion* J. G. Agardh, 1892, p. 27, type *Callithamnion elegans* Schousboe. Accepting this in place of *Plumaria* Schmitz, not Stackhouse, it will include *Gymnothamnion elegans* (Schousboe) J. G. Agardh, 1892, p. 27; *Callithamnion elegans* Schousboe in Agardh, 1828, p. 162; Bornet & Thuret, 1876, p. 32, Pl. X; *Ptilota Schousboei* Bornet in Bornet & Thuret, 1876, p. 34; *Plumaria Schousboei* Schmitz, 1896, p. 7. **G. sericeum** (Harvey) comb. nov.; *Ptilota sericea* Harvey,[18] 1846–1851, Pl. CXCI; *P. elegans* Bonnemaison 1828, p. 70; *Plumaria elegans* Schmitz, 1889, p. 450. **G. Harveyi** (Hooker) comb. nov.; *Ptilota Harveyi* Hooker, 1845, p. 271; *Plumaria Harveyi* Schmitz, 1896, p. 7. **G. pellucidum** (Harvey) comb. nov.; *Ptilota pellucida* Harvey in Hooker & Harvey, 1853–1855, p. 257; *Plumaria pellucida* Schmitz, 1896, p. 7; also a new species, described below.

The taxonomy is somewhat complicated; of the five species credited to this genus, two were published in 1828, *Ptilota elegans* and *Callithamnion elegans;* in 1876 Bornet transferred the latter to *Ptilota,* but as the specific name *elegans* was preoccupied, changed it to *P. Schousboei.* In 1896 Schmitz transferred both to *Plumaria* with specific names unchanged, but in 1892 J. G. Agardh had used *Callithamnion elegans* as the type of his new genus *Gymnothamnion,* hence

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18 *Fucus sericeus* Gmelin, 1768, p. 149, Pl. XV, fig. 3, from Kamtschatka, can hardly be a *Gymnothamnion.* See Ruprecht, 1856, p. 337.

in transferring to the latter the other species of Schmitz's *Plumaria*, a new specific name is needed for *Ptilota elegans*, and we have taken Harvey's name as the next in order.

G. bipinnatum sp. nov.; filamentis basalibus circa 20–25 μ diam., ramificatione opposita, cellulis diam. 4–5, raro 6–7 longis, membrana crassa, nodis subconstrictis; axibus erectis basi 20–25 μ diam. superne attenuatis, ad apicem circa 12 μ, cellulis cylindricis vel subclavatis, inferioribus circa 3 diam. longis, apicem prope 1–1½ diam.; ramis oppositis apice cellulae singulae exeuntibus, parallelis, angula 50°–60°, rectis vel leviter recurvatis, axi referentibus sed minoribus, raro 15 μ diam. superantibus; ramorum aliis simplicibus, aliis et pluribus ramulos secundatos latere superiore ferentibus; ramulis 1–2-cellularibus, perraro magis; circumscriptione frondis ovata vel lanceolata; cellulis terminalibus rotundatis. Filamentis prostratis ramulos rhizoideos descendentes ferentibus, axibus erectis oppositis, cellula terminali ad substratum disco affixa. Tetrasporangiis in ramis et ramulis terminalibus, sphaericis vel subovoideis, 30–35 μ diam., tripartitis. Plate IV, fig. 26.

Basal filaments about 20–25 μ diam., with opposite branching, cells 4–5 diam. long, rarely 6–7, wall thick, nodes somewhat constricted; erect axes of about the same size near the base as the prostrate filaments, diminishing to 12 μ at apex; cells about 3 diam. long at base, near apex 1–1½ diam., cylindrical or slightly clavate, each bearing at the upper end a pair of opposite branches, forming an angle of 50–60° with the axis, straight or slightly recurved, similar to the axis, but averaging smaller, seldom over 15 μ diam.; these branches either simple or more commonly bearing on the upper side, on part or all of the cells, a second series of branches, 1–2 cells long, rarely more, 8–10 μ diam.; outline of frond ovate or lanceolate; terminal cells all rounded. Basal filaments producing, opposite to the erect axes, rhizoids of one or many cells, the end cell forming a disk of attachment when it reaches the substratum. The end of a basal filament sometimes becoming erect and developing into a frond similar to the erect axes; the erect axis sometimes extending beyond the pinnation, and after an indefinite number of unbranched cells, developing a second series of branches; or the prolonged naked axis descending and forming a prostrate filament bearing erect axes and rhizoids. Tetrasporangia terminal on the branches of the first and second orders, spherical or slightly ovoid, 30–35 μ diam., tripartite. Cystocarps? Antheridia? On wall of cave, Gravelly Bay, April, Hervey, type in Collins herbarium; on *Wurdemannia*, Harrington

Sound, Jan., cave, Agar's Island, July, Aug., shore of Gibbet Island, Aug., cave, Ducking Stool, Dec., Collins. Tetraspores in April, Aug. and Dec.

Growing on walls and roofs of caves, or in smaller cavities in rocks, usually among other algae with a creeping base, such as *Rhodochorton* and *Spermothamnion.* We have found this quite a puzzling form, as there are three European species, in different genera, of similar size and habit, and with tetraspores similarly placed. Two of these, *Ptilothamnion pluma* Bornet in LeJolis, 1863, p. 118 and *Plumaria Schousboei* (Bornet) Schmitz, 1896, p. 7, while differing in cystocarps and antheridia, are almost identical otherwise, but a comparison of the plates, Bornet & Thuret, 1876, p. 32, Pl. X, and Bornet & Thuret, 1880, p. 179, Pl. XLVI, shows that the *Plumaria* has shorter cells throughout, and that the branches arise at the upper edge of the cells of the axis, while in the *Ptilothamnion* they are distinctly lower. The Bermuda plant agrees exactly with *Plumaria Schousboei* in form and proportions of cells, and place of insertion of branches; on that account we have placed it in the genus Gymnothamnion, recognizing, however, that when the sexual fruit is discovered, a different disposition may be necessary. The uniformly opposite character of the branching is quite noticeable; even in the prostrate filaments any other branching is rare and evidently abnormal, though in most species with opposite branching in the erect parts, the basal part is apt to vary from this. Moreover, every rhizoid that we have observed is opposite to an erect axis. Bornet and Thuret, describing *P. Schousboei,* say "ils adherent par des crampons semblables a ceux des Spermothamnion et des Polysiphonia"; but an examination of Pl. X, fig. 1, shows all the rhizoids opposite to erect axes, while this is not the case in *Spermothamnion flabellatum* shown in Pl. VIII, fig. 1. We are led to keep the Bermuda plant separate from *P. Schousboei* principally from the fact that all well developed fronds bear erect branches of a second order, in luxuriant individuals one such branch from every cell of a branch of the first order, always on the upper side of the latter. If these branches were in pairs, the distinction would be less important, and might mean merely a repetition of the normal branching in luxuriant individuals, but we have never seen an outgrowth from the under side of a branch of the first order. Curiously enough, this mode of branching is identical with that of *Antithamnion pteroton* (Schousb.) Bornet, 1892, p. 331, Pl. III, figs. 8–9, in regard to which the author says, "Cette élégante petite Algue ressemble beaucoup aux *Callithamnion pluma* et *elegans* mais elle est plus délicate, d'une couleur plus rose. Elle s'en distingue surtout, parce que ses pinnules, lorsqu'elles sont bien developpées, portent des pinnules de second ordre sur leur bord superieur et que les tétraspores sont divisés en croix." The tetraspores in the Bermuda plant are distinctly tripartite. As a secondary distinction we would note that a prostrate axis can become erect and an erect axis prolong itself and either develop a new branch system at some distance from the old, or be transformed into a prostrate axis.

The type specimen of the species is No. 7521 in the Collins herbarium; from the cave at Gravelly Bay, collected by Hervey in April, 1913.

ANTITHAMNION Nägeli.

A. CRUCIATUM (Ag.) Nägeli, 1847, p. 200; P. B.-A., No. 2191 *Callithamnion cruciatum* Agardh, 1827, p. 637; Harvey, 1846–51, Pl. CLXIV. Abundant and luxuriant on an old wreck, Castle Harbor, St. George's, April, on rock, Spanish Point, March, May, small form in cave, Gravelly Bay, Dec., Hervey.

Var. **radicans** (J. Ag.) comb. nov.;[19] P. B.-A., No. 2047; *A. cruciatum F. radicans* Hauck, 1885, p. 71; *Callithamnion cruciatum* var. *radicans* J. G. Agardh, 1841, p. 44. Creeping on perpendicular or overhanging rocks between tides, North Shore opposite Gibbet Island, Aug., Collins; Dec., Hervey. The main axis is prostrate, about 40 μ diam., the cells cylindrical, 2–5 diam. long; near the upper end of each cell is a pair of opposite branches; whorled branches were not seen. Successive pairs of branches are not in the same plane, but are more or less exactly decussate. The lower cell of each branch is short, no longer than broad, more or less rounded; the following cells are 2–4 diam. long, growing shorter upward; the diam. at the base of the branch, 20–25 μ. The short basal cell often bears a long, simple, rhizoidal branch, the cells up to 10 diam. long, about 15 μ diam., of paler color than cells elsewhere in the plant; the terminal cell of this rhizoid may form a discoid expansion, attaching itself to the substratum. All normal branches, whether issuing from the upper or the lower surface of the main filament, turn upwards; their branching is always alternate, a ramulus from each cell, all nearly or quite

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19 This combination occurs in Collins, 1900, p. 48, attributed by error to J. G. Agardh. No synonymy being given, it can hardly be considered a publication. The difference from the typical *A. cruciatum* seems too great to consider it as a form, as was done by Hauck.

in the same plane; these branches are of 2 or 3 orders, the ultimate about 12 μ diam., the cells about 2 diam. long, nodes more or less constricted; the end cell is distinctly acuminate or subulate. "Drusenzellen" are abundant, borne usually on the inner side of the lower cell of an ultimate branch, in the same way as a tetrasporangium; they are spherical, about 20 μ diam., or slightly elongate, $18 \times 24\ \mu$, with rather thin wall, strongly refringent, yellowish or pale aeruginous contents. Occasionally the cells of a branch or of a system of branches assume a spherical form, as if becoming seirospores, but the contents do not seem to become darker or denser; the end cell rounds the lower end, but remains pointed above. No fructification was observed. The plant is very small, the axis seldom over 1 cm. long, the branches hardly 1 mm.; it is possible that this is not the variety *radicans* of J. G. Agardh, of which we have not seen type specimens. Descriptions as far as we know have been short and imperfect, which has led us to describe the Bermuda plant in rather full detail.

Crouania J. G. Agardh.

C. attenuata (Bonnem.) J. G. Agardh, 1842, p. 83; Harvey, 1853, p. 226, Pl. XXXI. D; P. B.-A., No. 2048; *Batrachospermum attenuatum* Bonnemaison in Agardh, 1824, p. 51, as synonym under *Mesogloia attenuata*. Very young plants on *Caulerpa*, Harris Bay, Jan., Nov., plants up to 1 dm. high, washed ashore, Buildings Bay, Feb., March, Hervey.

Spyridia Harvey.

1. Branching mostly distichous.	3. S. complanata.
1. Branching radial.	2.
2. Recurved prickles at ends of ramuli.	2. S. aculeata.
2. No recurved prickles.	1. S. filamentosa.

1. S. filamentosa (Wulf.) Harvey in Hooker, 1833, p. 337; Harvey, 1846–51, Pl. XLVI; P. B.-A., No. 1897; *Fucus filamentosus* Wulfen, 1803, p. 64. Kemp; Tucker's Town, Feb., Harrington Sound, Jan., Feb., Nov., Hervey. Abundant, probably everywhere about the islands. Occasionally handsome plants can be found, but they are mostly matted and unattractive. The three species of *Spyridia* are much alike in habit; but generally easily distinguished on microscopic examination.

2. S. aculeata (Schimper) Kützing, 1843, p. 327; 1862, Pl. LI;

Ceramium aculeatum Schimper in Decaisne, 1841, p. 179. Kemp; Merriman; Harris Bay, Nov., Harrington Sound, Aug., Hervey. Tetraspores in Nov.

Var. BERKELEYANA (Mont.) J. G. Agardh, 1876, p. 272; *S. Berkeleyana* Montagne, 1846, p. 141, Pl. XV, fig. 8. Dense tufts on exposed flat rocks at low water, Gravelly Bay, April, Collins, with tetraspores. In this variety the recurved prickles characteristic of the species are usually present, but may sometimes be lacking, in which case it approaches *S. filamentosa.*

Var. HYPNEOIDES J. G. Agardh, 1876, p. 272; P. B.-A., No. 1946. Castle Harbor, near Walsingham House, April, Harris Bay, March, April, Hervey; tetraspores in collections of both months. The hooked tips of some of the branches, similar to those of *Hypnea musciformis,* characterize this form. The specimen marked *C. aculeata* in the Kemp herbarium belongs to this variety.

3. S. COMPLANATA J. G. Agardh, 1851, p. 343; 1876, p. 271; P. B.-A., No. 1947. Harris Bay, Jan., Feb., April, Pink Bay, March, Hervey; Hungry Bay, Nov., Elbow Bay, Dec., Collins. Growing in dense tufts on flat rocks near low water.

CERAMIUM Agardh.

1. Cortication continuous.	2.
1. Cortication at nodes only.	3.
2. Corticating cells in longitudinal series.	5. C. clavulatum.
2. Corticating cells not in series.	4. C. nitens.
3. Main axis creeping, attached by rhizoids.	4.
3. Main axis erect.	1. C. tenuissimum.
4. Tetraspores cruciate.	2. C. cruciatum.
4. Tetraspores tripartite.	3. C. transversale.

1. C. TENUISSIMUM (Lyng.) J. G. Agardh, 1851, p. 120; 1876, p. 94; P. B.-A., No. 1898. *C. diaphanum* var. *tenuissimum* Lyngbye, 1819, p. 120, Pl. XXXVII. B, fig. 4; *C. nodosum* Harvey, 1846–51, Pl. XC. Miss Peniston; Harrington Sound, March, Wadsworth; Harris Bay, Jan., Heron Bay, March, Harrington Sound, April, Hervey; Hungry Bay, May, Fairyland, Dec., floating, Collins. This is the plant that passes by this name on the New England coast, and also Miss Vickers Algues de la Barbade, No. 199; it does not have the reniform cells considered characteristic of *C. tenuissimum* by Petersen, 1908, p. 54, Pl. III; but in the present uncertainty of specific limitations in *Ceramium,* it had better retain the present name. No fruit of any kind has been observed by us.

Var. PATENTISSIMUM (Harv.) Farlow, 1881, p. 138; *C. arachnoideum* var. *patentissimum* Harvey, 1853, p. 217, Pl. XXXIII. B. Heron Bay, Jan., Hervey. The frequent wide forkings give a habit quite different from the typical form, but there is agreement in essentials.

Var. ARACHNOIDEUM (Ag.) J. G. Agardh, 1851, p. 117; 1876, p. 94; P. B.-A., No. 2098. *C. arachnoideum* Harvey, 1853, p. 217; *C. diaphanum* var. *arachnoideum* Agardh, 1824, p. 134. On *Cymodocea* and various algae, Grasmere, Feb., Harvey. A very slender and delicate form, but otherwise like the typical form.

Var. PYGMAEUM (Kütz.) Hauck, 1888, p. 460; P. B.-A., No. 2193; *Hormoceras pygmaeum* Kützing, 1862, p. 23, Pl. LXXV. On *Codium decorticatum*, Cooper's Island, Aug., Collins. With tetraspores.

2. **C. cruciatum** sp. nov.; P. B.-A., No. 2192. Minuta, ad algas alias repens; filamentis prostratis circa 200 μ diam., cylindricis vel ad nodos leviter constrictis, rhizoidis unicellularibus incoloratis affixis; filamentis erectis passim ad nodos evolutis; apice filamenti prostrati assurgente, in filamentum erectum transformato; cellulis inferne circa 3 diam. longis, superne brevioribus, prope apicem diametro brevioribus; ramulis penultimis 80–100 μ diam.; ramis repetite dichotomis, cellulis cylindricis vel plus minusve ad nodos constrictis; apicibus forcipatis; corticatione cellulis sensu filamenti elongatis constante, irregulariter positis, zonam arctam formante margine inaequali. Protoplasma cellularum inferiorum subcylindricum, superiorum subsphaericum, fasciis tenuissimis longitudinalibus notata, raro anastomosantibus, nec longitudinem cellulae aequantibus, plerumque spatio latitudinem fasciae aequali separatis. Tetrasporangiis ovoideis, circa $50 \times 35\,\mu$, membrana 6 μ crassa non inclusa, 1–4 ad nodum, cruciatis, modo regulariter, modo decussate; aut singulis ad nodum, seriem externalem longitudinalem formantibus, aut pluribus nodum circumdantibus; dimidio sporangii extra corticem emergente. Plate IV, figs. 27–28.

Minute, creeping on other algae; prostrate filaments of about 200 μ diam., cylindrical or slightly constricted at nodes, attached by unicellular, colorless rhizoids, issuing from the nodes; erect filaments occasionally arising at nodes; apex of prostrate filament becoming erect and assuming the character of an erect filament; cells about 3 diam. long below, diminishing towards the apex, to less than one diam.; penultimate branches 80–100 μ diam.; branches repeatedly forking, cells cylindrical or with nodes more or less constricted; apices forcipate; cortication consisting of cells elongate in the direction of the filament, in no definite order, band narrow, edge uneven.

Protoplast subcylindrical in the lower cells, subspherical in the upper, marked with a pattern of delicate, longitudinal bands, seldom anastomosing or extending the length of the cell, usually separated by spaces of about their own width. Tetrasporangia ovoid, about 50 × 35 μ, excluding wall about 6 μ thick, 1–4 at a node, cruciate, sometimes regularly, sometimes decussately; when singly at a node they form an external longitudinal series; when more than one, they are irregularly placed about the node; about half of the sporangium projecting beyond the cortication. On *Padina variegata*, Gibbet Island, Jan. 16, 1913, Hervey, type in Collins herbarium, No. 7418a; also on *Galaxaura*, Gravelly Bay, April, on various algae, Hamilton Harbor, Dec., Collins.

In habit like the following species, *C. transversale*, but a larger plant, and distinct by the division and position of the tetraspores, and the character of the cortication. Only tripartite tetraspores have been recorded for any of the numerous species of *Ceramium*, but as other characters agree, it does not seem desirable to remove it from the genus.

3. **C. transversale** sp. nov.; P. B.-A., No. 2049. Minuta, ad alias algas saxaque repens; filamento prostrato 60–90 μ diam., cellulis sesqui-8 diam. longis, cylindricis vel ad nodos leviter contractis, rhizoidis unicellularibus, incoloratis affixis, ad nodos singulis pluribusve ortis; filamentis erectis passim ad nodos evolutis; filamenti prostrati apice assurgente, in filamentum erectum transformato; ramulis penultimis circa 60 μ diam.; filamentorum erectorum cellulis ad 2 diam. longis, non amplius; prope apicem diametrum non aequantibus; filamentis erectis repetite dichotomis; cellulis inferioribus cylindricis, superioribus adparenter brevissime clavatis, causa corticationis ad apicem; corticatione a parte corticata distinctissima, super seriem cellularum transverse elongatarum series 2 vel 3 cellularum rotundo-angulatarum irregulariter positarum gerente. Protoplasma uniformiter granulosum vel striis tenuibus, parallelis, longitudinalibus notatum per totam longitudinem cellulae; in cellulis inferioribus cylindrica, in superioribus subsphaerica. Cystocarpio evoluto ad apicem segmenti 2–5-cellularis, cellulis supra incrassatis, cellula summa cellulam imam duplo plusve majore, nonnullos ramos paucicellulares involucrales, cystocarpios 1–2 includentes gerente; cystocarpiis adparenter terminalibus, atque axi plerumque ultra cystocarpios et involucrem protenso, ex cellulas paucas constante, cellula basali 2–3 diam. longa, ceteris, ut cellulis involucri, vix 1 diam. Tetrasporangiis tripartitis, ad 60 μ diam., membrana 8 μ crassa non

inclusa; uno, raro duobus ad nodum, corticatione fere liberis, secundum ramum longitudinaliter seriatis. Plate V, figs. 29–31.

Minute, creeping over other algae or rocks; prostrate filaments 60–90 μ diam., cells $1\frac{1}{2}$–8 diam. long, cylindrical or slightly constricted at nodes, attached by colorless, unicellular rhizoids issuing one or more at a node; an erect branch occasionally issuing at a node; apex of prostrate filament becoming erect and similar to an erect branch; penultimate branches about 60 μ diam.; cells in erect part not over 2 diam. long, near the apex less than one diam.; repeatedly forking; lower cells cylindrical, upper apparently very shortly clavate by the growth of cortication at the upper end; cortication sharply marked off from uncorticated portion, the lower portion of each band showing a series of transversely elongate cells passing around the central cell; the upper part of 2–3 series of irregularly placed roundish-angular cells. Protoplast uniformly granular, or with slender, parallel, longitudinal striations the whole length of the cell; the protoplast cylindrical in the lower cells, subspherical in the upper. Cystocarp borne at the end of a segment of 2–5 cells, which increase in size upward, the upper cell being twice the diam. of the lower or even more; on this are borne several wide-spread, few-celled involucral branches with one or two cystocarps between them, the cystocarps appearing terminal, but with usually an axis extended beyond them and the involucre, of few cells, the basal cell 2–3 diam. long, the others, as all the cells in the involucre, hardly 1 diam. long. Tetrasporangia tripartite, up to 60 μ diam. not including the wall 8 μ thick; one, occasionally two at a node, in longitudinal series, nearly free from the cortication.

On *Galaxaura*, Spanish Rock, April 10, 1914, Hervey, type in Collins herbarium, No. 8107. Also occurring on *Zonaria variegata*, Harrington Sound, May, on *Padina variegata*, Agar's Island, Nov., on *Thalassia*, Fairyland, Dec., Collins; on *Ascothamnion*, Tucker's Town, July, Howe.

The peculiar form of cortication, from which we have taken the specific name, does not seem to occur in any other species. *C. miniatum* Suhr, resembling it in some respects, has distichous branching, and small tetrasporangia sessile on both sides of the branches. Specially characteristic of *C. transversale* are the serrate outlines near the apices, due to the sharp limitation of the cortical growth there, and the tetraspores unusually large in proportion to the size of the frond. When two tetrasporangia are formed at a node, they are set side by side, the line made by the series of single sporangia passing between them. The cystocarps appear as if terminal, as the short prolongation of the axis is liable to be mistaken for an involucral branch. In younger parts the cells of the basal layer are seldom over 2 diam. long; in older parts these cells may be up to 8 diam.; the corticating band does not increase in width, but is as narrow and sharply limited in the longest cells as in the others.

4. C. NITENS (Ag.) J. G. Agardh, 1851, p. 130; P. B.-A., No. 1949; *C. rubrum* var. *nitens* Agardh, 1824, p. 136. Harrington Sound, Jan., Dec., Hervey; Inlet, Aug., Agar's Island, Fairyland, Nov., Dec., and dredged down to 18 m., Dec., Collins.

5. C. CLAVULATUM Agardh in Kunth, 1822, p. 2; P. B.-A., No. 1948; *Centroceras clavulatum* Harvey, 1853, p. 211, Pl. XXXIII. C. Rein; Kemp; Wadsworth, Harrington Sound, No. 18. As this plant is abundant practically everywhere, we give no detail of stations of our own collecting. It is very variable, and many species have been proposed in the past, only to be found unworkable; it may be that some time a successful segregation will be made, but it can hardly be done with habit characters, which are very inconstant. Tetraspores were found in Nov. & Dec., but no other fructification has been observed by us. In the Kemp herbarium are specimens marked respectively *C. rubrum* and *C. fastigiatum*, which belong to this species. *C. cryptacanthum* reported by Moseley is a synonym.

RHODOCHORTON Nägeli.

1. Saxicolous; prostrate filaments bearing erect filaments.
 1. R. speluncarum.
1. Endozoic; in tubes of bryozoans etc. 2. R. membranaceum.

1. **R. speluncarum** sp. nov. Filamentis prostratis 30–40 μ diam., membrana 4–5 μ crassa, cellulis 2–3 diam. longis; rhizoideis brevibus affixis, a parte media cellulae exeuntibus, in discum majorem minoremve desinentibus. Filamentis erectis cylindricis vel minime diminutis apicem versus, e superficie superiore filamenti prostrati exeuntibus, prope mediam partem cellulae, saepius rhizoideis oppositis, 24–30 μ diam., membrana 2–3 μ crassa, cellula inferiore 2–2½ diam. longa, cellulis ceteris 3–4 diam. longis, cellula terminali rotundata; filamentis erectis aut simplicibus aut ramis paucis alternatis vel secundis prope apicem munitis. Fructificatio ignota.

Prostrate filaments 30–40 μ diam., wall 4–5 μ thick, cells 2–3 diam. long, attached by short rhizoidal branches issuing from the middle part of a cell, ending below in a larger or smaller disk. Erect filaments cylindrical or very slightly tapering, issuing from the upper surface of the prostrate filament, near the middle of a cell, usually opposite a rhizoid, 24–30 μ diam., walls 2–3 μ thick, lower cell 2–2½ diam. long, other cells 3–4 diam. long, terminal cell rounded; erect filaments sometimes unbranched, sometimes with a few alternate or secund branches near the apex. Fructification unknown. On rocks between tides, cave, Agar's Island, Aug., Nov., Collins.

This plant forms a plush on flat rocks a little above low water mark, as does *R. Rothii* (Turton) Näg. in similar stations on the shores of the North Atlantic, and its manner of branching resembles that of the latter species but its dimensions are about double. We have examined many specimens of *R. Rothii,* from both coasts of North America as well as from Europe, and find very little variation in size among them. In *R. speluncarum* the chromatophores are numerous small granules, usually densely packed, occasionally looser and showing something like a network. Type in Collins herbarium, No. 8401, Nov. 23, 1915.

2. R. MEMBRANACEUM (Magnus) Hauck, 1885, p. 69; *Callithamnion membranaceum* Magnus, 1874, p. 67, Pl. II, figs. 7–15. In bryozoans, Bethel's Island, Dec., Collins.

FAMILY GRATELOUPIACEAE.

HALYMENIA Agardh.

1. Frond many times dichotomous, digitate, cylindrical. 4. H. Agardhii.
1. Frond plane, simple or proliferous. 2.
   2. Thin, not gelatinous. 1. H. bermudensis.
   2. Thicker, gelatinous. 3.
3. Large echinate cells in subcortex. 2. H. echinophysa.
3. Few or no echinate cells in subcortex. 3. H. pseudofloresia.

1. H. BERMUDENSIS Collins & Howe, 1916, p. 169; P. B.-A., No. 2050; Plate V, fig. 34, plate VI, fig. 37. In shallow water in clefts of rocks and among roots of mangroves, often in loose, unattached masses. Kemp. Aug., as *Rhodymenia palmata;* Walsingham, Feb., Farlow; Oct., Miss Peniston; near Hamilton, June, Tucker's Town, July, Howe; Green Bay, March, Wadsworth; Harrington Sound, Jan., Tucker's Town, Feb., Dec., Dingle Bay, March, Grasmere,

March, Old Ferry, April, Hervey; Castle Harbor, April, Tucker's Town, May, Collins.

2. H. ECHINOPHYSA Collins & Howe, 1916, p. 180. Dredged in 31 fathoms off Bermuda by members of the Challenger Expedition, 1873, and reported, Moseley, 1884, p. 117, as *Kallymenia reniformis* J. Ag. Type and only specimen in herbarium of Royal Botanic Garden, Kew, England.

3. H. PSEUDOFLORESIA Collins & Howe, 1916, p. 177; P. B.-A., No. 2099; Plate V, fig. 35, plate VI, fig. 36. Faxon; Feb., Farlow; Green Bay, Feb., Shark's Hole, March, Wadsworth; Castle Harbor near Tucker's Town, April, Collins; Walsingham, Jan., Hervey; Aug., H. A. Cross. At Castle Harbor in narrow shaded clefts of rocks, well below low water mark; at Walsingham loose and unattached, the older parts darker and coarser than the young growth.

The three preceding species show some superficial resemblance in habit, but we consider them distinct. Full details will be found in Collins & Howe, 1916.

4. H. AGARDHII De Toni, 1905, p. 1543; *H. decipiens* of American authors, not of J. Ag. Oct., Miss Peniston; W. Faxon; Castle Harbor, in 2–3 meters water, July, Howe; at low water mark, under overhanging rocks, shore near Gibbet Island, Aug., Collins.

CRYPTONEMIA J. G. Agardh.

1. Midrib distinct.	2. C. luxurians.
1. No midrib.	1. C. crenulata.

1. C. CRENULATA J. G. Agardh, 1847, p. 11; Kützing, 1869, Pl. XXXI; P. B.-A., No. 2100. Kemp; Gravelly Bay, April, Collins, Dec., Hervey. In somewhat matted masses in the cave at this station, on a sand-covered rock; a smaller form than that commonly found in Florida.

2. C. LUXURIANS (Ag.) J. G. Agardh, 1851, p. 228; *Sphaerococcus Lactuca* var. *luxurians* Agardh, 1822, p. 232; *Euhymenia luxurians* Kützing, 1869, Pl. XXXII. Kemp, as *Botryoglossum platycarpum;* Cooper's Island, Miss Wilkinson; Buildings Bay, Jan., Hervey. Apparently not common.

Family DUMONTIACEAE.

Dudresnaya Bonnemaison.

1. Peripheral filaments cylindrical or nearly so.	1. D. crassa.
1. Peripheral filaments distinctly moniliform.	2.
2. Auxiliary cell terminating the auxiliary branch.	3. D. caribaea.
2. Auxiliary cell in middle of auxiliary branch.	2. D. bermudensis.

1. D. crassa Howe, 1905, p. 572, Pl. XXVIII, XXIX, figs. 12–26; P. B.-A., Nos. 1900, 2196. Castle Harbor, Spanish Point, July, Howe; Castle Harbor, A. E. Wight in Farlow herb.; Salt Kettle, Feb., Buildings Bay, March, Spanish Point, March, Hervey; Shelly Bay, April, Collins. The plants from Buildings Bay, Spanish Point and Shelly Bay were washed ashore; at Salt Kettle, Paget, it grew just below low water mark; at the type station in Castle Harbor it grew at 3 m. depth at low water. It varies much in habit, from the form with short, stout branches, figured by Howe, to forms with slender, acute branches; from generally rounded outline to loosely pyramidal; from forms so dense that when spread out on paper they cover it continuously, without interstices between the branches, to quite open specimens, all branches distinct. The largest plant noted was about 25 cm. high and 15 cm. broad. Howe had only cystocarpic plants when describing the species, but we have found antheridia equally abundant, always on separate individuals. The antheridia are formed near the ends of the peripheral filaments, which here bear short, erect lateral branches, usually covered with minute densely branched ramuli of a few cells each, the terminal cell becoming the antheridium. According to the length of the axis and the amount of branching in the ramulus, the antheridia may be cylindrical, conical or ovoid. Sometimes the antheridia are so abundant on the peripheral filaments as to form a dense continuous mass, through which it is difficult to see the filaments, except the tips, which project beyond the antheridia. Both antheridial and cystocarpic plants were distributed as P. B.-A., No. 1900. Some forms are habitually not unlike *D. caribaea* and *D. bermudensis,* but are easily distinguished microscopically by the character of the peripheral filaments. It is often overgrown with *Acrochaetium corymbiferum,* and when both have abundant antheridia, it may be perplexing to one unfamiliar with the species.

2. D. bermudensis Setchell, 1912, p. 244, Pl. XXVII, fig. 8; P. B.-A., No. 2195. Cooper's Island, Feb., Farlow, washed ashore in abundance; St. George's, washed ashore, March, Hervey.

3. D. caribaea (J. Ag.) Setchell, 1912, p. 241, Pl. XXVI; *Calosiphonia caribaea* J. G. Agardh, 1899, p. 84. Cooper's Island, Feb., Farlow; washed ashore in abundance. This species and the preceding are very much alike in habit, and can be distinguished with certainty only by microscopic examination of plants in fruit.

These three species of *Dudresnaya* illustrate the possibilities of algae collecting. *D. bermudensis* is known only from Bermuda, from the material collected by Farlow on a single day in 1881 at Cooper's Island, and from a single collecting at St. George's in 1916 by Hervey; the Bermudian material of *D. caribaea* was all collected on the same day in 1881, and only one other station, Tortugas, Florida, is known; *Calosiphonia verticillifera* was collected at the same day and place, and is known elsewhere from the Tortugas station only. Material of all three species was abundant that day, but there is no record of any one of the species since, except the single collecting of *D. bermudensis,* though we have both been on the watch for them for the past five years, and have made visits to Cooper's Island at the same time of year as Farlow's collecting and at other times, to search for them. On the other hand we have found *D. crassa,* not known until 1905, in abundance at distant stations.

Family NEMASTOMACEAE.

Calosiphonia Crouan.

C. verticillifera (J. Ag.) Setchell, 1912, p. 247, Pl. XXVIII; *Helminthiopsis verticillifera* J. G. Agardh, 1899, p. 98. Cooper's Island, Feb., Farlow. As noted under *Dudresnaya,* this is one of the three species of handsome red fleshy algae, found in abundance on the same day in 1881, at Cooper's Island, and not observed since. In habit it is not unlike *Dudresnaya,* but is distinguished on microscopic examination by the shorter and stouter peripheral branches, forming a definite cortical layer.

Platoma Schmitz.

P. cyclocolpa (Mont.) Schmitz, 1889, p. 453; *Halymenia cyclocolpa* Montagne, 1840, p. 163; 1846, p. 116, Pl. XI, fig. b; *Nemastoma cervicornis* J. G. Agardh, 1879, Pl. IV, figs. 1–4. Cooper's

Island, Feb., Farlow, washed ashore; Castle Harbor, Gravelly Bay, April, Collins; Gravelly Bay, Dec., Hervey. Two large plants were collected in a narrow "chasm" in the rocky shore between Tucker's Town and Walsingham House, growing in company with *Halymenia bermudensis,* but while the latter grew plentifully at low water mark, the *Platoma* began about 5 dm. below, and seemed to extend down. Farlow's plants and ours from the cave at Gravelly Bay are smaller and of firmer substance; the Castle Harbor plants larger and looser, probably on account of being more developed.

Genus incertae sedis.

Porphyridium Nägeli.

P. cruentum (Eng. Bot.) Nägeli, 1849, pp. 71 & 139, Pl. IV. H; *Tremella cruenta* Eng., Bot., 1807, Pl. 1800. Roadside, Jan., Farlow. Forms a bright red film on the ground; is widely distributed and in northern countries is common in hothouses. It has been placed by different authors among green, blue-green and red algae respectively, but the latest investigations incline to the last. See Brand, 1908, p. 413.

SUMMARY.

Class.	Genera.	Species, marine.	Species, fresh water.
Myxophyceae	43	48	40
Chlorophyceae	56	95	28
Phaeophyceae	24	56	
Rhodophyceae	62	143	
Total	185	342	68
Total species		410	

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20 Though really only one edition was published of the Species Algarum of C. A. Agardh, copies are found with title pages of varying dates. As to actual dates of publication, see O. Nordstedt, The date of C. Agardh's Species Algarum, Bot. Notiser, 1914, p. 144.

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EXPLANATION OF PLATES.

PLATE I.

Oedogonium consociatum Collins & Hervey.

FIGURE 1. Large cluster of young filaments. 255 × 1.
FIGURE 2. Smaller cluster of same. 255 × 1.
FIGURE 3. Single filament with attached basal cell. 550 × 1.
FIGURE 4. Filament with oogonium (immature). 550 × 1.

Chaetomorpha minima Collins & Hervey.

FIGURE 5. Filament of two cells. 800 × 1.
FIGURE 6. Filament of five cells. 550 × 1.
FIGURE 7. Filament of five emptied cells. 550 × 1.

Nitophyllum Wilkinsoniae Collins & Hervey.

FIGURE 8. Whole plant. $\frac{4}{5}$ nat. size.

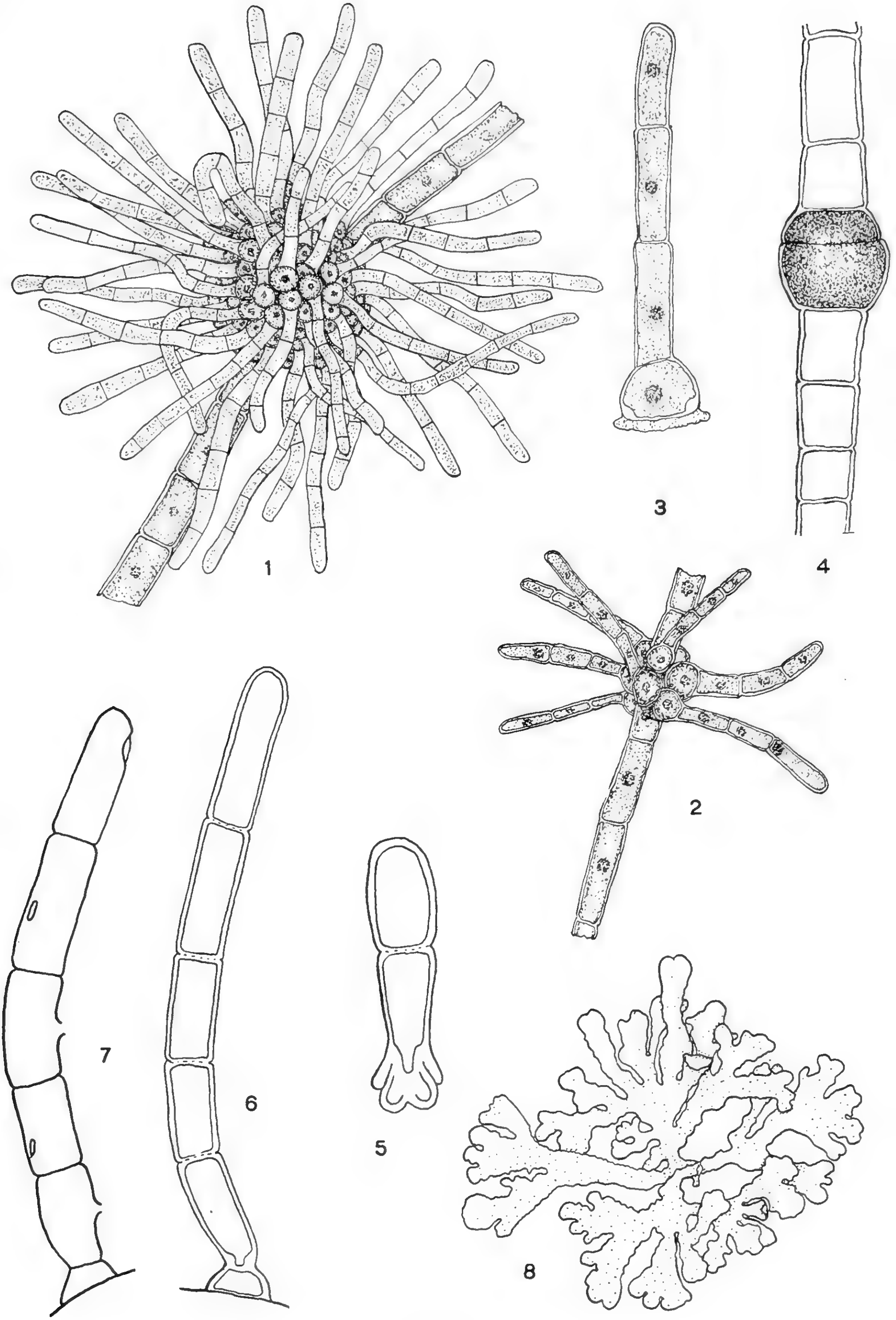


PLATE I.

PLATE II.

Nitophyllum Wilkinsoniae Collins & Hervey.

Figure 9. Margin of frond. 120 × 1.

Chondria curvilineata Collins & Hervey.

Figure 10. Portion of branch with ramulus and terminal leaves. 255 × 1.
Figure 11. Optical section of branch. 255 × 1.

Chondria polyrhiza Collins & Hervey.

Figure 12. Branch with rhizoids and tetraspores. 240 × 1.

Lophosiphonia Saccorhiza Collins & Hervey.

Figure 13. Tip of erect axis. 600 × 1.
Figure 14. Ramulus with tetraspores. 600 × 1.

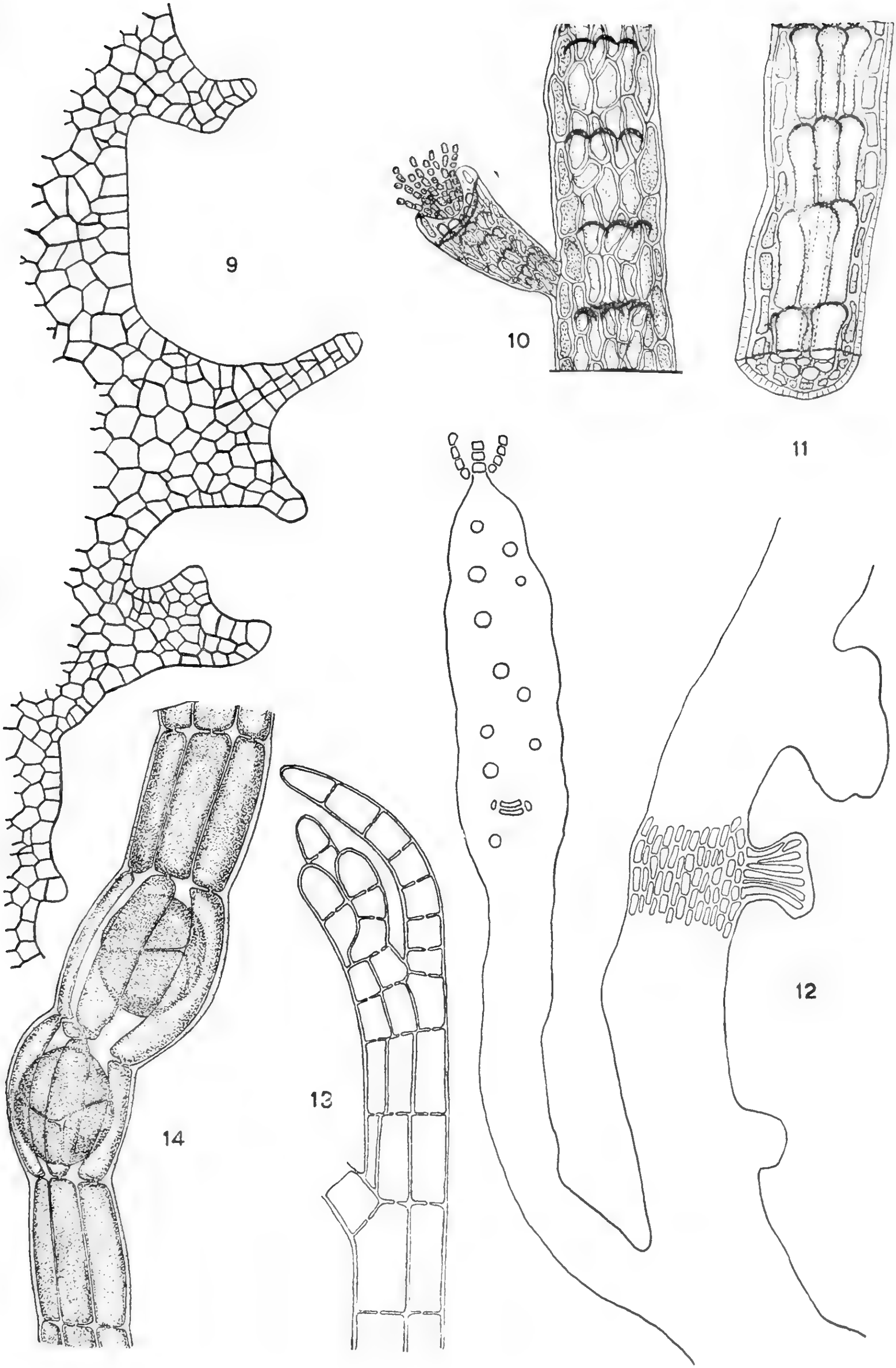


Plate II.

PLATE III.

Lophosiphonia Saccorhiza Collins & Hervey.

FIGURE 15. Tip of erect axis with antheridium and leaves. 330 × 1.
FIGURE 16. Cystocarp. 330 × 1.
FIGURE 17. Prostrate filament with rhizoids. 120 × 1.

Lophosiphonia bermudensis Collins & Hervey.

FIGURE 18. Prostrate filament with rhizoids and erect branches. 160 × 1.
FIGURE 19. Antheridia. 160 × 1.
FIGURE 20. Cystocarp. 160 × 1.
FIGURE 21. Tetrasporangia. 160 × 1.

Ceramothamnion Codii H. M. Richards.

FIGURE 22. Lateral union of two rhizoids from same node. 310 × 1.

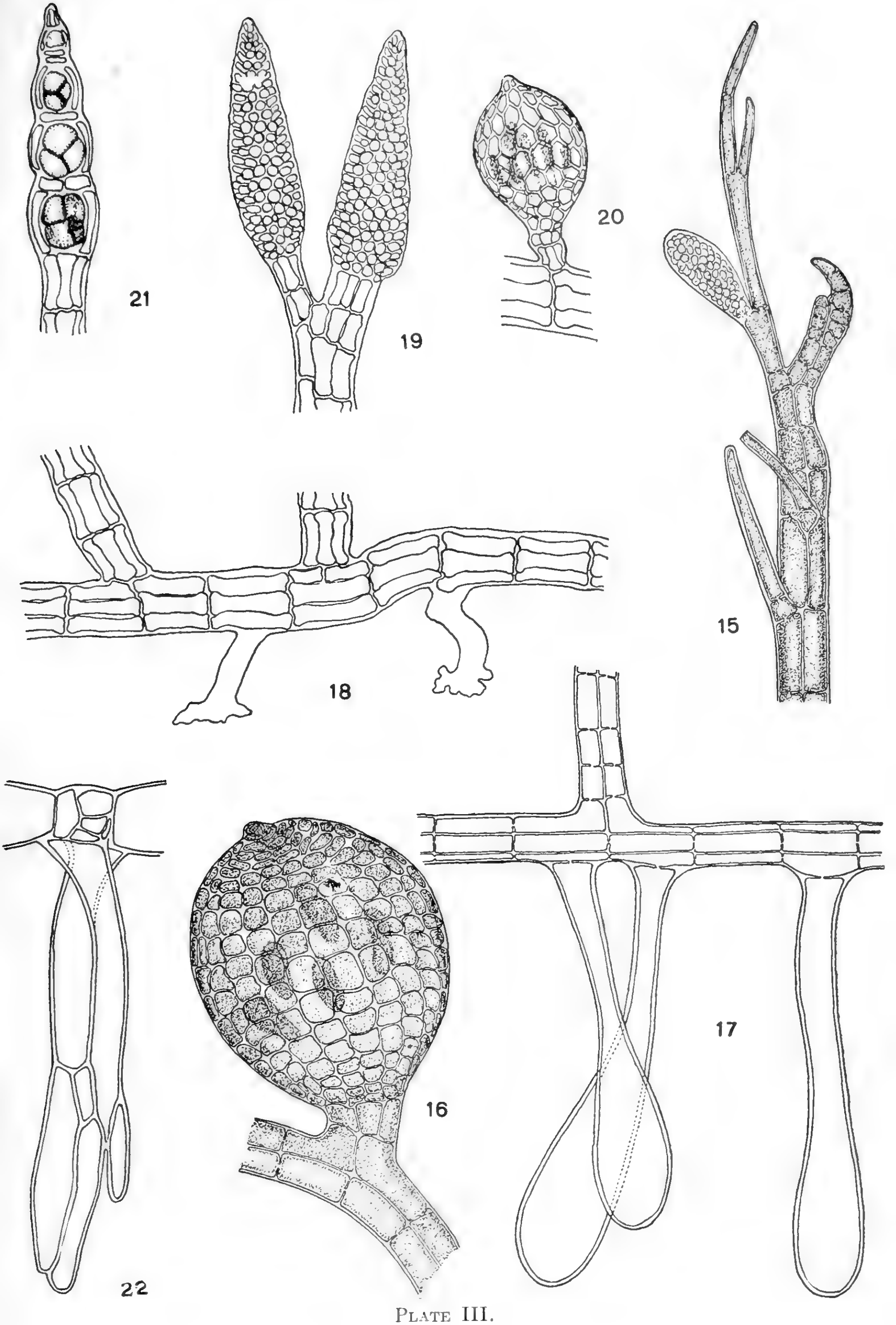


PLATE III.

PLATE IV.

Ceramothamnion Codii H. M. Richards.

FIGURE 23. Union of three rhizoids from different nodes. 310 × 1.

Dasya spinuligera Collins & Hervey.

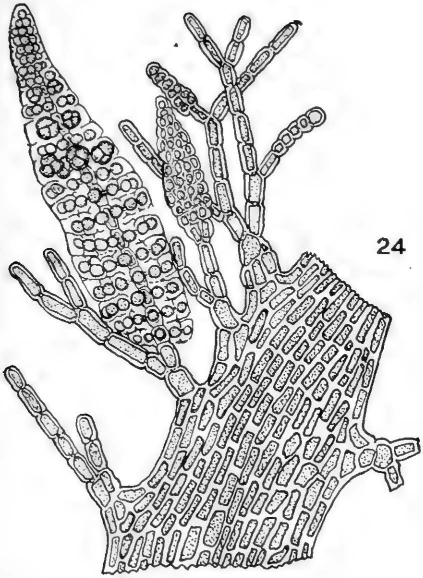
FIGURE 24. Branch with ramelli and young and mature stichidia. 120 × 1.
FIGURE 25. Cross section of branch. 160 × 1.

Gymnothamnion bipinnatum Collins & Hervey.

FIGURE 26. Prostrate filament with two erect and two descending axes. 300 × 1.

Ceramium cruciatum Collins & Hervey.

FIGURE 27. Prostrate filament with rhizoids and base of erect filament. 65 × 1.
FIGURE 28. Branch with tetraspores. 120 × 1.



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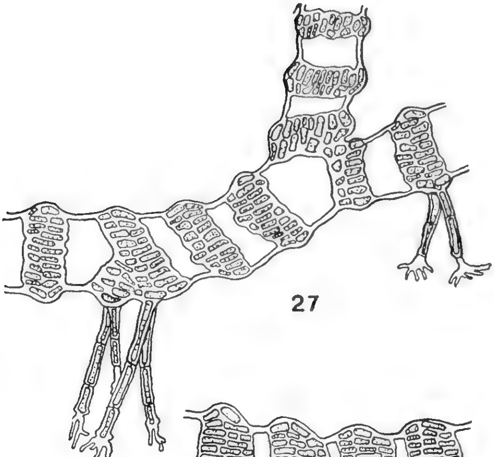

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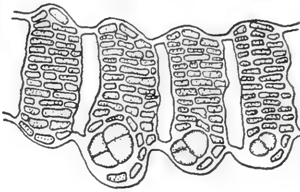

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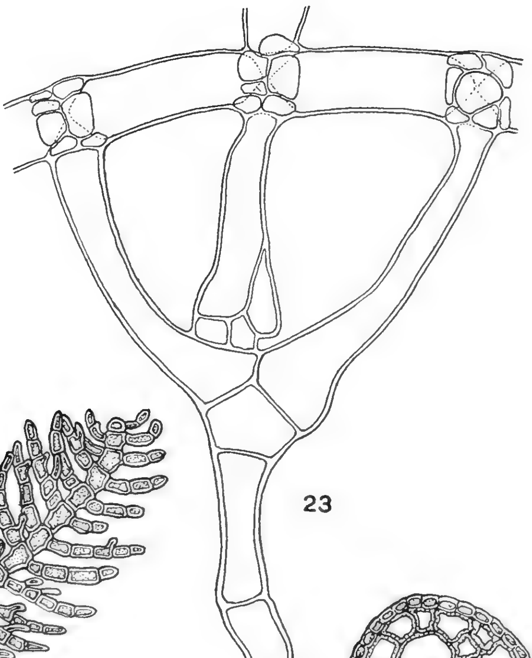

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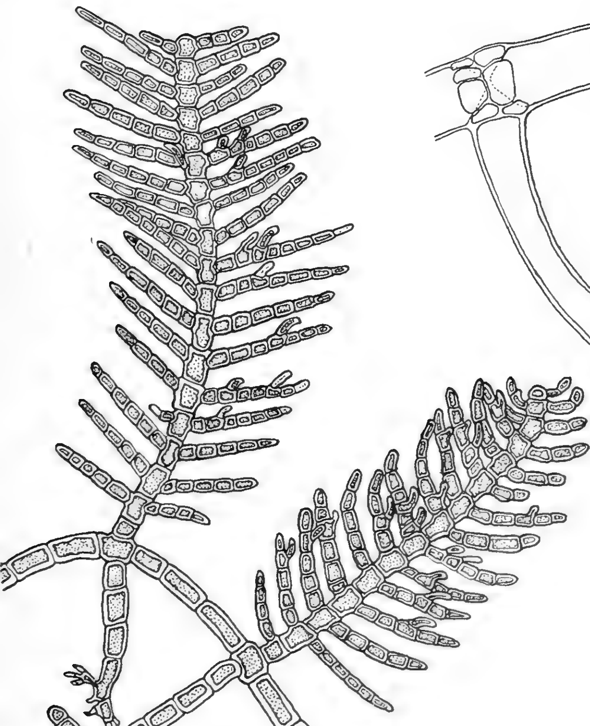

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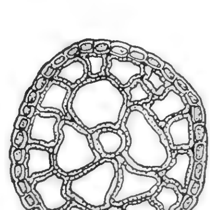

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PLATE IV.

PLATE V.

Ceramium transversale Collins & Hervey.

FIGURE 29. Prostrate filament with erect filament and rhizoids. 120 × 1.
FIGURE 30. Erect filament with branch. 255 × 1.
FIGURE 31. Branch with tetraspores. 160 × 1.

Nitophyllum Wilkinsoniae Collins & Hervey.

FIGURE 32. Section of frond through a sorus. 160 × 1.
FIGURE 33. Superficial view of a sorus. 160 × 1.

Halymenia bermudensis Collins & Howe.

FIGURE 34. Cross section. 255 × 1.

Halymenia pseudofloresia Collins & Howe.

FIGURE 35. Cross section. 130 × 1.

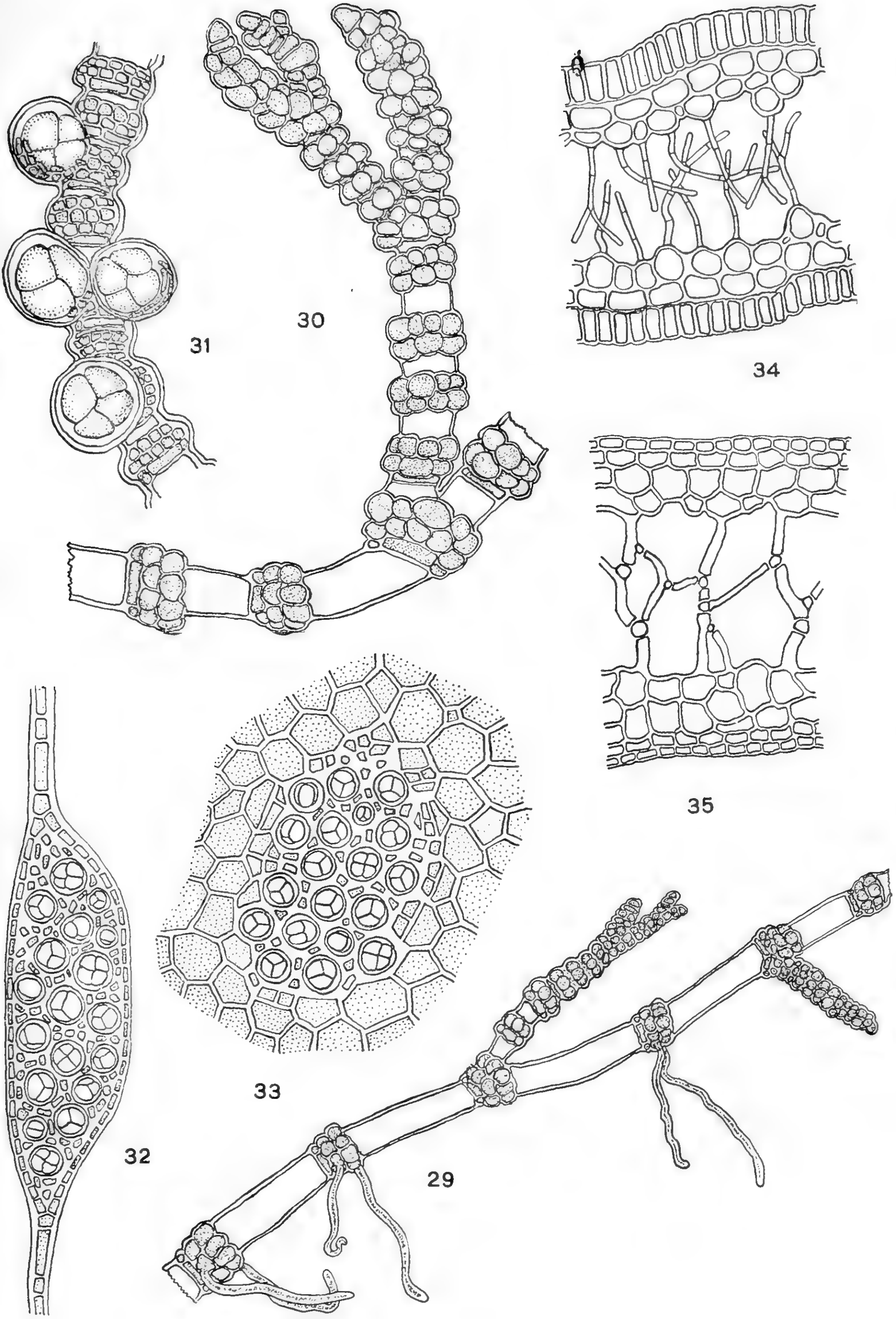


PLATE V.

PLATE VI.

Halymenia pseudofloresia Collins & Howe.

FIGURE 36. Whole frond, $\frac{2}{5}$ nat. size.

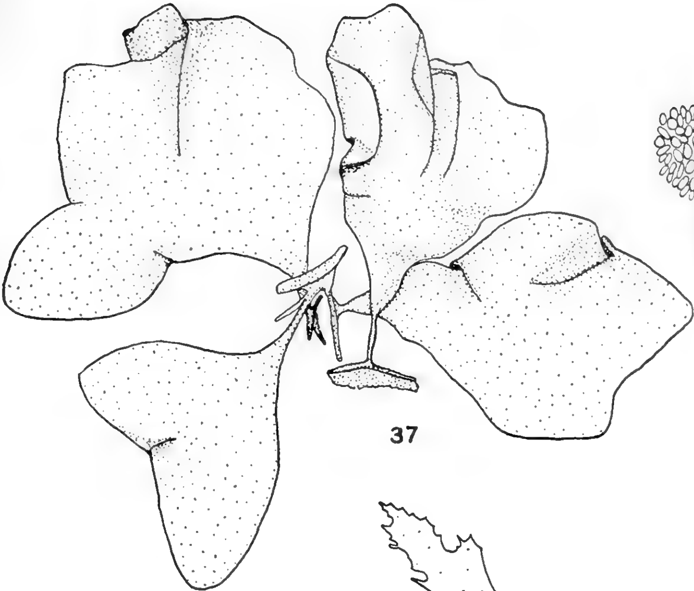
Halymenia bermudensis Collins & Howe.

FIGURE 37. Whole frond. $1\frac{3}{5} \times 1$.

Griffithsia tenuis Agardh.

FIGURE 38. Tip of tetrasporic branch. 160×1.
FIGURE 39. Node with antheridia. 300×1.

Habit figures were drawn from herbarium specimens, all others by camera lucida. Figures 5, 6, 7, 9, 12, 13, 14, 15, 16, 17, 22, and 23 are by F. D. Lambert; the others by A. C. Walton.



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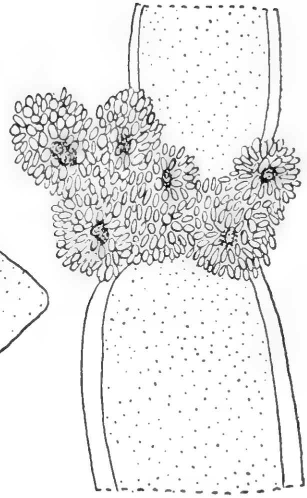

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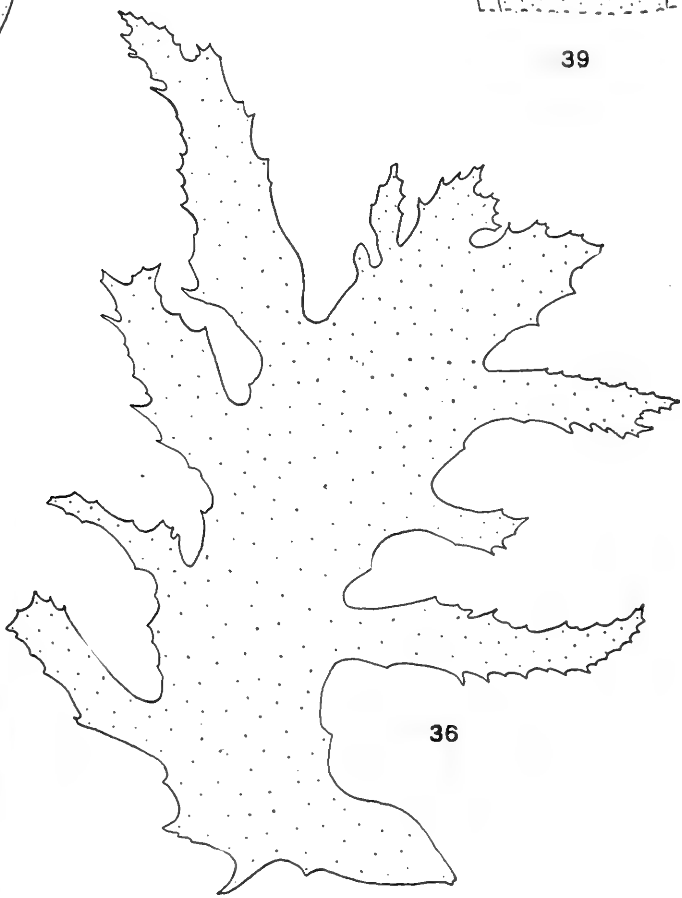

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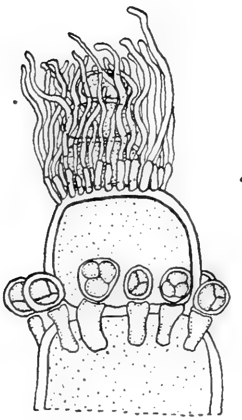

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PLATE VI.

INDEX.

Synonyms are printed in *italics*, also names of species, etc., not found in Bermuda, but which are incidentally mentioned. **Full-face type** indicates the principal reference for a species.

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THE GENUS FRAXINUS IN NEW MEXICO AND ARIZONA.

By Alfred Rehder.

THE GENUS FRAXINUS IN NEW MEXICO AND ARIZONA.

By Alfred Rehder.

Received April 15, 1917.

While collecting in Arizona and New Mexico for the Arnold Arboretum in the summer of 1914 and 1916 I paid special attention to the various species and forms of Fraxinus. There are at present six species of Fraxinus known from that region. One of them, *F. Lowellii* Sargent, is endemic to central Arizona; three, *F. velutina* Torrey, *F. Standleyi* Rehder and *F. cuspidata* Torrey, are found through a considerable part of the territory under consideration, while *F. anomala* Torrey occurs only in northern Arizona where it reaches the southeastern limit of its range, and the Mexican *F. papillosa* Lingelsheim just crosses the extreme southern border of New Mexico. Though these six species are easily distinguished from each other, as shown in the following key, they all exhibit a greater or lesser degree of variability like most other American Ashes; particularly *F. velutina* is extremely variable in its tomentum, in the size, shape and texture of its leaflets, in the length of the petiolules and in the shape and size of its fruits. The extreme forms might easily be taken for distinct species, if it were not for the fact that they are closely connected by intermediate forms and do not occupy separate geographical areas. This is particularly true of the glabrous and pubescent forms which I found in almost every instance growing side by side in the same locality.

This study is based on material in the herbarium of the Arnold Arboretum supplemented by a considerable number of specimens for the loan of which I am indebted to those in charge of the National Herbarium and of the Gray Herbarium; I also am under obligation to Dr. N. L. Britton for the permission to examine and photograph some of the types in the herbarium of the New York Botanic Garden. All the species except *F. papillosa* known so far within our area only from a single locality I have had the opportunity to observe and study in the field.

Key of the species.

Flowers with petals: branchlets slender, terete: leaves 3–9-foliolate.
1. **F. cuspidata.**

Flowers without petals.

Body of the fruit nearly terete with the wing almost terminal extending scarcely below the middle: branches terete.

Leaflets 3–7: body of the fruit narrowly cylindrical, gradually narrowed toward the base, 1.5–2 mm. thick, about 5–8 times as long as thick, wing shorter than the body, linear or spatulate, 3–5 mm. broad.
2. **F. velutina.**

Leaflets 7–9, rarely 5: body of the fruit ellipsoid to oblong, rather abruptly contracted at the base, 2.5–3.5 mm. thick, about 2–4 times as long as thick, wing usually longer then the body, linear-oblong, 5–7 mm. broad.

Under side of the leaflets green or glaucescent, not papillose.
3. **F. Standleyi.**

Under side of the leaflets glaucous, papillose......4. **F. papillosa.**

Body of fruit much compressed, with the wing extending to the base of the body: branchlets more or less quadrangular.

Leaves pinnate, 3–7-foliolate......................5. **F. Lowellii.**

Leaves simple, only occasionally 3-foliolate..........6. **F. anomala.**

1. **Fraxinus cuspidata** Torrey in *Rep. U. S. & Mex. Bound. Surv.* II. pt. 1 (*Bot.*) 166 (1859).— Gray, *Syn. Fl. N. Am.* II. pt. 1, 74 (1878).— Hemsley, *Bot. Biol. Am. Cent.* II. 304 (1881–82).— Wenzig in *Bot. Jahrb.* IV. 171 (1883).— Havard in *Proc. U. S. Nat. Mus.* VIII. 510 (1885).— Pringle in *Gard. & Forest,* I. 142 (1888).— Sargent in *Gard. & Forest,* II. 447 (1889); *Silva N. Am.* VI. 29 (excl. tab.) 1894); *Man. Trees N. Am.* 759 (excl. fig.) (1905).— Coulter in *Contrib. U. S. Nat. Herb.* II. 259 (1892).— Wesmael in *Bull. Soc. Bot. Belg.* XXXI. 80 (1892).— Britton, *Trees N. Am.* 810, fig. 142 (1908).— Schneider, *Ill. Handb. Laubholzk.* II. 820, fig. 514 k–m, 516 d (1912).— Wooton & Standley in *Contrib. U. S. Nat. Herb.* XIX. 496 (*Fl. N. Mex.*) (1915).

Ornus cuspidata Nieuwland in *Am. Midland Nat.* III. 187 (1914).

New Mexico. Otero Co.: Sacramento Mts., Fresnal Canyon, alt. 1800 m., August 18, 1914 and August 24, 1916, *A. Rehder* (Nos. 333, 422, 425, 425*b* (pubescent form). Dona Ana Co.: San Andreas Mts., Ash Spring Canyon, May 24, 1913, *E. O. Wooton* (U. S. Nat. Herb. No. 661852). Grant Co.: Big Hatchet Mts., May 18, 1892, *E. A. Mearns* (No. 127), alt. 2200 m., July 23, 1908, *E. A. Goldman* (No. 1337). Valencia Co.: McCarthy's Station, July 25, 1889, *Munson & Hopkins;* near Grant, June 6, 1904, *A. Chaves* (U. S. Nat. Herb. Nos. 560670, 738264). McKinley Co.: Fort Wingate, 1881, *W. Mathews* (No. 19); Gallup, June 14, 1916, *Alice Eastwood* (Nos. 5637, 5638). Without precise locality, 1851–52, *C. Wright* (No. 1698, in part); 1869, *E. Palmer* (No. 71).

Western Texas. Eagle Springs, June 21, 1855, and mouth of the Great Canyon of the Rio Grande, *C. C. Parry* & *J. M. Bigelow* (type specimen); Chisos Mts., August 1883, *V. Havard* (No. 69).

Mexico. Chihuahua: Santa Eulalia Mts., April 6 and June 6, 1885, *C. G. Pringle* (No. 137).

This species I have seen only as a tall shrub from 3–5 m. high branching from the base into slender upright stems; it is usually found on rocky slopes at an elevation of from 1600–2200 m. It is distributed from the provinces of Coahuila and Chihuahua of Mexico through western Texas and the southwestern half of New Mexico to northern Arizona; it does not seem to occur in northeastern New Mexico or in southwestern Arizona. It shows some variation in the serration and in the number of leaflets and the following varieties may be distinguished from the typical form which has 5–7, rarely 3, lanceolate to ovate-lanceolate leaflets occasionally sparingly serrate. Shrubs with rather densely pubescent and at the same time smaller and broader leaflets apparently represent merely a juvenile form, as I found such foliage only on stunted shrubs without fruit; only once I found a slightly pubescent shrub with a few fruits. Pringle has also distributed sterile branches with pubescent leaves under his number 137 from the Santa Eulalia Mountains in Chihuahua.

Fraxinus cuspidata var. **macropetala,** n. var.

Fraxinus macropetala Eastwood in *Bull. Torr. Bot. Club,* XXX. 494 (1903.)— Lingelsheim in *Bot. Jahrb.* XL. 216 (*Vorarb. Monog. Fraxinus,* 36) (1907).

Arizona. Coconino Co.: Grand Canyon, July 9, 1892, *E. O. Wooton* (U. S. Nat. Herb. No. 738265), July 13, 1892, *J. W. Toumey* (No. 273), June 1905, *C. A. Purpus,* June 13, 1913, *A. E. Hitchcock* (Nos. 76, 78); Red Canyon Trail, June 10, 1901, *L. F. Ward* (U. S. Nat. Herb. No. 410119); Bright Angel Trail, alt. 1400–2200 m., 1909, *E. W. Nelson* (No. 108), May 31 and August 19, 1913, *E. A. Goldman* (Nos. 2067, 2223), alt. 1400–2000 m., July 19, 1914, *A. Rehder* (No. 106); Hermit Trail, June 18, 1916, *Alice Eastwood* (No. 5822); Grand View Trail, June 16, 1916, *Alice Eastwood* (No. 5693). Sycamore Canyon, southwest of Flagstaff, Oct. 4, 1915, *Percival Lowell,* alt. 1350 m., Sept. 14, 1916, *A. Rehder* (No. 578).

This variety differs from the type chiefly in its 3–5-, rarely 7-foliolate leaves with broader, often ovate, entire leaflets; occasionally with simple leaves at the base of the branchlets. All the other distinguishing characters given in the original description of *F. macropetala* can be found in the typical form. In the type the divisions of the calyx are also attenuate and very unequal and the longer divisions equal or exceed the tube in length; the length of the corolla varies between 10 and 16 mm.; the shape of the fruit is very variable even in the same locality, and I have before me specimens from the Grand Canyon with fruits having a narrow wing, about 5 mm. wide, 2.8 mm. long and rounded at the apex and others with the wing of the fruit 7 mm. broad and only 2–2.5 mm. long and truncate and emarginate at the apex. On many flowering branchlets all the leaves are simple, as in Ward's specimen from the Red Canyon Trail; a sterile specimen collected by Percival Lowell in the Sycamore Canyon has most of the leaves simple and the others with only one pair of small leaflets at the base.

Fraxinus cuspidata, var. **serrata**, n. var.

Fraxinus cuspidata Sargent, *Silva N. Am.* VI. t. 260 (pro parte) (1894); *Man. Trees N. Am.* fig. 605 (pro parte) (1905) tantum quoad plantam depictam.

A typo recedit foliolis manifeste serratis ovatis v. ovato-lanceolatis, plerumque 7, rarius 9 v. 5, paribus inferioribus interdum 3-foliolatis.

Mexico. Coahuila: mountains east of Saltillo, April 15–20, 1880, *E. Palmer* (No. 796, type); San Lorenzo Canyon, 6 miles southeast of Saltillo, April 16, 1905, *E. Palmer* (No. 536); Sierra Madre, south of Saltillo, April 12, 1906, *C. G. Pringle* (No. 13742); Saltillo, cult. at Cotton mill, April 5, 1887, *C. S. Sargent.*

This variety seems to be restricted to Mexico and is connected with the typical *F. cuspidata* by intermediate forms; such are A. Chaves' specimen from Valencia Co., New Mexico, V. Havard's No. 69 from western Texas and Pringle's No. 137 from Mexico, all enumerated above under the typical *F. cuspidata.*

2. **Fraxinus velutina** Torrey in Emory, *Not. Reconnoiss. Leavenworth to San Diego,* 149 (1848).[1]— Sudworth, *Rep. Sec. Agric.* 1892,

[1] Not *F. velutina* Lingelsheim in *Bot. Jahrb.* XL. 216 (*Vorarb. Monog. Fraxinus,* 36) (1907) from Yunnan which belongs to the section Ornus and is related to *F. chinensis* Roxburgh; it is based on Henry's No. 11893. I propose for this species the name **F. Lingelsheimii**, n. nom. (*F. velutina* Lingelsheim, non Torrey).

326.— Sargent, *Silva N. Am.* VI. 41, (excl. tab.) (1894); *Man. Trees N. Am.* 774, (excl. fig.) (1905).— Britton, *Trees N. Am.* 799 (excl. fig.) (1908). — Elwes & Henry, *Trees Gr. Brit. & Irel.* IV. 912, t. 265, fig. 20 (1909).— Wooton & Standley in *Contrib. U. S. Nat. Herb.* XIX. 496 (*Fl. N. Mex.*) (1915).

Fraxinus pistaciaefolia Torrey in *Pacific R. R. Rep.* IV. 128 (1856); in *Rep. U. S. & Mex. Bound. Surv.* II. pt. 1 (*Bot.*), 166 (1859).— Hemsley, *Bot. Biol. Am. Centr.* II. 305 (1881–82).— Rusby in *Bull. Torr. Bot. Club,* IX. 54 (1882).—Gray, *Syn. Fl. N. Am.* II. pt. 1, 74 (1878).— Rothrock in *Rep. U. S. Geog. Surv. west 100th Merid.* VI. 186 (1878).— Watson in *Proc. Am. Acad.* XVIII. 113 (1883).— Sargent, *Forest Trees N. Am. 10th Census U. S.* IX. 106 (1884).— Lingelsheim in *Bot. Jahrb.* XL. 221 (*Vorarb. Monog. Fraxinus,* 41) (1907).

Fraxinus viridis S. Watson in *U. S. Geol. Explor. 40th Parall.* 284 (non Michaux) (1871).

Fraxinus americana var. *pistaciaefolia* Wenzig in *Bot. Jahrb.* IV. 182 (1883).— Wesmael in *Bull. Soc. Bot. Belg.* XXXI. 108 (1892).

New Mexico: Lincoln Co: White Mts., alt. 2500 m., August 25, 1907, *Wooton & Standley* (No. 3623). Otero Co.: Sacramento Mts., Fresnal Canyon, alt. 2000 m., August 24, 1916, *A. Rehder* (Nos. 409c, 418); Three Rivers, alt. 1600 m., *F. G. Plummer* (U. S. Nat. Herb. Nos. 564674, 564675). Dona Ana Co.: Organ Mts., alt. 2300 m., Sept. 20, 1900, *Wooton & Standley* (U. S. Nat. Herb. No. 499883), alt. 1300 m., September 1, 1897, *E. O. Wooton* (No. 432). Sierra Co.: between the waters of the Del Norte and the Gila, Oct. 15, 1847, *W. E. Emory* (type, in herb. N. Y. Bot. Gard.); Head & Wilson Ranch, July 13, 1900, *E. O. Wooton* (U. S. Nat. Herb. Nos. 738260, 738266); Black Range, Berendo Creek, alt. 1850 m., *O. B. Metcalfe* (No. 927); Tierra Blanca, 1904, *Mrs. I. N. Beals.* Socorro Co.: near Glenwood, August 14, 1914, *A. Rehder,* (No. 290). Grant Co.: Emory Spring, June 4, 1892, *E. A. Mearns* (No. 284); Dog Mts. June 4, 1892, *E. A. Mearns* (No. 285); Animas Mts., Indian Canyon, alt. 2000 m., August 7, 1908, *E. A. Goldman* (No. 1396); San Luis Mts., July 26, 1892, *E. A. Mearns* (No. 570).

Arizona. Navajo Co.: Tusayan, National Forest, June 12, 1912, *A. D. Read* (U. S. Nat. Herb. No. 583287). Graham Co.: San Carlos Indian Reserv., June 25, 1904, *F. V. Coville* (No. 1944). Cochise Co.: Huachuca Mts., Sept., 1882, *J. G. Lemmon* (No.

256); Bowie, September 16, 1884, *M. E. Jones* (No. 4235). Pima Co.: near Tucson, April 1908, *J. N. Rose* (No. 12131), March and October, 1895, *J. W. Toumey* (U. S. Nat. Herb. No. 619020). Yavapai Co.: Sierra Prieta, near Prescott, alt. 1850 m., Sept. 4, 1916, *A. Rehder* (No. 512b).

This Ash is widely distributed through New Mexico and Arizona except in the northeastern part of the former of these states, and is rather common along water courses at elevations of between 1000 to 2400 m. It is extremely variable and the most extreme forms have the appearance of distinct species, but they are all closely connected by intermediate forms so that it seems impossible to divide this group of forms satisfactorily into several species, but by selecting the most distinct forms as types the forms may be grouped under the following varieties.

To typical *F. velutina* I refer the specimens enumerated above; they resemble the type specimen in having few, usually 3–5, generally elliptic, short-stalked or nearly sessile leaflets and densely pubescent branchlets and leaves. In the type specimen most of the leaves are 3-foliolate; the leaflets of the 3-foliolate leaves are elliptic, acute at the ends, distinctly serrate, the larger terminal leaflets measure 5–5.5 cm. by 3–3.5 cm., while the lateral leaflets are similar, but smaller; the lateral leaflets of the 5-foliolate leaves are narrower and measure about 4 cm. by 1.5 cm. The fruits are about 2.3 cm. long, with a slender terete body slightly longer than the linear-oblong wing which is 3–4 mm. broad. Typical *F. velutina* is the most common form of this group in southern and western New Mexico and is also found in eastern and central Arizona.

Fraxinus velutina var. **Toumeyi**, n. var.

Fraxinus velutina Sargent, *Silva N. Am.* VI. t. 267 (pro parte (1894), tantum quoad plantam depictam.

Fraxinus attenuata Jones, *Contrib. West. Bot.* XII. 59 (pro parte) (1908, March 26), quoad specimen ex Arizona.— Wooton & Standley in *Contrib. U. S. Nat. Herb.* XIX. 496 (*Fl. N. Mex.*) (1915).

Fraxinus Toumeyi Britton, *Trees N. Am.* 803, fig. 732 (1908).

New Mexico. Guadalupe Co.: Guadalupe Canyon, July 28, 1892, *E. A. Mearns* (No. 582). Dona Ana Co.: Organ Mts., 1881, *G. R. Vasey* (U. S. Nat. Herb. No. 49369); Filmore Canyon, August 4, 1895, and April 15, 1899, *E. O. Wooton* (U. S. Nat. Herb. Nos. 735196, 738263). Sierra Co.: Lake Valley, 1916, *Mrs. W. G. Beals* (U. S. Nat. Herb. No. 424691). Socorro Co.: Dry Creek, alt. 1600 m., October 13, 1908, *E. A. Goldman* (No. 1571); Glenwood, August 14, *A. Rehder* (No. 292). Grant Co.: Pine Cienaga, July 17, 1900, *E. O. Wooton* (U. S. Nat. Herb. No. 738262); Redrock, September 28, 1908, *E. A. Goldman* (No. 1545); Crawford's Ranch, June 21, 1906, *E. O. Wooton* (U. S. Nat. Herb. No. 738261); Santa Rita, 1877, *E. L. Greene* (No. 36); Bear Mts., April, 1880, *H. H. Rusby* (No. 254); Animas Valley, July 17 and 27, 1892, *E. A. Mearns* (Nos. 500, 576); Alamo Veijo, May 27, 1892, *E. A. Mearns* (No. 176).

ARIZONA. Graham Co.: Fort Grant, June 17, 1912, *L. N. Godding* (No. 1063); Graham Mts., July 26, 1914, *E. A. Goldman* (No. 2337); Black River Lower Crossing, July 27, 1910, *L. N. Godding* (No. 686). Cochise Co.: Chiricahua Mts., Whitetail Canyon, alt. 1650 m., August 17, 1906, *J. C. Blumer* (No. 1250); Five Mile Creek, alt. 1650 m., August 12, 1906, *J. C. Blumer* (No. 1238); Fort Huachuca, 1894, *T. E. Wilcox* (Nos. 46, 202); Barbacomari Creek, alt. 1800 m., October 19, 1893, *E. A. Mearns* (No. 2617). Pima Co.: Tucson, March and October, 1895, *J. W. Toumey* (type of *F. Toumeyi*), July 2, 1891 and August 3, 1892 (No. 274), *J. W. Toumey*, 1891, *G. C. Neally* (No. 62), April 14, 1908, *J. N. Rose* (No. 11758); banks of Rillita Creek, June 17, 1881, *C. G. Pringle*, August 7, 1914, *A. Rehder* (No. 239); Santa Catalina Mts., Sabino Canyon, alt. 950 m., June 15, 1883, *J. J. Thornber* (No. 343), alt. 1800 m., September 1, 1916, *A. Rehder* (No. 499); mouth of Bear Canyon, alt. 1000 m., August 31, 1916, *A. Rehder* (No. 454); Santa Rita Mts., alt. 1400–2000 m., September 1880, *Engelmann & Sargent*. Gila Co.: Tonto Basin, July 19, 1892, *J. W. Toumey* (No. 274). Yavapai Co.: Sierra Prieta, near Prescott, alt. 1800 m., Sept. 4, 1916, *A. Rehder* (No. 512, 512c). "Ash Creek," July 1874, *J. T. Rothrock.* (No. 302).

MEXICO. Sonora: Guadalupe Canyon, August 28, 1893, *E. C. Merton* (No. 2072), Los Pintos, 2000 m., October 11, 1890, *C. V. Hartmann* (No. 127); without precise locality, June 1851, *G. Thurber* (No. 322).

This variety differs from the type chiefly in its 5–7, narrower, slender-stalked leaflets and in the less dense pubescence of its leaves and its branchlets. In the type specimens most of the leaves of the fruiting branch have 7 leaflets which are ovate-lanceolate or elliptic-lanceolate to lanceolate in shape and measure 3.5–5.5 in length and 1.2–1.6 in width, the leaflets of the middle pair being the largest, while the terminal leaflet equals those of the upper pair. The pubescence of the branches and the leaves is very short and rather thin; the fruits are 2–2.2 cm. long with a linear-oblong wing 3–4 mm. broad. The specimens I have referred to this variety show great variation in pubescence, in the shape and size of the leaflets, in the length of the petiolule and also in the fruits; many specimens are intermediate between the type and this variety and sometimes the leaves of weaker branchlets and those at the base of the vigorous shoots resemble those of typical *F. velutina,* while the upper leaves of vigorous shoots are those of var. *Toumeyi.* The fruits vary from 1.5–3.5 cm. in length with the wing usually narrowly oblong and from 3 to 4 mm. broad, sometimes the wing is spatulate and up to 5 mm. broad, of this the most extreme form is my No. 512 which has the spatulate wing 5 mm. broad and the whole fruit only 1.5–2 cm. long with the body of the fruit 0.8–1.2 cm. long.

This variety is the most common form in Arizona, while in New Mexico the type seems to be more widely distributed.

I have not taken up the name attenuata for this variety, though it is the oldest, because the two specimens cited by Jones under his *F. attenuata,* belong to different species or at least different forms, and none of them being designated as the type and the description apparently based on both, it remains uncertain which ought to be considered the type.

Fraxinus velutina var. **coriacea,** n. comb.

Fraxinus coriacea S. Watson in *Am. Nat.* VII. 302 (in part) (1873), exclud. planta coll. a Bigelow.[2]— Rothrock in *Rep. U. S. Geog. Surv. west 100th merid.* VI. 185, t. 22 (1878).— Coville in *Contrib. U. S. Nat. Herb* IV. 148 (*Bot. Death Valley Exped.*) (1892).

Fraxinus pistaciaefolia var. *coriacea* Gray, *Syn. Fl. N. Am.* II. pt. 1, 74 (1878).

Fraxinus americana var. *coriacea* Wenzig in *Bot. Jahrb.* IV. 182 (1883).— Wesmael in *Bull. Soc. Bot. Belg.* XXXI. 108 (1892).

NEVADA. "Ash Meadows," 1871, *G. M. Wheeler* (type).

UTAH. St. George, 1875, *E. Palmer,* 1898, *J. W. Carpenter.*

CALIFORNIA. Inyo Co.: Owens Lake near Olancha, June 5, 1906, *Hall & Chandler* (No. 7328, and probably No. 7322).

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[2] Bigelow's specimen from Devil's Run Canyon, western Texas, is *F. texensis* Sargent.

This variety differs from the type in the more coriaceous, slender-stalked and often more coarsely serrate leaflets and in the less densely pubescent or glabrescent branchlets and leaves. In the type specimen the leaflets are generally elliptic, 4.5–5.5 cm. long and 2.5–3 cm. broad, broadly cuneate at the base and abruptly and obtusely pointed, indistinctly serrulate, slightly and sparingly villose on both surfaces, pale yellowish green above and paler and reticulate beneath; a few leaves have obovate leaflets, truncate at the apex and rather coarsely dentate; the fruits are spatulate, 1.8–2.5 cm. long and 5–6 mm. broad below the emarginate apex. Hall & Chandler's No. 7328 is nearest to the type in shape and size of the leaflets, but it is nearly glabrous.[3]

This variety does not seem to occur in Arizona, but some specimens referred to var. *Toumeyi*, as Jones's No. 4235 and Toumey's No. 274, have rather coriaceous leaflets and may be considered transitions to var. *coriacea*.

Fraxinus velutina var. **glabra**, n. var.

Fraxinus glabra Thornber in U. S. Herb.

A typo et a varietatibus praecedentibus differt foliis ramulisque glabris et a var. *coriacea* foliolis tenuioribus subtus vix reticulatis.

New Mexico. Chaves Co.: near Roswell, alt. 1100 m., August 11, 1916, *A. Rehder* (No. 348). Dona Ana Co.: Ash Spring, San Andreas Mts., May 24, 1913, *E. O. Wooton* (U. S. Nat. Herb. No. 661851). Otero Co.: Sacramento, Cloudcroft, alt. 2800 m., August 20, and alt. 2500 m., August 25, 1916, *A. Rehder* (Nos. 384, 441); Fresnal Canyon, alt. 2000 m., August 24, 1916, *A. Rehder* (Nos. 409, 409b).

Arizona. Graham Co.: San Carlos Indian Reserv., June 25, 1904, *F. V. Coville* (No. 1945). Cochise Co.: Huachuca Mts., Tanner Canyon, August 24, 1910, *L. N. Godding* (No. 817); Miller's

3 Some Californian specimens distributed as *F. coriacea* do not belong here; they represent a glabrous or glabrescent variety of *F. oregona* Nuttall which is apparently identical with *F. oregona* var. *glabra* Lingelsheim in *Bot. Jahrb.* XL. 220 (*Vorarb. Monog. Fraxinus,* 40) (nomen nudum) (1907). To this variety I refer the following numbers which differ from the type in the glabrous or nearly glabrous branchlets and leaves. Kern Co.: Greenhorn Mts., alt. 1000–1200 m., 1897, *C. A. Purpus* (No. 5555). San Bernardino Co.: Lyth Creek Canyon, July 15, 1902, *Le Roy Abrams* (No. 2741); Cleghorn Canyon, July 6, 1908, *Le Roy Abrams & E. A. McGregor* (No. 703). Los Angeles Co.: Liebre Mts., June 20–23, 1908, *Le Roy Abrams & E. A. McGregor* (No. 400).

Canyon, June 19, 1909, *L. N. Godding* (No. 105). Pima Co.: Range Reserve, July 21, 1911, *E. H. Wooton* (U. S. Nat. Herb. No. 690667, type); banks of Rillita, 1881, *C. G. Pringle*. Yavapai Co.: Beaver Canyon, near Camp Verde, alt. 1500 m., Sept. 7, 1916, *A. Rehder* (No. 541); Sierra Prieta near Prescott, 1800 m., September 4, 1916, *A. Rehder* (No. 513).

This variety differs in the quite glabrous branchlets and leaves from the type and from var. *Toumeyi* to which it is nearest in the shape of its leaflets; from specimens of var. *coriacea* with narrower glabrescent leaflets it can be distinguished only by the thinner leaflets not strongly reticulate beneath. It seems to be not uncommon throughout New Mexico and Arizona and in the localities where I collected it I nearly always found it associated with pubescent forms.

3. **Fraxinus Standleyi,** n. sp.

Arbor, ramulis hornotinis teretibus glabris v. fere glabris, annotinis cinerascentibus, interdum atropurpureis, vetustioribus cinereis; gemmae ferrugineo-tomentulosae. Folia longe petiolata, 13–18 cm. longa, 7–9-foliolata; foliola sessilia v. brevissime petiolulata, ovata v. ovato-oblonga, rarius elliptica, acuta v. breviter acuminata, basi late cuneata, terminale sensim in petiolulum circ. 0.5 cm. longum attenuatum, omnia irregulariter et leviter serrulata, supra luteo-viridia, glabra, subtus glaucescentia, leviter reticulata, secus costam basin versus plus minusve villosa, cetera glabra v. fere glabra, rarius tota facie sparse minute villosula, minute punctulata, 4–6 cm. longa et 1.5–3 cm. lata in specimine typico, nervis utrinsecus 5–7 ante marginem dissolutis; petioli satis graciles, 2.5–5 cm. longi, interdum purpurascentes, supra applanati v. leviter concavi, basi leviter tantum dilatati, glabri; rhachis glabra, supra leviter canaliculata, leviter marginata. Flores non visi. Paniculae fructiferae 8–12 cm. longae, glabrae; pedicelli graciles; calyx persistens minutus, irregulariter inciso-dentatus et denticulatus; samara 2.5–3 cm. longa, capsula subteres v. leviter compressa, ellipsoidea v. oblonga, basi subito contracta, 1–1.3 cm. longa et 2.5–3.5 mm. diam., leviter striata; ala oblongo-spatulata, ad medium capsulae decurrens, 6–7 mm. lata, apice obtusiuscula v. leviter emarginata in specimine typica, interdum anguste oblonga.

New Mexico. Dona Ana Co.: Organ Mts., Van Pattens Camp, June 9, 1906, *P. C. Standley* (U. S. Nat. Herb. No. 560835, type). Lincoln Co. White Mts., Gilmore's Ranch, alt. 2500 m., August 17, 1908, *E. O. Wooton* (No. 3943). Luna Co.: Florida Mts., alt. 1900 m., September 8, 1908, *E. A. Goldman* (No. 1482). Grant Co.: San Luis Mts., June 25 and October 2, 1892, *E. A. Mearns* (No. 382); Santa Rita, "Copper Mines, N. E. of El Paso", 1851, *J. M. Bigelow.* Without precise locality, 1851, *C. Wright* (No. 1697).

ARIZONA. Graham Co.: White Mts., August 6–15, 1903, *D. Griffith* (No. 5390). Cochise Co.: Huachuca Mts., Ash Canyon August 6, 1909, *L. N. Godding* (No. 342); April, 1897, *J. W. Toumey.* Pima Co.: Santa Rita Mts., September 20 – October 4, 1902, *D. Griffith & J. J. Thornber* (No. 176). Coconino Co.: Oak Creek Canyon, alt. 2000 m. and 1800 m., September 15, 1916, *A. Rehder* (Nos. 581, 586); shaded ravine near head of Oak Creek, June 21, 1916, *F. Shreve* (No. 24); San Francisco Mts., Elden Mt., July 17, 1891, *D. T. McDougal* (No. 396).

MEXICO. Sonora: San José Mts., alt. 2400 m., August 7, 1903, *E. A. Mearns* (Nos. 1668, 1671).

This species seems most closely related to *F. velutina* Torrey, but differs chiefly in the usually 7–9-foliolate leaves and in the fruit which has a thick, terete, ellipsoid or oblong body, similar to that of *F. americana* Linnaeus and a wing longer than the body; the body is about 2 to 4 times longer than thick and finely striate, while in typical *F. velutina* the fruit has a thin slender body gradually narrowed toward the base, 5–7 times longer than broad and more or less irregularly grooved. The fruit of the latter resembles that of *F. pennsylvanica* Marshall except that it is smaller and has a relatively much shorter wing. From *F. americana* which it resembles in the fruit *F. Standleyi* is distinguished by the sessile smaller leaflets with the epidermis of the under side not papillose and by the smaller fruit.

This new species seems to be as variable as *F. velutina* and of the specimens quoted above no two are exactly alike. Wright's No. 1697 differs in the quite glabrous leaflets more glaucescent beneath and in the narrower, deeply emarginate wing of the fruit. Goldman's No. 1482 has also quite glabrous leaflets, but much smaller and never as many as nine. Griffith's & Thornber's No. 176 has narrower, more glaucescent leaflets and fruits with narrower pointed wings. Mearn's No. 382 has smaller leaflets sparingly short-pubescent on the whole under surface, a puberulous rhachis and fruits with narrower wings. McDougal's No. 396 has leaves with always 7, elliptic, distinctly petioluled leaflets and fruits with narrower wings. Godding's No. 343 has also elliptic leaflets always 7 in number and narrower fruits only 1.5–2 cm. long. Shreve's No. 24 and my own No. 581 have 7, rather large, short-stalked, elliptic or oval obtusish leaflets and quite glabrous and somewhat narrower fruits. My No. 586 has 7 quite glabrous oblong-lanceolate leaflets to 7 cm. long and pointed fruits to 3.5 cm. in length. Wooton's No. 3943 is similar but smaller and Mearn's No. 1671 has also 7 oblong-lanceolate leaflets and somewhat narrower emarginate fruits.

This species is distributed from southwestern New Mexico to southern and central Arizona and extends into northern Mexico.

Fraxinus Standleyi, var. **lasia**, n. var.

A typo recedit foliolis fere semper 7 subtus, ut petioli ramulique, dense velutinis. Foliola in specimine typico ovato-lanceolata, 4.5–8 cm. longa et 1.5–2.8 cm. lata; samara 3–3.5 cm. longa; capsula 1.2–1.5 cm. longa; ala anguste oblonga, circiter 6 mm. lata, emarginata.

ARIZONA. Coconino Co.: Oak Creek Canyon, alt. 1800 m., September 15, 1916, *A. Rehder* (No. 585, type), July 14, 1914, *A. Rehder* (Nos. 41, 42, 43, 44); Sycamore Canyon, southwest of Flagstaff, alt. 1700 m., September 14, 1916, *A. Rehder* (No. 576). Navajo Co.: Fort Apache, June 21–30, *E. Palmer* (No. 592). Graham Co.: White Mts., August 6–15, 1903, *D. Griffith* (No. 5390). Cochise Co.: Pine Canyon, Chiricahua Mts., Oct. 4, 1906, *J. C. Blumer* (No. 1302); Chiricahua Mts., April, 1897, *J. W. Toumey*. Pima Co.: Santa Rita Mts., alt. 2000 m., July 15, 1903, *J. J. Thornber* (No. 299).

NEW MEXICO. Grant Co.: Santa Rita del Cobre, 1877, *E. L. Greene* (No. 37).

This variety differs from the type chiefly in the tomentose branchlets and leaves; it shows considerable variation in size and shape of its leaflets and fruits. Thornber's No. 299 differs in its oblong-elliptic, nearly sessile leaflets. Greene's No. 37 has broader, elliptic to ovate-oblong leaflets. Palmer's No. 592 has similar leaflets, but narrower fruits from 1.5–3 cm. long. Blumer's No. 1302 has 5–7, rather broad, ovate to elliptic leaflets and is much less densely pubescent than the type. Also Griffith's No. 5390 is less pubescent and has 5–7 narrower, rather sharply serrate leaves.

4. **Fraxinus papillosa** Lingelsheim in *Bot. Jahrb.* XL. 219 (*Vorarb. Monog. Fraxinus,* 39) (1907).

NEW MEXICO. Grant Co.: west side of San Luis Mts., alt. 1950 m., October 2, 1893, *E. A. Mearns* (No. 2533).

MEXICO. Chihuahua: Sierra Madre, near Colonia Garcia, September 29, 1899, *Townsend & Barber* (No. 354, type); road from San Mateo to Guasarachi, September 24, 1898, *E. A. Goldman* (No. 153).

This species differs from the preceding species chiefly in the glaucous papillose under surface of the leaflets and from *F. americana* in its sessile smaller leaflets. Mearns's No. 2533 differs from the type in its larger, nearly entire leaflets 4–6 cm. long and 2–2.5 cm. broad and in the larger, many-fruited panicles.

5. **Fraxinus Lowellii** Sargent, n. sp.

Folia 9–15 cm. longa, petiolis crassiusculis glabris v. leviter villosis; foliola 5 v. rarius 3, ovata, acuminata, apice acuta v. rarius obtusa, basi cuneata, grosse serrata saepe tantum supra medium, luteo-viridia, supra glabra v. in costa puberula, subtus glabra v. rarius ad basin costae pallide luteae sparse villosula, 6–8 cm. longa et 2.5–3.5 cm. lata, nervis tenuibus arcuatis ante marginem leviter incrassatum et revolutum anastomosantibus; petioluli 5–15 mm. longi. Flores non visi. Fructus mense Julio maturantes, in paniculis longis glabris, oblongi-elliptici v. oblongo-obovati, basi calyce minuto leviter dentato instructi, apice dilatati v. sensim attenuati et rotundati, saepe emarginati, 2.5–3.5 longi et 7–9 mm. lati; ala ad basin capsulae valde compressae striatae 1.8–2.5 cm. longae decurrens.

Arbor 7–8-metralis, cortice fusco profunde fisso, ramulis validis quadrangulatis saepe alatis, interdum fere teretibus, hornotinis fusco-aurantiacis, annotinis cinereo-brunneis.

ARIZONA. C o c o n i n o C o.: Oak Creek Canyon, about 20 miles south of Flagstaff, *Percival Lowell*, June 1, 1911, *A. Rehder*, July 13, 1914 (No. 53, type). Y a v a p a i C o.: Copper Canyon, near Camp Verde, alt. 1500 m., *A. Rehder*, September 16, 1916 (Nos. 524, 526, and 529, a pubescent form). M o h a v e C o.: Peach Springs, 1884, *J. G. Lemmon* (No. 3242).

I take much pleasure in associating with this plant the name of the late Percival Lowell, the distinguished astronomer who has greatly added to our knowledge of the trees of northern Arizona.

C. S. SARGENT.

6. **Fraxinus anomala** Torrey in herb. apud S. Watson in *Rep. U. S. Geol. Explor. 40th Parall.* V. 283 (1871).— Parry in *Am. Nat.* IX. 203 (1875).— Gray, *Syn. Fl. N. Am.* II. pt. 1, 74 (1878).— Sargent, *Forest Trees N. Am. 10th Census U. S.* IX. 106 (1884); *Silva N. Am.*

VI. 39, t. 266 [4] (1894) *Man. Trees N. Am.* 765, fig. 611 [4] (1905).— Wenzig in *Bot. Jahrb.* IV. 186 (1883).— Wesmael in *Bull. Soc. Bot. Belg.* XXXI. 114 (1892).— Koehne, *Deutsche Dendr.* 511, fig. 90 D (1893).— Coville in *Contrib. U. S. Nat. Herb.* IV. 148 (*Bot. Death Valley Exp.*) (1892).— Britton, *N. Am. Trees,* 796, fig. 797 (1908).— Elwes & Henry, *Trees Gt. Brit. Irel.* IV. 900, t. 262, fig. 7 (1909).— Schneider, *Ill. Handb. Laubholzk.* II. 822, fig. 516 a–b, 518 p (1912).— Wooton & Standley in *Contrib. U. S. Nat. Herb.* XIX. 496 (Fl. N. Mex.) (1915).

Fraxinus anomala, var. *triphylla* Jones in *Proc. Calif. Acad. Sci.* ser. 2, V. 707 (*Contrib. W. Bot.* VII) (1895).

New Mexico. San Juan Co.: Carriso Mts., July 28, 1911, *P. C. Standley* (No. 7316).

Arizona. Coconino Co.: Grand Canyon, June 14, 1891, *D. T. McDougal* (No. 205), September 8, 1894, *C. S. Sargent,* September 12, 1894, *J. W. Toumey,* 1909, *E. W. Nelson* (No. 107), May 31, 1913, *E. A. Goldman* (No. 2068), June 30, 1913, *A. E. Hitchcock* (No. 79), July 19, 1914, *A. Rehder* (No. 105); two miles below Pagumpa, alt. 1300 m., April 21, 1894, *M. E. Jones* (No. 5088); Hermit Trail, June 18, 1916, *Alice Eastwood* (No. 5831).

Southern Utah. Labyrinth, Colorado River, 1859, *J. S. Newberry;* St. George, Virgin River, *E. Palmer;* Ranch, *A. L. Siler;* Johnson, *M. E. Jones.*

This very distinct species occurs within our area only in northern Arizona and in the extreme northwestern corner of New Mexico and extends into Utah and Nevada. It shows little variation; the variety *triphylla* Jones can hardly be considered a distinct form or variety, as trifoliolate leaves are likely to appear on any vigorous shoot of normal simple-leaved plants.

Arnold Arboretum, Harvard University.

[4] Except the sterile branch with pinnate leaves which was drawn from a cultivated plant supposed to be *F. anomala.*

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THE AUSTRALIAN ANTS OF THE PONERINE TRIBE CERAPACHYINI.

By William Morton Wheeler.

THE AUSTRALIAN ANTS OF THE PONERINE TRIBE CERAPACHYINI.[1]

By William Morton Wheeler.

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The Cerapachyini are of unusual interest to the myrmecologist, because they represent one of the most primitive sections of the most primitive subfamily of ants, the Ponerinæ, and because they are so closely related to the subfamily Dorylinæ as to suggest that the latter must have arisen from Cerapachyine ancestors. Owing, however, to the fact that all the species of the tribe are rare and sporadic and confined to warm countries, our knowledge of the habits and sexual forms of the species and of their distribution is still very inadequate. In a country like Australia which preserves such a large portion of the ancient Mesozoic ant-fauna, we should expect to find the tribe well represented in genera and species, and this proves to be true.

The workers of the Cerapachyini are easily recognized by their long, slender, jointed bodies; the petiole and postpetiole of the abdomen are distinct and in one of the genera (*Eusphinctus*) even the gastric segments are marked off from one another by pronounced constrictions. The eyes are often lacking, the antennæ are robust and well developed, the clypeus is very short and vertical, and the frontal carinæ are erect and closely approximated, so that the insertions of the antennæ are exposed. The thoracic sutures are very feeble or entirely absent. In the males the mandibles are well developed, the genital appendages are retracted and there are no cerci. The females are sometimes worker-like and apterous, though possessing eyes or both eyes and ocelli (*Nothosphinctus, Eusphinctus*); in other species the thorax has distinctly differentiated sclerites and bears wings, though the mesonotum and scutellum are very small; in still others the thorax has differentiated sclerites but bears no wings (*Cerapachys, Phyracaces*). The larva of only one species has been described, that of the Texan *Cerapachys* (*Parasyscia*) *augustæ* Wheeler (Psyche 1903, pp. 205–209). In the present paper I have sketched the larva

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[1] Contributions from the Entomological Laboratory of the Bussey Institution, Harvard University, No. 129.

of *Eusphinctus steinheili* Forel (Fig. 2). It is very long and slender, non-tuberculate and covered with bifurcate hairs. No pupæ of Cerapachyini have been seen, so that we are unable to say whether they are naked or enclosed in cocoons like the pupæ of all other Ponerinæ, except those of the genus *Discothyrea.*

Emery in the "Genera Insectorum" recognizes four genera of Cerapachyini, all of which are represented in Australia, namely, *Sphinctomyrmex, Cerapachys, Phyracaces* and *Lioponera,* the first comprising the subgenera *Sphinctomyrmex* s. str. and *Eusphinctus,* the second four subgenera: *Cerapachys* s. str., *Parasyscia, Oöceræa* and *Syscia.* Of the latter only *Syscia* is known to be represented in Australia. The taxonomic status of some of these groups is still doubtful, owing largely to incomplete information concerning their sexual phases. Emery (Zool. Jahrb. Abt. Syst. 8, 1895, p. 693, Pl. 14, Fig. 4) described and figured the genitalia of a male of an undetermined species of *Eusphinctus,* presumably from the Indomalayan region. He found that the inner paramera terminate as vertical plates with dentate inferior borders, and that the vosellæ are movably articulated, well differentiated and bear a vestigial lacinia at their bases. Of the males of the Australian species which have been included in the genus *Sphinctomyrmex,* nothing is known. Santschi has recently described a male ant from Africa as *S. rufiventris,* but its generic status seems to me to be open to doubt. The peculiarities of the females of the Australian forms have, in my opinion, an important taxonomic bearing, as will be evident from the following considerations.

The genus *Sphinctomyrmex* was erected by Mayr (Verh. zool. bot. Ges. Wien 16, 1866, p. 895, Pl. 20, Fig. 8) for the accommodation of a single deälated female specimen described from Brazil as *S. ståli.* During half a century no one has succeeded in again finding this insect. Mayr's figure shows that its thorax has well developed sclerites essentially like those in ordinary female ants. The antennæ are 12-jointed, the pygidium emarginate. In 1895 Emery erected a genus *Eusphinctus* for a worker ant (*E. furcatus*) from Lower Burmah, with 11–jointed antennæ, but with the pygidium emarginate and the gastric segments separated from one another by deep constrictions as in the Brazilian *ståli.* In 1897 a second species (*E. cribratus*) was described by Emery from New Guinea and Forel added a third from Bengal (*E. taylori*) in 1900. Only workers of these forms have come to light. In the meantime Forel received several species from Australia, some of which had 11-jointed, while others had 12-

jointed antennæ. He therefore concluded that *Eusphinctus* was merely a subgenus of *Sphinctomyrmex*. An examination of the Australian specimens convinced him that each colony of *Eusphinctus* contained two kinds of workers, one small and eyeless, the other large and possessing eyes and ocelli. As a somewhat similar dimorphism of the worker caste had been found in the European *Ponera eduardi*, he inclined to the view that the eyed individuals of *Eusphinctus* were gynæcoid workers, but he was baffled by these forms, which kept turning up, often in considerable numbers in colonies received from Australia. Later, in a species of what he regarded as *Sphinctomyrmex* s. str. (*S. imbecillis*) from South West Australia, he found a single large, eyeless individual, much like a worker, but more pilose, with more convex sides to the head and much larger gaster, more feebly constricted between the segments. This specimen he designated as an "ergatomorphic female" and noted its resemblance to the dichthadiigynes of the Dorylinæ on the one hand and to the large-eyed, shorter-headed and more pilose workers of *Eusphinctus* on the other, but confessed himself to be even more baffled in his attempts to interpret the personnel of colonies of Australian *Sphinctomyrmex*. In 1905 Ernest André (Rev. d'Ent. 24, 1905, p. 205) found the two types of individuals in a new species of *Eusphinctus* (*E. duchaussoyi*) from Sydney, N. S. W., and expressed the following opinion in regard to their meaning: "I consider the individuals with eyes and ocelli as ergatoid females and not as gynæcoid workers, although Forel inclines to the latter hypothesis so far as *E. steinheili* is concerned. My opinion is based on the fact that up to the present time no normal females have been found in any of the known species of the genus *Eusphinctus* and that probably such females do not exist but are replaced by ergatoids, a condition not without precedent in the ant-world. One may, of course, say by way of objection that the type of the genus *Sphinctomyrmex*, of which *Eusphinctus* is regarded as a subgenus, is based on a female with normal characters, but I would reply that its worker is still unknown, so that it is not certain that the described female, which is American, belongs to the same genus as the Asiatic and Australian species. I believe rather, till proof to the contrary is forthcoming, that the genus *Sphinctomyrmex* should be restricted to the single *S. ståli* of Brazil, which is the type, and that all the Asiatic and Australian species should constitute the genus *Eusphinctus* Emery, without distinction between those having 12 or 11 antennal joints. Besides such characters as may be exhibited by the still unknown worker of *Sphinctomyrmex*, this genus is characterized by a normal female, whereas the female of *Eusphinctus* is ergatomorphic."

Emery in the "Genera Insectorum" (Fasc. 118, 1911, p. 6) adopted André's interpretation of the eyed individuals but not his suggestion to restrict *Sphinctomyrmex* to the Brazilian type and to place all the Old World forms notwithstanding the differences in the number of antennal joints in the genus *Eusphinctus.* My study has led me not only to adopt André's suggestion but to go even further. There are evidently not two, but three groups of subgeneric status among the Australian forms. One of these comprises a single species, *E. turneri* Forel, known only from the worker, which is large, black, with 12-jointed antennæ, well-developed eyes, but without ocelli and with an emarginate pygidium. The two other groups have blind workers with entire pygidium, but differ in the number of antennal joints, *Eusphinctus* s. str. having 11, and the other group 12 (*Sphinctomyrmex* s. str. of Emery and Forel). Now the following facts show that the females of these two groups, though like the workers in form, differ in size and in the visual organs and shape of the pygidium:

1. No workers or worker-like individuals with well-developed eyes and ocelli are known in the group with 12-jointed antennæ (with the possible exception of *S. myops* Forel, which may be a female!).

2. An "ergatomorphic female" of *S. imbecillis* was described by Forel as being considerably larger than the worker, without eyes or ocelli, with scarcely constricted gastric segments and with emarginate pygidium.

3. Dr. W. M. Mann loaned me for study a fine colony of a new species closely related to *imbecillis,* which he recently discovered in New South Wales (*manni* sp. nov.). This colony comprises 227 blind workers varying from 3 to 5 mm. in length, and a single much larger, worker-like individual 7 mm. in length, with very minute eyes and the anterior ocellus, but in all other respects, except the somewhat larger size, like the ergatomorphic female of *imbecillis* described by Forel. Even in the field Dr. Mann at once recognized this individual as the queen of the colony.

4. In the known Australian species of *Eusphinctus* s. str. each colony contains several large, eyed and ocellate worker-like individuals. Since these individuals differ from the blind workers in many of the characters exhibited by the ergatomorphic females of *imbecillis* and *manni* (greater size and more voluminous gaster, shorter and laterally more convex head, more abundant pilosity), André's and Emery's view that they are the only true females among these ants, seems to

me more acceptable than Forel's supposition that we are here concerned with a peculiar dimorphism of the worker caste comparable with that observed in *Ponera eduardi*.[2] The colonies referred to *Eusphinctus* s. str. are polygynic whereas those referred to *Sphinctomyrmex* s. str. by Emery and Forel are monogynic, a difference naturally correlated with the size and development of the gaster in the females of the two groups. Since the reproductive function is distributed over several queens in *Eusphinctus*, each is more nearly of the normal stature of the largest workers than in the *Sphinctomyrmex* colony.

I therefore agree with André in leaving only *S. ståli* of Brazil in the genus *Sphinctomyrmex* and in regarding all the paleotropical species as belonging to the genus *Eusphinctus*, but believe that the latter should be divided into at least three subgenera, as follows:

1. *Eusphinctus* s. str. Workers and females with 11-jointed antennæ, with entire or emarginate pygidium, the workers blind, the females with eyes and ocelli. Habits hypogæic.

2. *Nothosphinctus* subgen. nov. Workers and females with 12-jointed antennæ; the former blind and with entire pygidium, the latter with emarginate pygidium and either blind or with very minute eyes and the anterior ocellus. Habits hypogæic.

3. *Zasphinctus* subgen. nov. Workers large, dark colored, with 12-jointed antennæ and well developed eyes, but without ocelli. Females unknown. Habits probably epigæic.

The worker of *E. cribratus* Emery of New Guinea has an entire pygidium and belongs with the Australian species in *Eusphinctus* s. str. but the workers of the Indian species *E. furcatus* Emery and *taylori* Forel have a notched pygidium. Should future investigation show that the pygidial characters are correlated with other peculiarities or with different types of female, it may be advisable to restrict the subgenus *Eusphinctus* to the two Indian species and to suggest a

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2 Cases of dimorphism of the worker among the Ponerinæ are extremely rare. The most remarkable case is that of the African *Megaponera fœtens* Fabr., which has two types of workers differing not only in size, but also in sculpture and the structure of the antennæ. As no winged females were known of this species Emery believed that their place in the colonies was usurped by the large workers but Arnold has recently discovered and described the true female (Ann. South Afr. Mus. **14**, 1915, p. 48 *nota*, Fig. 6). It is ergatoid and therefore resembles the females of *E. manni* and *imbecillis*. Among many specimens of *M. fœtens* recently collected in the Congo by Mr. H. O. Lang of the American Museum of Natural History I find both forms of worker in each colony.

new subgeneric name for the Australian and Papuan forms with 11-jointed antennæ.

In this connection attention may be called to the fact that the females of *Nothosphinctus* bear a surprising resemblance to those of the related tropical genus *Acanthostichus*, as will be seen by consulting Emery's description and figures of the female of *A. quadratus* (Zool. Jahrb. Abt. Syst. 8, 1895, p. 693, Pl. 14, Fig. 4 and Gen. Insect. Fasc. 118, 1911, Pl. 1, Figs. 4 and 4b). As Emery and Forel have remarked, these females resemble the only known females of the Dorylinæ (*Dorylus, Eciton, Aenictus, Leptanilla*) and may therefore have considerable phylogenetic significance. In previous publications I have described similar females in several Ponerine genera (*Onychomyrmex, Paranomopone, Leptogenys*.[3]

Turning to the other genera of the Cerapachyini we find that our knowledge of the females is even more incomplete than in *Sphinctomyrmex* and *Eusphinctus*. The female *Cerapachys imerinensis* Forel of Madagascar has well-developed wings and *Phyracaces pubescens* Emery of Borneo and *Ph. turneri* Forel of Queensland were described from deälated females, and I have winged females of an undescribed *Phyracaces* from the Congo, but the females of *Parasyscia augustæ* Wheeler and *Phyracaces elegans* sp. nov. show no traces of having borne wings, though the thorax is of the same structure as in the winged females. The same is true of the female of an undescribed species of *Syscia* recently taken in Fiji by Dr. W. M. Mann. In the Indian *Lioponera longitarsis* the female is ergatoid. These genera therefore exhibit various stages in the reduction of the normal winged female to the ergatoid type of *Eusphinctus* s. str. while *Nothosphinctus*

3 Consistency with the views here advanced would require that *Ctenopyga* Ashmead should be regarded as a distinct genus and not as a subgenus of *Acanthostichus*, since the females of the two known species, *C. texanus* Forel and *C. townsendi* Ashmead, are winged and quite different from that of *A. quadratus*. A too consistent following of the example of André and myself would, however, lead to difficulties in such cases as the European *Harpagoxenus sublævis*, an ant which in Sweden has only apterous, ergatoid females, but in Saxony has winged females of normal structure. I have perhaps overemphasized the differences between the paleotropical *Eusphinctus* and the neotropical *Sphinctomyrmex*, but my procedure may at least deter zoögeographers from citing *Sphinctomyrmex* as evidence of a former antarctic land connection between South America and Australia. It is often just such imperfectly known genera, which are confidently cited in support of ancient land-bridges; e. g. the genera *Myrmecocystus* and *Melophorus*. When carefully studied the Old World forms referred to *Myrmecocystus* are seen to be generically distinct and are now referred to *Cataglyphis*, while the South American forms referred to *Melophorus* really belong to a distinct genus, *Lasiophanes*.

may be said to show an early stage in the development of the dichthadiigyne of the Dorylinæ.

The distribution of the 75 known species of Cerapachyinæ is given in the following table:

	Ethiopian	Malagasy	Indomalayan	Papuan	Australian	Hawaiian	Neotropical
Sphinctomyrmex	......	......	......	......	......	......	1
Eusphinctus	1	......	2	1	2		
Nothosphinctus	......	......	......	......	7		
Zasphinctus	......	......	......	......	1		
Cerapachys	6	1	9	2			
Parasyscia	......	......	2	......	......	......	2
Oöceraea	......	......	2				
Syscia	......	......	2	2	1	1	
Phyracaces	4	2	2	1	16		
Lioponera	2	......	2	......	1		
Total	13	3	21	6	28	1	3

It will be seen that Australia has many more species than any other region, that the genus *Phyracaces* is especially well represented and that only four of the ten genera and subgenera are absent. One of these, however, *Cerapachys* s. str., occurs in New Guinea and will therefore probably be found in Northern Queensland. The present center of distribution of the whole group, with 50 species, representing all the genera except *Sphinctomyrmex*, is seen to cover the Indomalayan, Papuan and Australian regions. That the group was once cosmopolitan in range is shown by the survival of *Sphinctomyrmex ståli* in Brazil, *Parasyscia augustæ* Wheeler in Texas and *P. tolteca* Forel in Guatemala and by the occurrence of two large primitive Cerapachyine forms (*Procerapachys annosus* Wheeler and *P. favosus* Wheeler) in the Baltic Amber.

A difference of opinion has arisen between Emery and Forel in regard to the status of *Phyracaces*, the former now regarding it as a distinct genus, the latter as a subgenus of *Cerapachys*. While the distinctive characters of *Phyracaces*, namely the less pronounced development of the terminal antennal joint, the large eyes and the sharp lateral border of the petiole and often also of the postpetiole, are minor characters, they seem to be sufficiently constant to enable one to separate the species readily from those of *Cerapachys* and its subgenera. Moreover, at least the great majority of species of *Cerapachys* sens. lat. are hypogæic, whereas those of the genus *Phyracaces* forage on the surface of the ground.

Some meager notes on *Parasyscia augustæ* which I published many years ago, have remained up to the present time the only account of the habits of a Cerapachyine ant. During my sojourn in Australia I was able to gain a few additional glimpses of the behavior of one species of *Eusphinctus* and of several species of *Phyracaces*. My brief field notes on these insects may be here transcribed:

Nov. 30, 1914, I found a fine colony of *Eusphinctus steinheili* under a large log which was rather deeply embedded in sand in the bottom of a ravine at Hornsby, New South Wales. The colony, which comprised about 200 workers and females, was crowded into a few small burrows in the sand, with a large number of nearly full-grown larvæ. Dr. Mann found three smaller colonies of this species during December, 1916, at Leura in the Blue Mts., Sydney and Wentworth Falls, N. S. W. One of these also contained adult larvæ but no pupæ.

Sept. 16, at Southerland, New South Wales, I found a colony of about 70 workers and one wingless female of *Phyracaces elegans* sp. nov. huddled together in a mass under a block of sand-stone in a thin layer of soil which in turn was lying on the hard sandstone wall of one of the deep gorges so characteristic of the country about Sydney. As there was no brood in the colony and as it had rained heavily the preceding day, I inferred that the ants were merely bivouacking after having been washed out of their nest.

Sept. 19, a fine colony of about 50 workers of *Phyracaces larvatus* sp. nov. was found under a small stone in one of the deep sandstone ravines near Katoomba in the Blue Mts. of New South Wales.

Oct. 18. Near Cairns, Queensland, I happened on about a dozen workers of *Ph. fervidus* sp. nov. running rapidly over a patch of sand in the open forest. They moved much like workers of *Lobopelta*. Two of them entered a nest of *Pheidole* but soon returned to the surface and continued foraging.

Oct. 19. A few workers of *Ph. turneri* Forel were seen running about on dead leaves in the dark, tropical "scrub" at Kuranda, Queensland. The nest was not discovered.

Oct. 25. In the same locality and also in the tropical "scrub" I found a colony of about 25 workers of *Ph. binodis* Forel in a small cavity of a damp, red-rotten log.

Nov. 10. I found several workers of *Ph. scrutator* sp. nov. foraging under a stone in a dry depression at the base of the mountain at Toowong, near Brisbane, Queensland. The ants moved rapidly and seemed to be searching for the nests of other ants.

Nov. 26. At Salisbury Court, near Uralla, New South Wales, I saw a fine colony of *Ph. senescens* sp. nov. comprising about 150 workers running rapidly about on a hill-slope, very evidently on a foraging expedition. They reminded me of the small forays of *Formica sanguinea* in northern regions.

Dec. 3. In the Bulli Pass, New South Wales I came upon a dozen workers of *Ph. ficosus* sp. nov. running over the sand in a very loose file. Three or four of them were carrying the naked pupæ of some small Myrmicine ant in their jaws.

These observations show that, as I maintained in the case of *Parasyscia augustæ,* the *Cerapachyini* form small colonies, like most species of Ponerinæ, that the species of *Eusphinctus* (with the probable exception of *S. turneri*) are hypogæic in their habits, a peculiarity also indicated by the absence of eyes in the workers of nearly all the species and the small eyes of the females, and that the large-eyed *Phyracaces* forage in troops (or as whole colonies?) on the surface of the ground, their prey consisting of the brood of other ants. These facts are very significant in connection with the affinities of the Cerapachyini to the Dorylinæ, or driver ants, which in Africa and tropical America, forage in a similar manner, though in much larger companies, because their colonies are much more populous, and also feed on the brood of other ants when other insect food is not available. Still, what I have seen are only glimpses of the habits of the Cerapachyini. Any of my fellow entomologists in Australia who will undertake an intensive study of these ants will, I am sure, find many new and interesting ethological traits and solve many problems relating to the character of the sexual phases, in addition to finding many new forms, since practically every colony of *Phyracaces* I saw, during the limited time at my disposal, represented a different, undescribed species. In addition to the material collected by myself I have been able, through the kindness of Mr. A. M. Lea, to study the Cerapachyinæ of the Museum of South Australia, comprising specimens of *Eusphinctus steinheili* and its var. *hedwigæ, Zasphinctus turneri, Phyracaces heros, leæ, rugulinodis* and *mullewanus.* Mr. Henry Hacker of the Queensland Museum has presented me with specimens of *Eusphinctus hackeri* and *Syscia australis.*

The four genera of Cerapachyini occurring in Australia may be readily distinguished as follows:

1. Gaster elongate, cylindrical, the segments separated from each other by pronounced constrictions...... *Eusphinctus* Emery.
   Segments of the gaster not thus separated.................... 2.
2. Last antennal joint much thicker and larger than the preceding joint, forming a one-jointed club; petiole not marginate on sides *Cerapachys* F. Sm.
   Last antennal joint not enlarged, though longer than the preceding joint, and not forming a distinct club.................. 3.
3. Funiculus of antenna terminating in a 4-jointed club *Lioponera* Mayr.
   Funiculus not terminating in a 4-jointed club; petiole marginate on sides.............................. *Phyracaces* Emery.

The subgenera of Cerapachys are easily distinguished by the number of antennal joints, *Cerapachys* s. str. having 12, *Parasyscia* 11, *Oöceræa* 10 and *Syscia* 9 joints.

Genus **Eusphinctus** *Emery.*

The workers and females of the subgenera, species and varieties of *Eusphinctus* may be separated by the following dichotomy:

1. Antennæ 11-jointed (Subgen. *Eusphinctus*).................. 2.
   Antennæ 12-jointed....................................... 6.
2. Length 3.2–4 mm.. 3.
   Length not more than 3 mm................................ 4.
3. At least the head, thorax and petiole ferruginous brown; sides of postpetiole straight........................ *steinheili* Forel.
   Color uniformly reddish; sides of postpetiole convex. var. *hedwigi* Forel.
4. Length only 1.5 mm........................ *hackeri* sp. nov.
   Length 2.5–3 mm.. 5.
5. Pale ferruginous, head, thorax and petiole infuscated above; female with rather large, flat eyes. *steinheili* var. *duchaussoyi* Ern. André.
   Pale yellowish red; female with minute eyes. . var. *cedaris* Forel.
6. Large black species, 7–8.5 mm. long; worker with well developed eyes and emarginate pygidium (Subgen. *Zasphinctus* subgen. nov.)................................ *turneri* Forel.
   Smaller, ferruginous or yellow species; worker eyeless or with

very minute eyes, pygidium entire (Subgen. *Nothospinctus* subgen. nov.) .... 7.

7. Workers with minute eyes .... *myops* Forel.
Workers without eyes .... 8.

8. Postpetiole concave in front .... *emeryi* Forel.
Postpetiole not concave in front .... 9.

9. Head square, hardly longer than broad, thorax flattened above, marginate in front .... 10.
Head distinctly longer than broad; thorax at most submarginate in front 11

10. Mandibles punctate and coarsely striate; thorax only twice as long as broad; epinotal declivity marginate above and on the sides; petiole distinctly broader than long; head and thorax coarsely punctate .... *froggatti* Forel.
Mandibles merely punctate; thorax $2\frac{1}{2}$ times as long as broad; epinotal declivity marginate only on the sides; petiole scarcely broader than long; head and thorax finely punctate. *imbecillis* Forel.

11. Funicular joints 2–6 only slightly broader than long. *clarus* Forel.
Funicular joints 2–6 much broader than long .... 12.

12. Last antennal joint scarcely longer than the two preceding joints together .... *mjöbergi* Forel.
Last antennal joint fully as long as the three preceding joints together .... *manni* sp. nov.

1. **Eusphinctus** (**Eusphinctus**) **steinheili** Forel.

(Figs. 1 and 2.)

Sphinctomyrmex (*Eusphinctus*) *steinheili* Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 72, ♀ (nec ☿); Emery, Gen. Insect. Fasc. 118, 1911, p. 7.

Sphinctomyrmex steinheili Froggatt, Agric. Gaz. N. S. W., 1905, p. 15.

Sphinctomyrmex (*Eusphinctus*) *fallax* Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 73 ☿; Emery, Gen. Insect. Fasc. 118, 1911, p. 7.

Sphinctomyrmex fallax Froggatt, Agric. Gaz. N. S. W., 1905, p. 15.

Worker. Length 3.2–3.6 mm.

Head nearly $1\frac{1}{2}$ times as long as broad, as broad behind as in front, with very feebly convex sides, broadly excavated posterior border and short but rather pointed posterior corners. Occipital border strongly marginate, the margination running around the posterior corners and along the ventral surface on each side about $\frac{1}{3}$ the length of the head. Eyes and ocelli absent. Mandibles small, abruptly flexed at their bases, with deflected blades, the apical margins very indistinctly denticulate. Clypeus very short. Frontal carinæ closely approximated, in front surrounding the antennal insertions, behind fused and truncated in a depression which unites the antennal foveæ. Carinæ of cheeks sharp, abruptly and angularly turned inward behind towards the antennal foveæ. Antennæ robust; scapes about half as long as the head, thickened apically; first funicular joint as long as broad; joints 2–9 broader than long, apical joint enlarged, glandiform, as long as the four preceding joints together. Thorax about $2\frac{1}{2}$ times

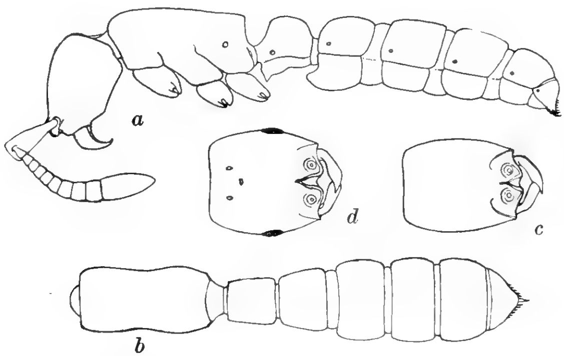

FIGURE 1. *Eusphinctus steinheili* Forel, *a*, worker in profile; *b*, thorax and abdomen of same, dorsal view; *c*, head of same, *d*, head of female.

as long as broad, its dorsal surface flattened, with a very feeble transverse depression marking the obsolete mesoëpinotal suture; epinotum abruptly truncated behind, distinctly concave in profile; pronotum marginate in front; epinotal declivity sharply marginate on the sides and above, on each side above very feebly subdentate. Mesopleuræ rather concave. Petiole from above rectangular, distinctly longer than broad, scarcely broader behind than in front, narrower than the epinotum, with straight, subparallel sides, rather rounded, convex dorsal surface and a sharp, angular tooth, directed forward and downward on its anteroventral surface. Postpetiole broader than the petiole, as long as broad and distinctly broader behind than in front, with straight sides and anterior border, its ventral portion in front very protuberant and rounded. First gastric segment $1\frac{1}{2}$, second and third segments twice as broad as long. Pygidium subtruncate behind, on each side and at the blunt tip minutely spinulate. Legs moderately long.

Shining; mandibles coarsely punctate; head, thorax and petiole covered with rather shallow, umbilicate, piligerous foveolæ, which are dense on the head and distinctly sparser on the thorax and petiole. Postpetiole and gaster evenly punctate.

Hairs pale yellow, slender, pointed, moderately long, suberect on the body, partly appressed and like long pubescence on the gaster.

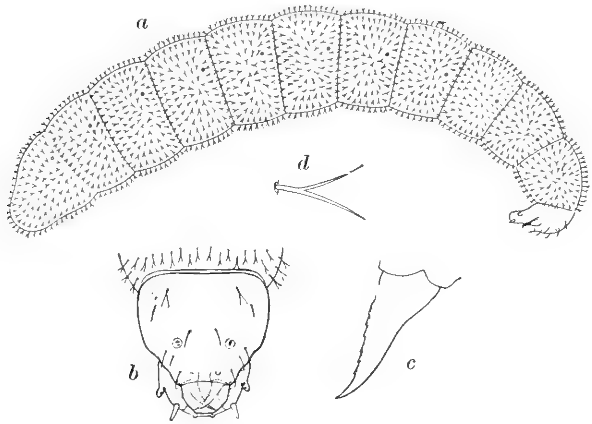

FIGURE 2. *a*, Larva of *Eusphinctus steinheili* Forel, lateral view. *b*, head of same, dorsal view; *c*, mandible; *d*, forked hair from body enlarged.

Antennæ and legs with very few erect hairs, but covered with rather abundant, appressed pubescence.

Ferruginous brown; mandibles, cheeks, antennæ, legs, postpetiole and gaster paler and more reddish.

Female. Length 3.5–4 mm.

Differing from the worker in its large side, in the proportionally broader head, which is scarcely $1\frac{1}{4}$ times as long as broad, the less distinct carinæ on the cheeks and the presence of eyes and ocelli, the eyes being moderately large, rather flat and placed a little in front of the middle of the sides of the head. The petiole is not longer than broad, the gaster more voluminous, with the constrictions between the segments less pronounced than in the worker. The erect hairs on the body and appendages are longer, more abundant and more bristly, even on the antennal funiculi. The appressed hairs on the gaster are also longer and more numerous.

Larva. Long and slender, cylindrical and not enlarged at the posterior end, with eleven distinct postcephalic segments, all uniformly clothed with short, erect, two-branched hairs. Head small, as broad as long, with vestigial antennæ and long falcate mandibles, which have finely serrate internal borders. There are few hairs on the head and these are simple, with the exception of a pair near the occipital border, which are two-branches like those on the body. The color of the larva is dull white.

Queensland: Mackay, type-locality (Turner).

New South Wales: Hornsby (Wheeler); Sydney, Wentworth Falls and Leura, Blue Mts. (W. M. Mann).

South Australia: Lucindale (Feuerheerdt).

I have examined a cotype of *steinheili* given me by Prof. Forel. It is indistinguishable from the females in the colonies I have seen from New South Wales and South Australia, the workers of which are evidently referable to Forel's *fallax*. The nests are found in sand under logs and stones.

2. **Eusphinctus** (**Eusphinctus**) **steinheili** var. **hedwigæ** Forel.

Sphinctomyrmex (*Eusphinctus*) *fallax* subsp. *hedwigæ* Forel, Rev. Suisse Zool. 18, 1910, p. 21 ☿ ♀; Emery, Gen. Insect. Fasc. 118, 1911, p. 7; Boll. Lab. Zool. Gen. Agrar. 8, 1914, p. 179.

Sphinctomyrmex hednigæ (sic!) Froggatt, Agric. Gaz. N. S. W., 1905, p. 15.

New South Wales: Walcha, type locality (W. W. Froggatt).

South Australia: Mt. Lofty (Silvestri; A. M. Lea); Adelaide (Mus. S. Austr.).

I am convinced from examination of a cotype worker and female and of many specimens of both phases from the two localities in South Australia that this is merely a variety of *steinheili*. The postpetiole has the sides more rounded in the worker than in the typical form of the species, but both this character and the width of the gastric segments of the two forms are somewhat variable, so that often they can be distinguished only by the coloration, *hedwigæ* having the body more uniformly reddish.

3. **Eusphinctus (Eusphinctus) steinheili** var. **duchaussoyi** Ern. André.

Eusphinctus duchaussoyi Ern. André, Rev. d'Ent., 1909, p. 205, ☿ ♀.

Sphinctomyrmex (*Eusphinctus*) *duchaussoyi* Emery, Gen. Insect. Fasc. 118, 1911, p. 7.

New South Wales: Sydney (A. Duchaussoy).

Judging from André's description this form, too, is hardly more than a variety of *steinheili*. It is distinctly smaller, the worker measuring only 2.5–3 mm., the female 2.7–3 mm. The color is paler as in *hedwigæ* and the punctures are different, being described as sparse and a little larger and less abundant on the head and thorax and finer and denser on the abdomen.

4. **Eusphinctus (Eusphinctus) steinheili** var. **cedaris** Forel.

Sphinctomyrmex (*Eusphinctus*) *fallax* var. *cedaris* Forel, Ark. f. Zool. 9, 1915, p. 16, ☿ ♀.

Queensland: Cedar Creek (E. Mjöberg).

Of about the same size as *duchaussoyi*, the worker measuring 2.5–2.6 mm., the female 2.9 to 3.1 mm. The petiole of the worker is more steeply truncate in front below than in *steinheili*, the punctures are sharper and denser on the abdomen, but feebler and sparser on the head. In the female the eyes are smaller, consisting of only about 8 or 9 indistinct facets.

5. **Eusphinctus (Eusphinctus) hackeri** sp. nov.

(Fig. 3.)

Worker. Length 1.5–1.7 mm.

Head rectangular, fully $1\frac{1}{2}$ times as long as broad, as broad behind as in front, with straight, parallel sides, rather deeply excised posterior border and short, blunt posterior corners. Occipital border marginate. Eyes and ocelli absent. Mandibles not abruptly flexed at the base, their apical and basal borders not distinctly separated, the former minutely denticulate. Frontal carinæ approximated, surrounding the antennal insertions in front, confluent behind and truncated in a depression connecting the antennal foveæ. Carinæ of cheeks short and indistinct. Antennæ robust; scapes about $\frac{1}{3}$ as long as the head, much thickened apically, first funicular joint as long as broad, joints 2–9 very transverse, terminal joint large, glandiform, fully as long as the five preceding joints together. Thorax about $2\frac{1}{2}$ times as long as broad, with flattened dorsum, rounded humeri and epinotal angles, as broad behind as in front, with very feebly indicated mesoëpinotal suture. Pronotum not marginate, epinotal declivity marginate only on the sides, in profile truncated and decidedly concave. Petiole narrower than the epinotum, rectangular, a little longer than broad and a little broader behind than in front, its dorsal surface convex, its anteroventral surface with a small, acute tooth. Postpetiole rectangular, broader than the petiole, as broad as long, a little broader behind than in front, with straight sides. Gastric segments 1–3

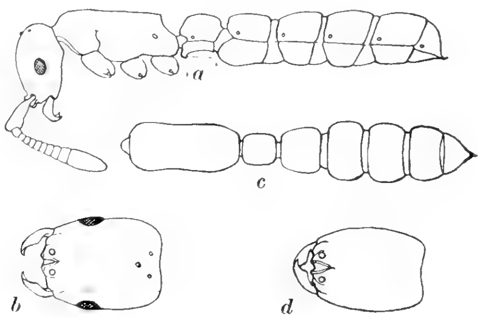

FIGURE 3. *a*, Female *Eusphinctus hackeri* sp. nov., lateral view; *b*, head of same, dorsal view; *c*, thorax and abdomen of worker, dorsal view; *d*, head of same.

nearly twice as broad as long. Pygidium short, broadly rounded and truncate behind, where it is bordered with minute spinules.

Shining; mandibles coarsely punctate; head, thorax, petiole and postpetiole covered with umbilicate, piligerous foveolæ, which are densest on the upper surface of the head, elongate on its front and sides; gaster rather coarsely and evenly punctate. Antennal scapes sparsely foveolate.

Hairs pale yellow, short, erect, moderately abundant, longer at the tip of the gaster; pubescence dilute. Legs with fine, dilute, appressed pubescence and a very few, erect hairs.

Uniformly brownish yellow, not infuscated.

Female. Length 1.8 to 2 mm.

Differing from the worker in size and in having eyes and ocelli, the former distinctly in front of the middle of the head, the broader and more rounded petiole and more voluminous gaster, with less pronounced constrictions between the segments. The sides of the postpetiole are straight as in the worker. The erect hairs on both the body and appendages are distinctly more abundant and more bristly.

Described from six workers and two females taken by Mr. Henry Hacker on Bribie Island, near Brisbane, Queensland.

This species is easily recognized by its very small size, rounded humeri and epinotal corners and the absence of marginations on the pronotum and upper portion of the epinotal declivity.

6. **Eusphinctus (Zasphinctus) turneri** Forel.

(Fig. 4.)

Sphinctomyrmex turneri Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 70, ☿; Rev. Suisse Zool. 18, 1910, p. 21, ☿; Froggatt, Agric. Gaz. N. S. W., 1905, p. 15; Emery, Gen. Insect. Fasc. 118, 1911, p. 7, Pl. 1, Fig. 1, ☿.

Worker. Length 7–8.5 mm.

Head subrectangular, a little longer than broad, as broad in front as behind, broadest through the eyes, which are moderately large and convex and a little in front of the middle of the sides; occipital border deeply and broadly excavated, marginate, the margin surrounding the posterior corners and extending forward on the gular surface about $\frac{1}{3}$ the length of the head. Ocelli absent. Carinæ of cheeks distinct but not dentate, running backward and inward towards the antennal foveæ. Mandibles rather small, subtriangular, deflected, their apical margins indistinctly denticulate. Clypeus short, with straight anterior border. Frontal carinæ short, erect, rounded, approximated and strongly truncated behind, surrounding the antennal insertions in front. Antennæ rather long, 12-jointed; scapes about $\frac{2}{3}$ as long as the head; funicular joints 1 and 5–10 distinctly broader than long, joints 2–4 as long as broad, terminal joint but slightly enlarged, as long as the three preceding joints. Thorax less than twice as long as broad, a little broader behind than in front, with rounded anterior and posterior corners, marginate anterior and prosternal borders, very feebly convex dorsal and slightly concave mesopleural surfaces, without promesonotal or mesoëpinotal sutures. The truncated surface of the epinotum is surrounded above and on the sides by a sharp margination. Petiole as long as broad, rounded-cuboidal, slightly broader behind than in front, distinctly narrower than the epinotum, in profile higher than long, rounded above, with vertical, truncated anterior and posterior surfaces and a powerful triangular tooth at the anteroventral end. Postpetiole broader than the petiole, a little broader behind than in front, with rectangular anterior corners, convex dorsal surface and its anterior ventral portion rounded and strongly protuberant. Gastric segments 1–3 broader than long, separated by very deep and broad constrictions. Pygidium trapezoidal, flattened or slightly concave above, submarginate on the sides and rather deeply notched at the tip, the sides and notch fringed with conspicuous spinules. Sting robust, curved. Legs rather long, posterior coxæ without lamellate appendages.

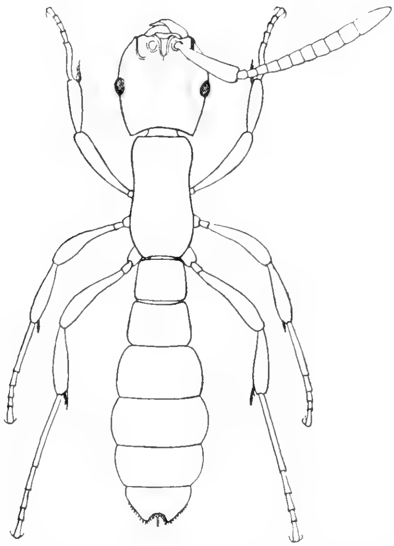

FIGURE 4. *Zasphinctus turneri* Forel. Worker.

Opaque; mandibles shining, coarsely punctate; head and thorax covered with round foveolæ, varying in size, their bottoms opaque and finely rugulose. These foveolæ are so close together that the spaces between them form coarse but not prominent reticulate rugæ. Remainder of body, including the legs and scapes coarsely and densely punctate. Epinotal declivity shining, very finely and transversely shagreened.

Hairs grayish yellow, abundant and rather long, in part suberect, both on the body and appendages, and in part appressed, the latter appearing on the appendages as long pubescence.

Black; tarsi, articulations of legs, antennal funiculi, mandibles, clypeus, frontal carinæ, cheeks and pygidium reddish.

Queensland: Mackay, type-locality (Gilbert Turner); Kuranda (Rowland Turner and F. P. Dodd).

I have redescribed this species from four specimens from Kuranda, two received from Prof. Forel and taken by Rowland Turner and two taken by F. P. Dodd and belonging to the Museum of South Australia.

E. turneri is readily recognized by its large size, black color, the presence of eyes and the emarginate pygidium.

7. **Eusphinctus** (**Nothosphinctus**) **froggatti** Forel.

(Fig. 5.)

Sphinctomyrmex froggatti Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 71, ☿; Froggatt, Agric. Gaz. N. S. W., 1905, p. 15; Emery, Gen. Insect. Fasc. 118, 1911, p. 7.

Worker. Length 4.5–5.5 mm.

Head nearly square when seen from above, scarcely longer than broad, as broad in front as behind, with feebly rounded sides, deeply excavated posterior border and sharp posterior corners. Margination of posterior border and corners continued forward on each side of the gula fully $\frac{2}{3}$ the length of the head. Mandibles strongly flexed inward at the base, with distinctly concave external border, the apical border denticulate and passing through a curve into the basal border. Clypeus very short, its anterior border broadly rounded. Frontal carinæ very short, erect, small, approximated, fused and strongly truncated behind and curving around the antennal insertions in front. Antennal foveæ confluent behind the frontal carinæ. Cheeks with small, indistinct carinæ, which border the antennal insertions on the sides. Antennæ short and stout; scapes about half as long as the head, thickened towards their tips; funicular joints 1–9 short, very distinctly broader than long, tenth joint as broad as long, terminal joint fully as long as the three preceding joints together. Thorax subrectangular, fully twice as long as broad, as broad through the pronotum as through the epinotum, with blunt anterior and posterior corners, flattened above and on the sides, which are scarcely submarginate, with sloping, concave, epinotal declivity. Mesoëpinotal suture very feebly indicated. Pronotum in front, prosterna, sides and upper border of epinotal declivity marginate. Petiole rounded cuboidal, as long as high, a little broader than long and a little broader behind than in front, its anterior surface flat and marginate on the sides; its ventral surface in front with a large, blunt, compressed tooth. Postpetiole fully $1\frac{2}{3}$ times as broad as long, broader than the petiole, broader behind than in front, with rounded anterior angles, and its ventral portion in front swollen and strongly protuberant. Pygidium flattened above, entire and blunt at the tip, with a row of

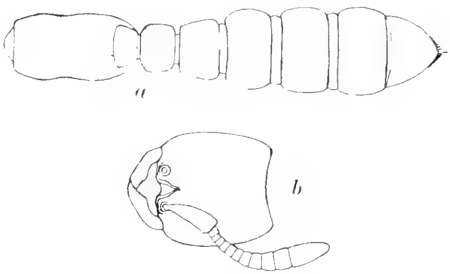

FIGURE 5. *a, Nothosphinctus froggatti* Forel, thorax and abdomen of worker, dorsal view; *b*, head of same.

spinules along each side. Legs moderately long; hind coxæ without lamellate appendage at the tip.

Shining; mandibles coarsely punctate, striate at the base; head, thorax, petiole and postpetiole covered with scattered foveolæ of varying size, denser on the head, very sparse in the mid-dorsal line of the thorax and on the petiole and postpetiole; gaster very finely shagreened and sparsely punctate.

Hairs pale yellow, short, moderately abundant, oblique or subappressed, shorter and more appressed on the appendages where they may be described as long; pubescence rather abundant, especially on the tibiæ.

Brownish red; scapes and legs somewhat paler; mandibles, anterior border of head and incisures of funicular joints blackish.

New South Wales: Minto, type locality (W. W. Froggatt); Sydney (A. M. Lea).

Redescribed from four specimens from the latter locality (Museum of South Australia).

8. **Eusphinctus (Nothosphinctus) emeryi** Forel.

Cerapachys emeryi Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 461, ☿.
Sphinctomyrmex emeryi Froggatt, Agric. Gaz. N. S. W. 1905, p. 15; Emery, Gen. Insect. Fasc. 118, 1911, p. 7.
North West Australia: Baudin Island (J. J. Walker).

9. **Eusphinctus (Nothosphinctus) myops** Forel.

Sphinctomyrmex emeryi var. *myops* Forel, Ann. Soc. Ent. Belg. 39, 1895, p. 421 ☿; Emery, Gen. Insect. Fasc. 118, 1911, p. 7.
S. emeryi race *clarus* var. *myops* Froggatt, Agric. Gaz. N. S. W., 1905, p. 15.
Queensland: Mackay (Gilbert Turner).

Forel does not state whether he regards the type as a normal or a gynæcoid worker. It may be the female of *emeryi*, or of an allied form, but if it is a normal worker, it should rank as a distinct species, since *emeryi* is eyeless. His brief description runs as follows: "Sculpture that of the type [*emeryi*]. Form and pilosity those of the race *clarus*. Color intermediate. Distinct from the two forms in possessing very small but distinct, flattened eyes situated at the middle of the sides of the head and comprising some thirty facets."

10. **Eusphinctus (Nothosphinctus) clarus** Forel.

Cerapachys emeryi var. *clarus* Forel, Ann. Soc. Ent. Belg. 37, 1893, p. 462, ☿.
Cerapachys clarus Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 72, ☿.
Sphinctomyrmex emeryi race *clarus* Forel, Rev. Suisse Zool. 10, 1902, p. 537; Froggatt, Agric. Gaz. N. S. W., 1905, p. 15.
Sphinctomyrmex clarus Emery, Gen. Insect. Fasc. 118, 1911, p. 7.
North West Australia: Adelaide River (J. J. Walker).

11. **Eusphinctus (Nothosphinctus) imbecillis** Forel.

Sphinctomyrmex froggatti subsp. *imbecillis* Forel, Fauna S. W. Austr. 1, 1907, p. 272, ☿, erg. ♀; Emery, Gen. Insect. Fasc. 118, 1911, p. 7.

South West Australia: Lion Mill.

I believe this form must be regarded as a distinct species as the characters in which it differs from *clarus*, are, according to Forel's statement, more than subspecific. The mandibles are not striated as in *froggatti* and are less geniculate at their bases, the anterior corners of the pronotum are more rounded, the thorax longer, the epinotum not marginate above, the petiole hardly broader than long, with shorter ventral tooth and the puncturation is feebler and sparser than in *froggatti*.

The "ergatomorphic female," described by Forel, is eyeless, with swollen epinotum, shorter and more rounded head, the petiole $1\frac{1}{3}$ times as broad as long, more voluminous gaster, emarginate pygidium, and the surface is more opaque, more punctate and more pubescent than in the worker. This singular individual measured 6.5 mm. It was found in the same vial with a number of workers and undoubtedly belonged to the same species. Forel believes that such individuals must represent the type from which the dichthadiiform females of the Dorylinæ have developed.

12. **Eusphinctus** (**Nothosphinctus**) **manni** sp. nov.

(Fig. 6.)

Worker. Length 3–5 mm.

Head distinctly longer than broad, a little broader in front than behind, with evenly rounded sides, feebly and broadly concave occipital border and short, blunt posterior corners. Eyes and ocelli absent. Occipital border marginate, the margination surrounding the posterior corners. Carinæ of cheeks very feebly developed. Mandibles not geniculate nor abruptly curved at the base, their apical borders finely denticulate. Frontal carinæ short, erect, surrounding the antennal insertions in front, truncated and fused behind in a depression uniting the antennal foveæ. Antennæ rather slender; scapes less than half as long as the head, thick at the apex, rather suddenly narrowed at the basal fourth; funicular joints 2–9 much broader than long, tenth joint as long as broad, terminal joint rather slender, fully as long as the three preceding joints together. Thorax fully $2\frac{1}{2}$ times as long as broad, distinctly narrowed in the mesonotal region, flattened above, submarginate on the sides; pronotum with rectangular humeri, vertically truncated and submarginate in front, the mesoëpinotal suture indicated by a feeble impression; epinotal declivity steep, slightly concave, its sides sharply, its upper border feebly but distinctly marginate. Petiole subcuboidal, narrower than the epinotum, slightly broader than long, distinctly broader behind than in front, its anterior surface truncated and flat, marginate on the sides and submarginate above, its ventral surface in front with a large, blunt, compressed, translucent tooth. Postpetiole broader than the petiole, about $\frac{1}{3}$ broader than long and broader behind than in front, its anterior and lateral borders straight, its anterior corners rounded,

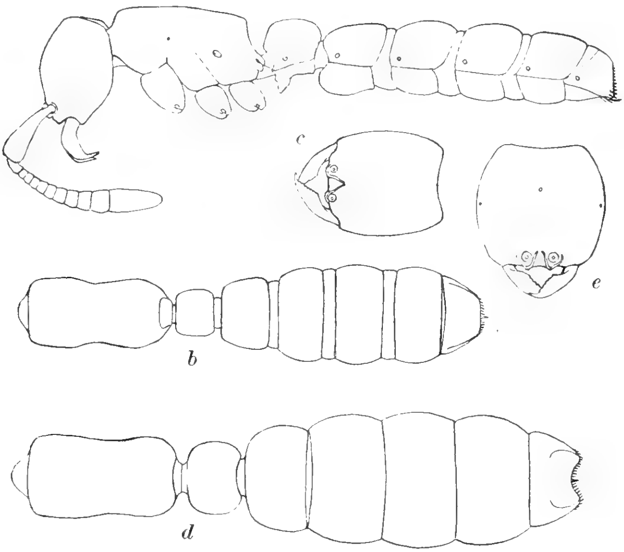

FIGURE 6. *a, Nothosphinctus manni* sp. nov. Worker, lateral view; *b*, thorax and abdomen of same, dorsal view; *c*, head of same; *d*, thorax and abdomen of female; *e*, head of same.

its posterior border feebly concave in the middle. Gastric segments 1–3 twice as broad as long, separated by pronounced constrictions. Pygidium truncated behind, with blunt, entire border, scarcely submarginate on the sides, the posterior border densely spinulate. Legs moderately long.

Shining; mandibles subopaque, coarsely punctate, body finely and unevenly punctate, the punctures denser on the head and legs, not larger on the thorax than on the gaster.

Hairs short, yellow, appressed or subappressed, longest on the gaster, especially at its tip. Tibiæ and gaster with a few suberect, delicate hairs.

Uniformly brownish yellow; mandibles, frontal carinæ and incisures of antennal joints fuscous.

Female. Length 7 mm.

Very similar to the worker but besides its larger size differing in the following characters: Head not longer than broad, with much more convex sides. Posterior ocelli absent; eyes and the anterior ocellus present but the former very small, reduced to three or four minute ommatidia. Thorax shorter and stouter, not more than twice as long as broad, pronotum and lateral borders not submarginate and margination of epinotum indistinct. Petiole as broad as the epinotum, broader in proportion to its length than in the worker, flattened above, its posterior border broadly concave in the middle, its anterior surface not submarginate. Postpetiole and gaster larger, the incisures between the segments of the latter much less pronounced than in the worker, the postpetiole flattened above, nearly twice as broad as long, as are also the three basal gastric segments. Pygidium broadly and rather deeply excised behind, its posterior surface truncated, with almost submarginate sides, the posterior excision beset with minute spinules. Sting short and stout.

Sculpture like that of the worker, the surface being quite as shining; the thorax and abdomen with fine punctures and in addition with large, scattered, shallow foveolæ.

Hairs much more abundant than in the worker, erect and bristly, conspicuous also on the appendages. Pubescence abundant and rather dense, especially on the head and gaster.

Color like that of the worker, but the mandibles are ferruginous red with their apical and basal borders black. Sting black.

Described from numerous workers and a single female taken from the same colony in December 1916 at Leura in the Blue Mts. of New South Wales by Dr. W. M. Mann.

This form is very close to *imbecillis* Forel, but the female and largest workers are larger and the former possesses small eyes and has a shining body like the worker, the pronotum has more pronounced corners, the epinotal declivity of the worker is distinctly marginate above, the petiole is broader, and both the large and small workers have the same pale coloration. Additional material may show that *manni* is to be regarded as a subspecies of *imbecillis*.

13. **Eusphinctus (Nothosphinctus) mjöbergi** Forel.

Sphinctomyrmex clarus subsp. *mjöbergi* Forel, Ark. f. Zool. 9, 1915, p. 16, ☿.

Queensland: Mt. Tambourine (E. Mjöberg).

This form, too, I believe, should be regarded as a distinct species, as the differences which, according to Forel, separate it from *clarus* and *emeryi* are considerable. It is much larger (5.2–5.3 mm.) than *clarus*, much stouter and of a much darker color, and the antennæ are very different, the scapes being longer and more gradually thickened towards their tips, funicular joints 2–6 are much more transverse and the terminal joint is shorter. The thorax and petiole are more convex than in *emeryi* and the petiole is not concave in front nor marginate above, the postpetiole is longer, the first gastric segment much broader, the gastric constrictions are less pronounced, the puncturation of the body is sparser, the pubescence more dilute and the color paler, brownish red.

Genus **Phyracaces** *Emery.*

Table for the Identification of the Workers.

1. Body entirely or partly red .... 2.
   Body black, at most with cheeks, front, pygidium and appendages red .... 13.
2. Large species, measuring 9 mm.; petiole narrowed and bilobed behind .... *heros* sp. nov.
   Smaller species, not exceeding 7 mm.; petiole rectangular, toothed at posterior corners .... 3.
3. Black, with red gaster .... *ficosus* sp. nov.
   At least the head red .... 4.
4. Abdomen black or dark brown .... 5.
   Body red throughout .... 6.
5. Head and thorax red. Length 6–6.2 mm.
   singularis Forel subsp. *rotula* Forel.
   Thorax more or less blackened. Length 3–3.5 mm.
   elegans sp. nov.
6. Head, thorax and pedicel subopaque. Length 3.6–4 mm.
   scrutator sp. nov.
   Body shining .... 7.

7. Postorbital carinæ present . . . . 8.
Postorbital carinæ absent . . . . 10.
8. Epinotal declivity longitudinally rugose . . . . *jovis* Forel.
Epinotal declivity smooth . . . . 9.
9. Head feebly excised behind. Length 7 mm. . . *singularis* Forel.
Head deeply excised behind. Length 6 mm. . . . . *mjöbergi* Forel.
10. Length 6–7 mm. . . . . 11.
Length not exceeding 5 mm. . . . . 12.
11. Eyes at middle of head; antennal scapes separated only by their own width from occipital border . . . . *sjöstedti* Forel.
Eyes a little behind the middle of the head; scapes reaching only to middle of eyes . . . . *emeryi* Viehmeyer.
12. Thorax distinctly narrowed in middle; body very shining. Length 5 mm. . . . . *leæ* sp. nov.
Thorax scarcely narrowed in middle, body more sharply shagreened and less shining. Length 3.8–4.2 mm. *fervidus* sp. nov.
13. Petiole, postpetiole and gaster with conspicuous appressed hairs besides the suberect hairs . . . . *senescens* sp. nov.
Petiole, postpetiole and gaster with suberect hairs only. . . . . 14.
14. Postpetiole scarcely larger than the petiole, as long as broad. *binodis* Forel.
Postpetiole larger than the petiole . . . . 15.
15. Eyes large, as long as distance between them and anterior border of head . . . . *adami* Forel.
Eyes distinctly smaller . . . . 16.
16. Cheeks red; funicular joints 2–9 broader than long. *larvatus* sp. nov.
Cheeks black; funicular joints 2–9 as broad as long. *turneri* Forel.

14. **Phyracaces heros** sp. nov.

(Fig. 7.)

Worker. Length 9 mm.

Head distinctly longer than broad and distinctly narrower in front than behind, with rather deeply and angularly excised posterior border, acute inferoposterior corners and rather large, convex eyes at the middle of the sides. Ocelli present, but small. Mandibles triangular, strongly deflected, with distinct apical and basal borders meeting at a rounded angle, the former finely denticulate, the external borders nearly straight. Clypeus very short, vertical, fused with the front. Frontal carinæ large, erect, rounded, truncated and confluent behind. Frontal groove short but distinct. Carina of cheeks bluntly dentate in front, curving inward behind and ending half way between the eye and antennal insertion. Posterior border of head marginate, the margination at the posteroinferior corner sending a horizontal carina forward nearly to the eye and another ridge downward and forward along the lateral surface of the gula half way to the anterior border of the head. Antennæ rather long and slender; scapes more than half as long as the head, slender at the base, gradually enlarging towards their tips; first funicular joint a little longer than broad, second twice and third nearly twice as long as broad; remaining joints $1\frac{1}{2}$ times as long as broad, except the last which is slender and pointed, twice as long as broad and not longer

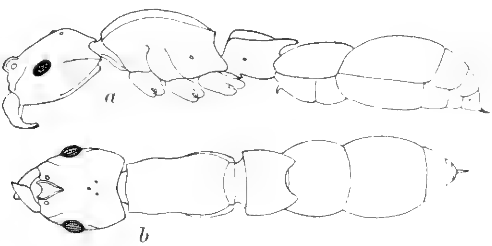

FIGURE 7. *Phyracaces heros* sp. nov. Worker; *a*, lateral view of body; *b*, dorsal view.

than the two preceding joints together. Thorax through the pronotum narrower than the head and the epinotum, narrowed in the mesonotal region, in profile evenly rounded and rather convex above to the epinotal declivity which is straight and sloping. Pleuræ concave. Anterior border, sides of thoracic dorsum and of epinotal declivity strongly marginate. Boundary between base and declivity of epinotum feebly marginate; corners of epinotum bluntly dentate. Petiole a little broader than the epinotum, a little broader than long, decidedly narrower behind than in front, with straight anterior and convex lateral borders, its posterior border deeply excised in the middle, with a flattened, rounded lobe at each corner. The whole border is marginate except in the middle behind. In profile the upper surface of the petiole is flattened, its anterior surface abrupt and truncate, forming a right angle with the dorsal surface and longer than the similar posterior surface. The ventral surface bears in front a thick, backwardly directed tooth. Postpetiole broader than the petiole, convex above and on the sides, a little broader than long, with marginate sides and a small, flattened tooth on the front of the ventral surface. First gastric segment scarcely broader than the postpetiole and of a similar shape. Pygidium with a narrow, median, longitudinal impression in front, its sides indistinctly marginate and spinulose. Legs rather long and slender; claws nearly straight; hind coxæ with a large rounded, translucent lamella at the tip on the inner side.

Surface of body smooth and shining. Mandibles coarsely punctate. Sides of front punctate-rugulose. Upper surface of body with very sparse, coarse, piligerous punctures; legs with finer and more numerous punctures. Sides of pygidium finely and densely punctate.

Hairs moderately abundant, coarse, bristly, erect, grayish or yellowish in some lights, blackish in others, long on the gaster, especially at its tip, shorter and sparser on other parts of the body, quite as long, erect and abundant on the legs and antennæ as on the head, thorax and petiole. Pubescence absent.

Rich red throughout, appendages not paler.

Described from a single example taken in Queensland (Mus. South Austr.).

This handsome species is readily distinguished by its large size, the shape of the antennæ and petiole, peculiar pilosity, etc.

15. **Phyracaces singularis** Forel.

Cerapachys singularis Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 69. ☿; Froggatt, Agric. Gaz. N. S. W., 1905, p. 14.

Phyracaces singularis Emery, Gen. Insect. Fasc. 118, 1911, p. 11.

South Australia (Wroughton).

16. **Phyracaces singularis** Forel subsp. **rotula** Forel.

Cerapachys (*Phyracaces*) *singularis* Forel race *rotula* Forel, Rev. Suisse Zool., 18, 1910, p. 21, ☿.

Cerapachys singularis var. *ratula* (sic!) Froggatt, Agric. Gaz. N. S. W., 1905, p. 15.

Phyracaces singularis var. *rotula* Emery, Gen. Insect. Fasc. 118, 1911, p. 11.

New South Wales: Inverall (W. W. Froggatt).

17. **Phyracaces emeryi** Viehmeyer.

Viehmeyer, Arch. f. Naturg. 79, 1913, p. 26, ☿.
South Australia: Killalpaninna.

18. **Phyracaces mjöbergi** Forel.

Cerapachys (*Phyracaces*) *mjöbergi* Forel, Ark. f. Zool. 9, 1915, p. 18, Pl. 1, Fig. 9, ☿.
North West Australia: Derby (E. Mjöberg).

19. **Phyracaces sjöstedti** Forel.

Cerapachys (*Phyracaces*) *sjöstedti* Forel, Ark. f. Zool. 9, 1915, p. 19, Pl. 1, Fig. 6, ☿.
North West Australia (E. Mjöberg).

20. **Phyracaces jovis** Forel.

Cerapachys (*Phyracaces*) *jovis* Forel, Ark. f. Zool. 9, 1915, p. 20, Pl. 1, Fig. 1, ☿.
Queensland: Alice River (E. Mjöberg).

21. **Phyracaces leæ** sp. nov.

(Fig. 8.)

Worker. Length 5 mm.

Head longer than broad, slightly narrower in front than behind, with truncated occipital surface, deeply and angularly excised posterior border and acute inferoposterior angles. Eyes rather large, moderately convex, just in front of the middle of the sides. Carinæ of cheeks forming acute angles in front, extending back to the anterior orbits and sending a branch inward to the antennal fossa. Postocular carina absent. Occipital border of head marginate, the margin surrounding the inferoposterior corners and extending forward as a pair of gular carinæ to the level of the middle of the eyes. Mandibles moderately large, triangular, deflected, their external borders concave, their apical borders without denticles. Frontal carinæ approximated, rounded, erect, not truncated behind where they fuse and join the short frontal furrow. Clypeus very short, vertical, with straight anterior border. Antennæ moderately thick; scapes a little more than half as long as the head, gradually incrassated towards their tips; first funicular joint nearly as long as broad, joints 2–9 broader than long, tenth joint as long as broad, terminal joint not longer than the two preceding joints together. Thorax rather robust, twice as long as broad, a little broader through the epinotum than through the pronotum, distinctly narrowed in the mesonotal region. Anterior border of pronotum not marginate; sides of dorsum, boundary between the epinotal base and declivity and the sides of the latter strongly marginate. In profile the dorsum is feebly convex, the epinotal declivity straight, with a small tooth above on each side. Petiole rectangular, a little broader than long, its sides straight, strongly marginate, produced behind as a pair of flat, acute teeth, its anterior border broadly concave, its anterior corners slightly rounded; in

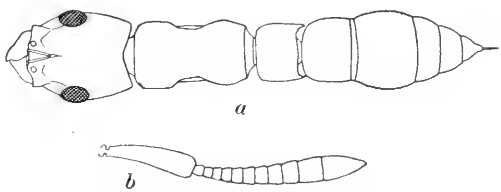

FIGURE 8. *Phyracaces leæ* sp. nov. Worker, *a*, dorsal view of body; *b*, antenna of same.

profile the dorsal surface is rather convex, its ventral surface without a tooth. Postpetiole rectangular, slightly broader than the petiole and slightly broader than long, its rounded anterior angles alone marginate. First gastric segment distinctly broader than the postpetiole, broader than long. Pygidium broadly concave above, its sides marginate and finely spinulate. Legs rather long; hind coxæ with a large, rounded, translucent lamella at the tip on the inner side.

Smooth and shining, the head and thorax very finely and superficially shagreened; mandibles more coarsely shagreened and sparsely punctate. Occipital region and upper surface of thorax and abdomen with scattered, shallow, piligerous foveolæ.

Hairs pale yellow, suberect, short, sparse and rather bristly, sparsest on the head, scapes and legs. Pubescence pale, dilute, distinct only on the legs.

Rich red throughout, antennal scapes paler, apical margins of mandibles and marginations of the head, thorax and petiole blackish.

Described from a single example taken by Mr. F. P. Dodd at Townsville, Queensland (Museum of South Australia).

This beautiful species, which is dedicated to Mr. A. M. Lea, resembles *Ph. fervidus*, but is distinctly larger, even more shining and has a differently shaped thorax.

22. **Phyracaces fervidus** sp. nov.

(Fig. 9.)

Worker. Length 3.8–4.2 mm.

Head longer than broad, distinctly broader behind than in front, with truncated occipital region and rather large, moderately convex eyes, situated at the anterior $\frac{2}{5}$ of the sides. Mandibles rather large, triangular, deflected, with concave external and edentate apical borders. Clypeus very short, vertical, broadly rounded in front;

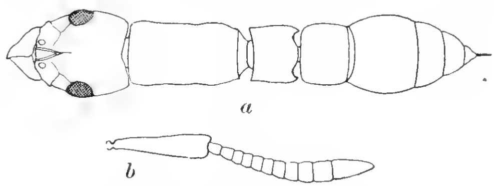

FIGURE 9. *Phyracaces fervidus* sp. nov. Worker, *a*, dorsal view of body; *c*, antenna of same.

frontal carinæ approximated, not truncate behind where they unite and join the short frontal furrow. Carina of cheeks very prominent, forming a projecting tooth and dividing behind to form two ridges, one of which runs to the anterior orbit, the other to the antennal fovea. Postocular carina absent. Occipital border of head deeply and subangularly excised and marginate, the margination surrounding the rather acute inferoposterior corners and extending forward on the sides of the gula to the level of the middle of the eyes. Antennæ rather slender; scapes about half as long as the head, gradually incrassated towards their tips, first and second funicular joints as long as broad; joints 3–9 distinctly broader than long; tenth joint as long as broad, terminal joint nearly as long as the three preceding joints together. Thorax rather robust; twice as long as broad, as broad in front as behind, very feebly narrowed in the mesonotal region. Anterior border, sides and boundary between base and declivity of epinotum sharply marginate, as are also the prosterna and the sides of the epinotal declivity. In profile the thoracic dorsum is feebly and evenly convex, the declivity abrupt and nearly straight, the mesopleuræ slightly concave. Petiole a little narrower than the epinotum, rectangular, broader than long, not broader behind than in front, its anterior border broadly excised, submarginate, the sides rather straight, strongly marginate and terminating behind in a pair of flat, pointed teeth. In profile the dorsal surface is feebly convex, as are also the truncated anterior and posterior surfaces; lower surface in front with a small, acute backwardly directed tooth. Postpetiole rectangular, a little broader than the petiole and slightly broader than long, the anterior border and anterior corners scarcely submarginate. First gastric segment decidedly broader than the postpetiole, broader than long, with broadly concave anterior border and convex sides. Pygidium broadly concave above, marginate and very finely spinulate on the sides. Legs rather long, hind coxæ with a large, rounded, translucent lamella at the tip on the inner side.

Shining; finely but distinctly shagreened, the head, thorax, petiole and postpetiole more sharply so that these parts are a little less shining than the gaster. Mandibles sparsely punctate, the occiput, dorsum of thorax and abdomen with sparse, shallow, piligerous foveolæ.

Hairs yellow, suberect, delicate, moderately long and abundant on the upper surface of the thorax and abdomen, sparser on the head, very sparse on the legs and scapes. Pubescence long and conspicuous on the legs, especially on the tibiæ and on the ventral surface of the petiole.

Uniformly red, of the tint of *Polyergus rufescens*, apical borders of mandibles and carinæ of head, thorax and petiole of a deeper color, almost blackish.

Described from 19 specimens taken Oct. 18, 1914 at Cairns, Queensland, foraging on a sandy spot in the forest.

This species resembles *Ph. scrutator* but differs in being slightly larger, with more robust thorax and in having the head, thorax, petiole and postpetiole shining, the pilosity more delicate and the pubescence much longer and more abundant on the legs.

23. **Phyracaces scrutator** sp. nov.

(Fig. 10.)

Worker. Length 3.6–4 mm.

Head decidedly longer than broad, slightly narrower in front than behind, with feebly rounded sides, deeply and angularly excised occipital border and truncated occipital surface, with the infero-posterior angles sharp when seen from behind. Eyes large and rather convex, slightly in front of the middle. Ocelli absent. Mandibles rather large and broad, triangular, deflected, their external borders feebly concave, their apical borders straight, without denticles. Clypeus short, vertical, its anterior border rounded and entire. Frontal carinæ erect, rounded, not truncated posteriorly but gradually continued back into the short frontal furrow. Carina of cheeks

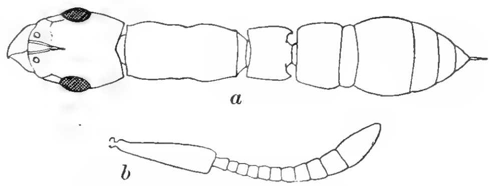

FIGURE 10. *Phyracaces scrutator* sp. nov. Worker, *a*, dorsal view of body, *b*, antenna of same.

short, prominent, but scarcely tooth-like, sending a branch backward to the anterior orbit and one inward to the antennal fovea. Occipital border of head sharply marginate, the margination surrounding the inferoposterior corners of the head and running forward on each side of the gula to a level with the posterior orbits. Postocular carina absent. Antennæ moderately long; scapes nearly $\frac{3}{5}$ as long as the head, incrassated at their tips; first funicular joint longer than broad; joints 2–9 a little broader than long, tenth joint as long as broad, terminal joint but slightly longer than the two preceding joints together. Thorax rather narrow, from above more than twice as long as broad, as broad through the pronotum as through the epinotum, feebly narrowed in the mesonotal region, sharply marginate in front, on the sides, between the base and declivity of the epinotum, along the lateral borders of the declivity and the prosterna. In profile the dorsal surface is rather flat, the epinotal declivity abrupt and slightly concave, the posterior corners of the epinotum minutely and indistinctly dentate and the mesopleuræ are concave. Petiole slightly broader than the epinotum, rectangular, scarcely broader behind than in front and somewhat broader than long, its anterior border broadly concave, the lateral borders straight, the anterior corners rectangular, the posterior produced as acute, flattened teeth. The anterior and lateral borders are sharply marginate. In profile the dorsal surface is feebly convex, the anterior surface truncate and concave, the ventral surface in front with a swelling but without a tooth. Postpetiole somewhat broader than the petiole, a little broader than long and broader behind than in front, its sides feebly convex; these and the anterior border not marginate. First gastric segment broader than the petiole and broader than long. Pygidium very feebly concave above, marginate and minutely spinulose on the sides. Legs moderately long; hind coxæ with a large, rounded, translucent lamella at the tip on the inner side.

Subopaque, or lustrous; mandibles, clypeus and gaster more shining. Mandibles shagreened and very sparsely and coarsely punctate. Head, thorax, petiole and postpetiole very densely and finely reticulate, posterior portion of head and dorsal surface of thorax, petiole and postpetiole also with shallow, evenly but very sparsely distributed, piligerous foveolæ. Gaster, scapes and legs more superficially reticulate than the thorax, the gaster also with scattered, coarse, piligerous punctures.

Hairs yellow, rather coarse and long, subappressed, very sparse on the upper surface of the head, more abundant on the dorsum of the rest of the body, absent on the scapes and legs which have only a long, dilute, yellowish pubescence.

Rich red throughout, of the tint of *Polyergus rufescens*, with only the apical border of the mandibles, the edges of the frontal carinæ and the marginations of the thorax and petiole of a deeper tint.

Described from several specimens taken Nov. 10, 1914 at Toowong, near Brisbane, Queensland. They were running about rapidly under a stone, evidently in search of the brood of other ants.

This species is easily distinguished from all the other red species of *Phyracaces* by the subopaque, finely reticulate surface of the head, thorax, petiole and postpetiole.

24. **Phyracaces rugulinodis** sp. nov.

(Fig. 11.)

Male. Length 5 mm.

Head, including the eyes, broader than long, broadly convex and rounded behind, cheeks very short, eyes and ocelli very large and convex. Mandibles large, triangular, deflected, with concave external and very finely and indistinctly denticulate apical borders. Occipital border strongly marginate, continued below into two gular marginations which run forward to a level with the anterior orbits. Clypeus very short, with straight anterior border; frontal area repre-

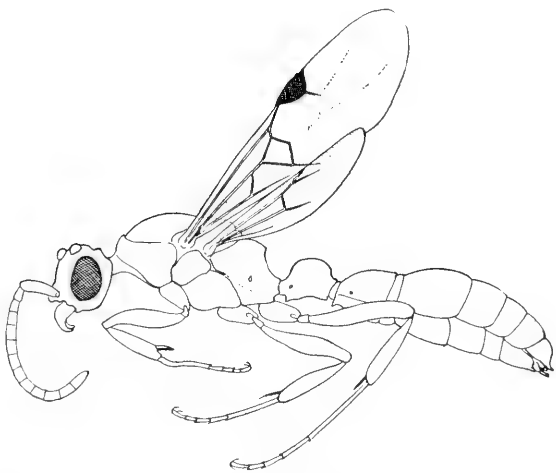

FIGURE 11. *Phyracaces rugulinodis* sp. nov. Male, lateral view.

sented by a deep pit; frontal carinæ subparallel, straight, half as long as the head. Antennæ 13-jointed, scapes reaching to the posterior orbit, cylindrical, not thickened at their tips; funiculus of uniform diameter throughout, all the joints longer than broad, cylindrical. Thorax narrower than the head through the eyes, pronotum swollen in the middle and on the sides; mesonotum rather regularly hexagonal, feebly convex, without Mayrian furrows. Epinotum with distinct base and declivity, the former feebly convex and sloping, the latter nearly vertical and concave, strongly marginate above and on the sides. Petiole from above subrectangular, a little longer than broad, as broad in front as behind, with straight anterior and posterior borders and evenly rounded sides; in profile the dorsal surface is strongly convex, the anterior and posterior surfaces short and slightly concave, the former strongly marginate above and on the sides, the ventral surface with a small, sharp tooth at the anterior end. Postpetiole decidedly broader than the petiole, as long as broad, broader behind than in front, with convex sides and dorsum, with a small acute tooth at its anterior border on the ventral side. Gaster rather slender. Pygidium evenly and broadly rounded at the tip. Cerci absent. Genital appendages blunt, retracted. Hypopygium with broad posterior border, feebly and narrowly emarginate in the middle. Legs slender, hind coxæ without lamellate tips. Wings short, with large, thick pterostigma. There is a well-developed discal cell but the veins distal to it are so nearly obsolete that those outlining a closed marginal and single cubital cell are scarcely visible as very delicate folds in the wing membrane.

Mandibles and space between the frontal carinæ shining; mandibles coarsely and sparsely punctate; remainder of head opaque, finely and densely punctate, with very uneven surface. Sides of pronotum, the mesonotum and mesopleuræ smooth and shining, the mesonotum with scattered, piligerous foveolæ; middle of pronotum, the whole epinotum, petiole and postpetiole subopaque, finely punctate and rugulose, the rugæ on the base and sides of the epinotum coarse, somewhat longitudinal on the base near the margination separating it from the declivity; the latter finely and densely punctate. Gaster shagreened, coarsely on the base of the first segment, finely elsewhere so that the surface is shining.

Hairs yellow, bristly, suberect, pointed, scattered, covering the body and legs rather uniformly, present only on the anterior surfaces of the scapes. Pubescence yellowish, distinct only on the scapes.

Red; ocellar region, middle portions of tibiæ and femora, middle of pronotum and anterodorsal portions of petiole and first gastric segment brown. Wings whitish hyaline, with yellow veins and very conspicuous dark brown pterostigma.

Described from a single specimen from Murat Bay, South Australia (Museum of South Australia). There is another defective specimen in the same collection from Ardrossan, South Australia (J. G. O. Tepper).

This may be the male of one of the smaller red species of *Phyracaces* described in the preceding pages.

25. **Phyracaces mullewanus** sp. nov.

Male. Length 5.4 mm.

Head, including the eyes, much broader than long, with broadly rounded posterior portion and short cheeks, truncated behind the ocelli, with strongly marginate occipital border, the margination extending forward on each side of the gula to the level of the middle of the eyes. Eyes and ocelli large and prominent. Mandibles triangular, acutely pointed, rather narrow, with oblique, finely and evenly denticulate apical and concave external borders. Clypeus short, with straight, entire anterior border. Frontal carinæ rather far apart, parallel in front, approximated behind, half as long as the distance between the anterior clypeal border and the posterior ocelli. Antennal scapes not reaching to the posterior orbits; all the funicular joints, except the last, a little broader than long, last joint twice as long as the preceding, pointed. Thorax robust, as broad through the wing-insertions as the head through the eyes. Pronotum not very convex; mesonotum convex above, hexagonal, narrower in front than behind. Epinotum with distinct base and declivity, the former in profile feebly convex, shorter than the vertical, concave declivity, the latter strongly marginate above and on the sides. Petiole as broad as long, cuboidal, its upper surface convex, the anterior marginate above and on the sides. Postpetiole broader than the petiole, broader than long, broader behind than in front, with convex dorsal and lateral surfaces. First gastric segment of a similar shape but broader. Pygidium and hypopygium with broadly rounded tips. Cerci absent. Genital appendages retracted. Legs slender and rather short; hind coxæ without lamellate tips. Wings short, venation much as in *rugulinodis*, but veins of the distal portion of the discal cell obsolete and the pterostigma smaller, though thick.

Shining; mandibles coarsely punctate, their bases, the epinotum and petiole subopaque, finely and densely punctate; base and sides of epinotum and upper surface of petiole also rugulose. Head and scutellum shagreened; surface of occipital region very uneven; mesonotum with large, coarse, deep, scattered, piligerous foveolæ; postpetiole and first gastric segment with smaller and more numerous foveolæ; gaster shagreened.

Hairs yellowish, sparse, erect, pointed, and coarse, moderately long, shorter on the legs. Pubescence absent, except on the antennal funiculi.

Rich red; mesonotum with three brown blotches. Wings whitish hyaline, veins pale yellow, pterostigma dark brown, very conspicuous.

Described from a single specimen taken by Miss F. May at Mullewa, West Australia (Museum of South Australia).

This species is readily distinguished from *rugulinodis* by its larger size, more robust stature, smaller eyes and ocelli, shorter funicular joints, shorter petiole, more shining postpetiole, etc. It may be the hitherto unknown male of *Ph. singularis* or of an allied species.

26. **Phyracaces ficosus** sp. nov.

(Fig. 12).

Worker. Length 5.5–6 mm.

Head slightly longer than broad, distinctly broader behind than in front, convex above and on the sides, with excised posterior border

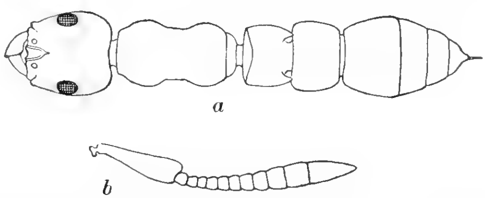

FIGURE 12. *Phyracaces ficosus* sp. nov. Worker, *a*, dorsal view of body, *b*, antenna of same.

and rather acute inferoposterior corners. Eyes rather large, feebly convex, at the middle of the sides of the head; ocelli absent. Mandibles triangular, deflected, with finely denticulate apical border passing through a rounded angle into the basal border; external border rather straight. Clypeus very short, vertical. Frontal carinæ large, erect, rounded, not truncated at their confluence behind. Carina of cheeks short, with a prominent blunt tooth. Postocular carina absent. Occipital border of head strongly marginate, the margination continued forward on each side of the gula to the level of the middle of the eyes. Antennæ stout; scapes a little less than half as long as the head, gradually incrassated towards their tips; none of the funicular joints, except the ultimate and penultimate, longer than broad, the ultimate tapering and pointed, not longer than the two preceding together. Thorax as broad through the pronotum as through the epinotum, distinctly narrowed in the middle, the dorsum feebly convex, the mesopleuræ rather concave, the epinotal declivity nearly vertical, feebly concave. The anterior border of the pronotum, the sides of the dorsum, the boundary between the epinotal base and declivity, the sides of the latter and the prosterna sharply marginate. Petiole as broad as the epinotum, nearly $1\frac{3}{4}$ times as broad as long, as broad behind as in front, with feebly and evenly rounded sides, concave anterior border and the posterior corners projecting as flattened, rather acute teeth. Only the anterior and lateral borders are marginate. In profile the dorsal surface is feebly convex, the anterior surface vertical and joining it at a right angle, the ventral surface with a strong, pointed tooth at the anterior end. Postpetiole broader than long, broader than the petiole and distinctly broader in front than behind, with distinctly rounded anterior, lateral and posterior borders, the lateral borders marginate. First gastric segment a little broader than long and a little broader than the postpetiole, distinctly broader behind than in front. Pygidium with a large concave depression on its dorsal side, marginate and minutely spinulose on the sides. Legs moderately stout; coxæ of hind pair with a small, translucent lamella at the tip on the inner side.

Smooth and shining; mandibles coarsely and sparsely punctate. Dorsal surface of body with small, scattered, piligerous punctures.

Hairs grayish yellow, erect, rather long, slender, pointed and sparse, not appreciably longer and denser on the gaster than on the remainder of the body, shorter and somewhat more oblique on the scapes and legs. Legs, coxæ and scapes with rather long, appressed, grayish pubescence.

Black; gaster, except the extreme base of the first segment rich, cherry red. Mandibles, except their bases and borders, insertions and terminal joints of antennæ, tarsi and articulations of legs and the space between the frontal carinæ, reddish brown.

Described from a dozen specimens taken Dec. 4, 1914 in the Bulli Pass, New South Wales. They were running over the sand in a loose file, carrying the nude pupæ of a Myrmicine ant whose nest they had just plundered.

This beautiful species is easily distinguished by its peculiar color and the shape of its petiole.

27. **Phyracaces elegans** sp. nov.

(Fig. 13.)

Worker. Length 3–3.5 mm.

Head longer than broad, broader behind than in front, convex above, with truncated occipital region and gula, blunt posterior corners and excised posterior border. Eyes rather large, flat, distinctly in front of the middle of the sides; ocelli absent. Carina of cheeks forming a blunt, rectangular tooth. Postocular carina absent. Posterior border of head marginate, the margination surrounding the infero-posterior corners and extending forward on each side of the gula about $\frac{1}{3}$ the length of the head. Mandibles triangular, deflected, with finely denticulate apical and rather convex external borders. Frontal carinæ moderately large, erect, rounded, confluent but not truncated behind. Antennæ rather robust; scapes half as long as

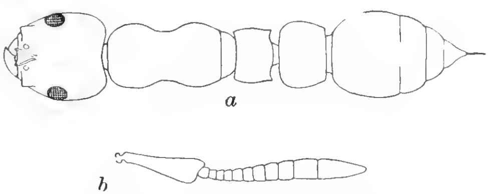

FIGURE 13. *Phyracaces elegans* sp. nov. Worker, *a*, dorsal view of body, *b*, antenna of same.

the head, gradually thickened towards their tips; funicular joints 1–9 distinctly broader than long, tenth joint longer than broad, terminal joint tapering and pointed, a little longer than the two preceding joints together. Thorax narrower than the head, as broad through the pronotum as through the epinotum, narrowed in the mesonotal region; in profile rather flat above, with straight, abrupt epinotal declivity. All four sides of the dorsum, the prosterna and sides of the epinotal declivity are distinctly marginate, and the epinotum bears a pair of small acute teeth. Petiole rectangular, somewhat broader than long, as broad as the epinotum, its anterior border slightly concave, the lateral borders marginate, with small acute, dentiform posterior corners. In profile the petiole is flat above and concave on the sides, the anterior surface is abrupt and forms somewhat less than a right angle with the dorsal surface, the ventral surface with a blunt, compressed tooth in front. Postpetiole a little broader than the petiole, subrectangular, scarcely broader behind than in front, convex above and on the sides, the latter sharply marginate. First gastric segment broader than long and broader than the postpetiole, a little broader behind than in front. Pygidium feebly concave above, marginate and minutely spinulose on the sides. Legs moderately stout; coxæ of the hind pair with a large, rounded, translucent lamella at the tip on the inner side.

Smooth and shining; mandibles coarsely and sparsely punctate. Upper surface of body with very sparse piligerous punctures, which are large on the vertex of the head and the middle of the postpetiole.

Hairs yellowish, sparse, rather long, slender, erect, shorter and more oblique on the appendages. Sides of petiole, coxæ, legs and antennal scapes with conspicuous grayish pubescence.

Reddish yellow; postpetiole and gaster, except the tip, black or very dark brown; pronotum and often also the sides of the mesonotum and sides and posterior portions of the base of the epinotum castaneous or reddish brown; mandibles, antennæ, legs and tip of gaster reddish brown, varying in depth of hue in different specimens.

Female. Length 4.5 mm.

Resembling the worker, but with larger eyes, ocelli and a different thorax. The latter is narrower than the head and like the thorax of the worker in shape, but with distinct pronotal, mesonotal, scutellar, metanotal, parapteral, sternal and mesepimeral sclerites, though there are no traces of wing stumps. The mesonotum is very small and flat, suborbicular, scarcely longer than broad. The gaster is much larger than in the worker, fully twice as long as broad.

Sculpture, pilosity and color much as in the worker, ocellar region with a brown cloud.

Described from forty workers and a single female, forming the greater portion of a single colony taken Sept. 16, 1914 near Southerland, a short distance from Sydney, New South Wales. The ants were bunched together under a large piece of sandstone in a thin layer of earth which in turn was lying on the sandstone wall of a deep ravine. There were no larvæ, and as the preceding night had been very rainy, I infer that the colony had been washed out of its nest and had taken refuge in the place in which it was found. Two workers taken by Mr. E. H. Zeck at Berowra, N. S. W., and belonging to Dr. W. M. Mann, are also referable to this species, which differs from all the preceding members of the genus in its peculiar color and small size.

28. **Phyracaces turneri** Forel.

(Fig. 14.)

Cerapachys (*Phyracaces*) *turneri* Forel, Rev. Suisse Zool. 10, 1902, p. 405, ☿ ♀; Ark. f. Zool. 9, 1915, p. 18, ☿.

Cerapachys turneri Froggatt, Agric. Gaz. N. S. W., 1905, p. 15.

Phyracaces turneri Emery, Gen. Insect. Fasc. 118, 1911, p. 11.

Worker. Length 3.5–4 mm.

Head longer than broad, a little narrower in front than behind, truncated and slightly constricted in the occipital region, convex above, with acute inferoposterior corners, rather deeply excised occipital border and moderately large, convex eyes, placed near the middle of the sides. Ocelli absent. Carina of the cheeks with a prominent tooth or angle. Postocular carina absent; occipital border of head strongly marginate, the margination surrounding the posterior angles and running forward on each side of the gula to a level with the posterior orbits. Clypeus short and vertical. Frontal carinæ erect, rounded, abruptly truncated behind where they are very close together. Antennæ rather robust; scapes longer than half the head, rapidly enlarging towards their tips; funicular joints 1–9 as long as broad, tenth joint longer than broad, terminal joint tapering, pointed, a little longer than the two preceding joints together. Thorax rectangular, scarcely more than $1\frac{1}{2}$ times as long as broad, robust, scarcely narrowed in the middle, evenly convex above in profile, with straight, vertical epinotal declivity; anterior and lateral borders, boundary between the epinotal base and declivity and sides of the latter sharply marginate, anterior pronotal angles and corners of epinotum acutely dentate. Petiole a little broader than the epinotum, rectangular, broader than long, a little broader behind than in front,

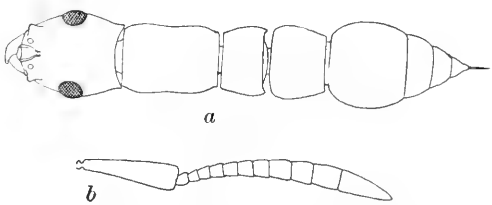

FIGURE 14. *Phyracaces turneri* Forel. Worker, *a*, dorsal view of body, *b*, antenna of same.

its posterior angles produced as small, flattened teeth, its sides, anterior and posterior borders marginate. In profile it is feebly convex above, concave on the sides, with abrupt, vertical anterior surface, joining the dorsal surface at a right angle, and the ventral surface with a blunt tooth at the anterior end. Postpetiole rectangular, a little broader than long, and a little broader than the petiole, slightly broader in front than behind, with straight sides, anterior and posterior borders and rounded, flattened anterior angles. The anterior and lateral borders are strongly marginate. First gastric segment a little broader than the postpetiole, with convex dorsum and sides. Pygidium bluntly pointed at the tip, concave above, marginate and minutely spinulose on the sides. Legs rather long; hind coxæ with a large, rounded, translucent lamella at the tip on the inner side.

Smooth and shining; mandibles coarsely punctate; head and body above with sparse, piligerous punctures, which are large and conspicuous on the vertex. Sides of pygidium and posterior borders of gastric segments densely and finely punctate. Scapes and legs with numerous, minute, piligerous punctures.

Hairs grayish yellow, erect, pointed, sparse, long and rather uniformly distributed on the body, shorter and more oblique on the appendages. Legs and scapes with distinct grayish pubescence.

Black; mandibles, pygidium, sting, antennæ and legs brownish red.

Female (deälated). Length 4.1 mm.

Like the worker except for the ocelli and thoracic sclerites. Mesonotum and scutellum very small and flat. Stumps of wings distinct.

Queensland: Mackay, type locality (Gilbert Turner); Cedar Creek (E. Mjöberg); Kuranda (Wheeler).

I have redescribed the worker from nine specimens which I found running over dead leaves in the dark tropical "scrub" near Kuranda. The description of the female is taken from Forel. The worker of this species is readily distinguished from that of the other black species of *Phyracaces* by the longer funicular joints and the shape of the petiole and postpetiole and from all but *Ph. senescens* by its short, thickset thorax.

29. **Phyracaces larvatus** sp. nov.

(Fig. 15.)

Worker. Length 3–3.6 mm.

Head longer than broad, a little narrower in front than behind, with feebly convex sides, concave posterior border and short, rather blunt inferoposterior corners. Eyes large and moderately convex, nearly as long as their distance from the anterior border, a little in front of the middle of the head. Carina of cheeks very prominent, forming a strong, rectangular tooth. Postocular carina absent. Occipital border of head marginate, the margination surrounding the inferoposterior corners and running forward on each side of the gula to the level of the posterior orbits. Mandibles triangular, deflected, with concave external and finely denticulate apical borders. Frontal carinæ rather far apart, suberect, feebly emarginate but not truncate behind before they meet. Antennæ rather stout; scapes a little longer than half the head, gradually incrassated towards the tip; funicular joints 1–9 distinctly broader than long, tenth joint not longer than broad, terminal joint pointed, nearly as long as the three preceding joints together. Thorax subrectangular, nearly twice as long as broad, as broad through the pronotum as through the epinotum, very feebly narrowed in the middle, in profile evenly convex above, epinotal declivity flat, very abrupt. There are marginations on the

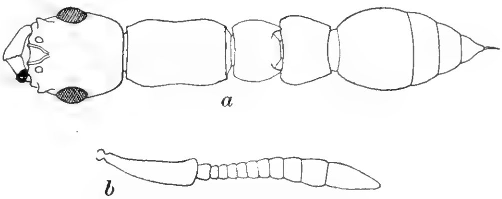

FIGURE 15. *Phyracaces larvatus* sp. nov. Worker, *a*, dorsal view of body, *b*, antenna of same.

anterior and lateral borders, between the epinotal base and declivity, along the sides of the latter and extending down the prosterna. Above the epinotum bears a pair of minute teeth. Petiole slightly narrower than the epinotum, broader than long, as broad behind as in front, with rounded sides, rather sharp, flattened, posterior teeth and concave anterior border. The anterior and lateral borders are marginate. In profile the dorsal surface is feebly convex, the anterior surface vertical and truncated, and there is a small, translucent, backwardly directed tooth on the anteroventral surface. Postpetiole decidedly broader than the petiole, a little broader than long, broader in front than behind, separated by a strong constriction from the gaster; its anterior corners are rounded and flattened, its sides straight, its anterior and posterior borders are concave, its anterior and lateral borders sharply marginate. First gastric segment broader than the postpetiole, a little broader than long and a little broader behind than in front. Pygidium concave above, with marginate, minutely spinulose sides. Legs moderately long; hind coxæ with a large, angular, translucent lamella at the tip on the inner side.

Smooth and shining; mandibles coarsely punctate; head and thorax above with numerous piligerous foveolæ, gaster with piligerous punctures.

Hairs covering the body and appendages sparse, white, rather long, suberect and delicate. Pubescence pale, dilute, distinct only on the appendages.

Black; mandibles, cheeks, front, clypeus, legs, sting, pygidium and incisures of abdomen, dark red.

Described from numerous specimens from a single colony taken Sept. 19, 1914 from under a small stone in the bottom of one of the deep gorges at Katoomba in the Blue Mts. of New South Wales.

This species seems to be very close to *Ph. adamus* Forel, but differs in its smaller size, less rectangular petiole, somewhat smaller eyes, broader eighth and ninth funicular joints and the red front of the head.

30. **Phyracaces adamus** Forel.

Cerapachys (*Phyracaces*) *adamus* Forel, Rev. Suisse Zool. 18, 1910, p. 18, ☿.

Phyracaces adamus Emery, Gen. Insect. Fasc. 118, 1911, p. 11, ☿.

Queensland: Kuranda (Rowland Turner).

The worker of this species, which I have not seen, is, according to Forel, close to *turneri*, but larger (4.2–4.8 mm.), with the eyes much more developed and the head of a different conformation.

31. **Phyracaces senescens** sp. nov.

(Fig. 16.)

Worker. Length 3.6–4 mm.

Head longer than broad, as broad in front as behind, with moderately large, flattened eyes, placed at the middle of its sides. Ocelli absent. Upper surface of head convex, occipital surface truncated, sides scarcely convex, occipital border broadly excised, marginate, the margination surrounding the rather acute inferoposterior corners and running forward on each side of the gular surface to the middle of the head. Postocular carina absent. Carina of cheeks well developed, produced as a prominent angle. Mandibles triangular, deflected, with nearly straight external and finely denticulate apical borders. Clypeus short, vertical. Frontal carinæ erect, not very prominent, rather small, not truncated before their confluence behind. Antennal scapes not more than half as long as the head, gradually incrassated toward their tips, funicular joints 1 and 10 slightly longer than broad, joints 2–9 distinctly broader than long, terminal joint rather swollen and scarcely tapering, a little longer than the two preceding joints together. Thorax a little more than twice as long as broad, as broad through the pronotum as through the epinotum, slightly narrowed in the mesonotal region and with concave mesopleuræ. Marginations developed on the anterior and lateral borders, on the boundary between the epinotal base and declivity, along the sides of the latter and the prosterna. Upper corners of epinotum not

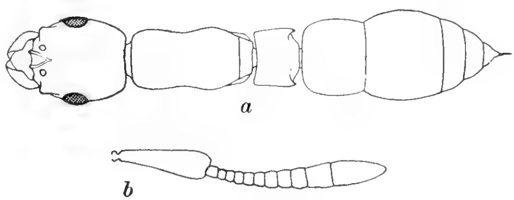

FIGURE 16. *Phyracaces senescens* sp. nov. Worker, *a*, dorsal view of body, *b*, antenna of same.

dentate. In profile the thoracic dorsum is very feebly and evenly convex, the declivity of the epinotum steep and straight. Petiole as broad as the epinotum, rectangular, broader than long, broader behind than in front, with concave anterior, straight lateral and nearly straight posterior border and its posterior angles produced as acute, slightly incurved teeth. The lateral borders are marginate, the anterior border submarginate. In profile the dorsal surface is flat and forms a right angle with the truncated, vertical anterior surface, the posterior surface is concave and slightly sloping, the ventral surface bears a pointed, triangular tooth at its anterior end. Postpetiole broader than the petiole, nearly as long as broad, not very sharply separated from the gaster, with rounded dorsal and lateral surfaces and anterior angles. First gastric segment broader than long and decidedly broader than the postpetiole. Pygidium with a shallow elliptical impression on its dorsal surface, its sides beset with a row of minute spinules. Legs rather stout; tip of hind coxæ on the inner side produced as a rounded, translucent lamella.

Mandibles shining, coarsely punctate; head and thorax smooth and shining, above with coarse, sparse, piligerous punctures; petiole, postpetiole and gaster, except the intersegmental regions, more opaque, finely and densely punctate.

Hairs white, rather long and delicate, suberect and pointed; on the petiole, postpetiole and gaster in part appressed and more abundant, but not concealing the sculpture. Pubescence abundant and rather long, whitish, confined to the coxæ, legs and venter.

Black; mandibles, pygidium, sting, funiculi, tips of scapes, tarsi, coxæ and bases and tips of femora and tibiæ castaneous.

Described from numerous workers taken at Salisbury Court, near Uralla, New South Wales, from a single colony which was running about on a foraging expedition.

This species is easily distinguished from the other black species of *Phyracaces* by its subopaque abdomen and its long, appressed, pale hairs, which give it a grayish appearance.

32. **Phyracaces binodis** Forel.

(Fig. 17.)

Cerapachys (*Phyracaces*) *binodis* Forel, Rev. Suisse Zool. 18, 1910, p. 20, ☿.

Phyracaces binodis Emery, Gen. Insect. Fasc. 118, 1911, p. 11.

Worker. Length 3.8–4 mm.

Head longer than broad, nearly as broad in front as behind, moderately convex above and truncated in the occipital region. Eyes rather large and flat, situated a little in front of the middle of the sides. Ocelli absent. Carina of cheeks forming a prominent angle. Postocular carina absent. Occipital border of head broadly excised, strongly marginate, the margination surrounding the acute infero-posterior corners and running forward on each side of the gular surface about $\frac{1}{3}$ the length of the head. Mandibles triangular, convex, deflected, their apical borders minutely denticulate, their external borders slightly concave. Clypeus short and vertical. Frontal carinæ erect, rounded, truncated behind where they meet. Antennæ rather long; scapes about $\frac{3}{5}$ as long as the head, all the funicular joints, except the last, distinctly broader than long, last joint rather large and swollen, longer than the two preceding joints together. Thorax subrectangular, about twice as long as broad, as broad through the pronotum as through the epinotum, distinctly narrowed in the middle, with concave mesopleuræ; anterior border straight and transverse, submarginate; prosterna, lateral borders and boundary between the epinotal base and declivity marginate, sides of the latter scarcely submarginate. Epinotum above with a pair of distinct teeth. Petiole nearly as long as broad, rectangular, marginate only on the sides, its anterior corners sharp, its posterior corners forming short, acute, flattened teeth, its anterior border feebly concave. In profile the dorsal surface is rather flat, the anterior surface very abrupt, forming less than a right angle with the dorsal surface, the posterior surface sloping, the ventral surface with an acute, translucent, backwardly directed tooth. Postpetiole of much the same shape as the

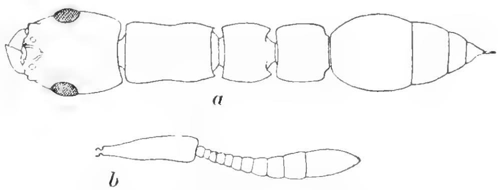

FIGURE 17. *Phyracaces binodis* Forel. Worker, *a*, dorsal view of body, *b*, antenna of same.

petiole but somewhat longer, though not broader and with the anterior corners less acute; it is very strongly constricted off from the first gastric segment and has the anterior and lateral borders marginate. First gastric segment broader than the postpetiole, longer than broad, broader behind than in front. Pygidium feebly impressed on the dorsal side, bordered with minute spinules. Legs rather slender, coxæ of hind pairs with an erect, translucent lamella at the tip on the inner side.

Smooth and shining; mandibles coarsely punctate; upper surface of body with rather evenly distributed, coarse, piligerous punctures.

Hairs delicate, whitish, rather long, pointed, erect, covering the body and appendages, somewhat shorter and more oblique on the latter. Pubescence very feebly developed, distinct only on the coxæ and antennal scapes.

Black; mandibles, antennæ, front, cheeks, legs including coxæ, pygidium and incisures of the abdomen on the ventral side reddish brown.

Queensland: Kuranda (Rowland Turner).

Redescribed from a cotype received from Prof. Forel and numerous specimens taken Oct. 3, 1914 at Kuranda from a single colony, which was nesting in a small cavity in a red-rotten log in the dark "scrub."

This form is readily distinguished by the shape of the petiole and postpetiole and the pronounced constriction between the latter and first gastric segment.

Genus **Cerapachys** *F. Smith.*

33. **Cerapachys (Syscia) australis** Forel.

Syscia australis Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 68, ☿; Froggatt, Agric. Gaz. N. S. W., 1905, p. 14.

Cerapachys (*Syscia*) *australis* Emery, Gen. Insect. Fasc. 118, 1911, p. 10, ☿; Crawley, Ann. Mag. Nat. Hist. (8) 15, 1915, p. 133, ☿.

Worker. Length 3–3.5 mm.

Head about $\frac{1}{5}$ longer than broad, subrectangular, as broad in front as behind, with evenly convex sides, broadly excised posterior border and short, rather pointed posterior corners. Eyes absent. Mandibles subtriangular, deflected, with distinctly dentate apical and basal borders. Clypeus extremely short. Frontal carinæ approximated, erect, surrounding the antennal insertions in front, converging and truncated behind where they fuse in a depression uniting the antennal foveæ. Carinæ of cheeks indistinct. Antennal scapes robust, slender at their insertions, less than half as long as the head; first funicular joint as long as broad, joints 2–7 broader than long, terminal joint large, glandiform, as long as the four preceding joints together. Thorax decidedly narrower than the head, a little more than twice as long as broad, as broad behind as in front, slightly narrowed in the mesonotal region, without transverse sutures; humeri and corners of epinotum rounded; in profile the dorsal surface is straight, the epinotal declivity abrupt, marginate on the sides and submarginate above; the pronotum submarginate in front. Petiole narrower than the epinotum, rounded cuboidal, scarcely broader than long and scarcely broader behind than in front, with convex sides and a blunt, compressed tooth on its anteroventral surface. Postpetiole resembling the petiole but broader, distinctly broader than long and a little broader behind than in front, with rounded anterior corners, feebly convex sides and a very protuberant anteroventral surface. First gastric segment very large, about $\frac{1}{3}$ longer than broad, much longer than the remaining segments together, distinctly flattened dorso-ventrally and with feebly convex sides. Pygidium small, truncated, entire, its border spinulose. Legs rather long.

Shining; mandibles coarsely punctate; head, thorax, petiole and postpetiole covered with large, sparse, piligerous punctures; gaster somewhat more finely and densely punctate.

Erect hairs yellow, rather abundant, moderately long, and of uneven length, covering the body and appendages, longest on the tip of the gaster. Pubescence dilute, conspicuous only on the gaster, legs and scapes.

Yellowish red; legs, scapes and terminal antennal joint paler; mandibles, frontal carinæ and anterior border of cheeks brownish.

Queensland: Mackay, type-locality (Turner); Bribie Island, near Brisbane (H. Hacker).

Northern Territory: Darwin (G. F. Hill).

Redescribed from a couple of cotypes received from Prof. Forel. Mr. Henry Tryon informs me that this ant is not uncommon in some parts of Queensland but is easily overlooked because it leads a hypogæic life.

34. **Cerapachys (Syscia) australis** var. **edentata** Forel.

Syscia australis var. *edentata* Forel, Ann. Soc. Ent. Belg. 44, 1900, p. 69, ☿.

Syscia australis var. *endentata* (sic!) Froggatt, Agric. Gaz. N. S. W., 1905, p. 14, ☿.

Cerapachys (*Syscia*) *australis* var. *edentula* (sic!) Emery, Gen. Insect. Fasc. 118, 1911, p. 10, ☿.

Queensland: Mackay, type-locality (Turner); Brisbane (H. Tryon).

This form differs from the typical *australis* in its deeper, more reddish coloration, somewhat feebler and sparser puncturation, somewhat more transverse first to seventh funicular joints and especially in lacking teeth on the apical and basal borders of the mandibles.

Genus **Lioponera** *Mayr.*

35. **Lioponera australis** Forel.

Lioponera longitarsis Mayr var. *australis* Forel, Ann. Soc. Ent. Belg. 39, 1895, p. 422, ☿; Froggatt, Agric. Gaz. N. S. W., 1905, p. 8; Emery, Gen. Insect. Fasc. 118, 1911, p. 12.

Queensland: Mackay (Turner).

Owing to the profound differences between the Australian ant fauna and that of India it is improbable that this from is merely a variety of *L. longitarsis* Mayr of the latter country. Forel, in his brief description calls attention to the following peculiarities of *australis,* but the study of more material will in all probability reveal others: Length 3.4 mm. It is smaller than *longitarsis* and has somewhat smaller and more convex eyes. The petiole is transversely rectangular, whereas in *longitarsis* its anterior corners are more projecting and its anterior border is distinctly concave. The sculpture of *australis* is more regularly punctate and the postpetiole is blackish brown, with two large, reddish spots.

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THERMO-ELECTROMOTIVE FORCE, PELTIER HEAT, AND THOMSON HEAT UNDER PRESSURE.

By P. W. Bridgman.

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CONTENTS.

Introduction.

The effect of pressure on the electrical resistance of a large number of metals over a considerable range of pressure and temperature (0° to 100° C, and 0 to 12000 kg/cm^2) has formed the subject of two recent papers.[1] The facts there presented suggested new points of view concerning the mechanism of electrical conduction in metals. Since, however, conductivity is only one of the electrical properties of metals, we would expect that information regarding all electrical

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[1] P. W. Bridgman, Proc. Amer. Acad. **52**, 571–646, 1917.
Phys. Rev. **9**, 269–289, 1917.

properties would be desirable in attempting to picture the complete electrical mechanism. I stated in the previous papers that I hoped to obtain additional measurements on thermo-electrical properties.

In this paper these thermo-electric measurements are carried out. The change in the thermo-electric properties of nearly all the metals whose electrical resistance was there measured is here given over the same range of pressure and temperature; a few only of the metals were not adapted to these measurements and could not be used. In addition, new data are given for the effect of pressure on both electrical resistance and thermo-electric properties of the alloys manganin and constantan. In most cases measurements of the thermo-electromotive force were made either on identical pieces of wire, or on pieces from the same specimen as were the resistance measurements. In the few cases where new specimens of metal had to be used, the temperature coefficient of resistance at atmospheric pressure has also been measured, in order to define the electrical character of the metal as completely as possible.

The results of this paper, unlike those of the previous paper on resistance, are almost entirely novel; the nature of the results to be expected was not known, and accordingly these effects, so far as affected by pressure, were not available for any theoretical considerations. Previous measurements on the effect of pressure on thermal e.m.f. are very few in number, and cover a very restricted range. The maximum pressure reached has been by Wagner,[2] 300 kg., over the same temperature range as that used here, 0° to 100°. Over a pressure range so small, the effect is in most cases so minute as to be on the limits of the readily measurable. Previous measurements have been almost entirely confined, of necessity, to determining the total effect of the maximum pressure and temperature. It was not possible to find at all accurately whether the effect was linear with pressure and temperature within the range employed. On a few metals Wagner made measurements of the effect of varying temperature, and found that within his limits of error the effect was linear. The effects are so much larger over the much greater pressure range of this paper that I have been able to make accurate measurements of the variation of the effect with pressure and temperature within the range. This is important, especially the variation with temperature. For it is well known that the Peltier heat is determined by the first derivative of the thermal e.m.f., and the Thomson heat by the second. Previously

[2] E. Wagner, Ann. d. Phys. **27**, 955–1001, 1908.

we had only rough indications of the initial direction of variation of Peltier heat with pressure and no indication whatever as to even the sign of the change of Thomson heat. The present measurements afford fairly accurate data about the Peltier heat over the entire range of temperature and pressure, and somewhat less accurate information, but still accurate enough to give the essential features of the situation, with regard to the Thomson heat.

In one other particular these measurements have an advantage over previous ones in this field. Recent improvements in moving coil galvanometers, as well as the greater size of the effect, have made it possible for me to use this type of galvanometer, instead of some form of Thomson galvanometer. Every one knows how enormously more convenient the moving coil galvanometer is than the Thomson. It was possible to make these measurements like any others of physical routine, at all times of the day, with no disturbance from outside changes, instead of waiting for the exceptionally favorable conditions of the early morning hours, as previous observers have been forced to do.

In addition to the effect of hydrostatic pressure on thermo-electric quality, this paper contains measurements on the effect of tension. In my previous work on resistance effects, it appeared that there is a simple relation between the effects of hydrostatic pressure and tension on resistance, which had theoretical significance. I hoped for a similar state of affairs with respect to thermo-electric properties, but on looking up previous data found such discrepancies between different observers on the effect of tension, as to cast doubt on even the sign of the effect in some cases. I therefore made a fresh experimental examination with some of the metals of the pressure measurements. It appears that the discrepancies between different observers is due to the inherent nature of the effect. Results are not at all reproducible, sometimes different lengths from the same spool give effects of different sign. The situation with respect to tension is therefore quite different from that with regard to hydrostatic pressure. The effects produced by hydrostatic pressure on thermo-electric quality have a definite physical significance; reproducible results are obtainable, and different observers may agree, at least for normal metals, as is shown by the quite unexpectedly good agreement between the results of Wagner and myself over the range common to our work. But the tension effects show no such regularity, and apparently depend more on accidental incidents, such as difference in mechanical handling. In the following, little space is devoted to this aspect of the question, therefore, but I have taken the opportunity to record at least the general nature of the results.

The plan of presentation of the paper is this: first is given the methods of measurement and computation, and then the detailed account of the effect of hydrostatic pressure on thermal e.m.f., Peltier heat, and Thomson heat; this is followed by a brief presentation of the effect of tension on thermo-electric quality; finally the results are collected for a general survey, and some theoretical deductions suggested. This work was distinctly disappointing regarding theoretical conclusions or suggestions as to mechanism. It appears from these measurements that thermo-electric properties, as we measure them, are probably a residual of different effects, sometimes working in opposite directions, and that, for the present at least, these results cannot be as suggestive as I had hoped for an electron theory of metals.

In trying to interpret these results I have been obliged to think through the general subject of thermo-electric phenomena, and have been much impressed by the confusion that reigns in this field, even respecting fundamental matters. As a preliminary to further work I have brought together a number of general considerations, which I hope may form a basis for at least consistent thought. These general considerations seem proper subject for a separate paper, and I hope to publish them elsewhere; they may, however, be read in connection with this paper if the reader should at any time find himself in doubt as to my precise position.

Apparatus and Experimental Methods.

The general method is that which naturally suggests itself for measuring an effect as small as this, and is the same as that used previously by Wagner.[2] Instead of using an ordinary thermo-couple, say of copper-constantan, subjecting the whole couple to hydrostatic pressure, and measuring the change in thermal e.m.f. at different pressures when the difference of temperature of the terminals is predetermined, the two branches of the couple are made of the same metal, the metal under examination, and one branch only is subjected to pressure. The metal under pressure behaves effectively like a different metal from that not under pressure, and we measure the thermal e.m.f. of the metal against itself in the uncompressed state. The advantage of this, of course, is that except for inhomogeneities in the wire the entire effect measured is the effect sought, instead of only a small change in a relatively large effect.

Such a couple involves both temperature and stress gradients. The stress gradient is rendered ineffective by keeping the regions in which there is such a gradient at constant temperature. Thermodynamics shows that no closed circuit of the same or different metals under different or varying stresses can possibly be the seat of an e.m.f. if the whole is at one constant temperature. If, then, all regions of

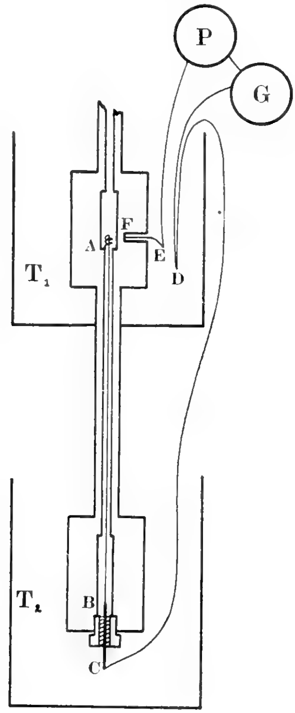

FIGURE 1. The electrical connections in place in the pressure cylinders.

varying temperature in a complete circuit are regions of no stress gradient, we are sure that stress gradients in other parts of the circuit can produce no resultant e.m.f. around the circuit.

The part of the apparatus concerned in the thermal e.m.f. measurements consists of two heavy cylinders connected by a heavy tube. The two cylinders are maintained at any required difference of temperature by thermostats. Through the tube connecting the cylinders, and insulated from it, runs the wire on which measurements are to be made. This is metallically connected to the inside of the upper cylinder, but passes out through an insulating plug at the bottom of the lower cylinder. The circuit is completed outside the cylinders by a wire of the same metal, making connection through the insulating plug at the lower end, and at the upper end making a screw contact with the steel of the upper cylinder. The return wire is broken by the insertion of copper leads connecting with the galvanometer and the potentiometer for measuring the electro-motive force. The terminals of the copper leads are connected to the return wire inside a constant temperature bath so that no e.m.f. (or at least no variable e.m.f.) is introduced here. The two cylinders and the connecting pipe are filled with liquid to which pressure may be applied.

The circuit consists of the metal AB about 18″ long under a constant hydrostatic pressure, between the two ends of which there is a known temperature difference equal to the difference of temperature of the two thermostated baths; a length of nickel steel BC which forms the stem of the insulating plug, in which there is a stress gradient from the whole hydrostatic pressure inside to zero at the outer end, but in which there is no temperature gradient; a length CD about 4 ft. long of the metal under examination, running at atmospheric pressure from the temperature of the lower bath to that of the upper bath; the copper part of the circuit from D to E, entering and leaving at the same temperature; a short length, about 6 inches, of the metal under examination running from the copper at E to mechanical contact with the steel of the cylinder at F; and finally the circuit is completed through the solid steel of the cylinder between F and A, in which there is an intense stress gradient, but no temperature gradient. It is evident that the e.m.f. of this circuit is merely that of the uncompressed metal against the compressed metal between the temperatures of the two baths.

The measurements consist in finding the e.m.f. in circuits of different metals under different temperature differences and different pressures. Of course, if the inside and outside wires are precisely alike, there is no e.m.f. for any temperature difference unless there is also a pressure difference. But this ideal condition was seldom attained, as the wires were never precisely alike; the readings had to be corrected by the zero reading, which of course varied with the temperature difference.

The two cylinders were connected to the apparatus for producing pressure through a tube screwed into the upper end of the top cylinder.

This was the same apparatus as that used in much previous work,[3] and has been described so thoroughly that no further description is needed here. The pressure was measured throughout with the same coil of manganin wire as that used for the measurements of pressure coefficient of resistance. It was calibrated from time to time. The pressure part of all this work went more smoothly than ever before; the complete set of measurements on 24 different specimens was made without a single rupture, except one pinching off of the stem of an insulating plug, and with only a few leaks due to defective washers.

Various details of manipulation had to be carefully observed in order to get good results. It is well known that thermal e.m.f. is exceedingly sensitive to slight mechanical changes. For instance, the wire of an ordinary constantan thermo-couple cannot be bent without changing its constants. I was prepared, therefore, to expect very large irregularities at these high pressures, and was most pleasantly disappointed to find that, with some precautions, reliable measurements could be obtained. It is above all else necessary to avoid all permanent distortion. The viscosity of most liquids becomes so great under high pressure that permanent distortion may easily result. The connecting tube is about 18 inches long, and the hole $\frac{1}{8}$ inch diameter. When pressure is increased or decreased the entire liquid in the tube moves bodily one way or the other, because of change of volume in the liquid in the lower cylinder, and if the liquid is sufficiently viscous will carry the wire with it, and in some cases may easily break it. The magnitude of this viscous drag depends on the diameter of the wire; the smaller the diameter the larger the ratio of surface to cross section, and the larger the effect. It was desirable for this reason to use in many cases a wire larger than that on which resistance measurements were made, and I therefore prepared a number of new wires from the same samples as the old wires. Viscous drag may result either in a permanent distortion of the wire, showing itself as a permanent change of the zero reading, or it may produce an effect within the elastic limit which disappears with release of pressure. Such an elastic effect was shown by several of the smaller wires; it may be eliminated by reversing the direction of the change of pressure. The viscous effect can be reduced in most all cases to negligible proportions by using a very thin liquid to transmit pressure, changing pressure slowly, and by running pressure back and forth several times over a small range before making a reading. The liquid found suitable was petroleum ether, which had also been

3 P. W. Bridgman, Proc. Amer. Acad. **49**, 627–643, 1914.

used before in the resistance measurements partly mixed with kerosene. This was always now poured pure into the lower part of the apparatus without admixture of kerosene. The upper of the three cylinders was initially filled with a mixture of equal parts kerosene and ether. This liquid remains so thin under even the highest pressures that somewhat more trouble was found from minute leaks than ever with undiluted kerosene. The bearing surfaces of the washers must be in very good condition, otherwise leak takes place along scratches on the steel too minute to be sufficiently closed by the plastic flow of the steel at high pressures. However, all these minute leaks closed up automatically under sufficiently long duration of pressure, and never could introduce any error in the readings, which were made only after leak had disappeared. Leak merely made the manipulation somewhat more inconvenient. The use of petroleum ether made it impossible, because of its low boiling point, to make measurements at atmospheric pressure at the higher temperatures. Above 25°, therefore, the initial readings were made at pressures of 300 kg., and extrapolation made to atmospheric pressure.

The effect of viscous drag was further increased by the necessity for insulating the wire AB from the steel tube. The wire was in most cases bare, and insulation was provided by slipping over the wire short lengths ($\frac{1}{2}$ inch long) of thin glass tube. It was necessary to choose these of the best diameter. If they were too large, the viscous resistance between the glass and the wall of the steel tube was so great that all the pieces moved together bodily, and might cut off the wire at the upper end; whereas if the glass tube was too small the viscous resistance between the glass and the wire was so great that the stress on the wire was no longer truly hydrostatic. The best size for the glass was found after several trials. That the effect of viscous drag was finally successfully eliminated is shown by the fact that even for metals as soft as lead and thallium the permanent change of zero after a run to 12000 kg. was less than 1/10% of the total effect.

The inner wire was attached to the lower insulating plug with soft solder, except in a few cases such as magnesium or aluminum, when connection was made by wrapping the joint with small copper wire and smothering over the outside with soft solder. Slight variations of resistance at the contacts evidently were of no importance, and it therefore was not necessary to take the precautions used in the resistance measurements. At the upper end, a flexible connection to allow for inequalities of compression and relative motion between the cylinder and the core of the insulating plug was made by soft soldering the wire to a helix of copper wire, which was in turn soldered to the connecting tube. Connection between the tube and the cylinder was amply provided by the mechanical contact through the threads, which supported the entire thrust of the internal pressure. The soldered connection at the top of the wire was not made until after the bottom connection had been made and screwed into position, so that all initial strains of tension or torsion were avoided. The outer wire was protected over its entire length by a loosely fitting rubber tube, which slipped over the outer end of the insulating plug and prevented contact with the water of the bath. The connections at E and D to the copper leads to the electrical part of the apparatus were made with soft solder. The wire FE and part of the copper lead in the upper bath were also protected with rubber tubing. The two connections E and D were placed close together and tied to the outside of the upper cylinder. They were protected from direct contact with the water of the bath with a covering of felt 1 inch thick. The temperature of these junctions was therefore controlled by the large mass of the cylinder and remained constant in spite of small fluctuations in the bath liquid. The copper leads from E and D were taken from the same spool and were so homogeneous that no undesirable e.m.f. was ever introduced by this part of the circuit. The connection at F was a mechanical connection. A small hole was bored from the outer surface of the cylinder to within $\frac{1}{2}$ inch of the inner surface. Against the flat bottom of this hole a steel tube which contained the wire was forced by a nut. This wire was lead axially through the tube, and insulated from it, except at the very end, where it was soldered in place with enough soft solder to make a little mound at the bottom of the tube. When forced into place by the screw, this mound was flattened out, making at the same time good electrical contact and preventing contact between the water of the bath and the wire. This wire was brought as close as possible to the inside of the cylinder in this way in order to reduce to a minimum any disturbance arising from slow fluctuations in the temperature of the bath. Any irregularity introduced by flow of heat into the bath along the pressure tubing, either above or below, may be shown by a simple computation to be absolutely negligible; any such effect is certainly less than 10^{-6} degrees. The upper bath was the variable bath, and was controlled by a thermostat within 2 or 3 thousandths of a degree. In virtue of the precautions just described all appreciable errors due to temperature control were eliminated. In the lower bath, slow variations in temperature would be of greater effect, because of the long stem of the insulating plug, so that it was necessary that the two ends of this stem be at exactly the same temperature. This source of error was reduced to a minimum by always using the lower bath as an ice bath. The lower tank was kept full of ice and water, well packed down, and a violent circulation of water through the ice was maintained with a stirrer. The bath was also heavily lagged. The result was completely satisfactory, but I have been impressed during this work, as well as in some other, by the absolute necessity of maintaining a violent circulation of water if complete uniformity of temperature is to be secured. An ice bath, even when continuously repacked, develops local inequalities of temperature, unless the water is stirred. Of course the conditions here were somewhat severe, because there was a constant rather large inflow of heat from the upper bath along the pressure tubing.

The electrical-measurements part of the apparatus now requires description. There were two entirely independent electrical systems involved. One was for measuring the pressure by means of the change of resistance of the manganin coil.[4] This has already been fully described. The other was to measure the thermal e.m.f. The range of e.m.f. to be measured was from a fraction of a micro volt to 0.0007 volts. The galvanometer used was of the Leeds and Northrup high sensitivity D'Arsonval type. It was specially constructed to my specifications; was critically damped on 5 ohms external resistance, with a period of 7.8 seconds and a sensitivity of 1.5 cm. at 1 m. distance for 10^{-6} volts. Its internal resistance was 12 ohms, so that as long as the resistance of the external circuit remained under 5 ohms its performance was sufficiently constant. The wires used were almost always large enough to meet this requirement. In use the galvanometer was set up at 3 m. distance and gave 4.5 cm. deflection for 10^{-6} volts. The method used was a double throw null method, and the steadiness was great enough so that 0.1 mm. could be easily obtained. Readings could therefore be made to 10^{-9} volts. I have to express special obligations to the Leeds and Northrup Co. for this instrument. At the time, certain of the materials necessary for the construction of a new instrument were not to be obtained in the market, and they were so kind as to take from their own shops one of their experimental instruments and rebuild it to specifications.

The method of measuring e.m.f. was a potentiometer method, in which the unknown e.m.f. is tapped off around a fixed resistance, and

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4 P. W. Bridgman, Proc. Amer. Acad. **47**, 321–343, 1911.

the current in the potentiometer circuit varied by means of a suitable resistance until balance is obtained. This has the advantage over the ordinary slide wire form of avoiding all possible e.m.f's. at the sliding junctions. In order to provide the very small e.m.f's. required, the known source of e.m.f. was stepped down twice. The comparison cell was a battery of ten acid Weston cells connected in parallel. The advantage of the acid cell is that its e.m.f. does not fluctuate, even when a comparatively large current is drawn. This was most kindly loaned to me by Professor H. N. Davis, by whom it had been personally constructed. I am also indebted to him for a number of the other pieces of standard apparatus used. The e.m.f. of the acid cell varies somewhat with the external resistance; it was measured by standard potentiometer methods against a standard Weston cell for external resistances from 1000 to 10000 ohms. The e.m.f. at the terminals varied under these conditions from 1.0410 to 1.0425 volts. This was measured several times in the course of the work, and the voltage under any given external resistance remained constant within 1/100%. The temperature effect was negligible for temperature fluctuations within the range of this work.

The working cell was connected through a reversing switch with a 10,000 and a 10 ohm. coil in series. The 10 ohm coil was tapped by a second circuit containing a variable Leeds and Northrup decade box reading to 10,000 ohms, and guaranteed to 1/10%, and three other coils, of seasoned copper, of 10, 1 and 0.1 ohm. According to its magnitude, the e.m.f. in the pressure circuit could be tapped across either the 10, 1, or 0.1 ohm coil. Readings were made by a null method by the method of reversals. Reversing switches in the pressure circuit, but not in the galvanometer circuit, and in the second stage of the potentiometer circuit allowed the reversal of both the e.m.f. being measured and the balancing e.m.f. The decade box was set until no throw was obtained on reversing both these circuits. The range covered with the apparatus set up as above was from approximately 10^{-8} volts, with 1000 ohms in the decade box and 0.1 ohm tapped, to 10^{-5} volts with 1000 in the decade box and 10 ohms tapped. For larger voltages the working cell could be directly connected with the potentiometer circuit, increasing the range in this way from 10^{-5} to 10^{-2} volts, still with never less than 1000 ohms in series with the working cell. E.m.f's. less than 10^{-8} volts were read by the deflection of the galvanometer without attempting to balance. Of course the e.m.f's. corresponding to the stated resistances are not exactly those given, but there are slight corrections. The corrections as a function of the resistance may be readily calculated by Kirchhoff's laws, and such corrections were applied in all the computations.

It is not worth while to go into greater detail about this electrical installation, except to say that in designing it and setting it up I profited much by suggestions in various papers of White.[5] All leads were of copper from the same spool. All connections were either soldered (with pitch) or were the clothes pin type of spring clip, with the in-leading wire thermally protected by wrapping with copper strip, as advocated by White. All switches, both single throw and reversing, were of the jack knife type, and of all-copper construction. All the connections and switches, except the pressure connections already described and the connections to the galvanometer binding posts, were inclosed in a single covered box, to secure temperature equality, and all switches were operated through the sides of the box with rods. The reversing switches were so connected together with a sliding rod as to be operated by a single push or pull, and were so related in phase than an unbalanced e.m.f. was never thrown on the galvanometer at any stage of the reversal. The copper resistance coils of 10, 1, and 0.1 ohms were immersed in an oil bath of Bureau of Standards resistance oil inside the same box as that housing the switches, and the oil was stirred and the temperature read with a thermometer reaching through the walls of the box after every reading of e.m.f. The resistance of the copper coils was measured at 22° on a Carey Foster bridge against coils calibrated at the Bureau of Standards. The temperature coefficient was not measured, but was assumed to be 0.00382 at 22°. This corresponds to copper of conductivity 98%. If the copper were actually anywhere from 96% to 100% conductivity, which is greater than the variation met with in commercial copper, the error so introduced would remain less than 0.1% over a temperature range of 10°, which was the maximum variation in room temperature during this work.

In addition to all these, several coils not already mentioned were introduced either in parallel or in series with the galvanometer so that its sensitiveness could be appropriately varied.

The galvanometer itself was protected with a shield of heavy sheet iron heavily covered on the outside with cotton. Internal thermal e.m.f. in the galvanometer was never entirely absent, rising sometimes to as much as $\frac{1}{3} \times 10^{-6}$ volts, but the method of measurement, reversing

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5 W. P. White, Jour. Amer. Chem. Soc. **36**, 1856–1868, 1868–1885, 2011–2020, 2292–2313, 2313–2333, 1914.

the other circuits but not the galvanometer circuit, eliminated this as a source of error. An eliminating switch about the 0.1, 1, and 10 ohm coils, as described by White, showed that there were no parasitic e.m.f's. in this part of the circuit. The construction of the rest of the circuits assures that any other parasites, except in the pressure part, are overwhelmed and masked by the applied e.m.f., and parasites in the pressure part, provided they stay constant, are eliminated by the zero correction. All switches and the galvanometer were further protected by a leakage shield, as advocated by White. The whole apparatus was surprisingly satisfactory in its performance, and except with some of the more inhomogeneous metals the steadiness was such that even over the maximum temperature range individual readings could be made to the limit of sensitiveness, about 10^{-9} volts.

The accuracy of the readings was of course not usually as high as 10^{-9} volts, but varied greatly for the different metals; the details will be given later. In general, the precautions necessary to ensure reproducible results were to previously season the metal by several preliminary applications of pressure and to change pressure slowly, in order to avoid viscosity effects from the transmitting medium. Most of the metals showed no hysteresis, and the pressure measurements might have been made in any order, but they were, as a matter of fact, nearly all made alternately with rising and falling pressure.

Measurements on a single metal consisted of readings at four different temperatures of the variable bath (25°, 50°, 75°, and 95°) and seven different pressures (0, 2000, 4000, 6000, 8000, 10000, and 12000 kg./cm.^{2}). The procedure was usually as follows. The apparatus was set up and seasoned by several preliminary applications of pressure to the maximum at room temperature. The lower bath was then filled with ice and the upper bath adjusted at 25°. E.m.f. measurements were then made at 0, 4000, 8000, 12000, 10000, 6000, 2000, and 0 kg. This might occupy two hours. The time required for dissipation of heat of compression after every change of pressure was cut down by secondary variations of pressure, as has already been described in previous papers.[6] The upper bath was then changed to 50°, the lower one still being packed with ice, and e.m.f. measurements were made at the same pressures as before. This was repeated at 75° and 95°. The temperature of the bath was read on a Tonnelot thermometer calibrated at the Paris Bureau of Weights and Measures.

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[6] P. W. Bridgman, Proc. Amer. Acad. **49**, 14, 1913.

In addition to the pressure measurements, the thermal e.m.f. of each of the specimens was found at atmospheric pressure against lead. The same potentiometer was used as for the pressure measurements, and no special comment is necessary. One terminal of the couple was kept in an ice bath; the other was placed successively in baths at 25°, 50°, 75°, and 95°. Twelve couples were made up and measured simultaneously. As a matter of fact, the readings were actually made against copper; the e.m.f. against lead was obtained by a subtraction. The e.m.f. against temperature of each of these couples could be represented within the limits of error by a power series in t (three terms were always sufficient). These formulas are given in the following as a further means of identifying the metal. By one and two differentiations the Peltier heat against lead and the Thomson heat at atmospheric pressure may be at once obtained. These are also listed in the following. A positive e.m.f. means that the positive current flows from lead to the metal at the hot junction.

Methods of Computation.

The thermal e.m.f. in the pressure circuit was first computed for each reading, applying all corrections, including temperature corrections. The points were then plotted on a large scale, thermal e.m.f. against pressure, and smooth curves drawn through the points at each temperature. In this way four smooth curves were obtained for each substance, or really five curves, because the curve corresponding to 0° coincides with the pressure axis. From this bundle of smooth curves the thermal e.m.f. could be read as a function of temperature at constant pressure. The curves were in this way replotted, giving thermal e.m.f. against temperature at constant pressure. Six pressures were chosen, 2000, 4000, 6000, 8000, 10000, and 12000, giving six smooth curves of thermal e.m.f. as functions of temperature. The smoothing so far was done graphically. A further smoothing was next performed by calculation. The ordinates were read from the six smooth curves at intervals of 10°, and the differences of successive ordinates computed. The curves were now further adjusted so that the successive differences should lie on a smooth curve when plotted on a scale 10 times as large as the original curve. This second adjustment was of course performed so as not to produce any changes greater than the uncertainties in the original plot. The smoothed first differences, obtained in this way, are equal, without appreciable error, to ten times the slope of the curves at the mid-temperatures of the 10° intervals. This gives immediately, therefore, $\frac{dE}{dt}$. Multiplying this by the absolute temperature gives, by a well known formula, the Peltier heat at the hot junction. The Peltier heat was so calculated and is tabulated in the following. From the tabulation of first differences the second differences were next found by successive subtractions. These were plotted and smoothed graphically, giving at once $\frac{d^2E}{dt^2}$. This, multiplied by absolute temperature, gives the difference of the Thomson heat in the compressed and the uncompressed metal at the temperature in question. This is also tabulated in the following. Perhaps to give the results as accurately as possible an additional smoothing for pressure should have been introduced. But this seemed to me an additional refinement not justified by the reproducibility of the results.

The convention adopted for the sign of the effect requires explanation. In the following, the thermal e.m.f. of the circuit is called positive if at the hot junction the current flows from uncompressed to compressed metal. The Peltier heat is considered positive if heat is absorbed by the positive current from the surroundings on flowing from uncompressed to compressed metal. A positive $\frac{d^2E}{dt^2}$ means a larger Thomson heat in the compressed than the uncompressed metal, and the Thomson heat is itself considered positive if heat is absorbed by the positive current in flowing from cold to hot metal. In other words, a positive Thomson heat corresponds to a positive specific heat of the positive current, or a negative specific heat of the current of electrons. The opposite convention is sometimes used for the Thomson heat.

The detailed presentation of data follows. The order of arrangement of the metals is the same as that in the previous paper on resistance. Four metals used there could not be used in this investigation. These were: Indium and Tantalum, of which I did not have a large enough supply, and Antimony and Tellurium, which are so brittle as to make hopeless any manipulation of continuous pieces four feet long. In addition to the metals of the resistance paper, two alloys, manganin and constantan, are included at the end of the list. The pressure effect on the resistance as well as on the thermal e.m.f. has been measured.

The data are chiefly given by tables and diagrams. There are in general three tables for each metal. The first table shows the total e.m.f. of a circuit composed of uncompressed and compressed metal. The lower junction is always at 0°; the entries in the table show the e.m.f. for different temperatures of the upper junction, and for different pressures of the compressed branch. The temperature interval of this table is 10°, and the pressure interval 2000 kg. The e.m.f. corresponding to 0° is, of course, zero for all pressures. The second table gives the Peltier heat absorbed by unit quantity of positive electricity in passing from uncompressed metal to metal compressed to the pressure in the table, both uncompressed and compressed metal being at the temperature indicated in the table. The temperature interval is 20°, and the pressure interval 2000 kg. in the second table. The third table shows how much greater the Thomson heat is in metal compressed to the pressure of the table than in uncompressed metal, both uncompressed and compressed metal being at the temperature indicated in the table. The temperature interval of the third table is also 20°, and the pressure interval 2000 kg. The diagrams give graphically the results of the tables, plotted at constant pressures against temperature. The scale of the diagrams of Peltier heat and Thomson heat is half that of the e.m.f. diagrams. The smaller scale for the two heats has been chosen because of their smaller accuracy. The corresponding tables for all metals are given in the same sized units, so as to facilitate direct comparison.

Detailed Data.

Tin. This was Kahlbaum's "K" tin, from the same small ingot as that whose resistance under pressure was measured, but not the identical piece of wire. It was made by extrusion at 100° into wire 0.02 inches in diameter, considerably larger than the resistance wire, and was annealed in an electric furnace to 120° for several hours. It was not subjected to a preliminary pressure seasoning for the runs; this is unnecessary for soft metals.

Tin was one of the most unsatisfactory metals measured, because of the minuteness and irregularity of the effect. Tin is known to form other allotropic modifications below 20°, the reaction usually not running because of internal viscosity. During the experiment, therefore, the lower end of the wire was probably always in the metastable region, and the readings themselves gave evidence of internal instability. The readings were never steady, but continually flickered by small amounts which might rise to as much as 0.04×10^{-6} volts at the highest temperature. Furthermore, all runs showed considerable hysteresis, which of course is characteristic of a substance not in perfect equilibrium. The zero was usually recovered with fair accuracy; at 98° the zero error was hardly 1% of the total effect, but at 75° there was some sort of progressive change during the run, which of course produced the largest effect at zero. The readings at 75° failed by about 30% to fall on a smooth curve with those at other temperatures, and the 75° points were accordingly disregarded in drawing the curves.

In spite of the irregularities, the uncertainties never became great

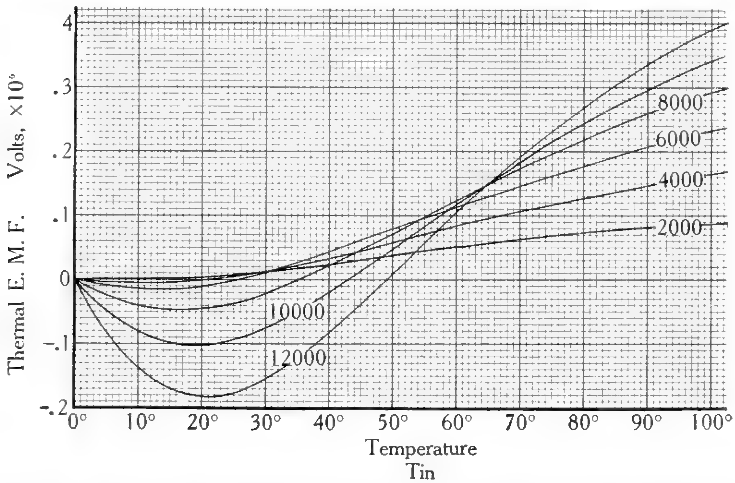

FIGURE 2. Tin. Thermal E. M. F. of a couple composed of one branch of uncompressed metal, the other branch compressed to the pressure in kg./cm.² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

enough to obscure the essential character of the results, which are most curious. The results are shown in Figure 2, and Table I, in which e.m.f. at constant pressure is plotted against temperature. The effect is small, rising at the most to 0.4×10^{-6} volts, and reverses in sign with temperature. At 12000 kg. the e.m.f. passes through a negative maximum of 0.18×10^{-6} at about 25°, and then reverses sign, rising to 0.4×10^{-6} volts at 100°. Or if the results are plotted as a function of pressure at different constant temperatures (which

TABLE I.

Tin.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.^{2}					
	2000	4000	6000	8000	10000	12000
10°	+.001	−.004	−.014	−.041	−.083	−.136
20	+.003	.000	−.010	−.045	−.103	−.182
30	.012	+.012	+.011	−.020	−.075	−.154
40	.024	+.033	+.042	+.021	−.019	−.081
50	.038	.058	.078	+.070	+.048	+.010
60	.052	.083	.111	.122	+.117	+.103
70	.064	.106	.146	.172	.183	.191
80	.074	.127	.176	.218	.243	.269
90	.082	.147	.206	.258	.296	.335
100	.087	.165	.232	.292	.341	.390

is the way in which they were obtained experimentally) they are equally curious. At 25°, the effect is initially positive, passing through a very flat maximum of about 0.005×10^{-6} volts at 2500 kg., and from here on becomes rapidly negative, reaching -0.185×10^{-6} at 12000 kg. This curve is concave downwards. The approximate effect of higher temperatures is merely to rotate this curve bodily, without distortion, anticlockwise about the origin. At 50° the effect is throughout positive, the curvature displaying itself as a maximum near 7000 kg., and at 75° and 100° the rotation has become great enough to obliterate the maximum.

The Peltier and Thomson heats deduced from these measurements are shown in Figure 3 and Table II. Of course when the fundamental data are so irregular there must be much uncertainty in the derivatives, but I believe that the essential features of the situation, with respect to changes of sign etc., are correctly given, and that the numerical values of the Thomson heat are correct to within perhaps 50%. Both Peltier and Thomson heats change sign in the range. At low temperatures the effect of all pressures is to give a negative Peltier heat; that is, heat is absorbed by the positive current in flowing across the junction from compressed to uncompressed metal, but at higher temperatures, at all pressures, the Peltier heat becomes positive, passes through a maximum, and decreases again. The Thomson heat, on the other hand, is initially positive for low temperatures, but becomes negative at higher temperatures.

Tin was one of the metals measured by Wagner.[2] He made only one measurement, at 300 kg. and 100°, and found for the effect -0.95×10^{-12} volts per degree per kg. The measurements above

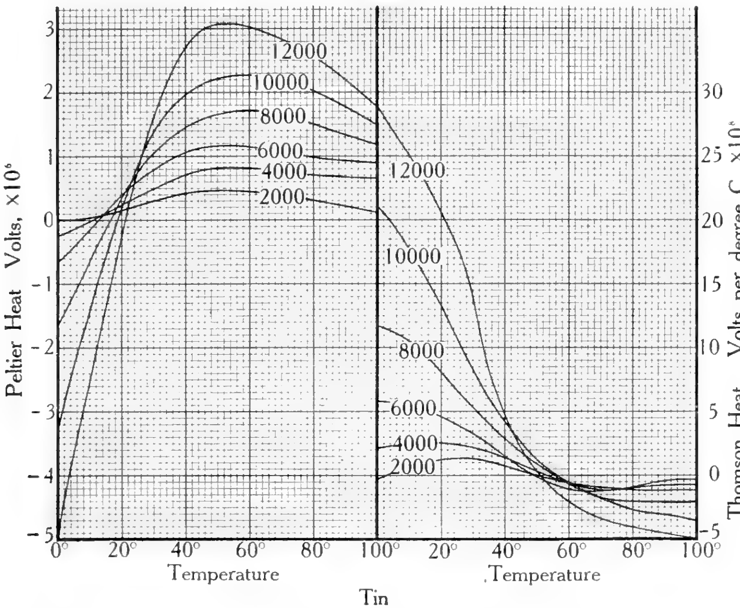

FIGURE 3. Tin. On the left, the heat absorbed by unit quantity of electricity on flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

make the effect positive at all pressures for a temperature range of 100°, and would indicate, if interpolation is justifiable, $+ 0.43 \times 10^{-12}$ volts per degree per kg. Wagner's one reading allowed him to form no idea of the complicated state of affairs for this metal. There can be no comparison between his results and mine, because it will be shown later in the case of Al and Fe, which also show reversals in sign like Sn, that small variations in the purity of the metal, or the

TABLE II.

Tin.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	0.	−.25	− .66	−1.64	−3.28	−4.92
20	+.15	+.23	+ .38	+ .32	+ .15	− .23
40	+.41	+.72	+1.06	+1.44	+1.94	+2.68
60	.43	.80	1.13	1.73	2.27	+3.03
80	.30	.71	.99	1.52	2.01	2.54
100	.11	.65	.90	1.19	1.49	1.75

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	− .3	+2.2	+5.9	+11.7	+21.0	+28.9
20	+1.3	+2.5	+4.4	+ 8.2	+13.2	+20.3
40	+ .6	+1.4	+1.6	+ 3.0	+ 4.4	+ 6.6
60	− .5	− .5	−1.0	− .7	− .5	− 2.0
80	−1.1	− .7	− .9	− 1.9	− 2.6	− 4.1
100	−1.1	− .4	− .7	− 2.0	− 3.5	− 5.0

mechanical treatment, although they leave the general character of the results unaltered, may nevertheless produce large changes in the numerical values. For instance, a slight shift in the position of the flat maximum would produce changes even of sign in the neighborhood of 500 kg.

The thermal e.m.f. of tin was measured at atmospheric pressure against lead between 0° and 100°. Over this range its thermal e.m.f. is given approximately by the formula:

$$E = (0.230\,t - 0.00067\,t^2) \times 10^{-6} \text{ volts.}$$

The Peltier heat against lead is

$$P = (0.230 - 0.00134\,t)\,(t + 273) \times 10^{-6} \text{ volts,}$$

and the Thomson heat is

$$\sigma = -0.00134\,(t + 273) \times 10^{-6} \text{ volts/°C.}$$

This assumes the Thomson heat of lead to be zero. A positive e.m.f. means that the current flows from lead to tin at the hot junction.

Thallium. A different specimen from that of the resistance measurements had to be used, the former piece having become very badly oxidized. A fresh lot was obtained from the United States Smelting Company. As provided by them it contained considerable impurity of lead and cadmium. I purified it by electrolysis, by well known methods. It was dissolved in excess c.p. H_2SO_4 and electrolyzed from dilute aqueous solution onto a copper cathode with platinum anode. The deposit is in the form of trees. These were repeatedly washed in pure water, dried in a paraffine bath at 200° in a stream of H_2, and finally melted in a glass tube in a stream of H_2. The H_2, however, was not perfectly pure, and a thin film of the yellow oxide formed on the surface of the metal during melting. This was scraped off, and the ingot formed into a wire by cold extrusion to 0.028 inch diameter. The wire was kept under pure water while waiting for use, which effectively prevented tarnishing. The outer wire was shellaced immediately before assembling. There was no such trouble from oxidation as that experienced during the resistance measurements.

The purity of this sample was not so high as that of the previous one, as shown by its temperature coefficient of resistance. The average coefficient between 0° and 100° was 0.00475, which is considerably less than that of the former sample, 0.00518. The several crystallizations in the form of various salts of the previous sample doubtless accounts for its higher purity. The relation between temperature and resistance of this new sample was sensibly linear within the range 0° to 100°.

The thermo-electric behavior of a thallium-lead couple at atmos-

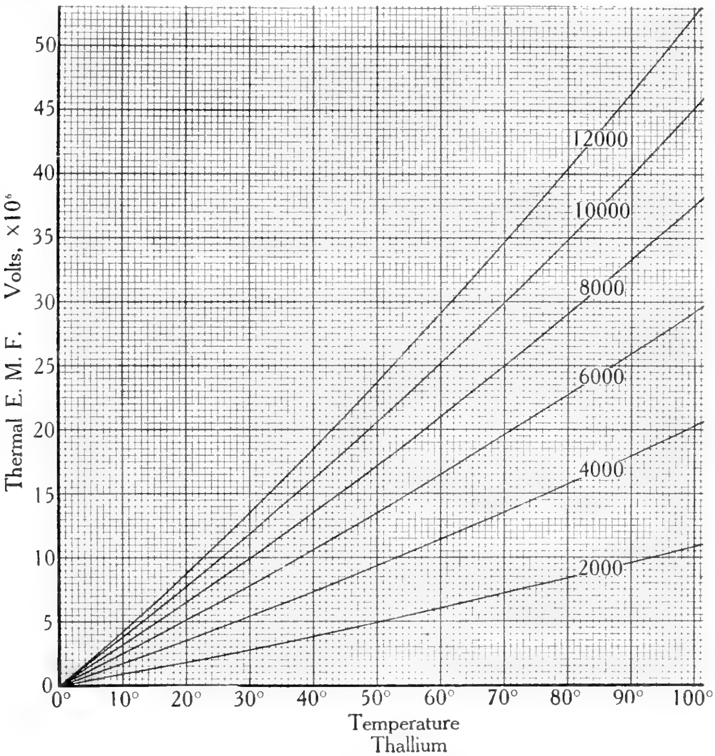

FIGURE 4. Thallium. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.[2] indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

pheric pressure is represented within the limits of measurement by the formulas

$$E = (1.659\, t - 0.00134\, t^2 - 0.0000056\, t^3) \times 10^{-6} \text{ volts},$$
$$P = (1.659 - 0.00268\, t - 0.0000168\, t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (-0.00268 - 0.0000336\, t)\,(t + 273) \times 10^{-6} \text{ volts/°C}.$$

The pressure measurements were very satisfactory. The effect is large and positive, equilibrium was quickly reached, the readings

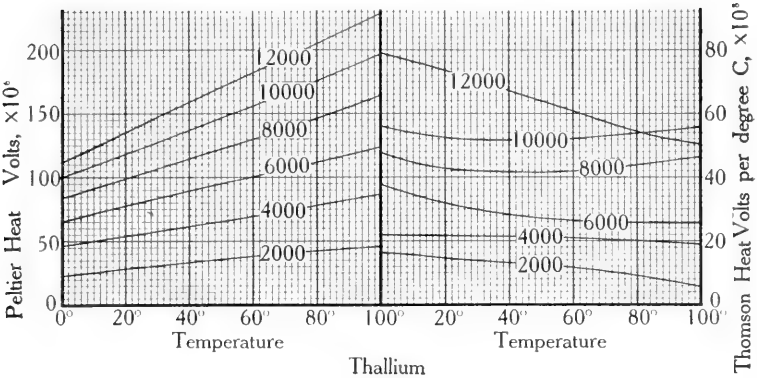

FIGURE 5. Thallium. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE III.

THALLIUM.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+.88	+1.74	+2.47	+3.14	+3.78	+4.26
20	1.81	3.55	5.07	6.44	7.72	8.78
30	2.80	5.43	7.78	9.88	11.84	13.53
40	3.84	7.37	10.59	13.46	16.13	18.53
50	4.93	9.38	13.49	17.17	20.58	23.75
60	6.07	11.45	16.48	21.01	25.19	29.15
70	7.24	13.57	19.55	24.97	29.96	34.73
80	8.43	15.75	22.70	29.08	34.89	40.49
90	9.64	17.99	25.92	33.29	39.97	46.40
100	10.87	20.29	29.21	37.63	45.20	52.46

TABLE IV.

Thallium.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+23.	+46.	+66.	+83.	+100.	+112.
20	28.	54.	78.	99.	118.	136.
40	33.	62.	89.	114.	137.	160.
60	38.	69.	101.	130.	156.	183.
80	42.	78.	112.	147.	177.	206.
100	46.	87.	124.	164.	197.	229.

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+16.	+22.	+38.	+48.	+56.	+79.
20	15.	22.	32.	42.	53.	73.
40	12.	20.	28.	42.	52.	67.
60	12.	20.	27.	41.	52.	60.
80	9.	19.	26.	44.	55.	55.
100	6.	19.	26.	47.	56.	50.

were perfectly steady, and the permanent change of zero was almost imperceptible. The maximum departure of any point from a smooth curve was 0.4% of the total effect. It was very gratifying that this soft substance showed no permanent zero change, since permanent distortions must very easily be introduced into it.

The numerical results are shown in Tables III and IV, and Figures 4 and 5. The e.m.f. is positive and increases regularly with pressure and temperature; the Peltier heat between compressed and uncompressed metal is also positive and increases with pressure and temperature, and the Thomson heat increases with pressure, except at the maximum temperature and pressure, but decreases regularly with rising temperature.

There are no previous measurements whatever on this substance for comparison.

Cadmium. This was a piece of new wire 0.02 inch diameter, from the same original piece as the resistance wire. It was extruded at a temperature of 180°, and seasoned after extrusion by several hours at 120° in an electric oven.

The thermo-electric behavior at atmospheric pressure against lead may be represented by the formulas:

$$E = (12.002\,t + 0.1619\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (12.002 + 0.3238\,t)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = 0.3238(t + 273) \times 10^{-6} \text{ volts/°C}.$$

The pressure effect is not regular, and the readings were never steady, indicating an incomplete state of internal equilibrium. The material was seasoned by two preliminary applications of 12000 at room temperature, and five runs were made, at 25°, 50°, 75°, 95° and 25° again. There was much hysteresis; this was larger at the higher temperatures, and amounted at the maximum to 5% of the total effect. The run at 25° was repeated in order to find whether the hysteresis would disappear by accommodation after several runs at different temperatures, but it did not change. The first run at 25° almost exactly repeated itself, hysteresis and all. Wagner found similar effects over so low a range as 300 kg.; he found an abnormally long time required to reach equilibrium and a hysteresis which never disappeared, no matter how long he waited.

It will be recalled that Cd is one of the metals for which Cohen [7] claims different allotropic forms. The evidence of this paper corro-

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7 E. Cohen and W. D. Helderman, Proc. Amster. Acad. **17,** 1050–1054, 1915.

borates the theory that Cd may be in a state of unstable internal equilibrium, or at any rate of internal equilibrium which is very slowly readjusted after any change of external conditions. The measurements of the previous paper did not suggest any such state of affairs, but this need not be surprising, because it is known that thermo-

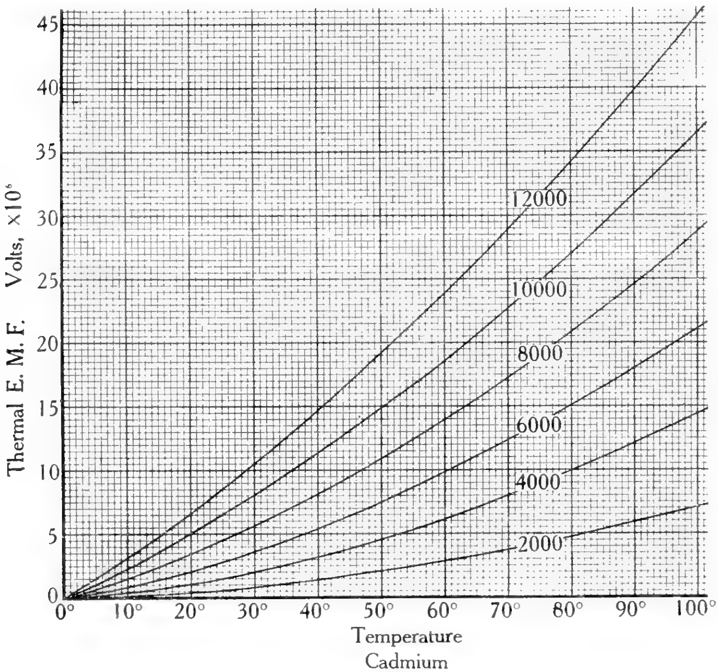

FIGURE 6. Cadmium. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.^{2} indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

electric quality is much more sensitive to slight changes than resistance. At the same time, it does not seem to me that unstable internal equilibrium necessarily points to polymorphism as an explanation. I have already discussed this matter in some detail in another paper.[8] With regard to the bearing of these particular measurements on the

8 P. W. Bridgman, Proc. Amer. Acad. **52**, 636, 1917.

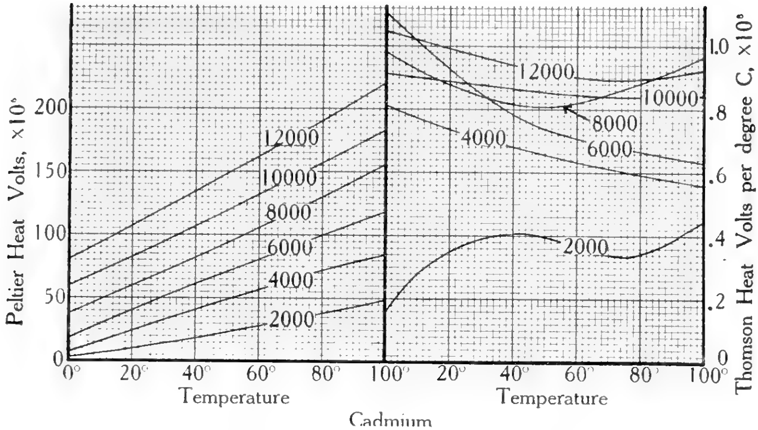

FIGURE 7. Cadmium. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE V.

CADMIUM.

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+0.14	+0.42	+0.88	+1.54	+2.36	+3.16
20	0.42	1.10	2.10	3.46	5.04	6.68
30	0.84	2.06	3.64	5.70	8.04	10.54
40	1.38	3.22	5.48	8.20	11.34	14.72
50	2.04	4.62	7.56	10.96	14.82	19.18
60	2.82	6.22	9.88	13.98	18.66	23.92
70	3.72	8.02	12.42	17.28	22.76	28.92
80	4.74	9.98	15.14	20.84	27.10	34.20
90	5.88	12.10	18.06	24.66	31.70	39.74
100	7.12	14.38	21.16	28.74	36.52	45.56

TABLE VI.

Cadmium.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+3.8	+7.6	+18.6	+38.3	+60.1	+81.3
20	10.0	24.3	41.0	60.7	83.1	108.
40	18.8	40.1	61.6	82.3	107.	135.
60	28.0	56.7	80.7	105.	132.	162.
80	38.1	72.0	99.8	130.	157.	191.
100	48.5	83.2	118.	156.	183.	221.

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+16.	+82.	+109.	+98.	+91.	+105.
20	35.	73.	94.	88.	89.	99.
40	41.	69.	78.	81.	87.	94.
60	37.	63.	70.	83.	84.	90.
80	35.	60.	67.	88.	84.	90.
100	45.	56.	63.	97.	84.	93.

question, it is to be noticed that the effects were found at all temperatures of the range, increasing at the higher temperature. If the effect were due to a polymorphic transition, we would expect to find it above a definite temperature only. Cohen located the transition temperature at about 67°.

The mean curves of thermal e.m.f., that is the curves through the mean of the points with ascending and descending pressure, disregarding hysteresis, when plotted against pressure at constant temperature, are somewhat unusual in that they are concave upward, the proportional effect of a given increment of pressure thus becoming greater at higher pressures. This is not what one would expect, and is the reverse of the behavior of most metals.

The uncertainty introduced by hysteresis was so large that rather large readjustments were necessary in order to obtain smooth curves when the curves of thermal e.m.f. at constant pressure, plotted against temperature, were read from those at constant temperature against pressure. The greatest readjustment necessary was at 8000 kg. and 75°, where it was 4% of the total effect. The probable error of these readjusted curves, computing by the mean square formula from the departure of the individual points, was 0.34% of the maximum effect.

The numerical results are shown in Figures 6 and 7 and Tables V and VI. The thermal e.m.f. is large and positive, rising with pressure and temperature somewhat more steeply than normal; the Peltier heat is positive and rises with temperature and pressure, the Thomson heat is positive, and rises with temperature at the low pressures, but falls at the high pressures.

The value found by Wagner for 0° to 100° to 300 kg. was $+ 36.3 \times 10^{-12}$ volts per degree per kg., against 35.6×10^{-12} above. The agreement is much better than could be expected in view of the large hysteresis.

Lead. This was Kahlbaum's "K" lead, freshly extruded into wire 0.0288 inch diameter. It would have been desirable if I could have used the same excessively pure lead from Professor Richard's laboratory that was used for the resistance measurements, but no more was available, and the wire of the resistance measurements was too fine for this. However, this "K" lead is exceedingly pure, its temperature coefficient having been found to be only 0.2% lower than that of the purest, and it is doubtless as good as the inherently less accuracy of this work justifies.

This lead is used as the standard in this paper against which the thermal e.m.f. of the other metals is given. Experimentally, the comparisons were all made against pieces of copper, cut from the same spool, and the figures given were obtained by subtraction. It is assumed here, from the work of previous observers, that the Thomson heat of this lead was zero; no direct examination of this question was made for these experiments, as it would have required extensive measurements with special apparatus.

As a preliminary to the pressure measurements, one previous application of 12000 kg. was made at room temperature to season.

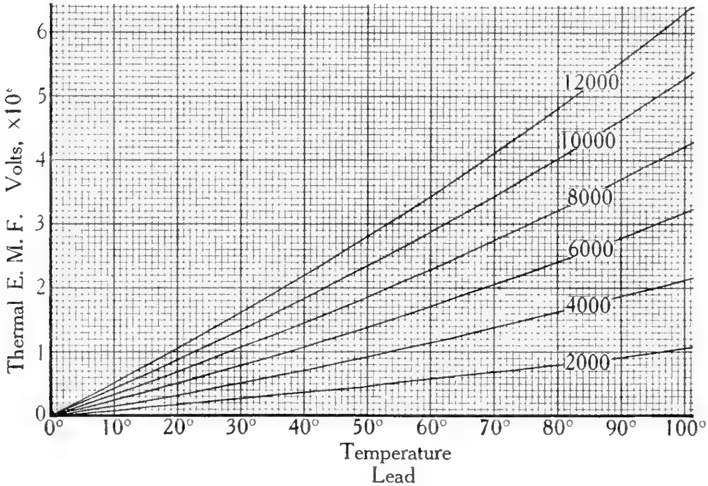

Figure 8. Lead. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

The pressure measurements were very satisfactory, being much like those on Thallium, although not quite so regular. The maximum effect, which is positive, is 6×10^{-6} volts against 50×10^{-6} volts for Tl. This doubtless accounts for the somewhat greater proportional irregularity. The observed e.m.f's. are sensibly linear against pressure at constant temperature. Such linearity is surprising in so soft a metal as lead. The resistance curves against pressure were distinctly not linear. There was no appreciable change of zero at any temperature, which again is most gratifying for so soft a metal.

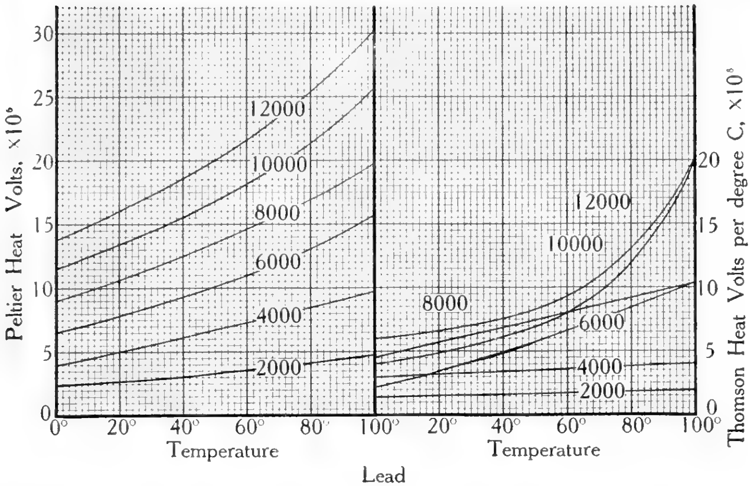

FIGURE 9. Lead. On the left, the heat absorbed by unit quantity of electricity on flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE VII.

LEAD.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.^{2}					
	2000	4000	6000	8000	10000	12000
10°	+.08	+.15	+.25	+.34	+.43	+.52
20	.17	.32	.51	.69	.88	1.06
30	.26	.51	.79	1.06	1.35	1.62
40	.36	.71	1.08	1.45	1.84	2.20
50	.46	.92	1.39	1.86	2.35	2.81
60	.57	1.14	1.71	2.29	2.88	3.44
70	.68	1.37	2.05	2.74	3.44	4.11
80	.80	1.61	2.41	3.21	4.02	4.81
90	.92	1.86	2.79	3.70	4.64	5.55
100	1.05	2.12	3.19	4.21	5.30	6.33

TABLE VIII.

Lead.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+2.4	+4.0	+6.6	+9.0	+11.5	+13.8
20	2.7	5.0	7.8	10.6	13.4	16.0
40	3.0	6.2	9.3	12.5	15.5	18.6
60	3.6	7.3	11.0	14.6	18.1	21.6
80	4.1	8.5	13.0	16.9	21.3	25.4
100	4.7	9.7	15.7	19.7	25.7	30.2

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+1.4	+3.0	+2.2	+4.6	+4.1	+6.0
20	1.5	3.2	3.5	5.9	4.7	6.7
40	1.6	3.4	5.0	6.9	6.3	7.5
60	1.7	3.7	6.7	8.0	8.0	9.3
80	1.8	3.9	8.5	9.2	12.0	13.1
100	1.9	4.1	10.4	10.4	20.1	20.1

According to Cohen,[9] lead also is in unstable internal equilibrium, and has allotropic modifications. No evidence whatever of anything of this kind was found above. If there had been, it should certainly have manifested itself as a change of zero. The maximum departure of any single observed point from linearity was 1.7% of the maximum effect, and the average numerical departure of all the observed points was 0.25%. Since no readjustment whatever was necessary in passing from the curves at constant temperature to those at constant pressure, the results may be accepted with considerable confidence.

The numerical results are shown in Tables VII and VIII and Figures 8 and 9. The thermal e.m.f. rises regularly with pressure and temperature, as do also the Peltier heat and the Thomson heat. All three of these are positive. The fact that there is an appreciable Thomson heat between the compressed and the uncompressed metal has an interesting bearing on the question whether there is a Thomson heat at atmospheric pressure. It is a matter of rather general experience that zero, or atmospheric, pressure, is no preferred pressure, but the properties of a substance change without discontinuity on going from negative to positive pressure. This is in accord with a point of view, fruitful in many situations, that a substance at atmospheric pressure is actually under a high internal pressure, and that changes in external pressure produce the same effect as proportionally small changes in total pressure (internal plus external). The fact, therefore, that compressed lead has a Thomson heat against uncompressed lead makes it probable that the Thomson heat of uncompressed lead is not rigorously and exactly zero but is merely too small to be measured conveniently.

Wagner is the only previous observer on lead; he gives $+ 5.6 \times 10^{-12}$ volts per degree per kg. for 0° to 100° and to 300 kg. The results above for the same range would be interpolated as $+ 5.2 \times 10^{-12}$; the agreement is satisfactory.

Zinc. This was Kahlbaum's "K" grade, from the same rod as the resistance specimen, but it was not the identical piece of wire. It was extruded to 0.020 inch diameter at a temperature of 330°, and was annealed in an electric oven for several hours at 120°.

At atmospheric pressure its thermo-electric behavior against lead is given by the formulas:

$$E = (3.047\, t - 0.00495\, t^2) \times 10^{-6} \text{ volts},$$
$$P = (3.047 - 0.0099\, t)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = -0.0099(t + 273) \times 10^{-6} \text{ volts/°C}.$$

9 E. Cohen and W. D. Helderman, Proc. Amst. Acad **17**, 822–828, 1914.

The behavior under pressure is in many respects like that of cadmium. Zinc evidently is in a state of unstable internal equilibrium as shown by unsteadiness and irregularity of reading, and hysteresis. The hysteresis was not as marked as that of cadmium, however, and the permanent changes of zero were comparatively small, rising at the maximum to 1.2% of the total effect. Five runs were made,

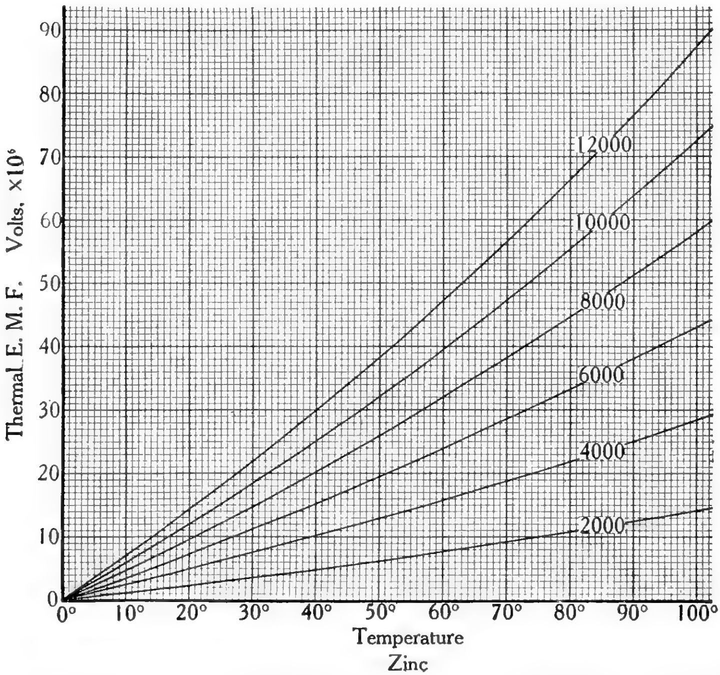

FIGURE 10. Zinc. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

at 25°, 50°, 75°, 95°, and 25° again. The last run at 25° was made to find whether any permanent change had been produced by the many changes of pressure and temperature, but there was none, the last run at 25° giving the same average deflection and also the same hysteresis as the first run. In order to reduce to a minimum uncertainties from changing internal equilibrium, two applications of the maximum

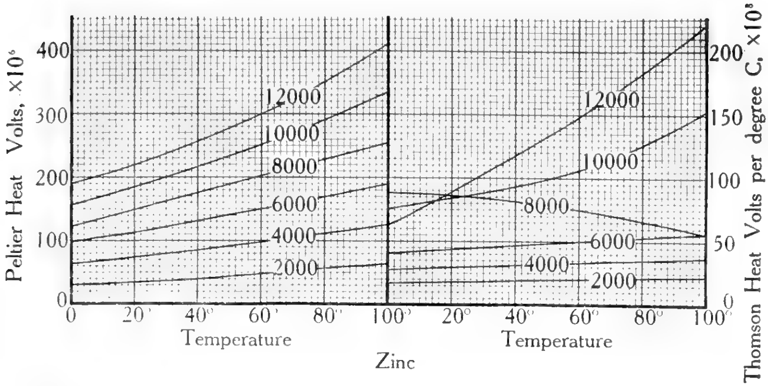

FIGURE 11. Zinc. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE IX.

ZINC.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+1.1	+2.4	+3.6	+4.7	+5.9	+7.1
20	2.3	4.9	7.3	9.6	12.0	14.4
30	3.5	7.5	11.2	14.8	18.4	22.0
40	4.8	10.2	15.3	20.3	25.1	30.1
50	6.2	13.0	19.6	26.1	32.2	38.5
60	7.8	15.9	24.0	32.1	39.6	47.4
70	9.3	18.9	28.6	38.3	47.3	56.7
80	10.8	22.0	33.3	44.7	55.3	66.4
90	12.4	25.2	38.1	51.3	63.7	76.6
100	14.1	28.5	43.0	58.1	72.5	87.4

TABLE X.

Zinc.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+30.	+64.	+98.	+123.	+155.	+190.
20	35.	75.	110.	149.	185.	218.
40	41.	86.	131.	176.	216.	257.
60	48.	98.	150.	203.	252.	300.
80	56.	111.	169.	229.	289.	351.
100	63.	125.	190.	255.	355.	412.

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+17.	+27.	+41.	+88.	+75.	+63.
20	18.	29.	44.	86.	84.	89.
40	19.	31.	47.	82.	93.	118
60	20.	33.	50.	75.	106.	148.
80	21.	35.	53.	71.	126.	183.
100	22.	37.	56.	55.	153.	220.

pressure were made before the runs at 25°, 50°, and 75°, instead of at 25° only, as usual, but this seemed to make no difference. Within the limits of error, the relation between thermal e.m.f. and pressure at any constant temperature is linear. This is surprising for so large an effect, which rises to $+ 80 \times 10^{-6}$ volts, larger than for any metal except bismuth. The maximum departure from linearity of any single point observed was 6% of the maximum effect. This point was situated at 8000 kg. and 75°; the discrepancy is almost entirely due to the width of the hysteresis loop. On changing from the curves at constant temperature to those at constant pressure, readjustments of as much as 4% were necessary. By a curious accident, the points as first plotted at each pressure lay accurately on two straight lines, intersecting at a negative temperature, the points at 0°, 25°, and 50° forming one group, and those at 75° and 100° another. I thought at first that this was due to a polymorphic transition, but a moment's consideration shows that a transition cannot produce a discontinuity in the actual ordinates of a thermal e.m.f. curve, but only an abrupt change in the direction. Such was not the case here. Zinc is also one of the substances for which Cohen [10] supposes polymorphic transitions. His transition point is at 25°, whereas here evidence of internal instability was found at every temperature above 0°.

Wagner found $+ 40 \times 10^{-12}$ volts per degree per kg. between 0° and 100° at 300 kg. This is to be compared with 70×10^{-12} deduced from the measurements above. The lack of agreement is not surprising in view of the hysteresis and its dependence on pressure. Wagner found the same hysteresis effects as were noted above, and says that the results are doubtful for this reason. With respect to this behavior he puts Zn and Cd in a class by themselves.

Magnesium. This was from the same piece of commercial magnesium as the resistance specimen, but was extruded at a different time into wire 0.020 inch diameter. The specimen whose pressure coefficient of resistance had been measured was too small and too much oxidized to use again. It was not annealed in the electric oven, as were the other newly extruded wires, for fear of too great oxidation.

The thermal e.m.f. against lead at atmospheric pressure is very small, and is given by the formulas:

$$E = (-0.095\,t + 0.00004\,t^2) \times 10^{-6} \text{ volts,}$$
$$P = (-0.095 + 0.00008\,t)\,(t + 273) \times 10^{-6} \text{ volts,}$$
$$\sigma = 0.00008(t + 273) \times 10^{-6} \text{ volts/°C.}$$

10 E. Cohen and W. D. Helderman, ZS. phys. Chem. **89**, 742–747, 1915.

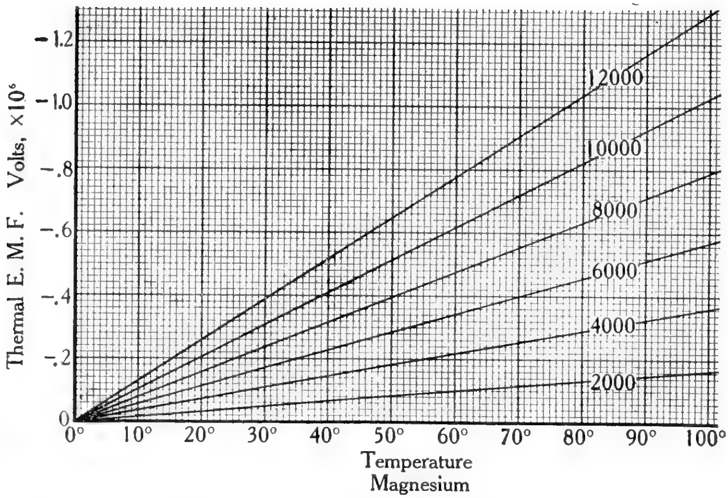

FIGURE 12. Magnesium. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.[2] indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

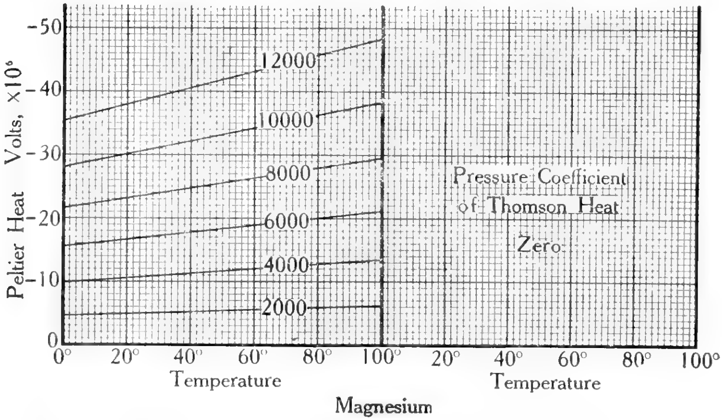

FIGURE 13. Magnesium. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. The Thomson heat of magnesium is not affected by hydrostatic pressure.

TABLE XI.

Magnesium.

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.^{2} 2000	4000	6000	8000	10000	12000
10°	−.17	−.36	−.57	−.75	−1.03	−1.30
20	.33	.72	1.04	1.58	2.06	2.59
30	.50	1.09	1.61	2.37	3.09	3.89
40	.67	1.45	2.18	3.16	4.12	5.18
50	.84	1.81	2.86	3.95	5.15	6.48
60	1.00	2.17	3.43	4.75	6.18	7.78
70	1.17	2.53	4.00	5.54	7.21	9.07
80	1.34	2.90	4.57	6.33	8.24	10.37
90	1.50	3.26	5.14	7.12	9.27	11.66
100	1.67	3.62	5.71	7.91	10.30	12.96

TABLE XII.

Magnesium.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb × 10^6.

Temp. C degrees	Pressure, kg./cm.^{2} 2000	4000	6000	8000	10000	12000
0°	−4.56	−9.9	−15.6	−21.6	−28.2	−35.4
20	4.91	10.6	16.7	23.3	30.2	38.0
40	5.24	11.3	17.9	24.7	32.3	40.6
60	5.56	12.1	19.0	26.3	34.3	43.2
80	5.89	12.8	20.1	27.9	36.3	45.8
100	6.23	13.5	21.1	29.6	38.4	48.4

The effect of pressure on the Thomson heat is everywhere zero.

The pressure effect on thermal e.m.f. could be measured without the sources of error which made the resistance measurements inaccurate. It is very difficult to make good electrical connections to magnesium, since it cannot be soldered, and any mechanical connection encounters the resistance of the rapidly formed layer of oxide. Any change of resistance introduces, however, no error in any potentiometer method of measuring e.m.f. like the present, so that it was possible to make e.m.f. measurements over the entire range, as for any other metal, whereas the resistance measurements could be made only at 25°. More readings were made on magnesium than on other metals because of irregularities in the earlier runs due to insufficient stirring of the ice bath. The final runs were satisfactory. The maximum zero correction was 0.75% of the maximum effect and the maximum divergence of any single observation from a smooth curve was 3.1% of the maximum, but the average numerical departure was only 0.22%. In passing from the curves at constant temperature to those at constant pressure an adjustment of the 75° curve of 3% of the maximum effect had to be made; elsewhere the readjustment was very slight.

The numerical values are shown in Tables XI and XII and Figures 12 and 13. The e.m.f. is negative and comparatively large, rising to nearly 13×10^{-6} volts at 100° and 12000 kg. The curves of e.m.f. at constant temperature against pressure are concave upwards, showing an increasing proportional effect at higher pressures, contrary to the normal behavior. At constant pressure, e.m.f. against temperature is linear. The Peltier heat is also negative, increasing numerically with both temperature and pressure. The Thomson heat is unaffected by pressure; this of course follows directly from the linearity of the effect with temperature at constant pressure.

There are no other measurements for comparison.

Aluminum. The material was freshly extruded wire of 0.02 inch diameter from the same rod as the wire on which the resistance measurements were made. The original resistance wire was too small for this purpose. The wire was annealed after extrusion by several hours at 120° in an electric oven. The effects with aluminum were so unusual that the measurements were repeated on a second specimen, this time of commercial wire. As purchased, this wire was about $\frac{1}{16}$ inch diameter; it was drawn down for this experiment through steel dies to 0.0265 inches, and annealed by heating in boiling water for about an hour.

The average temperature coefficient of resistance at atmospheric pressure between 0° and 100° of the commercial aluminum was 0.004307. According to this test it would seem, therefore, only slightly less pure than the pure aluminum from the American Aluminum Co.; its coefficient as found in the resistance paper was 0.00434. The relation between resistance and temperature of commercial aluminum was sensibly linear.

At atmospheric pressure the thermo-electric behavior of pure aluminum against lead is given by the formulas;

$$E = (-0.416\,t + 0.00008\,t^2 - 0.00001\,t^3) \times 10^{-6} \text{ volts},$$
$$P = (-0.416 + 0.00016\,t - 0.00003\,t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (0.00016 - 0.00006\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C}.$$

For commercial aluminum the corresponding formulas are:

$$E = (-0.378\,t - 0.00005\,t^2 + 0.0000094\,t^3) \times 10^{-6} \text{ volts},$$
$$P = (-0.378 - 0.0001\,t + 0.0000282\,t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (-0.0001 + 0.0000564\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C}.$$

The numerical values of the differences between the constants for these two different specimens are small, thus bearing out the observation on temperature coefficient.

Under pressure, the effects are more complicated, and for the most part very small. It would not have been possible to carry through these readings except for the perfect steadiness of the galvanometer, allowing readings to be made to the limit of sensitiveness. This was true both for the commercial and the purer samples. Wagner remarked also on the same behavior of his specimen. This is somewhat surprising, because one would be inclined at first to explain the complicated nature of the effects, which involves reversals of sign, by assuming two modifications in varying proportions. But there was no evidence whatever for any incompleteness of internal equilibrium; if there is such an effect, the change of equilibrium must occur immediately.

Measurements on the purer sample were made first. This was exposed twice to 9000 kg. at room temperature, then the apparatus taken apart to remedy a leak, and pressure then applied again twice to 12000 at 25° before beginning readings. Regular runs were made at 25°, 50°, and 75°, but at 95° the wire broke with increasing pressure, evidently because the transmitting medium was too stiff, being one half kerosene and one half ether, instead of entirely ether as usual. It was set up again with a new piece of wire, a contiguous piece from the same length as the first piece, and this was seasoned by two applications of 12000 kg. at room temperature. The point at 4000 with this agreed with the point found with the other wire before it broke. After the run at 95° with the new piece, another run with the new piece was made at 63°. This fitted smoothly between the two runs

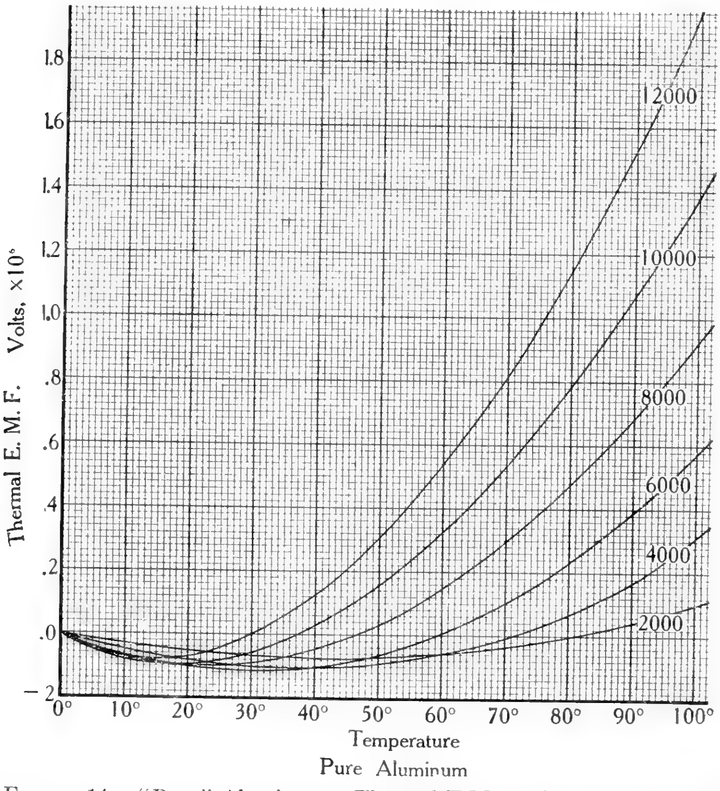

FIGURE 14. "Pure" Aluminum. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other of metal compressed to the pressure indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

with the first specimen, so that we may be confident that no error was introduced by changing pieces.

The experimental points with the purer aluminum lie smoothly. The maximum zero correction was 1.5% of the maximum effect, the maximum departure of any point from a smooth curve was 2% of

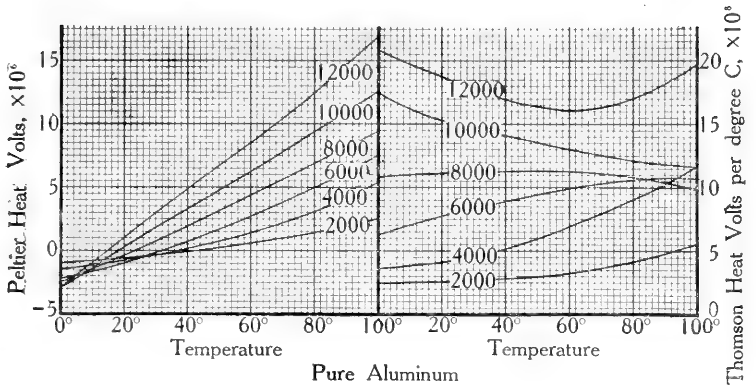

FIGURE 15. "Pure" Aluminum. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE XIII.

ALUMINUM (PURE).

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	−.031	−.048	−.068	−.070	−.076	−.069
20	−.054	−.081	−.098	−.098	−.095	−.068
30	−.068	−.100	−.114	−.089	−.056	+.003
40	−.073	−.104	−.103	−.046	+.030	+.130
50	−.070	−.091	−.063	+.032	+.158	.312
60	−.058	−.060	+.005	+.146	.328	.543
70	−.035	−.008	+.103	.296	.538	.821
80	−.002	+.066	.231	.478	.786	1.151
90	+.043	+.166	.389	.689	1.070	1.531
100	+.101	+.294	.577	.929	1.384	1.962

TABLE XIV.

Aluminum (Pure).

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	− .98	−1.48	−2.18	−2.43	−2.86	−2.86
20	− .53	− .76	− .91	− .29	+ .35	+1.03
40	− .03	+ .12	+ .78	+1.94	+3.35	+4.68
60	+ .60	+1.37	+2.73	+4.40	6.33	8.52
80	+1.41	3.10	5.07	6.94	9.39	12.42
100	2.50	5.37	7.59	9.41	12.56	16.90

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^9$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+2.4	+3.7	+6.3	+10.8	+17.5	+20.9
20	2.6	4.2	7.8	11.1	15.3	18.8
40	2.8	5.2	8.8	11.3	14.1	16.9
60	3.0	6.9	9.9	11.2	12.9	16.1
80	4.2	9.0	10.6	10.6	12.1	17.0
100	5.6	11.7	10.7	9.8	11.6	19.8

the maximum effect, and the average departure from a smooth curve was 1/2%. At the lower temperatures, 25° and 50°, where the effect is very small and the curve passes through a flat minimum, the regularity of the points is much greater. No adjustment whatever was necessary in passing from the curves at constant temperature to those at constant pressure. The numerical results are shown in Tables XIII and XIV and Figures 14 and 15. The reversals in sign and the maximum remind one of the behavior of tin, but a detailed examination shows many differences. The effect at 25° is small and negative throughout the entire range, passing through a flat minimum of about -0.1×10^{-6} volts at 6000 kg. At 50° the effect for the first 5000 kg. is much the same as at 25°, but above this it becomes rapidly different, rising through zero and reaching $+0.3 \times 10^{-6}$ volts at 12000 kg. At 75° the effect is positive for most of the range, and the negative minimum has been pushed back to 1500 kg. At 100° the curve probably starts out negative, but almost immediately reverses, rising to 2×10^{-6} volts at 12000 kg. At all temperatures the curves remain concave upwards. It is evident that no comparison between these results and those of Wagner is possible, because he used only one pressure, 300 kg., and one temperature interval. The effect he found was very small and negative, -0.59×10^{-12} volts per degree per kg. Since the effect is changing so rapidly it is not safe to use my results by interpolation in this region to find figures to compare with his.

The behavior of the Peltier heat is on the whole simpler than that of e.m.f. itself. The curves change sign and cross in a complicated way, but there are no maxima or minima, and the curvature is slight. The Thomson heat is still more simple; it is throughout positive. At the lower temperatures it increases regularly with pressure, but at the higher temperatures there is a rather complicated crossing of the curves.

Measurements with commercial aluminum were made only at 25°, 50°, and 75°. I would have been glad to complete the series at 95°, but after 75° the inside connection, which was merely wrapped, pulled apart, and since the purpose of the readings with this specimen was merely to see whether the effects were qualitatively the same, I did not feel justified in taking the time to set up the apparatus again. The wire was seasoned for the runs by a preliminary application of 12000 kg. at room temperature as usual. The results, as far as the broad outlines go in which aluminum is so strikingly different from other metals, were the same as for the purer specimen, but the numerical details were very different. The values of e.m.f. are shown in Table XV and Figure 16; the Peltier heat and the Thomson heat are not given in detail. The effect is, as before, initially negative, the curves of e.m.f. at constant temperature passing through a very flat

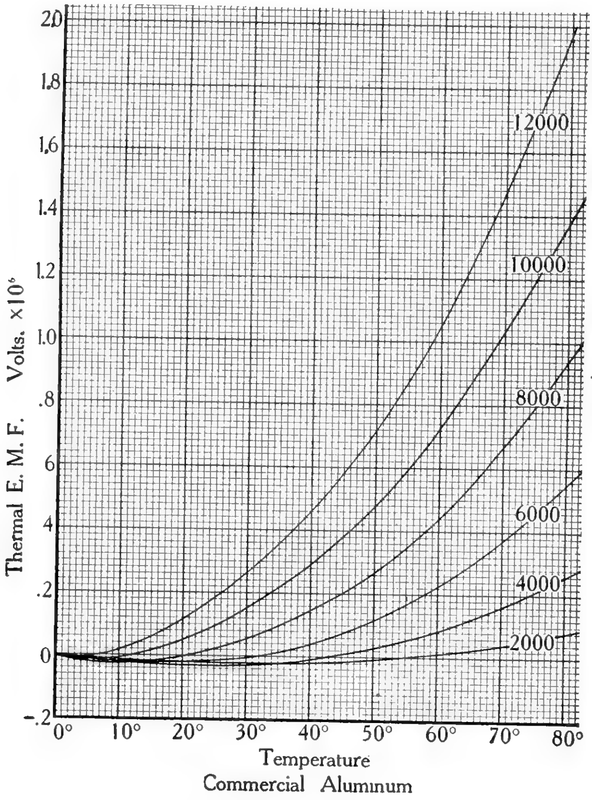

FIGURE 16. Commercial Aluminum. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.^{2} indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

minimum and then rising. The pressure and the absolute value of the minimum both decrease rapidly at higher temperatures. The curves are throughout concave upwards. But at 25° the numerical value at the minimum is only -0.03×10^{-6} against -0.1×10^{-6} for the purer material, and beyond the minimum the rise is much more rapid, so that at 12000 kg. the e.m.f. has become $+0.2 \times 10^{-6}$. This change of sign was not found until 50° with the purer sample. In general, the tendency towards positive values is much greater with this specimen than with the purer material. At 75°, the e.m.f. is 1.7×10^{-6} at 12000 kg., against 1.0×10^{-6} of the purer. One is tempted to generalize and say that the effect of increasing impurity

TABLE XV.

Aluminum (Commercial).

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	−.012	−.019	−.017	−.020	−.006	+.018
20	−.019	−.028	−.019	.000	+.050	+.116
30	−.023	−.027	−.002	+.057	+.154	.265
40	−.019	−.010	+.040	+.148	.293	.464
50	−.008	+.026	+.117	.270	.480	.720
60	+.011	+.084	.227	.440	.727	1.050
70	+.040	.162	.373	.670	1.035	1.473
80	+.080	.260	.550	.944	1.380	1.976

is to obliterate the peculiarities characteristic of aluminum itself and make the behavior approach that of a normal metal.

The Peltier heat of the impurer metal is much like that of the purer, but it passes through a greater range of values, from negative to positive, and the curvature is not so uniform. The Thomson heat is throughout positive, but much more irregular. The range of values is about the same as before, but there are maxima with respect to temperature near 60° for all pressures above 2000 kg., and at 8000, 10000, and 12000 there are in addition minima near 30°.

Silver. The same wire was used as that on which the resistance measurements were made. The silk insulation was removed to prevent viscous drag by the transmitting fluid, and measurements were

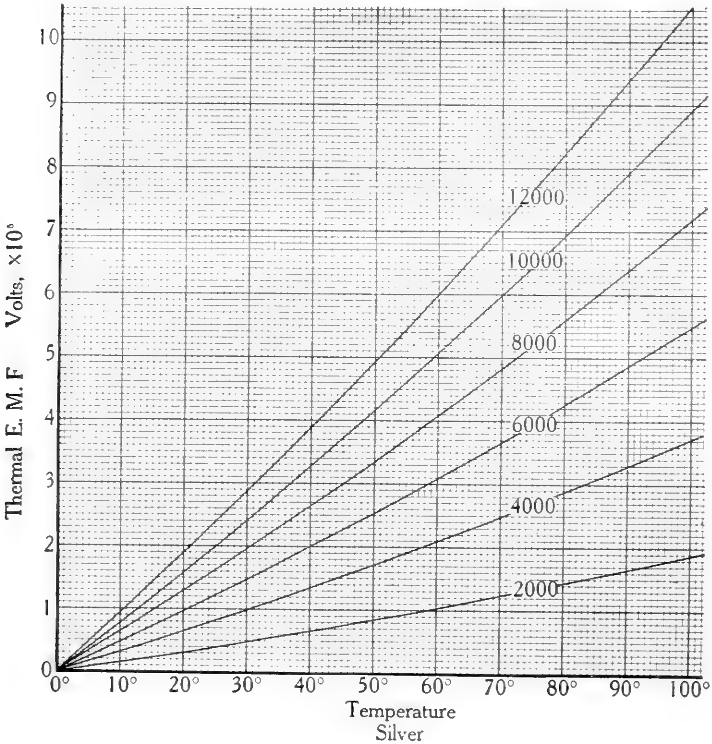

FIGURE 17. Silver. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

made on five strands in parallel. The use of strands in parallel has several advantages; it reduces viscous drag, reduces danger of breakage during handling (the wire was 0.003 inch in diameter), and reduces the resistance of the circuit so that the galvanometer is more sensitive.

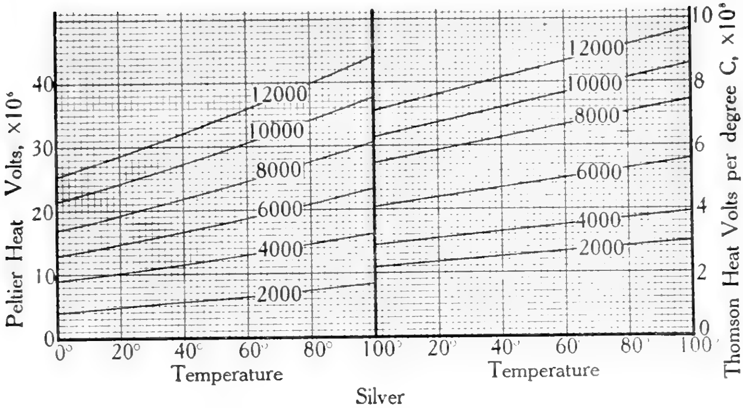

FIGURE 18. Silver. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE XVI.

SILVER.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+.15	+.32	+.48	+.63	+.79	+.94
20	.31	.66	.97	1.28	1.60	1.90
30	.48	1.00	1.48	1.95	2.43	2.89
40	.66	1.36	2.00	2.64	3.29	3.91
50	.84	1.72	2.54	3.35	4.17	4.95
60	1.03	2.10	3.10	4.08	5.07	6.02
70	1.23	2.49	3.67	4.83	5.99	7 12
80	1.44	2.89	4.26	5.60	6.94	8.24
90	1.65	3.30	4.87	6.38	7.91	9.39
100	1.87	3.72	5.49	7.19	8.91	10.56

TABLE XVII.

Silver.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+3.9	+8.9	+12.9	+16.9	+21.6	+25.3
20	4.8	10.1	14.6	19.3	24.1	28.5
40	5.6	11.4	16.6	21.9	27.4	32.1
60	6.5	12.8	18.8	24.6	30.5	36.0
80	7.4	14.5	21.0	27.5	33.9	40.0
100	8.4	16.1	23.3	30.6	37.6	44.2

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+2.2	+2.9	+4.1	+5.5	+6.3	+7.1
20	2.3	3.1	4.4	5.9	6.7	7.6
40	2.5	3.3	4.7	6.3	7.2	8.1
60	2.7	3.5	5.0	6.7	7.7	8.7
80	2.8	3.7	5.3	7.1	8.1	9.2
100	3.0	3.9	5.6	7.5	8.6	9.7

The thermo-electric behavior at atmospheric pressure against lead is given by the formulas:

$$E = (2.556\,t + 0.00432\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (2.556 + 0.00864\,t)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = 0.00864(t + 273) \times 10^{-6} \text{ volts/}^\circ\text{C}.$$

For the pressure measurements it was seasoned in the regular way by two applications of 12000 kg. at room temperature. The readings under pressure went perfectly smoothly, without incident of any sort. The maximum zero correction was at 98°, 0.7% of the maximum effect; there was only one bad point, at 10000 kg. and 75°, where there was a discrepancy of 2.5%. Except for this, the maximum departure of any point was 1.2%, and the average arithmetical departure from a smooth curve was only 0.11%. In changing from the curves at constant temperature to those at constant pressure the maximum readjustment necessary was 0.3%.

The numerical results are shown in Tables XVI and XVII and Figures 17 and 18. At constant temperature the curves of e.m.f. against pressure are concave toward the pressure axis, which is what one would expect. At constant pressure, on the other hand, the curves are convex toward the pressure axis. The e.m.f. is positive and increases regularly with pressure and temperature. The Peltier heat is positive and increases regularly with pressure and temperature. The Thomson heat is also positive; it increases with rising pressure, and at any constant pressure is proportional to the absolute temperature.

Wagner gives up to 300 kg. and between 0° and 100° $+ 8.7 \times 10^{-12}$ volts per degree per kg., against 9.3×10^{-12} interpolated from the data above.

Gold. This was the same piece of wire whose resistance was measured under pressure. It was used bare, in parallel strands. The runs at 25°, 50°, and 75° were with four strands, but at 97° two only were used because the other two had been accidentally broken during manipulation.

The thermo-electric behavior at atmospheric pressure against lead is given by the formulas:

$$E \doteq (2.899\,t + 0.00467\,t^2 - 0.00000166\,t^3) \times 10^{-6} \text{ volts},$$
$$P = (2.899 + 0.00934\,t - 0.00000498\,t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (0.00934\,t - 0.00000996\,t)\,(t + 273) \times 10^{-6} \text{ volts/}^\circ\text{C}.$$

The manipulation demanded by the pressure measurements was difficult because of the great fragility of the wire, which was only

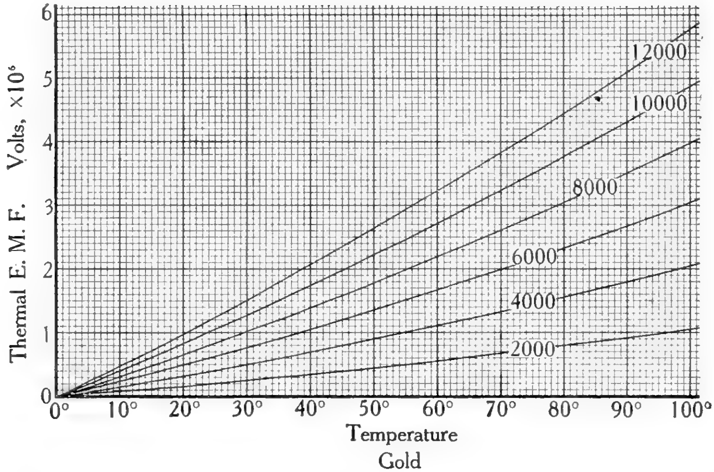

FIGURE 19. Gold. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other at the pressure in kg./cm.[2] indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

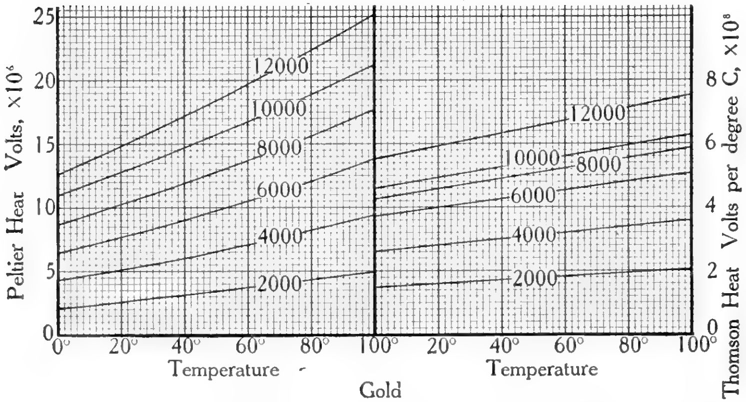

FIGURE 20. Gold. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

0.004 inch in diameter. Before the runs the wire was seasoned by a single application of 12000 kg. at room temperature. At the first run at 25° all four strands broke at the lower end above 8000 kg., possibly due to cutting by the glass insulating covering during the small motion necessarily incident to change of pressure. The apparatus was set up again, and three runs successfully made at 25°, 50°, and 75°, but after 75° two of the strands broke, because of imperfect functioning of the bye-pass on release of pressure, and the run at 97° was made with the remaining two strands.

The measurements of e.m.f. were regular and satisfactory. Equilibrium was rapidly reached, and there was no unsteadiness or other evidence of internal instability. The maximum departure of any observed point from a smooth curve was 1.3% of the maximum effect, and the average arithmetical departure was 0.2%. The maximum readjustment necessary in passing from curves at constant temperature to those at constant pressure was 0.86%.

TABLE XVIII.

GOLD.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+.080	+.162	+.242	+.327	+.411	+.485
20	.165	.333	.498	.670	.839	.990
30	.257	.514	.767	1.028	1.284	1.515
40	.354	.705	1.049	1.402	1.745	2.061
50	.456	.905	1.345	1.791	2.224	2.627
60	.564	1.115	1.655	2.196	2.719	3.213
70	.678	1.334	1.978	2.617	3.230	3.819
80	.797	1.563	2.315	3.054	3.760	4.446
90	.922	1.802	2.665	3.506	4.305	5.093
100	1.052	2.051	3.029	3.974	4.867	5.760

The numerical values are shown in Tables XVIII and XIX and Figures 19 and 20. The e.m.f. is positive, increasing regularly with pressure and temperature to 5.76×10^{-6} volts at 100° and 12000 kg.

TABLE XIX.

Gold.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb × 10⁶.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+2.1	+4.3	+6.4	+8.7	11.0	13.0
20	2.6	5.2	7.7	10.3	12.8	15.1
40	3.1	6.1	9.1	11.9	14.8	17.4
60	3.7	7.1	10.5	13.7	16.8	19.8
80	4.3	8.2	12.1	15.7	18.9	22.5
100	4.9	9.4	13.8	17.8	21.3	25.2

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C, × 10⁸.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+1.5	+2.6	+3.7	+4.3	+4.6	+5.5
20	1.6	2.8	4.0	4.6	4.9	5.9
40	1.7	3.0	4.25	4.9	5.25	6.3
60	1.8	3.2	4.5	5.2	5.6	6.7
80	1.9	3.4	4.8	5.5	5.9	7.1
100	2.0	3.6	5.1	5.9	6.3	7.5

The pressure effects on Peltier heat and Thomson heat are both positive, and both increase regularly with pressure and temperature. At constant pressure the Thomson heat is proportional to absolute temperature.

Wagner found between 0° and 100° and up to 300 kg. $+ 4.6 \times 10^{-12}$ volts per degree per kg. The value indicated by interpolation of the data above is 5.3×10^{-12}.

Copper. This was electrolytic copper from the same length of wire as that whose resistance was measured under pressure, but not

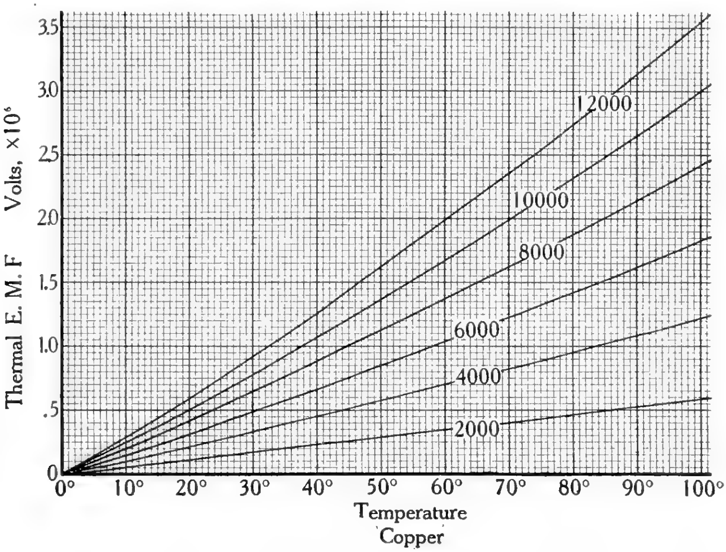

FIGURE 21. Copper. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.² indicated on the curves, the junctions being 0°C and the temperature plotted as abscissae.

the identical piece of wire. It was drawn down to 0.028 inch in diameter through steel dies, annealed to redness, and the surface rubbed off with emery paper.

At atmospheric pressure its thermo-electric behavior against lead is given by the formulas:

$$E = (2.777\,t + 0.00483\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (2.777 + 0.00966\,t)(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = 0.00966(t + 273) \times 10^{-6} \text{ volts/°C}.$$

This electrolytic copper did not differ greatly in thermo-electric properties from commercial copper. The thermal e.m.f. of electrolytic against commercial copper was found to be given by the expression:

$$E = (0.03468\,t + 0.0000133\,t^2) \times 10^{-6} \text{ volts.}$$

The measurements under pressure went satisfactorily, but the results were somewhat more irregular than usual because of the smallness

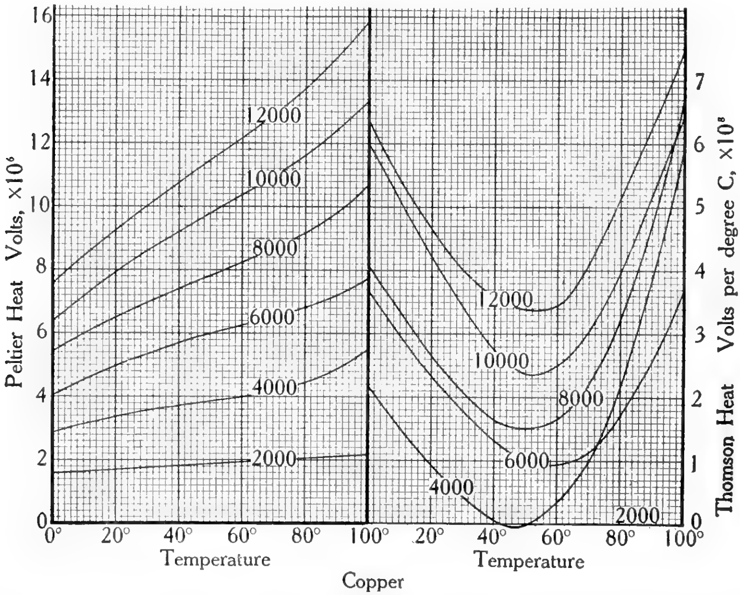

FIGURE 22. Copper. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

of the effect. The maximum zero correction was 1.5% of the maximum effect; this was also the maximum departure of any point from a smooth curve. The average arithmetical departure of all the observed points from a smooth curve was 0.31%. The maximum readjustment necessary in passing from the constant temperature to the constant pressure curves was 0.8%.

The numerical results are shown in Tables XX and XXI and Figures 21 and 22. At constant temperature the e.m.f. curves are nearly linear, but are slightly concave toward the pressure axis, as is natural. At constant pressure the e.m.f. curves are convex toward the temperature axis. The thermal e.m.f. is positive, rises regularly with pressure and temperature to 3.546×10^{-6} volts at 100° and 12000 kg. The Peltier heat is positive and rises with pressure and temperature. The Thomson heat is zero at the lower pressures, becomes positive at the higher, and at each constant pressure passes through a minimum with rising temperature.

TABLE XX.

COPPER.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
10°	+.058	+.110	+.154	+.206	+.244	+.288
20	.117	.224	.318	.424	.506	.596
30	.175	.340	.490	.650	.784	.918
40	.234	.460	.668	.884	1.072	1.256
50	.292	.580	.852	1.124	1.372	1.616
60	.350	.700	1.038	1.370	1.678	1.976
70	.409	.822	1.226	1.620	1.994	2.348
80	.467	.946	1.418	1.876	2.318	2.732
90	.526	1.076	1.624	2.142	2.654	3.130
100	.584	1.216	1.828	2.420	3.004	3.546

The value found by Wagner between 0° and 100° at 300 kg. was $+3.2 \times 10^{-12}$ volts per degree per kg. against 2.9×10^{-12} indicated by interpolation of the data above.

Copper is one of the metals for which Cohen[11] finds allotropic forms. No evidence of this has been found by Burgess and Kellberg,[12] however, from measurements of electrical resistance, and my thermal e.m.f. measurements above also suggest nothing of the kind.

11 E. Cohen and W. D. Helderman, ZS. phys. Chem. **89**, 638–639, 1915.
12 G. K. Burgess and I. N. Kellberg, Jour. Wash. Acad. Sci. **5**, 657–662, 1915.

TABLE XXI.

Copper.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+1.6	+2.9	+4.1	+5.4	+6.4	+7.6
20	1.7	3.4	5.0	6.5	7.9	9.3
40	1.8	3.7	5.7	7.4	9.2	10.8
60	1.9	4.0	6.3	8.2	10.4	12.2
80	2.1	4.4	6.8	9.2	11.6	13.7
100	2.2	5.5	7.8	10.7	13.4	15.9

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Tem C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	0	+2.2	+3.7	+4.1	+6.0	+6.3
20	0	.9	2.3	2.6	4.2	4.7
40	0	+ .1	1.3	1.6	2.7	3.5
60	0	+ .4	1.0	1.7	2.5	3.4
80	0	2.3	1.8	3.3	4.2	5.2
100	0	6.0	3.8	6.7	6.5	7.5

Nickel. This was the same piece of wire as that whose resistance under pressure was measured. The insulation was stripped, and it was used in five parallel strands of bare wire. The points obtained are not as regular as could be desired because of failure of the tempera-

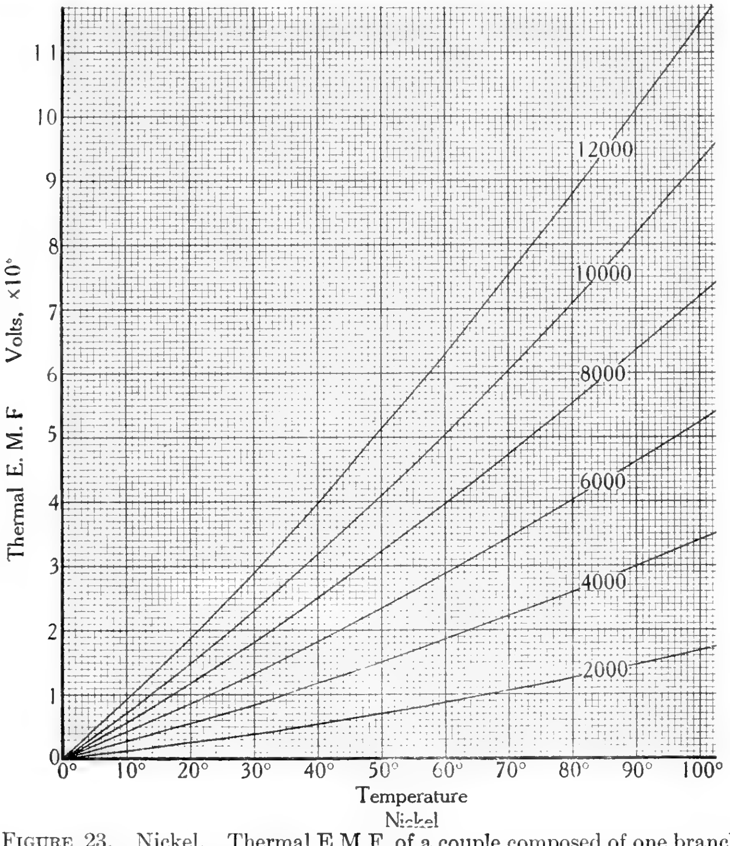

FIGURE 23. Nickel. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.^{2} indicated on the curves, one junction being at 0°C and the other at the temperature plotted as abscissae.

ture regulator to work perfectly. The regulator was cleaned after these runs, and was again perfectly satisfactory. It did not seem worth while to repeat the runs on nickel for the sake of the slightly greater obtainable accuracy.

At atmospheric pressure the thermal behavior against lead is given by formulas:

$$E = (-17.61\,t - 0.0178\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (-17.61 - 0.0356\,t)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = -0.0356(t + 273) \times 10^{-6} \text{ volts/}^\circ\text{C}.$$

The measurements under pressure went without incident except for somewhat greater irregularities than usual due to imperfection

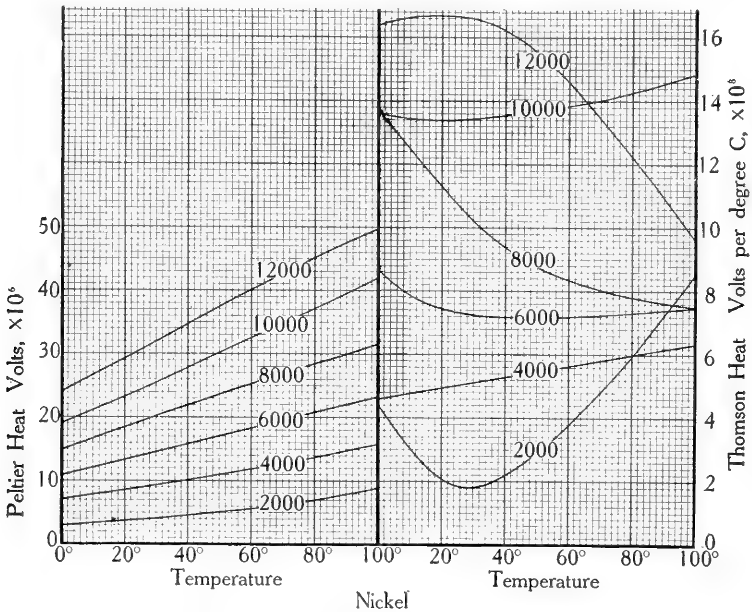

FIGURE 24. Nickel. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicate on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

of temperature control already mentioned. The pressure manipulation of this substance was a matter of some difficulty, because temporary effects due to elastic drag are easy to get. There was no evidence of incomplete internal equilibrium. The maximum zero correction was 1% of the total effect, and the maximum departure of any single observed point from a smooth curve was 3.6%, and the average arithmetical departure 0.72%. The maximum adjustment in passing from constant temperature to constant pressure curves was 2.3%.

The numerical results are shown in Figures 23 and 24 and Tables XXII and XXIII. At constant temperature the e.m.f. curves are convex toward the pressure axis, which is unusual, but at constant pressure the curvature is convex toward the temperature axis, as is normal. The e.m.f. is positive, increasing regularly with pressure and temperature to 11.4×10^{-6} volts at 100° and 12000 kg., but it is

TABLE XXII.

NICKEL.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure ,kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+.12	+.27	+.41	+.56	+.73	+.91
20	.25	.55	.85	1.17	1.50	1.88
30	.39	.85	1.32	1.82	2.32	2.91
40	.54	1.17	1.82	2.51	3.19	4.00
50	.70	1.50	2.34	3.23	4.10	5.14
60	.87	1.85	2.88	3.97	5.05	6.32
70	1.05	2.21	3.44	4.74	6.05	7.55
80	1.25	2.59	4.02	5.53	7.09	8.81
90	1.45	2.99	4.62	6.35	8.17	10.11
100	1.68	3.40	5.24	7.19	9.29	11.44

not as large as one would expect from the thermo-electric activity of nickel against other metals at atmospheric pressure. The Peltier heat is positive, increasing with pressure and temperature. The Thomson heat is also positive, but at low pressures it passes through a minimum with rising temperature and at high pressures it decreases over the entire range with increasing temperature.

Wagner's value up to 300 kg. between 0° and 100° is $+ 9.6 \times 10^{-12}$ volts per degree per kg. against 8.4 interpolated from the data above. The difference may well be due at least in part to insufficient purity of my specimen.

TABLE XXIII.

Nickel.

Peltier heat, from uncompressed to compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+3.0	+7.1	+10.9	+14.8	+19.1	+24.1
20	3.9	8.5	13.2	18.4	23.2	29.3
40	4.7	10.2	15.8	21.9	27.7	34.7
60	5.7	11.8	18.3	25.3	32.5	40.1
80	7.1	13.8	20.8	28.4	37.2	45.1
100	8.9	15.7	23.3	31.5	42.1	49.9

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+4.4	+4.6	+8.6	+13.7	+13.6	+16.4
20	2.1	5.0	7.4	11.3	13.4	16.5
40	2.2	5.3	7.2	9.4	13.5	16.2
60	3.8	5.6	7.2	8.3	13.8	14.6
80	6.0	6.0	7.3	7.8	14.3	12.2
100	8.6	6.3	7.5	7.5	14.9	9.6

Cobalt. This was from the same length as the resistance specimen, but was not the identical piece. Part of this wire had not been previously annealed, and it was therefore annealed before these runs exactly as was the resistance piece. Five strands in parallel were

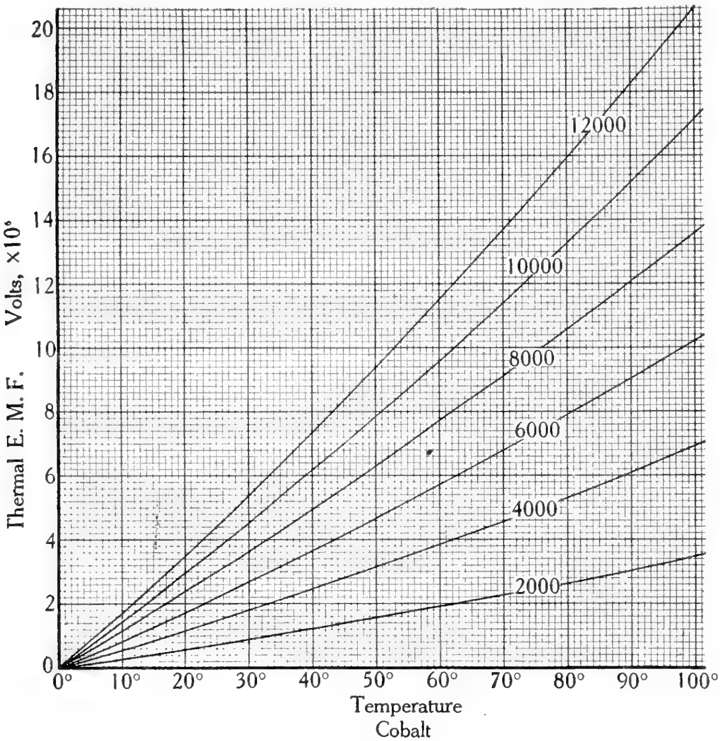

FIGURE 25. Cobalt. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.^{2} indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

used, insulated as usual with short pieces of glass. The wire is more inhomogeneous than most of the other metals, as was shown by the rather large permanent zero effect, which was two or three times larger than the total pressure effect. However, the permanent zero remained so constant that fairly good measurements could be obtained.

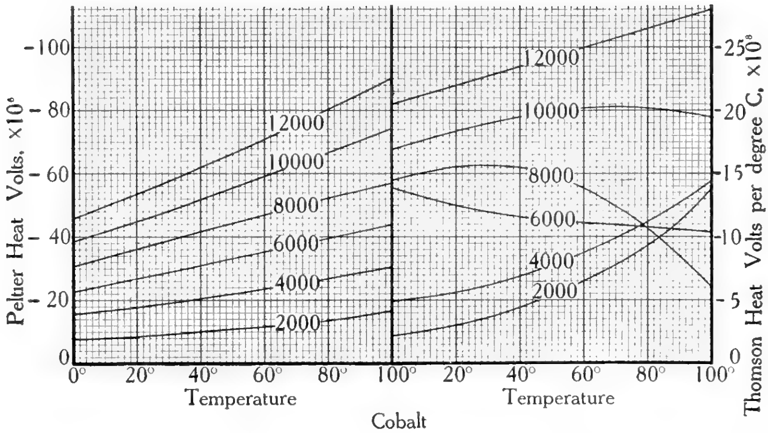

FIGURE 26. Cobalt. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicate on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE XXIV.

COBALT.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	−.29	−.59	−.86	−1.16	−1.44	−1.72
20	.59	1.20	1.76	2.37	2.95	3.52
30	.90	1.83	2.71	3.63	4.52	5.39
40	1.22	2.48	3.69	4.94	6.15	7.34
50	1.56	3.16	4.71	6.30	7.84	9.37
60	1.91	3.86	5.75	7.70	9.59	11.47
70	2.27	4.58	6.82	9.13	11.40	13.65
80	2.65	5.33	7.92	10.59	13.26	15.90
90	3.05	6.11	9.05	12.08	15.18	18.22
100	3.48	6.92	10.21	13.60	17.15	20.61

TABLE XXV.

COBALT.

Peltier heat, between uncompressed and compressed metal, Joules per coulomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
0°	−7.6	−15.8	−22.7	−30.8	−38.5	−45.9
20	8.8	18.2	26.9	36.1	44.9	53.6
40	10.3	20.7	31.3	41.6	52.0	62.2
60	11.6	23.7	35.3	47.3	59.4	71.0
80	13.8	26.8	39.5	52.3	66.7	80.3
100	16.8	30.9	44.0	57.0	74.6	90.5

Thomson heat, excess in compressed over uncompressed metal, Joules per coulomb $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
0°	−2.2	−4.9	−13.9	−14.5	−16.9	−20.5
20	2.9	5.6	12.6	15.5	18.5	22.0
40	4.4	6.9	11.6	15.3	19.4	23.5
60	6.7	8.7	11.3	13.7	20.0	25.0
80	9.2	11.3	10.9	10.6	20.1	26.4
100	13.8	14.5	10.4	6.0	19.4	28.0

At atmospheric pressure the thermal electric behavior against lead is given by the formulas:

$$E = (-17.32\,t - 0.0390\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (-17.32 - 0.078\,t)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = -0.078(t + 273) \times 10^{-6} \text{ volts/°C}.$$

For the pressure measurements it was seasoned twice at room temperature to 12000 kg. Successful runs were made at 25°, 50°, 75°, and 97°. At 97° the zero was displaced by an unusually large amount after the run. This displacement apparently had no connection with the other readings, and was probably accidental; this point was discarded. Except for this point, the maximum zero correction was 1.5% of the total effect, the maximum departure of any point from a smooth curve was 4.5%, and the average arithmetical departure 0.81%. The maximum readjustment in going from curves at constant temperature to those at constant pressure was 1%.

The numerical results are shown in Tables XXIV and XXV and Figures 25 and 26. The effect is negative and large, increasing regularly with pressure and temperature to -20.61×10^{-6} at 12000 kg. and 100°. The Peltier heat is negative, increasing in magnitude with pressure and temperature. The Thomson heat is also negative, in general increasing in magnitude with pressure and temperature, but at the highest temperature it passes through a pressure minimum near 8000 kg.

There are no previous results for comparison. Cobalt has the largest negative effect of any metal measured. One would expect anomalies because of the unusually large Thomson heat at atmospheric pressure.

Iron. Three different samples of iron were used; the effects were complicated as for tin and aluminum, and it therefore seemed desirable to find how the effect varied with different material. The first sample was of American Ingot Iron, from the same piece as that of the resistance measurements under pressure. It was drawn down to 0.020 inch diameter, and annealed to redness in the air. Except for the difference of diameter, this was the same treatment as the resistance specimen received. Another specimen of the same wire was used, but it was left unannealed after drawing from 0.017 to 0.0105 inches in diameter. Its average temperature coefficient between 0° and 100° at atmospheric pressure was 0.006080, against 0.006206 for the same material when annealed. The third specimen was a commercial soft iron wire such as is used for binding hay bales etc. It was drawn from 0.06 to 0.03 inches diameter, and annealed to redness after the final drawing. The commercial wire must have been of unusual purity, because the average temperature coefficient of resistance at atmospheric pressure between 0° and 100° had the high value 0.00596, and its resistance shows the same striking departure from linearity with temperature as does the pure iron.

At atmospheric pressure the thermal electric behavior of these various specimens against lead is given by the following formulas. Ingot iron, annealed,

$$E = (16.18\,t - 0.0089\,t^2 - 0.000086\,t^3) \times 10^{-6} \text{ volts},$$
$$P = (16.18 - 0.0178\,t - 0.000258\,t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (-0.0178 - 0.000516\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C}.$$

Ingot iron, hard drawn,

$$E = (15.92\,t - 0.0106\,t^2 - 0.000056\,t^3) \times 10^{-6} \text{ volts},$$
$$P = (15.92 - 0.0212\,t - 0.000168\,t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (-0.0212 - 0.000336\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C}.$$

Commercial iron, annealed,

$$E = (16.56\,t - 0.0033\,t^2 - 0.000122\,t^3) \times 10^{-6} \text{ volts},$$
$$P = (16.56 - 0.0066\,t - 0.000366\,t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (-0.0066 - 0.000732\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C}.$$

The behavior of these different specimens is therefore not unlike.

Under pressure, each specimen was subjected to the same treatment. They were seasoned twice by applications of 12000 kg. at room temperature, and runs were then made as usual at 25°, 50°, 75°, and 95°. The behavior of all was qualitatively the same, with numerical differences. A longer time than normal was always required to reach steady readings, and there were rather large irregularities, suggesting that all three samples were in a state of incomplete internal equilibrium. This is what would be expected from the behavior of iron in other particulars.

Of course the greatest interest attaches to the annealed ingot iron, this approaching most closely to pure iron in a state of complete ease. Even this shows much hysteresis, which increases greatly at the higher temperatures. At 25°, the e.m.f. is negative throughout, and is small. For the first 4000 kg. the curve is exceedingly flat, and hugs the axis closely. The curvature is downward, the negative effect increasing numerically by larger fractions of itself for equal pressure increments at the higher pressures. At 25° the hysteresis is one eighth of the total effect at 25°. At 50° the e.m.f. is throughout positive, but the direction of curvature is the same as at 25°, which allows a maximum at about 6000 kg. The effect at 50° does not at its maximum attain one half the numerical value at 25°, and the hysteresis at 50° is one third the total effect at 50°. At 75° the effect is much larger; the curvature is the same, and the maximum has disappeared. The indications are that there is a maximum at some much higher pressure

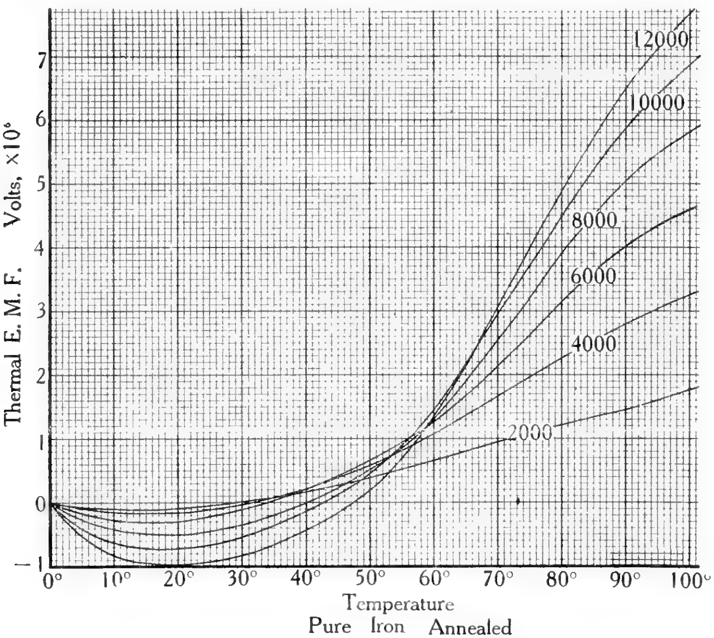

FIGURE 27. American Ingot Iron, Annealed. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.^{2} indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

than 12000 kg. The hysteresis at 75° is 12% of the maximum at 75°. At 75° and 50° the hysteresis is abnormal in direction, being a hastening forward instead of a lagging behind. It should properly not be called a hysteresis at all; and must be due to a different kind of failure of internal equilibrium from the ordinary effect. At 99° the character of the curve is the same as at 75°; the greatest e.m.f. is twice that at

75°, and the hysteresis is about the same fraction of itself, but is in the normal direction. No readjustment was necessary in passing from the constant temperature to the constant pressure curves.

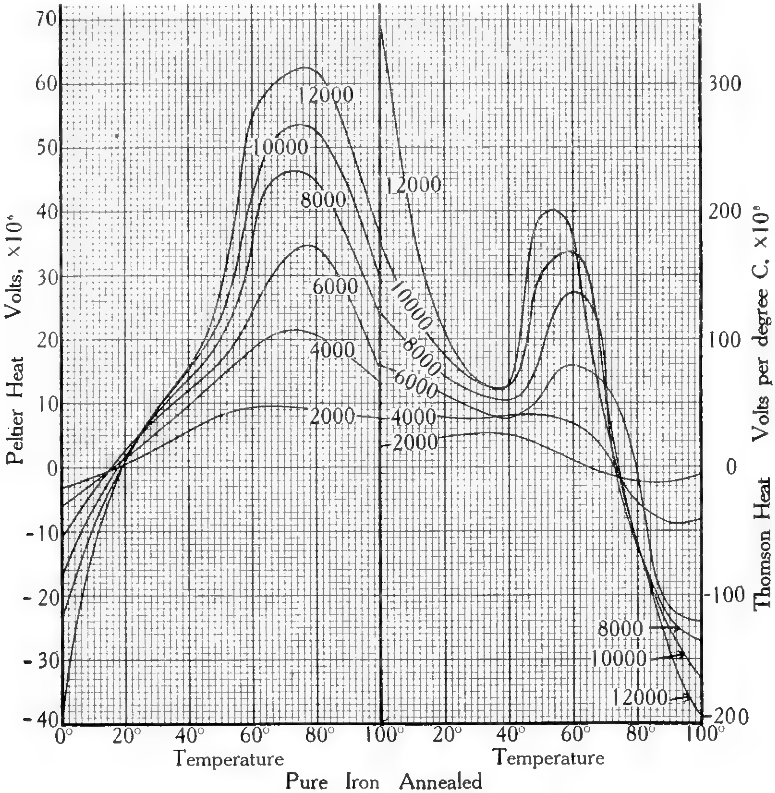

FIGURE 28. American Ingot Iron, Annealed. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

The numerical results are shown in Tables XXVI and XXVII and Figures 27 and 28. The Peltier heat is at first negative at all pressures, becomes positive with increasing temperature, passes through a positive maximum and decreases. The behavior of the Thomson heat is complicated. On the whole the course is, at every pressure, from positive values at 0° to negative values at 100°, but near 40° the normal course is arrested, the effect reversing in direction and passing through a maximum between 50° and 60°, and then resuming its fall to negative values.

It will not pay to go into the behavior of the other two specimens in such detail. Tables and diagrams are given showing the e.m.f. but not the Peltier and the Thomson heats. Both showed qualitatively the same behavior as the pure specimen; the effect was negative at

TABLE XXVI.

Iron (Pure, Annealed).

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	−.08	−.15	−.27	−.42	− .64	− .84
20	−.08	−.15	−.28	−.50	− .74	− .99
30	+.03	−.02	−.10	−.34	− .54	− .81
40	+.17	+.22	+.22	+.02	− .13	− .41
50	.39	+.59	+.67	+.53	+ .46	+ .22
60	.66	1.08	1.27	1.31	+1.45	+1.40
70	.94	1.67	2.14	2.57	2.94	3.08
80	1.21	2.28	3.15	3.91	4.48	4.89
90	1.45	2.81	4.03	5.03	5.85	6.49
100	1.67	3.25	4.60	5.82	6.86	7.68

low temperatures (plotted against pressure), rising to normally high positive values at 100°. The direction of curvature is the same as for the annealed iron, but the anomaly in direction of hysteresis was not repeated. The hysteresis effects were of about the same magnitude as for the first specimen, except that at 95° the hard drawn specimen showed large permanent changes. This is not surprising. The numerical values of thermal e.m.f. against temperature at constant pressure are plotted in Figures 29 and 30. At low temperature all three sets of curves for the three specimens are alike, but between 75° and 100° the hard drawn and the commercial iron do not show the

TABLE XXVII.

IRON (PURE, ANNEALED).

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	−3.3	−6.0	−10.9	−16.9	−23.3	−38.3
20	+ .9	+1.8	+ 2.6	+ 1.8	+ 1.2	+ 1.2
40	+5.6	+9.7	+12.2	+13.8	+15.4	+15.7
60	+9.3	18.3	24.7	34.0	42.6	50.0
80	8.8	20.4	34.3	44.5	52.4	62.2
100	7.5	13.1	14.9	23.1	29.4	35.8

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 4000	4000	6000	8000	10000	12000
0°	+17.	+38.	+ 79.	+120.	+175.	+347.
20	23.	38.	56.	72.	88.	106.
40	25.	41.	37.	52.	63.	63.
60	5.	33.	79.	137.	167.	180.
80	−10.6	−28.	− 11.	− 63.	− 64.	− 56.
100	− 5.6	−41.	−121.	−136.	−166.	−194.

reversal in direction of curvature that the annealed iron does. The numerical values are also very different. At 100° and 12000 kg. the thermal e.m.f. of soft ingot iron is 7.68×10^{-6}, of hard drawn ingot iron 12.80, and of annealed commercial iron 9.56. The mechanical treatment apparently makes more difference than slight differences in chemical composition.

It is not worth while to give the Peltier and Thomson heats of these two other specimens; if any one is especially interested they may be

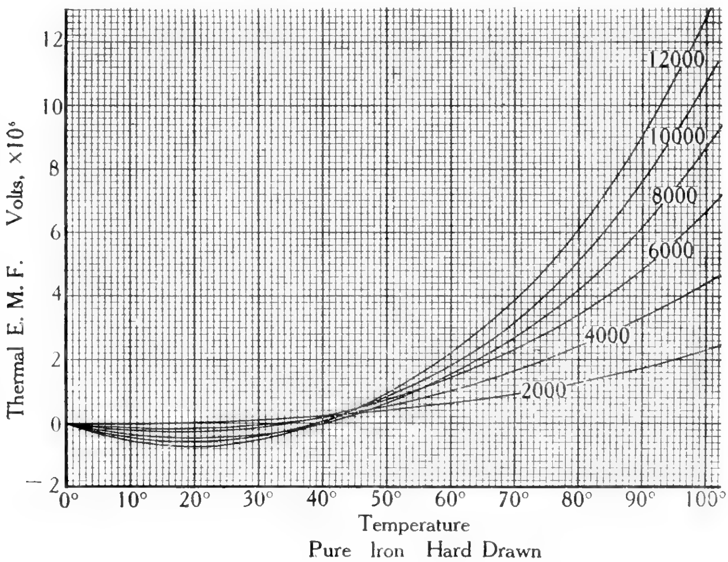

FIGURE 29. American Ingot Iron, Hard Drawn. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

obtained by calculation from the curves, or I will be glad personally to send him the figures. The general character of the effects is quite different from that of the annealed pure iron, due to the reversal in curvature of pure iron between 75° and 100° already mentioned. The Peltier heat of both of these specimens rises from initial negative values to high positive values. The general course of the Thomson heat is from low to high positive values with rising pressure and temperature, but both specimens show minima near 40°.

Previous measurements by Wagner were only to 300 kg. and from 0° to 100°. Of course he could not suspect the complicated actual state of affairs, and comparison of our results is of little use. He

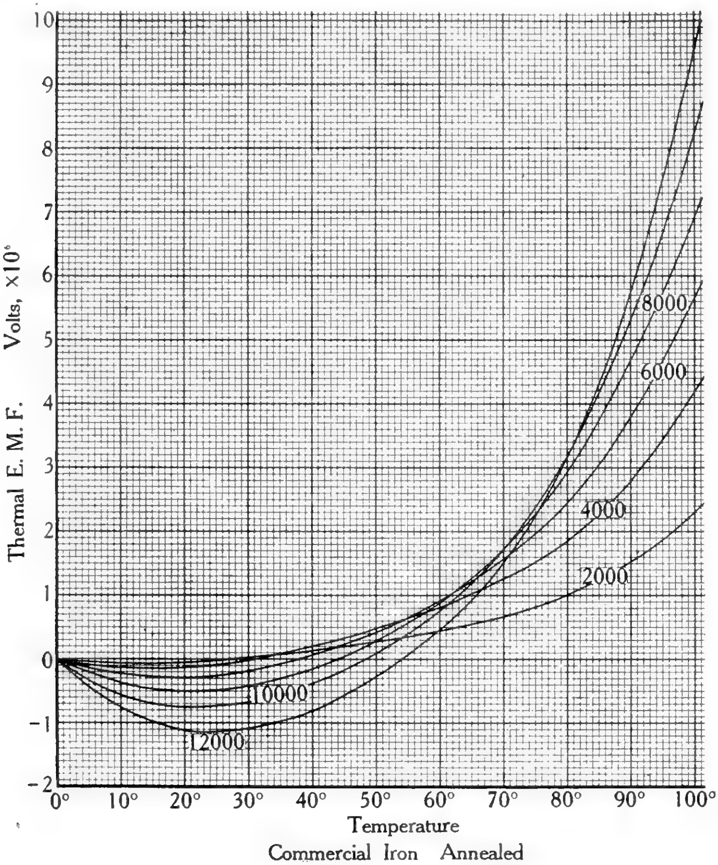

FIGURE 30. Commercial Iron, Annealed. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.[2] indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

found $+ 12.5 \times 10^{-12}$ volts per degree per kg. against $+ 8.3 \times 10^{-12}$ interpolated from the data above for annealed pure iron. His value would correspond more with my value for the hard drawn specimen.

TABLE XXVIII.

Iron (Pure, Hard-drawn).

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	−.01	−.13	−.21	− .35	−.43	−.57
20	+.02	−.15	−.24	− .45	−.54	−.74
30	+.10	−.05	−.11	− .36	−.37	−.54
40	.23	+.18	+.21	− .02	+.10	+.01
50	.40	+.55	+.74	+ .63	+.86	+.95
60	.62	1.04	1.43	+1.54	1.85	2.20
70	.91	1.66	2.30	2.69	3.20	3.85
80	1.27	2.42	3.40	4.20	5.11	6.12
90	1.73	3.34	4.83	6.17	7.59	9.05
100	2.30	4.42	6.69	8.70	10.70	12.80

TABLE XXIX.

Iron (Commercial).

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	−.04	−.11	−.22	−.37	−.55	− .75
20	−.03	−.11	−.29	−.50	−.75	−1.12
30	+.04	.00	−.19	−.42	−.69	−1.10
40	+.15	+.22	+.07	−.15	−.40	− .82
50	.29	+.50	+.44	+.30	+.07	− .28
60	.46	.82	.93	+.88	+.75	+ .44
70	.68	1.25	1.57	1.72	1.72	+1.52
80	1.02	1.85	2.47	2.94	3.18	3.19
90	1.55	2.79	3.82	4.69	5.33	5.79
100	2.34	4.20	5.68	6.94	8.25	9.56

Palladium. This was the same piece of wire whose pressure coefficient of resistance was measured. The silk insulation was removed, and it was used in three parallel strands; there was not enough material at hand to use more than three strands. More trouble from breakage was found with this substance than with any other. Twice during the runs it broke, and the apparatus had to be taken apart and set up again. Fortunately the breaks occurred at the end of the wire, so that it was sufficient merely to resolder them. The breakage was probably intimately connected with the small size of the wire and the small number of strands. Much care had to be

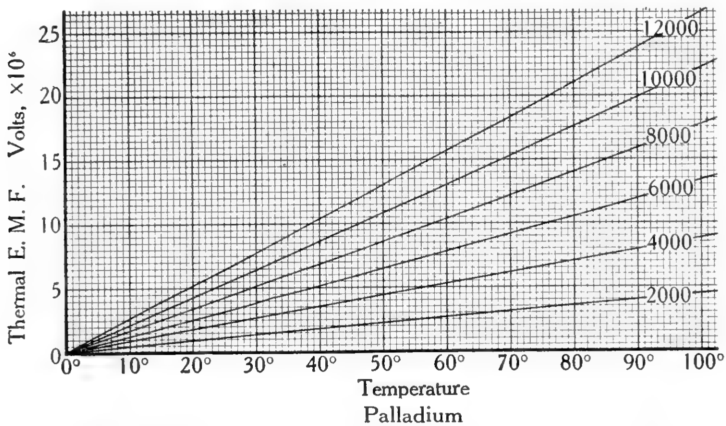

FIGURE 31. Palladium. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

taken to so manipulate the pressure as to avoid tension effects from viscous drag.

At atmospheric pressure its thermo-electric behavior against lead is given by the formulas:

$$E = (-5.496\,t - 0.01760\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (-5.496 - 0.0352\,t)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = -0.0352(t + 273) \times 10^{-6} \text{ volts/°C}.$$

The readings under pressure went smoothly, except for the two breaks mentioned. The irregularities were somewhat greater than normal; probably the effect of viscous drag was not entirely elimi-

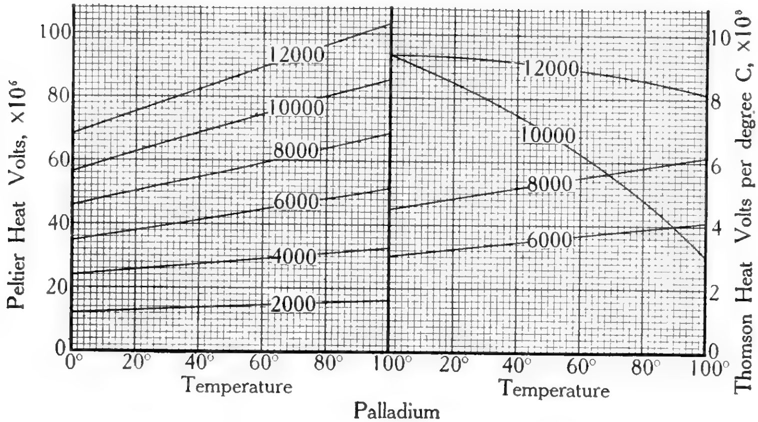

FIGURE 32. Palladium. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE XXX.

PALLADIUM.

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.^{2}					
	2000	4000	6000	8000	10000	12000
10°	+.44	+.88	+1.28	+1.69	+2.10	+2.53
20	.88	1.76	2.57	3.40	4.23	5.09
30	1.32	2.64	3.87	5.13	6.39	7.69
40	1.75	3.52	5.18	6.87	8.58	10.32
50	2.19	4.40	6.51	8.63	10.80	12.97
60	2.63	5.28	7.85	10.41	13.04	15.64
70	3.07	6.16	9.20	12.21	15.30	18.33
80	3.50	7.04	10.56	14.02	17.57	21.04
90	3.94	7.92	11.93	15.85	19.85	23.77
100	4.38	8.80	13.31	17.69	22.14	26.52

TABLE XXXI.

Palladium.

Peltier heat, between uncompressed and compressed metal, Joules per coulomb $\times 10^5$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+12.0	+24.0	+34.9	+46.0	+56.7	+68.5
20	12.9	25.8	38.1	50.5	62.7	75.3
40	13.8	27.5	41.4	54.8	68.8	82.4
60	14.6	29.3	44.6	59.4	74.6	89.0
80	15.5	31.0	48.2	64.2	80.3	96.0
100	16.4	32.8	51.7	69.0	85.6	103.4

Thomson heat, excess in compressed over uncompressed metal, Joules per coulomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	0	0	+3.0	+4.5	+9.3	+9.3
20	0	0	3.2	4.8	8.5	9.4
40	0	0	3.4	5.2	7.5	9.1
60	0	0	3.7	5.5	6.3	9.0
80	0	0	3.9	5.8	4.9	8.5
100	0	0	4.1	6.2	3.0	8.2

nated. The zero corrections were negligible; the maximum deviation of any single reading from a smooth curve was 3% of the total effect, and the average numerical departure was 0.47%. The maximum readjustment in passing from constant temperature to constant pressure curves was 0.27%.

The numerical results are shown in Tables XXX and XXXI and Figures 31 and 32. Both at constant pressure and constant temperature the e.m.f. curves are nearly linear. The e.m.f. is positive and one of the largest found, rising to 26.5×10^{-6} volts at 100° and 12000 kg. The Peltier heat is positive, rising regularly with pressure and temperature. The Thomson heat above 5000 kg. is positive, falling with rising temperature at the higher pressures and rising at the lower pressures. Below 5000 kg. it is approximately zero.

The value given by Wagner at 300 kg. between 0° and 100° was $+23.7 \times 10^{-12}$ volts per degree per kg. against 21.9×10^{-12} interpolated from the data above.

Platinum. Readings were made on the same piece of Heraeus platinum, loaned by Professor H. N. Davis, as were the resistance measurements under pressure. I wanted to procure especially good data for platinum, because so much work has been done on its other physical properties, but unfortunately the results are among the most unsatisfactory. The piece was so short that only one strand could be used, and even then an especial procedure had to be adopted to make the outside connections. Furthermore, the wire had been previously used for a resistance thermometer, wound on a small mica frame, and it was consequently full of small tortuosities which could not be removed without danger of altering the properties of the wire. The roughness of the wire and its small size conspired to make the tension effects of viscous drag particularly high. The same effect was responsible for the wire breaking during the application of seasoning pressure at room temperature. It was fused together again by arcing. The viscous drag might give rise to an error of as much as 20% in the total effect, but this can be very greatly cut down by careful manipulation.

In addition to the measurements on Heraeus platinum, a complete series of readings was also made on an impurer sample from Baker. The pressure effect on the resistance of this has also been measured previously. This wire was used bare, four strands in parallel. No such trouble was found from viscous drag as with Heraeus platinum, and the results were considerably more satisfactory.

At atmospheric pressure the thermo-electric behavior of the two grades of platinum against lead is given by the following formulas.

Heraeus platinum:

$$E = (-3.092\,t - 0.01334\,t^2) \times 10^{-6} \text{ volts,}$$
$$P = (-3.092 - 0.02668\,t)\,(t + 273) \times 10^{-6} \text{ volts,}$$
$$\sigma = -0.02668(t + 273) \times 10^{-6} \text{ volts/°C.}$$

Baker's platinum:

$$E = (-1.788\,t - 0.0173\,t^2 + 0.000042\,t^3) \times 10^{-6} \text{ volts,}$$
$$P = (-1.788 - 0.0346\,t + 0.000126\,t^2)\,(t + 273) \times 10^{-6} \text{ volts,}$$
$$\sigma = (-0.0346 - 0.000252\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C.}$$

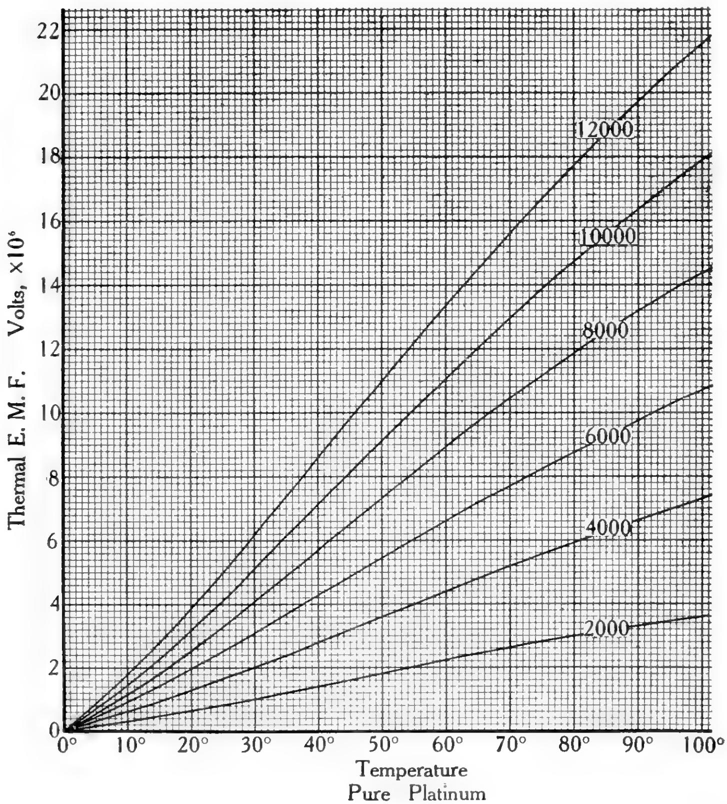

FIGURE 33. Heraeus Platinum. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

There are, therefore, considerable differences in the thermo-electric behavior. We would expect large differences in the behavior under pressure.

The pressure measurements on Heraeus platinum were made in an order the reverse of usual, beginning at 95° and ending at 25°. On the first application of seasoning pressure at room temperature the wire broke at 12000 kg. It was therefore evident that viscous

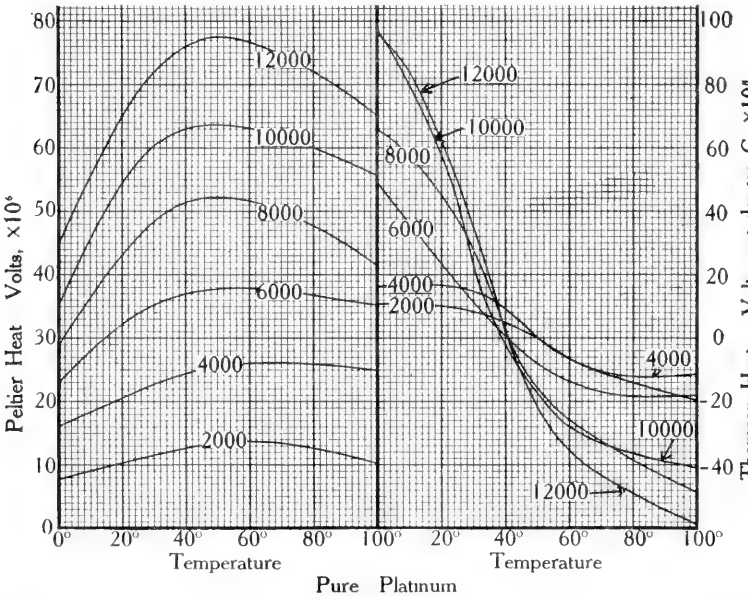

FIGURE 34. Heraeus Platinum. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

drag was going to be troublesome, and the reverse procedure was therefore adopted to insurę getting as many readings as possible before rupture occurred. The four regular runs were successfully made, but at 75° the effect of drag was very large. After the four runs an attempt was made to repeat the run at 75°. Only three points were obtained, at 0, 4000, and 8000 kg., the wire breaking again at 12000. The points obtained lay about 3% lower than those of the previous run at 75°, and in the direction necessary to make the points at 75° lie smoothly with those of other temperatures. The pressure runs on Baker's platinum were accomplished without incident. Two applications of 12000 were made at room temperature to season.

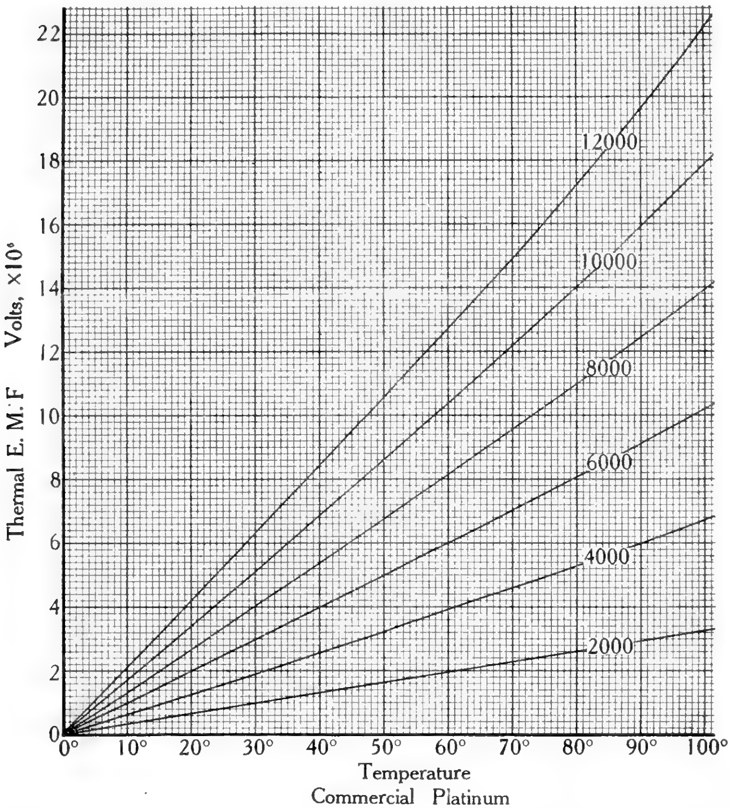

FIGURE 35. Baker's Platinum. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

Equilibrium was reached so rapidly as to suggest no shifting of internal equilibrium.

For the Heraeus platinum, the maximum departure of any single observed point from a smooth curve was 7.8% of the maximum effect, except for the two bad points mentioned at 75°. The maximum zero correction was 2.5%, and the average numerical departure of all points from smooth curves was 0.81%. At constant temperature the relation between e.m.f. and pressure was linear. In passing to the curves at constant pressure from those at constant temperature it was necessary to disregard the 75° points, the discrepancy amounting to 4.3%, but the other points required no readjustment. If the second run at 75° could have been carried through, the adjustment

TABLE XXXII.

Platinum (Pure).

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.^{2}					
	2000	4000	6000	8000	10000	12000
10°	+0.30	+.62	+.91	+1.18	+1.44	+1.79
20	.63	1.29	1.96	2.56	3.21	3.88
30	1.00	2.02	3.10	4.10	5.15	6.19
40	1.40	2.80	4.28	5.73	7.16	8.60
50	1.81	3.60	5.46	7.37	9.16	11.03
60	2.23	4.39	6.61	8.96	11.09	13.39
70	2.62	5.16	7.72	10.47	12.94	15.64
80	2.98	5.91	8.76	11.88	14.70	17.76
90	3.31	6.63	9.76	13.18	16.35	19.74
100	3.60	7.31	10.70	14.35	17.90	21.57

at 75° would have been only about 1%, so that there is reason to trust the results obtained.

For Baker's platinum, the maximum zero correction was 1.5% of the maximum effect, the maximum departure of any single observed point from a smooth curve was 3.1%, and the average numerical departure was 0.80%. At constant temperature the curves of e.m.f. against pressure are convex toward the pressure axis, not what one would expect, and the curves of e.m.f. at constant pressure against temperature are also convex toward the temperature axis. In passing from e.m.f. curves at constant temperature to those at constant pressure the maximum readjustment necessary was 1.1%.

TABLE XXXIII.

Platinum (Pure).

Peltier heat, between uncompressed and compressed metal, Joules per coulomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+7.7	+16.1	+23.0	+29.0	+35.3	+44.8
20	10.3	20.5	32.2	43.0	54.5	64.8
40	12.8	24.7	37.0	51.4	62.9	76.0
60	13.7	26.0	37.6	51.7	63.0	76.6
80	12.7	25.7	36.6	47.5	59.9	72.3
100	10.1	25.0	35.1	41.4	55.6	64.9

Thomson heat, excess in compressed over uncompressed metal, Joules per coulomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+10.9	+16.4	+49.2	+65.6	+97.0	+95.7
20	10.0	16.7	24.6	44.6	56.3	61.9
40	5.0	8.8	1.6	2.5	−2.2	2.5
60	−6.3	−6.7	−13.3	−26.0	−28.0	−36.0
80	−13.4	−12.0	−18.3	−38.8	−36.1	−48.6
100	−19.8	−11.2	−17.9	−48.9	−41.0	−59.0

The numerical results are shown in Tables XXXII, XXXIII and XXXIV and Figures 33, 34 and 35; only the e.m.f. is given for Baker's platinum. For both grades of platinum the e.m.f. is positive and rather large, increasing with pressure and temperature to 21.6 × 10^{-6} volts for the Heraeus platinum, and to 22.2 for Baker's at 12000 kg. and 100°. The similarity of these figures is somewhat unexpected in view of the difference in thermo-electric behavior at atmospheric pressure. The Peltier and Thomson heats are quite different, however. The Peltier heat of Heraeus platinum is positive, increasing

TABLE XXXIV.

PLATINUM (IMPURE).

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
10°	+.32	+.64	+1.01	+1.33	+1.70	+2.12
20	.65	1.28	2.01	2.67	3.41	4.23
30	.97	1.93	3.00	4.02	5.13	6.34
40	1.29	2.58	3.99	5.38	6.86	8.45
50	1.61	3.24	4.99	6.76	8.61	10.57
60	1.93	3.91	6.00	8.15	10.38	12.72
70	2.25	4.59	7.01	9.56	12.18	14.92
80	2.58	5.28	8.04	10.99	14.02	17.20
90	2.91	5.99	9.10	12.44	15.91	19.61
100	3.23	6.72	10.20	13.92	17.87	22.20

with pressure at constant temperature, but at each constant pressure passing through a maximum with rising temperature. The Peltier heat of Baker's platinum is also positive throughout, is somewhat larger than that of Heraeus platinum, and rises throughout with both temperature and pressure. The Thomson heat of Heraeus platinum changes sign, starting with positive values at low temperatures, and at each constant pressure becoming negative at higher temperatures. The Thomson heat of Baker's platinum rises to its highest positive values at the highest temperature, and for several pressures is negative at the lower end of the temperature range.

The value given by Wagner up to 300 kg. between 0° and 100° is $+18.6 \times 10^{-12}$ volts per degree per kg. The values found above by interpolation are 18.0 for the Heraeus, and 16.1 for Baker's platinum. The agreement with the purer specimen is as good as could be expected.

Molybdenum. This was a fresh piece, obtained through the kindness of Dr. W. D. Coolidge of the General Electric Company. The piece whose resistance under pressure had been measured was not

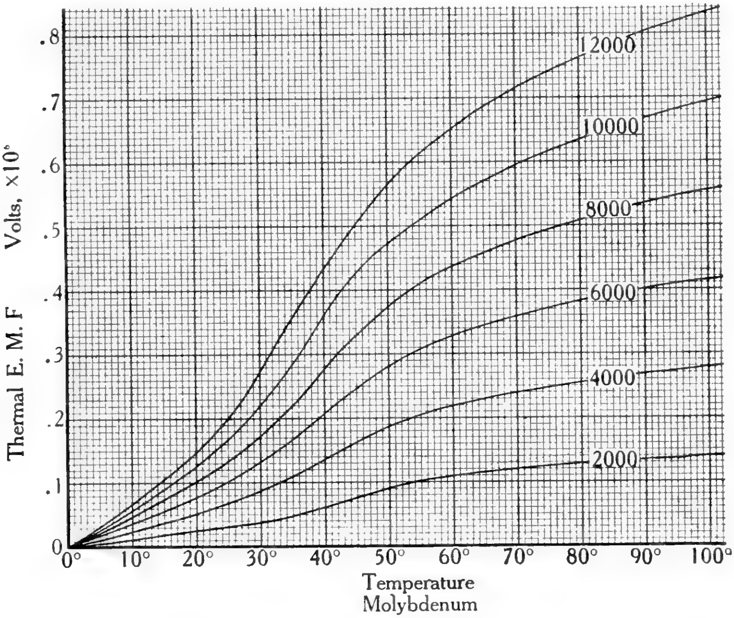

FIGURE 36. Molybdenum. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.[2] indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

large enough in diameter or long enough for use in this apparatus. The new piece was 0.008 inch in diameter, with a resistance of 0.54 ohms per ft. when cold. A piece 18 inches long, the piece to be exposed to pressure, was annealed by heating to a white heat with an electric current in an atmosphere of hydrogen. The hydrogen was not entirely free from oxygen, however, and there may have been some chemical effect. The outer connecting piece of wire was left

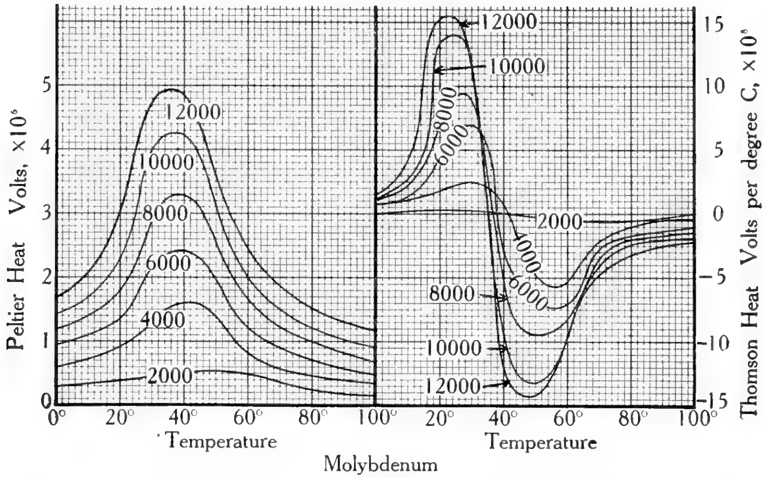

FIGURE 37. Molybdenum. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE XXXV.

MOLYBDENUM.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+.012	+.024	.037	.047	.057	.066
20	.025	.052	.078	.101	.124	.146
30	.039	.087	.133	.175	.219	.271
40	.065	.136	.209	.279	.357	.430
50	.093	.187	.282	.375	.472	.562
60	.109	.218	.328	.436	.543	.649
70	.121	.239	.359	.477	.594	.712
80	.129	.255	.383	.509	.634	.761
90	.135	.268	.401	.535	.666	.800
100	.140	.278	.415	.555	.693	.833

TABLE XXXVI.

MOLYBDENUM.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+.30	+.60	+.95	+1.20	+1.45	+1.69
20	.38	.91	1.35	1.79	2.28	2.93
40	.53	1.60	2.41	3.29	4.23	4.83
60	.47	.83	1.23	1.67	2.00	2.44
80	.25	.49	.74	1.02	1.23	1.52
100	.15	.33	.48	.67	.93	1.16

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	.0	+ .8	+ .8	+1.1	+ 1.2	+ 1.6
20	+ .6	+1.8	+4.4	+7.0	+13.2	+15.2
40	+ .3	+ .6	−2.5	−5.0	− 9.4	−11.6
60	−1.3	−5.3	−7.0	−8.0	− 9.3	− 9.7
80	−1.1	−1.1	−1.8	−2.1	− 2.5	− 3.2
100	+ .0	− .4	−1.1	−1.5	− 1.9	− 2.2

unannealed. This produced a large permanent zero reading, but should not introduce any error.

At atmospheric pressure the average temperature coefficient of resistance between 0° and 100° was found to be 0.00461; the relation between temperature and resistance was sensibly linear. This coefficient is considerably higher than that of the piece whose pressure coefficient was previously measured, for which the mean temperature coefficient was 0.00434. Both molybdenum and tungsten are known to vary considerably in properties with the amount of mechanical working, so that the difference between these two specimens may have been accountable for by the difference of size, and not by a difference of chemical constitution.

The thermo-electric behavior at atmospheric pressure against lead is given by the formulas:

$$E = (5.892\,t + 0.02167\,t^2 - 0.000025\,t^3) \times 10^{-6} \text{ volts,}$$
$$P = (5.892 + 0.04334\,t - 0.000075\,t^2)\,(t + 273) \times 10^{-6} \text{ volts,}$$
$$\sigma = (0.04334 - 0.000150\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C.}$$

For the pressure measurements the wire was seasoned by two applications of 12000 kg. at room temperature. The e.m.f. under pressure is small, reaching at the most at 12000 kg. and 100° only $+0.8 \times 10^{-6}$ volts. Individual readings showed large variations; the zero readings did not vary so much as those at high pressures. 32 readings in all were made; of these 6 were bad, showing variations from 7 to 50% of the total effect. The remaining 26 readings were not so bad, the maximum departure from a smooth curve being 5% of the total effect, and the average numerical departure 1.2%. It was not necessary to make any readjustment in passing from the e.m.f. curves at constant temperature to those at constant pressure.

The numerical results are shown in Tables XXXV and XXXVI and Figures 36 and 37. At constant temperature the relation between e.m.f. and pressure is linear; at constant pressure the curves against temperature pass through a point of inflection. This means a complicated behavior of both Peltier and Thomson heats. The Peltier heat is throughout positive, but at constant pressure passes through a pronounced maximum near 40°. The Thomson heat is both positive and negative, passing through pronounced positive maxima near 25°, and negative minima near 50°.

There are no previous results for comparison.

Tungsten. This, like molybdenum, was a fresh sample from Dr. W. D. Coolidge of the General Electric Company, the specimen used previously for the resistance measurements not being large enough. This also was 0.008 inch in diameter. A piece long enough for both inside and outside pieces was annealed at one time by heating white hot with an electric current in an atmosphere of hydrogen under reduced pressure. The hydrogen was not pure, however, and there was appreciable formation of oxide. This treatment was successful in keeping the permanent zero reading down to a normal value.

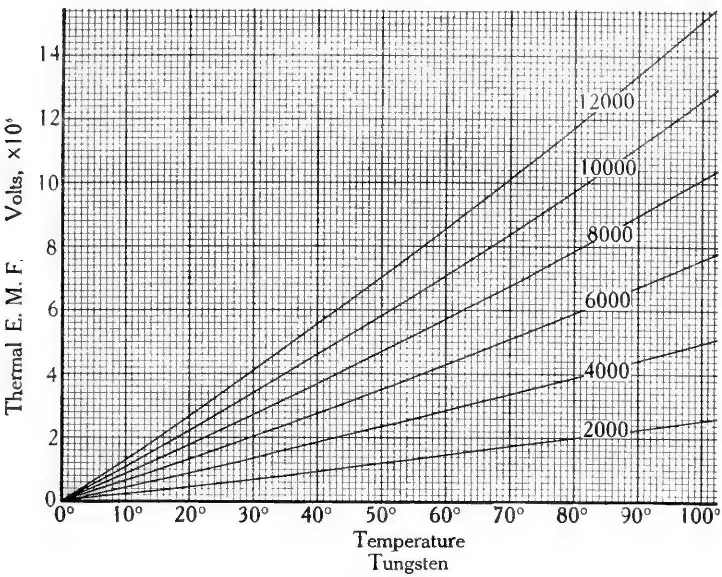

FIGURE 38. Tungsten. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.^{2} indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

At atmospheric pressure the average temperature coefficient of resistance between 0° and 100° was 0.04317, the resistance being sensibly linear with temperature. The coefficient of the resistance specimen, which was only 0.0004 inch in diameter, was 0.00322. The considerable difference may again be due to the difference of mechanical treatment.

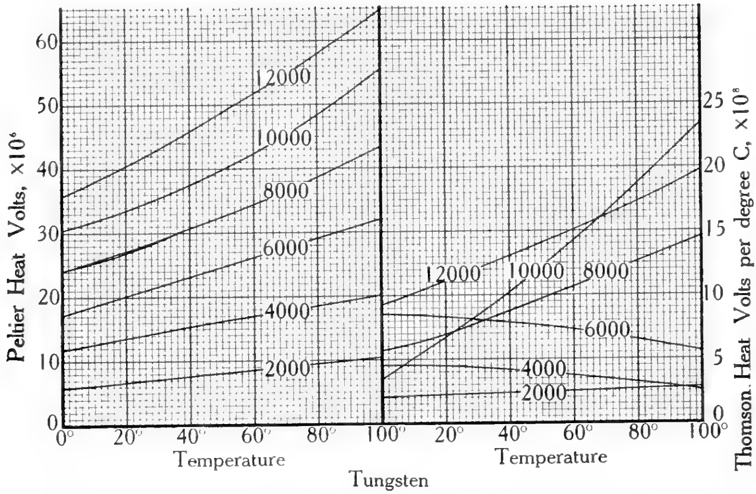

FIGURE 39. Tungsten. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE XXXVII.

TUNGSTEN.

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
10°	+.22	+.44	+.65	+.89	+1.12	+1.33
20	.45	.90	1.33	1.80	2.26	2.70
30	.69	1.38	2.03	2.73	3.42	4.11
40	.94	1.87	2.76	3.69	4.61	5.56
50	1.19	2.36	3.52	4.69	5.84	7.05
60	1.45	2.87	4.30	5.72	7.10	8.58
70	1.71	3.39	5.00	6.78	8.40	10.15
80	1.98	3.92	5.92	7.86	9.75	11.76
90	2.25	4.45	6.75	8.97	11.15	13.42
100	2.53	4.99	7.60	10.12	12.61	15.14

TABLE XXXVIII.

TUNGSTEN.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+5.9	+11.7	+17.2	+24.1	+30.4	+35.7
20	6.7	13.6	20.1	27.2	33.5	40.5
40	7.7	15.5	23.1	30.7	37.5	45.9
60	8.7	17.1	27.1	34.4	42.3	51.8
80	9.5	18.6	29.0	38.6	48.3	58.0
100	10.4	20.3	32.0	43.4	55.4	64.8

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+2.0	+4.5	+8.5	+5.7	+3.5	+9.3
20	2.2	4.5	8.3	7.0	6.7	11.1
40	2.3	4.2	7.8	8.8	10.2	13.1
60	2.5	3.7	7.3	10.6	14.3	15.1
80	2.6	3.2	6.5	12.6	18.7	17.3
100	2.8	2.6	5.6	14.6	23.5	19.8

The thermo-electric behavior at atmospheric pressure against lead is given by the formulas:

$$E = (1.594\,t + 0.01705\,t^2) \times 10^{-6} \text{ volts,}$$
$$P = (1.594 + 0.0341\,t)\,(t + 273) \times 10^{-6} \text{ volts,}$$
$$\sigma = 0.0341(t + 273) \times 10^{-6} \text{ volts/°C.}$$

For the pressure measurements it was annealed once to 12000 kg. at room temperature. At 25°, 50°, and 75°, the readings under pressure went as smoothly as could be desired, but at 98° there was greater irregularity; here there was a permanent change of zero of 7% of the total effect. This was also the maximum departure of any point from a smooth curve. The average arithmetical departure of all points from smooth curves was 0.72%. In passing from curves of e.m.f. at constant temperature to those at constant pressure a maximum readjustment of 1% of the total effect was necessary.

The numerical results are shown in Tables XXXVII and XXXVIII and Figures 38 and 39. The effect is positive, increasing regularly with pressure and temperature, and is rather large, being 20 times as great as that of molybdenum. This was a surprise; the pressure coefficients of resistance of these two metals are nearly equal. The Peltier heat is positive, rising with pressure and temperature. The Thomson heat is positive, at the two extremes of the pressure range rising with temperature at constant pressure, but at intermediate pressures it falls with rising temperature.

There are no previous measurements for comparison.

Bismuth. This was electrolytic bismuth, prepared at the same time as the resistance specimen, but it was from the deposit on another electrode, so that the two specimens are not of necessity exactly alike. From the electrode deposit, the metal was made into wire by the same steps as the previous wire; the die through which this was extruded was 0.0285 inches in diameter, somewhat larger than the previous specimen. After extrusion, it was annealed by slow heating and cooling from room temperature to 100°, being maintained at 100° for 30 minutes. Much care was necessary in getting it in place in the pressure apparatus, but this was successfully accomplished without a single mishap.

At atmospheric pressure the average temperature coefficient of resistance between 0° and 100° of this specimen was 0.004372, which is somewhat lower than that of the previous specimen, 0.00441; the difference is no greater than has been formerly found to be due to differences of handling. The curve of resistance against temperature at atmospheric pressure is strikingly convex toward the temperature axis, as was that of the other specimen. The two specimens are probably of equal purity.

The thermal electric behavior at atmospheric pressure against lead is given by the formulas:

$$E = (-74.42\,t + 0.0160\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (-74.42 + 0.0320\,t)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = 0.0320(t + 273) \times 10^{-6} \text{ volts/°C}.$$

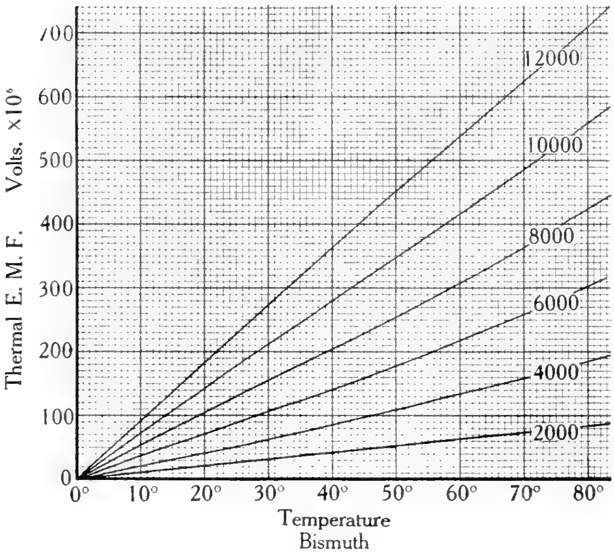

FIGURE 40. Bismuth. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.^{2} indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

The pressure measurements of e.m.f. were satisfactory. The run at 25° was made without previous seasoning, in the desire to obtain all possible information before the confidently expected rupture, but this fear proved groundless, and the series of runs was completed without incident. Furthermore, it proved that seasoning was not necessary, the zero correction at 25° after the first application of 12000 kg. being only 0.16% of the maximum effect. Readings could be easily made, there was no hysteresis or other evidence of incomplete internal equilibrium. The effect was so large that it was necessary to use the potentiometer direct connected. The maximum departure of any point from a smooth curve was 2.1% of the total effect, and the average numerical departure was 0.53%. As with the resistance specimen, the run at 100° was made impossible by breaking of the connection because of the low melting point of the alloy of bismuth with solder. In passing from curves at constant temperature to those at constant pressure no appreciable readjustment was necessary.

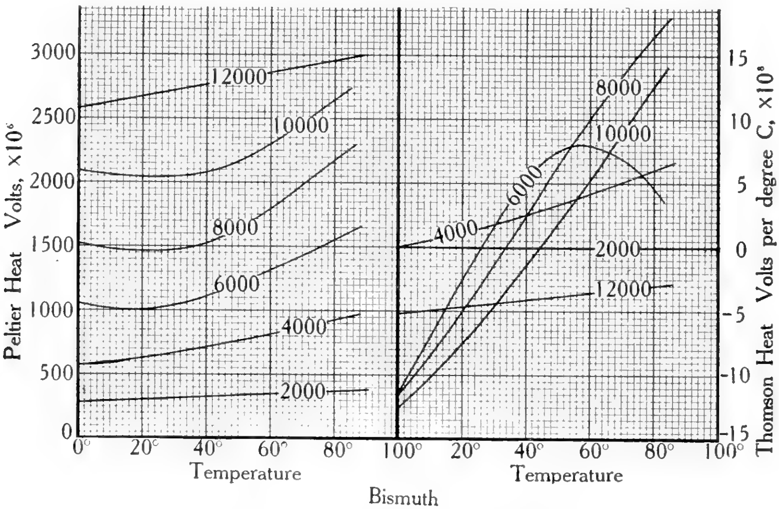

FIGURE 41. Bismuth. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal, to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

The numerical results are shown in Tables XXXIX and XL and Figures 40 and 41. The e.m.f. is positive and very large, increasing regularly with pressure and temperature to 710×10^{-6} volts at 100° and 12000 kg. The largest effect found for any other metal was for thallium, which gave only 52.5. Except for the largeness of the value, the only unusual feature is the upward curvature of the e.m.f. curves at constant temperature plotted against pressure; this denotes a greater proportional effect for the same pressure increment at the higher pressures. The Peltier heat is positive; in general it increases with rising pressure and temperature, but at the middle of the range it passes through a flat minimum with rising temperature. The Thomson heat shows complicated behavior; at 2000 kg. it is throughout zero, at 4000 it is negative, and at higher pressures it is initially negative, rising to positive values.

Wagner found at 300 kg. between 0° and 100° the value 707×10^{-12}

TABLE XXXIX.

BISMUTH.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+11.	+21.	+38.	+54.	74.	93.
20	21.	42.	73.	106.	145.	185.
30	32.	64.	107.	156.	214.	275.
40	42.	87.	141.	205.	281.	364.
50	53.	110.	177.	255.	348.	452.
60	64.	134.	218.	308.	416.	539.
70	74.	159.	259.	365.	487.	625.
80	85.	185.	302.	425.	560.	710.

volts per degree per kg. The value indicated by interpolation and extrapolation of the data above is 531×10^{-12}. The agreement is not good. In view of the great differences found in the previous work in the electrical properties of bismuth of different origins, and the large effect of minute impurities, it would have been most desirable if Wagner had allowed some estimate of the purity of his sample by stating its temperature coefficient at atmospheric pressure.

TABLE XL.

Bismuth.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+289.	+574.	+1070.	+1530.	+2080.	+2580.
20	311.	644.	1030.	1490.	2050.	2670.
40	332.	720.	1090.	1530.	2070.	2760.
60	353.	800.	1330.	1790.	2300.	2860.
80	374.	950.	1550.	2180.	2650.	2960.

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	0	0	+1150.	−1150.	−1250.	−520.
20	0	+117.	− 290.	− 500.	− 760.	−470.
40	0	250.	+ 500.	+ 250.	− 160.	−440.
60	0	430.	+ 800.	+1000.	+ 530.	−370.
80	0	600.	+ 460.	+1660.	+1270.	−280.

Constantan. This was obtained from the Electrical Alloys Co. of Morristown, N. J., and is sold by them under the trade name "Ideal." The chemical analysis given by them is: Copper 55%, Nickel 44%, Manganese 1%, and Iron 1.4%. The diameter of the wire was 0.010 inches. There is of course not a great deal of interest at the present stage of affairs in the behavior of a substance so complicated; the study of alloys as such would begin with simpler ones. This alloy is used extensively in electrical measurements, however, and there is some practical interest in its behavior. I have not previously given data for any of the electrical properties of this substance; the list here given is composed of (1) the temperature coefficient of resistance at atmospheric pressure, (2) thermal e.m.f. at atmospheric pressure against lead, (3) pressure coefficient of resistance, (4) pressure effect on thermo-electric quality.

At atmospheric pressure the resistance passes through a maximum with rising temperature near 12°. The values found for the resistance were as follows: at 0°, 1.0000; at 25°, 1.0000; at 50°, 0.9998; at 76° 0.9994, and at 97°, 0.9989. The change is, therefore, as slight as that of manganin for any small range, but the minimum of manganin is more pronounced than the maximum of this, so that the total change between 0° and 100° of "Ideal" is greater than of manganin.

The thermo-electric behavior at atmospheric pressure against lead is given by the formulas:

$$E = (-34.76\,t - 0.0397\,t^2) \times 10^{-6} \text{ volts},$$
$$P = (-34.76 - 0.0794\,t)(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = -0.0794(t + 273) \times 10^{-6} \text{ volts/°C}.$$

Its thermal e.m.f. against commercial copper is represented by

$$E = -(38.50\,t + 0.0445\,t^2) \times 10^{-6} \text{ volts}.$$

This may be compared with results of Johnston and Adams [13] for wire from the same source. They give their results in the form of a table; the maximum discrepancy between their results and that above is at 100°, where they give 4227 × 10^{-6} volts against 4295 above. The difference is not greater than one would expect in different specimens with different handling.

The pressure coefficient of resistance was measured by the method described in the previous paper. The wire was wound bare on a

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13 J. Johnston and L. H. Adams, Amer. Jour. Sci. **31**, 510, 1911.

bone core. It had been previously seasoned by alternately heating to 140° for 30 minutes, and slowly cooling to room temperature for 15 minutes, repeating three times. For the pressure measurements it was seasoned by a single application of 12000 at room temperature. After this first application of pressure there was a permanent decrease of resistance amounting to 0.03% of the total resistance. The effect of pressure is to increase the resistance very slightly, instead of to decrease it, as for pure metals. Measurements were made at three temperatures; 0°, 50°, and 97°. Within these limits the coefficient

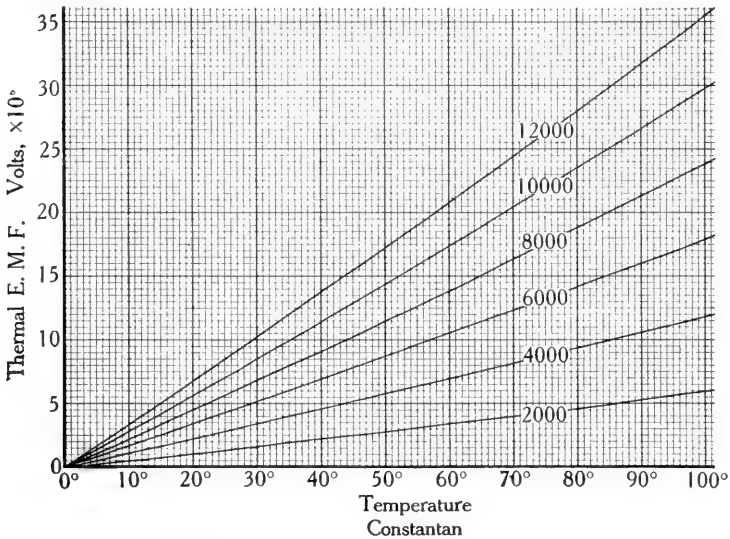

FIGURE 42. Constantan. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other being at the pressure in kg./cm.^{2} indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

is independent of temperature, and the relation between pressure and resistance is linear up to 12000 kg. The pressure coefficient between 0° and 100° up to 12000 kg. was found to be $+0.0_6409$, pressure measured in kg./cm.^{2}. The smallest coefficient found in the previous work for a pure metal was that of tungsten, which was -0.0_5125.

In contrast to the very small effect of pressure on resistance is its very large effect on thermo-electric quality. The effect is positive, as it is for the majority of metals, and is exceeded in value only by bismuth and thallium. The wire was seasoned for the pressure runs on thermal e.m.f. by raising pressure to 11300 kg. at room temperature, then raising temperature to 100° for $2\frac{1}{2}$ hours, the pressure rising to 11500. Large permanent zero readings might be expected with this substance, because its thermal e.m.f. against iron is so high, but its homogeneity was so great that the zero effect was only about 5% of the pressure effect at any temperature. A curious effect was

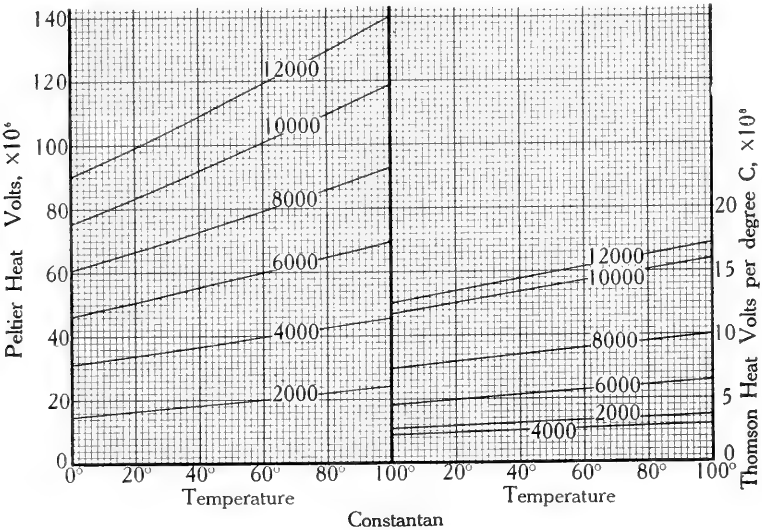

FIGURE 43. Constantan. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

observed immediately after changes of pressure, before temperature equilibrium was reached; there were violent oscillations of e.m.f., changing sign with a period of a few seconds, which gradually disappeared. This is possibly an effect of shifting internal equilibrium connected with the complicated nature of the alloy, but is more probably a pure temperature effect, and is particularly prominent here because of the unusually large e.m.f. between constantan and the steel of the cylinders. The immediate effect after a change of pressure is a difference of a difference, the residual effect being the difference between the e.m.f's. at the hot and cold ends brought about by the difference of temperature produced by compression between the inside and the outside of the cylinder. When one considers that the instantaneous rise of temperature by compression might be 10°, it does not seem surprising that there should be such oscillations with a galvanometer sensitive enough to be thrown off the scale by 6×10^{-6} volts. The e.m.f. between iron and constantan is 50×10^{-6} volts per degree.

Because of the complications involved in any interpretation of the

TABLE XLI.

Constantan.

Thermo-electromotive Force, volts $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.²					
	2000	4000	6000	8000	10000	12000
10°	+0.55	+1.14	+1.71	+2.25	+2.78	+3.35
20	1.11	2.29	3.44	4.53	5.60	6.75
30	1.68	3.45	5.18	6.84	8.47	10.19
40	2.26	4.62	6.94	9.17	11.38	13.67
50	2.85	5.80	8.72	11.53	14.34	17.20
60	3.45	6.99	10.51	13.82	17.34	20.77
70	4.06	8.18	12.32	16.36	20.38	24.38
80	4.68	9.38	14.14	18.81	23.46	28.03
90	5.31	10.59	15.98	21.29	26.58	3.73
100	5.95	11.81	17.84	23.79	29.74	35.47

instantaneous effects, I gave up the attempt to observe them after a few metals had been measured. The effects may change sign with the same metal with pressure and temperature. I did not happen to make observations like those on constantan with any other substance except manganin, also an alloy. This is probably only a coincidence.

The pressure measurements of e.m.f. went fairly smoothly. Except for two points at 96° with discrepancies of 4.0 and 2.3%, the maximum departure of any point from a smooth curve was 1.3% and the average numerical departure was 0.26% of the total effect. The

TABLE XLII.

Constantan.

Peltier heat, between uncompressed and compressed metal, Joules per conlomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+15.	+31.	+46.	+61.	+75.	+90.
20	17.	34.	51.	67.	83.	99.
40	18.	37.	55.	73.	92.	109.
60	20.	40.	60.	79.	105.	119.
80	22.	43.	65.	86.	109.	130.
100	24.	46.	70.	93.	119.	140.

Thomson heat, excess in compressed over uncompressed metal, Joules per conlomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+2.7	+2.2	+4.6	+7.4	+11.7	+12.6
20	2.9	2.3	5.0	7.9	12.6	13.5
40	3.1	2.5	5.3	8.4	13.4	14.4
60	3.3	2.7	5.7	9.0	14.3	15.3
80	3.5	2.8	6.0	9.5	15.2	16.2
100	3.7	3.0	6.4	10.1	16.0	17.2

maximum zero correction was 1.1%. In passing from the curves of e.m.f. at constant temperature to those at constant pressure the maximum readjustment was 0.60%.

The numerical results are shown in Tables XLI and XLII and Figures 42 and 43. The effect is positive, rising regularly with pressure and temperature to 35.5×10^{-6} volts at 100° and 12000 kg. At constant temperature the relation between e.m.f. and pressure is linear. The Peltier heat is positive, rising with pressure and temperature. The Thomson heat is also positive, and rises with pressure and temperature; at every constant pressure it is directly proportional to the absolute temperature.

Constantan, of unstated composition, was one of the substances measured by Wagner. He gives to 300 kg. and between 0° and 100° 31.1 and 26.4×10^{-12} volts per degree per kg. for two different specimens. The value given by interpolation of the data above is 29.7, falling within Wagner's limits.

Manganin. This was from the same spools as the coils used in measuring resistance, and is of German origin, probably nearly 20 years old. The resistance at atmospheric pressure shows a maximum near 30°. The following values of resistance were found: at 0°, 1.0000; at 26°, 1.0007; at 50°, 1.0006; at 76°, 1.0002; and at 97°, 0.9995.

The thermo-electric behavior at atmospheric pressure against lead is given by the formulas:

$$E = (1.366\,t + 0.000414\,t^2 + 0.0000112\,t^3) \times 10^{-6} \text{ volts},$$
$$P = (1.366 + 0.00828\,t + 0.0000336\,t^2)\,(t + 273) \times 10^{-6} \text{ volts},$$
$$\sigma = (0.00828 + 0.0000672\,t)\,(t + 273) \times 10^{-6} \text{ volts/°C}.$$

The resistance of this wire was also measured because I now had apparatus for getting more accurately the variation with temperature of the pressure coefficient than formerly. Previously I had measured the same coil successively at different temperatures against an absolute gauge, and found only a small variation in the pressure coefficient up to 80°. The change may be slightly different for different specimens, even from the same spool. This procedure was now improved upon by simultaneously measuring two coils, both exposed to the same pressure, but placed in different pressure cylinders and maintained at different temperatures with two different thermostats. The one coil, that with which pressure was measured, was always maintained at the same temperature, 40°, whereas the temperature of the other coil was varied for different runs. The new coil was seasoned by baking at 140° for several hours, and by several applications of 12000 at room temperature. After this seasoning there was no appreciable change of resistance after a run under pressure. At 0° and 25° the pressure coefficient of resistance is practically the same; as it is also at 50°, 75° and 100°, but between 25° and 50° there was an increase of coefficient of 0.7%. However, the measurements were not as good as they might be, and the isolated change between 25° and 50° is probably not real.

The e.m.f. measurements under pressure were made in the regular

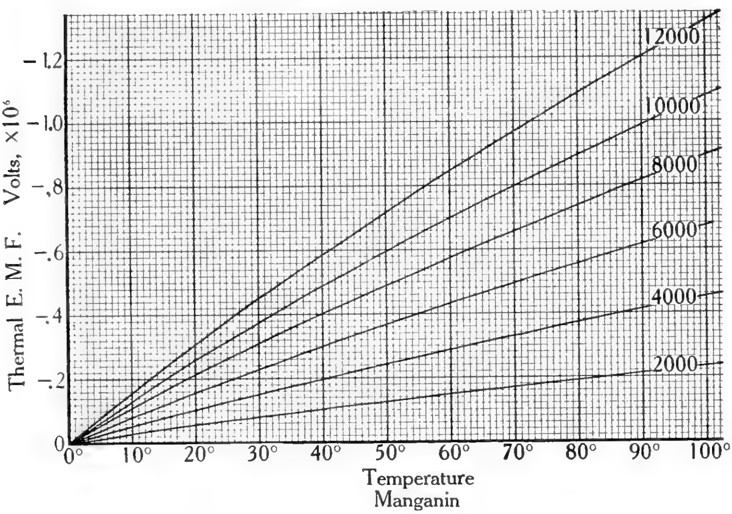

FIGURE 44. Manganin. Thermal E.M.F. of a couple composed of one branch of uncompressed metal, the other compressed to the pressure in kg./cm.² indicated on the curves, the junctions being at 0°C and the temperature plotted as abscissae.

way. The effect is small and negative. The wire was seasoned for the e.m.f. measurements by baking to 140° at atmospheric pressure, and by one application of 12000 kg. at room temperature. The measurements at the lower temperatures were regular, but at the higher temperatures the irregularities increase very rapidly. This is as one would expect in an alloy. The greatest discrepancy was shown by the final zero point at 97° which lies off a smooth curve by 18% of the maximum effect at 97°; at this temperature the average arithmetic departure is 7.7%; at 75° the maximum departure is at 8000

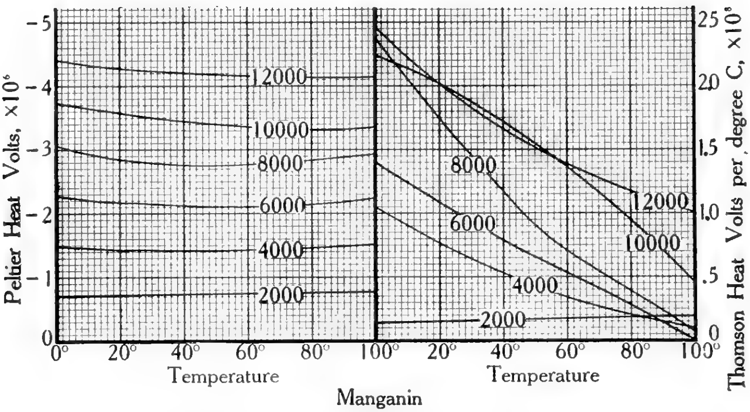

FIGURE 45. Manganin. On the left, the heat absorbed by unit quantity of electricity in flowing from uncompressed metal to metal compressed to the pressure indicated on the curves, as a function of temperature. On the right, the excess of Thomson heat in metal compressed to the pressure indicated on the curves over uncompressed metal, as a function of temperature.

TABLE XLIII.

MANGANIN.

Thermo-electromotive Force, volts × 10^6.

Temp. C degrees	Pressure, kg./cm.^{2}					
	2000	4000	6000	8000	10000	12000
10°	+.026	−.053	−.081	−.111	−.133	−.158
20	.057	.103	.157	.215	.258	.308
30	.076	.151	.230	.311	.377	.451
40	.100	.197	.300	.402	.490	.588
50	.123	.242	.367	.489	.597	.719
60	.146	.286	.431	.573	.700	.846
70	.168	.329	.493	.655	.799	.968
80	.190	.371	.554	.736	.895	1.087
90	.211	.412	.614	.816	.988	1.202
100	.232	.452	.673	.894	1.079	1.314

TABLE XLIV.

Manganin.

Peltier heat, between uncompressed and compressed metal, Joules per coulomb $\times 10^6$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	−.71	−1.50	−2.27	−3.07	−3.74	−4.41
20	.73	1.44	2.20	2.90	3.56	4.28
40	.74	1.44	2.13	2.77	3.45	4.20
60	.75	1.43	2.12	2.77	3.36	4.15
80	.76	1.47	2.14	2.83	3.32	4.13
100	.77	1.51	2.24	2.94	3.35	4.14

Thomson heat, excess in compressed over uncompressed metal, Joules per coulomb per °C $\times 10^8$.

Temp. C degrees	Pressure, kg./cm.² 2000	4000	6000	8000	10000	12000
0°	+.14	+1.04	+1.40	+2.38	+2.24	+2.46
20	.15	.77	1.08	1.75	2.02	2.01
40	.16	.53	.78	1.17	1.72	1.66
60	.17	.34	.53	.70	1.36	1.39
80	.18	.25	.28	.39	.95	1.17
100	.19	.10	.00	.07	.46	1.01

kg. and is 3.8% of the maximum effect at 75°, while the average departure is 2.4%; at 50° the maximum departure is 2.8% of the maximum effect at 50° and the arithmetical average is 1.07%; and at 25° the maximum departure is 3% of the maximum effect at 25°, and the average departure 0.6%. Within these limits of error the relation between e.m.f. and pressure at constant temperature is linear. In passing from curves of e.m.f. at constant temperature to those at constant pressure the maximum readjustment was at 97°, as was to be expected; here it was 12% of the maximum effect. No appreciable readjustment was necessary at the lower temperatures. The following data are to be expected, therefore, to have considerably greater relative accuracy at the lower part of the temperature range.

The numerical results are shown in Tables XLIII and XLIV and Figures 44 and 45. The effect is negative, increasing regularly with pressure and temperature to -1.31×10^{-6} at 12000 kg. and 100°. The effect is among the smallest found. It is interesting to compare the small effect of pressure on the resistance of constantan and its large effect on thermal e.m.f. with precisely the reverse behavior here. The Peltier heat is negative, increasing with pressure, but at each constant pressure it is nearly independent of temperature. The Thomson heat, on the other hand is positive, at the lower pressures changing but little, but at the higher pressures falling with rising temperature.

Wagner gives between 0° and 100° and to 300 kg. -8.5×10^{-12} volts per degree per kg. The value given by interpolation of the data above is -11.6×10^{-12}. The agreement is perhaps as close as could be expected in an alloy from presumably different sources.

Effect of Tension on Thermo-Electric Quality.

The general method of measurement is the same as that employed in measuring the effect of hydrostatic pressure on thermo-electric quality, namely to measure the thermal e.m.f. of a couple composed of two branches of the same metal, one of which is under tension, and the other of which is free. The connections are shown schematically in Figure 46. A length of the wire to be measured is doubled on itself, running from A to E to C. At E it is fastened to a heavy block capable of withstanding any load that is to be applied to the wire. At A and C the ends of the wire are fastened to the under sides of the left and right hand pans respectively of two equal arm balances, indicated in the figure by the arrows AB and CD, by means of which a load may be applied to either wire separately or together. The upper and lower ends of the wires are surrounded by two thermostated baths, indicated by the open rectangles in the figure, which may be kept at any desired two different temperatures. In use the lower bath was always packed with ice, and the upper bath was set at any desired temperature between 0° and 100° C. The two wires

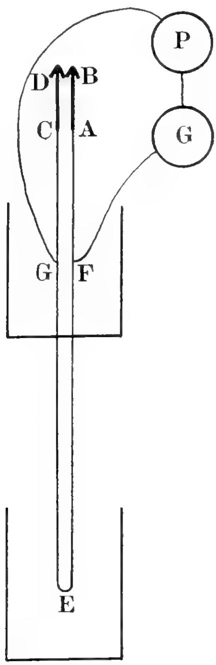

FIGURE 46. Scheme of connections used in finding effect of tension on thermo-electric quality.

are tapped at the middle of the upper bath by two flexible leads of copper connecting to the galvanometer G and the potentiometer P. These instruments were the same as were used in the previous measurements. The balances are insolated from each other, so that the circuit runs from G to P to G to F to E to G. If the two wires are precisely alike, there is no thermal e.m.f. in this circuit for any difference of temperature between GF and E, but if one of the wires is loaded, the material of the two branches of the couple now becomes effectively different, and a thermal e.m.f. appears. This was measured as a function of tension and temperature difference.

Various precautions were taken in performing the experiment which need not be gone into here at length. The two wires passed through a heavy glass tube for their entire length, and in this way were protected from contact with the water of the bath. To secure temperature equality and diminish error from heat conduction along the wires from one bath to the other, the glass tube was filled, up to the level of the water in the upper bath, with Bureau of Standards resistance oil. As a further precaution against slight variations in temperature, the glass tube was covered for the entire length of immersion in the upper bath with a compound tube of $\frac{1}{4}$ inch thick copper on the inside fitting closely into an outer iron tube also $\frac{1}{4}$ inch thick. Since the lower bath was always filled with ice and consequently was not exposed to slight oscillations of temperature, such a precaution was not necessary below. The approximate dimensions were; depth of each bath 1 ft., free distance between baths 2 ft., diameter of glass tubing 1 inch.

It has been already stated that the results of these experiments were very irregular, the effect varying with the nature of the specimen. In the following the nature of the results will be briefly indicated; each result given is the mean of determinations on the right and the left hand wires.

Nickel. Wire from the same manufacturers but from a different spool from the pressure sample was used. This was 0.005 inches in diameter. A maximum tension of 2000 kg./cm.^{2} was applied. The results were fairly good; the two samples agreed on the average within about 5%. The thermal e.m.f. may be represented by the following equations:

$$\begin{aligned} &\text{At } 31^\circ \quad \text{e.m.f.} = (.00335\text{T} - 0.0_6 60\text{T}^2) \times 10^{-6} \text{ volts,} \\ &\text{at } 51^\circ \quad = (.00577\text{T} - 0.0_5 132\text{T}^2) \times 10^{-6}, \\ &\text{at } 77.5^\circ \quad = (.0081\ \text{T} - 0.0_5 175\text{T}^2) \times 10^{-6}, \\ &\text{at } 94.5^\circ \quad = (0121\ \text{T} - 0.0_5 37\text{T}^2) \times 10^{-6}. \end{aligned}$$

In these formulas T is the tension in kg./cm.^{2} The direction of the e.m.f. is from unstretched to stretched at the hot junction. Paying attention only to the change of volume, this would correspond to a pressure effect of from compressed to uncompressed at the hot junction This is of the opposite sign from the observed pure pressure effect.

Copper. This was commercial wire of 0.020 inches diameter.

The maximum tension applied was 700 kg./cm.[2] Within this range the e.m.f. was linear with tension. Trustworthy measurements were obtained only at 95°. Here the two specimens differed from the mean by 20%.

$$\text{e.m.f.} = 0.00056\text{T} \times 10^{-6} \text{ volts.}$$

The direction of e.m.f. is from unstretched to stretched at the hot junction. This corresponds to from compressed to uncompressed at the hot junction, and is opposite in sign from the pure pressure effect.

Iron. This was annealed "ingot" iron, from the same piece of metal as that of the pressure measurements. Its diameter was 0.025 inches, and it was subjected to a maximum tension of 500 kg./cm.[2] Satisfactory readings were obtained at two temperatures; the two wires differed by less than 10%. The results are covered by the formulas:

$$\begin{aligned} \text{At } 52° \quad \text{e.m.f.} &= (0.0120\text{T} - 0.0_4235\text{T}^2) \times 10^{-6} \text{ volts,} \\ \text{at } 95° \quad &= (0.0223\text{T} - 0.0_442\text{T}^2) \times 10^{-6}. \end{aligned}$$

The effect has a pronounced maximum near the middle of the tension range; this recalls the complicated behavior under hydrostatic pressure, although the range of tension is comparatively much lower than the range of pressure. The e.m.f. is from unstretched to stretched at the hot junction, corresponding to from compressed to uncompressed. This corresponds to the sign of the pure pressure effect over the first portion of the pressure range.

Aluminum. Commercial stock of 0.0195 inches diameter was used. Satisfactory results were obtained at two temperatures; the two wires differing by about 10% from the mean. The results are given by the formulas:

$$\begin{aligned} \text{At } 50.5° \quad \text{e.m.f.} &= (0.0088\text{T} - 0.0_567\text{T}^2) \times 10^{-6} \text{ volts,} \\ \text{at } 76° \quad &= (0.0088\text{T} - 0.0_547\text{T}^2) \times 10^{-6}. \end{aligned}$$

The departure from linearity, contrary to what one might expect, is only slight. The abnormal behavior under pressure, however, is reflected in the slight change of e.m.f. with temperature. The direction of e.m.f. is from unstretched to stretched at the hot junction, corresponding to from compressed to uncompressed. This corresponds to the initial direction of the pressure effect.

Brass. This was commercial wire of 0.008 inches diameter. The tension range was high, 2800 kg./cm.^{2} Under the most unfavorable conditions the two wires differed 50% from the mean. The results are given by the formulas:

$$\begin{aligned} &\text{At } 52^\circ \quad \text{e.m.f.} = (0.00022T - 0.0_73T^2) \times 10^{-6} \text{ volts,} \\ &\text{at } 77^\circ \quad = (0.00013T - 0.0_712T^2) \times 10^{-6}, \\ &\text{at } 94^\circ \quad = (0.00047T - 0.0_75T^2) \times 10^{-6}. \end{aligned}$$

At 52° the departure from linearity is so great that the e.m.f. passes through a maximum. This disappears at the higher temperatures. E.m.f. is from stretched to unstretched at the hot junction, corresponding to from uncompressed to compressed for the pure pressure effect. This is the first example met of an effect of this sign. The pure pressure effect was not measured.

Manganin. This was from the same stock as the pressure sample, but not from the same piece. The range of tension was 1300 kg./cm.^{2} The two samples, contiguous lengths, did not give the same sign for the effect. The one showing the smaller effect reversed in sign with changing temperature, at the lower temperatures being opposite in sign from the more active piece, but at 98° becoming of the same sign, although only 10% of it. The effect for the more active specimen was not linear, but is less proportionally at the higher temperatures, and at 32° actually passes through a flat maximum near $\frac{3}{4}$ of the maximum tension. The maximum values of e.m.f. for this piece were: 0.1, 0.25, 0.38, and 1.33×10^{-6} volts at 32°, 50°, 75°, and 95° respectively. The direction is from unstretched to stretched at the hot junction, corresponding to a pressure effect from compressed to uncompressed. This agrees with the pure pressure effect.

Dependence of Thomson Heat on Temperature Gradient.

Although it is not directly connected with the immediate object of this work, I nevertheless made experimental examination of one other point, both because I was in a position to make the experiment with comparatively little effort, and because this point is indirectly involved as an assumption made in deriving the formulas used in deducing the Peltier and the Thomson heats from the total e.m.f. The assumption is always made that the Thomson heat depends only on the temperature at a point, and not on the temperature gradient, that is, on the rate of flow of heat. The existence of such a dependence on gradients would mean the possibility of the existence of thermoelectric currents in unequally heated circuits of a single homogeneous metal. This effect was often looked for in the early days of the subject, and the concensus of opinion was that the effect does not exist; whenever an effect like it was obtained, it was always explainable by imperfect homogeneity in the metal. At the same time there seems to be no reason why the effect might not exist, and it occurred to me that with present apparatus we are in a position to push the limits within which the effect must lie much further than before. The circuit on which I experimented consisted of liquid mercury, and was therefore completely homogeneous. The mercury was contained in a quartz capillary; at the center of the circuit the capillary was drawn down with thin walls to perhaps 0.5 mm. diameter and 0.25 mm. thickness of wall. Over the neck in the capillary was slipped a piece of tightly fitting mica. A simple arrangement allowed a jet of water to be directed against the quartz on one side of the mica and on the other side a small gas flame. In the mercury underneath the mica there was, therefore, an intense temperature gradient. The two ends of the quartz capillary were led to an ice bath, and from this connection made through copper leads to a galvanometer. There was therefore no chance for thermo-electric action unless there were one due to the temperature gradient. The galvanometer was a very sensitive Thomson galvanometer constructed by Coblentz; I owe the opportunity to use it to the kindness of Dr. I. Gardner. With this I could establish that there was no e.m.f. in the mercury of as much as 3×10^{-11} volts, up to temperature gradients steep enough to vaporize the mercury at one end of the constriction in the capillary. Care had to be taken in establishing this result; for example, if the part of the circuit containing the gradient is not horizontal, an effect will be found due to the effect of pressure differences on thermo-electric quality.

The effect, if it exists, is therefore exceedingly minute. The equations above show that if the effect exists consequences with regard to other effects are involved. We have the equation

$$\frac{d}{dt}\left(\frac{P_{AB}}{t}\right) + \frac{1}{t}(\sigma_A - \sigma_B) = 0$$

Hence if σ_A for example, depends on the temperature gradient, then P_{AB} must also, or the Peltier heat would depend on the total quantity of heat flowing into the junction. Such an effect has not been observed, and therefore inferentially the Thomson heat is independent of temperature gradient. However, the observations on Peltier heat have presumably been no more accurate than those on the freedom of total e.m.f. from effects of gradient.

General Survey of Results.

The first impression given by the measurements under pressure is of bewildering and perhaps hopeless complexity, but there are nevertheless certain uniformities and normal types of behavior. Let us for the first discussion disregard detail and take as a measure of the effects the maximum e.m.f., Peltier heat, and Thomson heat listed in the tables above. The normal effect of pressure on e.m.f. is positive; there are only three out of 20 cases, manganin, Mg, and Co, in which the effect is persistently negative to the highest pressures and temperatures; and for only three other metals, Fe, Al, and Sn is the effect negative over any part of the range. The range of values of maximum e.m.f. is from $+710 \times 10^{-6}$ volts for Bi to -20.6×10^{-6} for Co. Similarly, the normal pressure effect on Peltier heat is positive, that is, heat is absorbed by the positive current in flowing from uncompressed to compressed metal. There are only four cases of negative Peltier heat under pressure, manganin, Sn, Mg, and Co. The range of values is from 2960×10^{-6} for Bi to -90.5×10^{-6} for Co. The Thomson heat under pressure is also normally positive, Co, Fe, and Bi being the only negative cases. The range of values is from 220×10^{-8} for Zn to -280×10^{-8} for Bi.

When, however, we try to correlate the thermo-electric behavior with other electrical properties of the metals we find complete lack of connection. In table XLV the metals are arranged in a number of columns, in each column the order being the order of relative magnitude of the property standing at the head of the column. In the first place, the pressure effect on e.m.f. is not greatest for the most compressible metals, as we might expect, but the effect is apparently quite independent of the compressibility. Compare, for example, the positions of Pb and Mg in the compressibility column with their positions in the pressure e.m.f. column. It was pointed out in a previous paper that the effect of pressure on resistance is approximately proportional to its effect on volume; this is shown in the table by the similarity of the columns of compressibility and pressure effect on resistance. There is accordingly very little connection between the pressure effect on resistance and that on e.m.f. The conclusion suggests itself that there is little connection between the mechanism which determines the thermo-electric behavior of a metal and its electrical conductivity. This is further borne out by the lack of parallelism between the columns of pressure effect on resistance with those of pressure effect on Thomson and Peltier heat.

There is almost exact parallelism between the columns of pressure effect on e.m.f. and on Peltier heat; these two columns differ only by two single inversions, Al with Cu, and manganin with Sn. This of course means that nearly all the total e.m.f. in a pressure thermo-

TABLE XLV.

THE METALS IN ORDER OF DECREASING NUMERICAL MAGNITUDES OF VARIOUS PROPERTIES.

The horizontal bars in some columns show where the effect changes sign.

Specific Resist-ance	Temp. Coeff. of Resis. 0°–100° at 0 kg.	Thomson heat at 0° and 0 kg.	Peltier heat against Pb at 0° and 0 kg.	Pressure effect on resist-ance	Pressure effect on E.M.F.	Pressure effect on Peltier heat	Pressure effect on Thomson heat
Bi	Fe	Cd	Fe	Pb	Bi	Bi	Zn
Cons.	Tl	Mo	Cd	Tl	Zn	Zn	Pt
Man.	Ni	W	Mo	Sn	Tl	Tl	Cd
Pb	Sn	Bi	Zn	Cd	Cd	Cd	Tl
Tl	Bi	Cu	Au	Mg	Cons.	Cons.	Sn
Fe	Al	Au	Cu	Zn	Pd	Pd	Pb
Ni	Mo	Ag	Ag	Al	Pt	Pt	Al
Sn	Cu	Man.	Tl	Ag	W	W	W
Pt	Cd	Al	W	Au	Ni	Ni	Cons.
Pd	Pb	Mg	Man.	Fe	Ag	Ag	Ni
Co	Zn	Pb	Sn	Pd	Fe	Fe	Mo
Cd	Ag	Sn	Pb	Pt	Pb	Pb	Ag
Zn	Au	Tl	Mg	Cu	Au	Au	Pd
W	Mg	Zn	Al	Ni	Cu	Al	Au
Mg	Pt	Fe	Pt	Mo	Al	Cu	Cu
Mo	Co	Pt	Pd	W	Mo	Mo	Man.
Al	W	Pd	Co	Co	Sn	Man.	Mg
Au	Pd	Ni	Ni	Cons.	Man.	Sn	Co
Cu	Cons.	Co	Cons.	Man.	Mg	Mg	Fe
Ag	Man.	Cons.	Bi	Bi	Co	Co.	Bi

electric couple (that is, a couple of two branches of the same metal, one compressed and the other not) is provided by the difference of Peltier heat at the hot and cold junctions, and comparatively little by the pressure effect on the Thomson heat. This has been otherwise obvious from the fact that the relation between e.m.f. and temperature at constant pressure has been in most cases approximately linear.

The columns of pressure effect on Peltier heat and Thomson heat are not obviously related. Most striking is the transposition of Bi from the head of one column to the bottom of the other; the pressure effect on Peltier heat of Bi is the maximum positive, and on the Thomson heat the maximum negative. One draws the conclusion that the

TABLE XLVI.

Ration of Maximum Change of Thomson Heat within the Range 0°–100° C and 0 to 12000 kg./cm.^{2} to Thomson Heat at 0°C and 0 kg.

Sn	− .81
Tl	− .108
Cd	+ .0105
Pb	∞
Zn	− .81
Mg	0
Al	+4.5
Ag	+ .041
Au	+ .0295
Cu	+ .0285
Ni	− .017
Co	+ .013
Fe	+ .40
Pd	− .0098
Pt	−0.131
Mo	+ .013
W	+ .021
Bi	− .32
Cons.	− .0079
Man.	+ .011

Thomson heat mechanism and the Peltier heat mechanism are not intimately related. The pressure effect on Thomson heat inclines to show parallelism to the pressure effect on resistance.

The thermo-electric behavior at atmospheric pressure (Peltier heat against lead and Thomson heat) also shows little direct connection with the pressure effects. There is no obvious connection between other pairs of columns; the thermo-electric mechanism seems to stand in a class by itself.

The magnitude of the change in the Thomson heat produced by pressure compared with the total Thomson heat under atmospheric conditions is of interest. The relative effect of pressure on the properties of most solids is comparatively small; for example, the maximum effect found before on resistance was 14% for lead, and the effect on volume is only a few per cent. We should expect a similar state of affairs with the Thomson heat. This is true, except for the anomalous metals. The total pressure effects with Al, Bi, Fe, Sn, and Zn, are all of the order of magnitude of the whole effect at atmospheric conditions, but the other metals show the smallness of the effect to be expected. The results are shown in Table XLVI.

So far, we have considered the effects only in broad outline, but when we come to consider the detailed variations with pressure and temperature we find great complexity. The normal behavior of e.m.f. is a regular rise with pressure and temperature; the slope of the e.m.f. curves at constant pressure increasing with rising temperature, but the slope at constant temperature decreasing with rising pressure. Fe, Al, and Sn are examples of complicated variations of e.m.f. with pressure and temperature, and we have also met other examples where the slope at constant pressure may decrease with rising temperature, or the slope at constant temperature may increase with rising pressure. As for the detail of variation of Peltier heat or Thomson heat with pressure and temperature, so many different types are presented that it is useless to try to enumerate them.

The Entropy of Electricity.

By an extension of a remark made by Professor E. H. Hall with regard to the ordinary thermo-electric diagram, we may find a function giving the entropy of the electricity in the metal as a function of pressure and temperature.

A couple composed of two branches of the same metal, one at 0 pressure, the other at pressure p, running between 0° and t° has a definite e.m.f., E. E is a function of p and t. If we add to E (p,t) $E_{pb}(t)$, that is, the e.m.f. against lead at atmospheric pressure, we shall obtain a function ξ (p,t) such that $t\left(\frac{\partial^2\xi}{\partial t^2}\right)_p$ is the Thomson heat at any pressure and temperature and $t\left(\frac{\partial^2\xi}{\partial t\partial p}\right)$ is the Peltier heat.

That is
$$\left(\frac{\partial Q}{\partial t}\right)_p = t\left(\frac{\partial^2 \xi}{\partial t^2}\right)_p,$$
and
$$\left(\frac{\partial Q}{\partial p}\right)_t = t\,\frac{\partial^2 \xi}{\partial p \partial t}.$$

It is obvious that $\left(\frac{\partial \xi}{\partial t}\right)_p$ is equal to the entropy of one coulomb of electricity, because
$$dQ = tdS,$$
and
$$\left(\frac{\partial Q}{\partial t}\right)_p = t\left(\frac{\partial s}{\partial t}\right)_p = t\left[\frac{\partial}{\partial t}\left(\frac{\partial \xi}{\partial t}\right)_p\right]_p, \text{ and } \left(\frac{\partial Q}{\partial p}\right)_t = t\left(\frac{\partial s}{\partial p}\right)_t = t\left[\frac{\partial}{\partial p}\left(\frac{\partial \xi}{\partial t}\right)_p\right]_t.$$

If we had some means of determining the work done on electricity as well as the entropy we would be in a position to completely determine its behavior.

This function ξ gives at once the means of finding on the p, t plane the slope of the lines of constant entropy. I have made this computation for all the metals listed above. As is to be expected, the line assumes every possible slope. It thus appears that there is no simple relation between the ordinary thermodynamic properties of a metal and the thermodynamic properties of the electricity in the metal.

Conclusion and Summary.

In this paper measurements are given of the thermal e.m.f. of couples composed of two branches of the same metal, one of the branches being under uniform hydrostatic pressure and the other branch at atmospheric pressure, the junctions between the branches being at 0°C and some other variable temperature. The range of the work covers 20 pure metals and 2 alloys, and all pressures up to 12000 kg./cm.^{2} and all temperatures between 0° and 100°. From these measurements of e.m.f. the Peltier heats and the Thomson heats may be deduced by the ordinary thermodynamic reasoning as a function of pressure and temperature. By the Peltier heat of the couples measured in this work is meant the heat absorbed by unit quantity of electricity in flowing across the junction from uncompressed to compressed metal, and by the Thomson heat of the couple is meant the excess of heat absorbed by unit quantity of electricity in flowing through one degree temperature difference in the compressed metal over the uncompressed metal. With regard to these heats, my position in this paper has been that the ordinary thermodynamic argument, by which the formulas have been deduced, allows conclusions only as to the quantities of heat, and that no conclusion is justified as to the local e.m.f's. corresponding to these heats. Complete diagrams and tables are given for the e.m.f., Peltier, and Thomson heats of these couples.

The nature of the results was unexpectedly complicated. The normal state of affairs is apparently a positive effect of pressure on both Peltier and Thomson heats, but there are numerous examples of negative effects, and almost none of the metals show regular variation of these quantities with pressure and temperature within the range. Three metals, tin, iron, and aluminum, show complicated variations of the e.m.f. of the couple, there being maxima and minima with both pressure and temperature within the range.

The effect of tension on thermo-electric quality of a few of the 20 metals was measured, and the results again were complicated. In general the pure volume effect on thermo-electric quality is different, according as the change of volume is brought about by a hydrostatic pressure or a tension. This is the reverse of the behavior of electrical resistance, which is determined primarily by the change of volume, regardless of whether it is produced by tension or hydrostatic pressure.

As a bye-product, the dependence of Thomson heat on temperature gradient has been measured for mercury, and the possibility of such an effect of gradient has been made more remote than before.

The unexpected complications found makes these results disappointingly meagre in their suggestions as to the nature of the thermo-electric mechanism. The conclusions are mostly negative in character. The most unmistakable inferences may be drawn as to the untenability of the old gas-free-electron theory of metals, but this is not now new enough to be worth the experimental trouble. This conclusion was drawn 10 years ago by Wagner from his data up to 300 kg., and the results of this paper can add nothing to the conclusions of Wagner in this regard, since our results are in essential agreement over our common range. Further than this, the results suggest most strongly that the thermo-electric mechanism must be comparatively complicated, that it cannot be at all of the simplicity imagined by the free electron theory and that most likely the effects which we measure are the resultant of different effects, which some times, at least, work in opposite directions. What these effects may be, we are not in a position at present to speculate.

In the projected paper mentioned in the introduction on general considerations on thermo-electric action, it will be pointed out that the data of this paper allow certain information to be gathered about the behavior of various constants of thermionic emission under pressure. The latent heat of vaporization of electrons, the density of the electron atmosphere, and the Volta contact force between an uncompressed and a compressed metal may be determined as a function of both pressure and temperature, except for an undetermined function of pressure alone.

Finally, it may not be too daring to say that it seems to me that much of my previous work on high pressure effects at least suggests a direction in which we may look for the explanation of these complicated effects. The thermodynamic properties of liquids under high pressures and all the mutual relations of the polymorphic forms of solids have been found to be quite as complicated under pressure as the thermo-electric properties above. I have shown in detail that probably the properties of both liquids and solids are to be explained in terms of the same agency, the effect of the characteristic shape of the atoms, or, if one prefers to express it so, the nature of the field of force surrounding the atom. It seems most probable that the electrons in passing from atom to atom, or in playing about between the atoms, may be subjected to forces changing in a complicated way as the atoms are forced by pressure into positions of varying degrees of adaptation to each others irregularities.

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THE DYADICS WHICH OCCUR IN A POINT SPACE OF THREE DIMENSIONS.

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In his Ausdehnungslehre, Grassmann gave a discussion of linear transformations of space in which he considered each transformation as determined by a Brucke,[1] or fraction. By using products which he called indeterminate,[2] Gibbs showed that the transformations could be determined by means of bilinear forms called dyadics. These were applied to the study of linear vector functions in three dimensions in the Gibbs-Wilson Vector Analysis. Extensions of this to higher dimensions were given by Gibbs in his lectures on Multiple Algebra an outline of which is contained in an article by E. B. Wilson.[3] H. B. Phillips[4] applied the dyadic to the study of projective transformations in a plane. The fraction of Grassmann does not lend itself readily to algebraical manipulation. This is remedied by the dyadic of Gibbs. The symbol ϕ used by Gibbs does not, however, suggest the nature of the particular dyadic or the invariants and covariants determined from it. In the paper of Phillips a symbolic notation was introduced by which the dyadic appears as the product of a single pair of letters from which invariants and covariants and combinations with other dyadics are obtained by processes of multiplication analogous to the Grassmann products of space elements.

In this paper we have given an exposition of the symbolic notation and have used it to discuss with some completeness the various dyadics occurring in a point space of three dimensions. To aid in the understanding of this we first develop the elements of Grassmann's analysis

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1 Ausdehnungslehre, 1862, page 240. A good exposition of this is found in Whitehead's Universal algebra, Chapter VI. Book IV.

2 On Multiple Algebra, an address before the section of mathematics and physics of the American Association for the Advancement of Science, by the Vice-President. Proceedings of the American Association for the Advancement of science, **35**. This address is reprinted in the Scientific Papers, **2**.

3 On the theory of double products and strains in hyperspace. Transactions of the Connecticut Academy of Arts and Sciences, **14**, 1908.

4 Some invariants and covariants of ternary collineations, American Journal of Mathematics, **36**, 1914.

in three dimensions and apply the theory to the study of the complex line. The dyadics are of four main types: (a) Those which transform points into points or planes into planes, (b) those which transform points into planes or planes into points, (c) those which transform lines or complexes into lines or complexes, (d) those which transform points or planes into lines or complexes and those which transform lines or complexes into points or planes. The first class represent the collineations and to this type belong most of the dyadics hitherto discussed. The second class represent the correlations. The last two types so far as we know have not been discussed before. These are not in general contact transformations.

By means of double multiplication of two dyadics (one of which may represent an identical transformation) we determine many invariants and covariants. From the geometrical interpretation of this double product we obtain a series of descriptive theorems analogous to the Pappus theorem for the hexagon inscribed in a plane two-line.

INTRODUCTION.

I. Matrices and Outer Products.

1. **Progressive Matrices.** In a former paper [5] we gave an interpretation of the products of Grassmann [6] in which we represented points, lines, etc. as rectangular matrices and expressed the products as operations performed on those matrices. As those products form a fundamental part of the present paper, we shall here briefly outline the method there used.

Our space is a projective point space of three dimensions and so we represent a point A by the matrix

$$A = \| a_1 \, a_2 \, a_3 \, a_4 \| \equiv \| a_i \| \tag{1}$$

where a_1, a_2, a_3, a_4 are the homogeneous coordinates of the point. Two matrices of this kind will be called equal when their corresponding

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[5] A theory of linear distance and angle, These Proceedings, **48**, 1912.

[6] Expositions of Grassmann's product theory can be found in the following places:

Ausdehnungslehre, 1862.

Whitehead's Universal Algebra, Chapter I, Book IV.

Encyclopedia, French edition, Complex Number, tome 1, **1**.

The treatment here given is somewhat different from any of the above.

elements are equal. The matrix will be said to be zero only when all its elements are zero.

If two points A and B have coordinates a_i and b_i respectively and $a_i = k\, b_i$, we shall write

$$A = kB.$$

Geometrically A and B are the same point. *But in Grassmannian analysis a point has magnitude as well as position.* The magnitude of A is k times that of B. In this paper we have no need to define unit magnitudes and therefore have not done so.

A linear function of two or more points A, B, C etc. is defined by the matrix

$$\lambda A + \mu B + \nu C + \ldots = \| \lambda a_i + \mu b_i + \nu c_i + \ldots \| \tag{2}$$

If the matrix does not vanish identically, it represents a point in the space determined by A, B, C, etc. Conversely, any point in that space can be represented in that way. For example any point on a line can be represented as a linear function of two, any point in a plane as a linear function of three not on a line, and any point in space as a linear function of four not in a plane. If the matrix vanishes identically, and the multipliers λ, μ, ν, etc. are not all zero, those points lie in a space of lower dimensions than that determined by a like number of independent points.

The Plücker coordinates [7] of a line are certain two rowed determinants

$$p_{ik} = \begin{vmatrix} a_i & a_k \\ b_i & b_k \end{vmatrix}$$

in the matrix

$$\begin{Vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \end{Vmatrix} \tag{3}$$

where a_i and b_i are the coordinates of any two distinct points A and B on the line. We shall represent the line AB by the one-rowed matrix

$$[AB] = \| p_{12}\ p_{13}\ p_{14}\ p_{23}\ p_{24}\ p_{34} \|. \tag{4}$$

As above the matrix will be considered zero if all its elements are zero,

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7 The facts concerning Plücker coordinates and line geometry in general which are here assumed are all to be found in Jessop's Line Complex, Cambridge, 1902.

that is, if the points A and B coincide. One matrix is a multiple of another if corresponding elements are proportional. If P, Q are any two distinct points on the line AB, $[PQ]$ is a multiple of $[AB]$. For numbers $\lambda_1, \lambda_2, \mu_1, \mu_2$ can then be found such that

$$P = \lambda_1 A + \lambda_2 B,$$
$$Q = \mu_1 A + \mu_2 B.$$

From these equations, by use of (2) it is easy to show that

$$[PQ] = \begin{vmatrix} \lambda_1 & \lambda_2 \\ \mu_1 & \mu_2 \end{vmatrix} [AB].$$

Thus a matrix in addition to representing a line has a definite magnitude.

The sum of two matrices $[AB]$ and $[CD]$ is the matrix each element of which is the sum of corresponding elements of $[AB]$ and $[CD]$. In general the elements of this sum are not the two-rowed determinants of a matrix of the type (3), just as the sum of corresponding Plücker coordinates of two lines are not in general coordinates of a line. A matrix

$$\| c_{12}\ c_{13}\ c_{14}\ c_{23}\ c_{24}\ c_{34} \| \equiv \| C_{ik} \| \tag{5}$$

whose elements c_{ik} are the determinants of (3) will be called simple. Such a matrix represents a line. If, however, the elements c_{ik} cannot be so represented, the matrix will be called complex, we shall say that this represents a *complex line.* The relation of this to the linear complex will be shown later (§5). In what follows the word line will always mean simple line.

If the lines AB and CD intersect in a point P, we can find points Q and R on those lines and assign to them such magnitudes that

$$[AB] = [PQ], \qquad [CD] = [PR].$$

Then

$$\begin{aligned} [AB] + [CD] &= [PQ] + [PR] \\ &= \| p_i(q_k + r_k) - p_k(q_i + r_i) \| = [P(Q + R)]. \end{aligned} \tag{6}$$

Therefore *the sum of two intersecting lines is a line.*

If the points A, B, C are not collinear, the coordinates of the plane ABC are the three-rowed determinants of the matrix.

$$\begin{Vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \end{Vmatrix}. \tag{7}$$

We shall represent the plane by the matrix

$$[ABC] = \left\| \alpha_1 \ \alpha_2 \ \alpha_3 \ \alpha_4 \right\| \tag{8}$$

where α_i is the coefficient of x_i in the expansion of the determinant

$$\begin{vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \\ x_1 & x_2 & x_3 & x_4 \end{vmatrix}.$$

Linear functions of planes are defined as in the case of points. If P, Q, R are any three points in the plane ABC, it can be shown as in the case of a line that a number λ can be found such that

$$[PQR] = \lambda[ABC].$$

Thus $[ABC]$ in addition to representing a plane has a magnitude.

From four points A, B, C, D we can form a four-rowed matrix. Since this matrix contains only one four-rowed determinant, we shall consider it as a determinant

$$(ABCD) = \begin{vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \\ d_1 & d_2 & d_3 & d_4 \end{vmatrix}.$$

Such a matrix of one element we shall consider as a number and indicate this by the use of the parenthesis in the symbol $(ABCD)$.

2. **Progressive Products.** The most fundamental law of multiplication is the distributive law which can be stated in the two forms

$$(A + B)C = AC + BC,$$
$$A(B + C) = AB + AC.$$

The matrix $[AB]$ has this property. For as in equation (6) it is easy to show that

$$[(A + B)C] = [AC] + [BC], \tag{9}$$
$$[A(B + C)] = [AB] + [AC]. \tag{10}$$

Hence we consider $[AB]$ as a product of A and B. The process of multiplication consists in placing the matrix A over the matrix B to form the two-rowed matrix

$$\begin{Vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \end{Vmatrix}$$

and from this determining the elements of the matrix $[AB]$. From the definition it is clear that

$$[AB] = -[BA], \tag{11}$$
$$[AA] = 0. \tag{12}$$

Similarly the matrix $[ABC]$ can be regarded as a product of $[AB]$ and C, of A and $[BC]$ or of A, B, and C, the process of multiplication consisting always in forming the matrix

$$\begin{Vmatrix} a_1 & a_2 & a_3 & a_4 \\ b_1 & b_2 & b_3 & b_4 \\ c_1 & c_2 & c_3 & c_4 \end{Vmatrix}$$

and determining the matrix $[ABC]$ by using the determinants in this as elements. From this definition it is evident that

$$[A \cdot BC] = [AB \cdot C] = [ABC],$$
$$[AB(C + D)] = [ABC] + [ABD],$$
$$[ABC] = -[ACB] = [CAB].$$

The dot is used throughout our work to show the order of operations. Thus

$$[A \cdot BC] = [A[BC]].$$

Products involving the complex line will be considered in §5.

Since the coordinates $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ of a plane can have arbitrary values, not all zero, a linear function of planes is a plane unless it vanishes identically.

The quantity $(ABCD)$ can be regarded as a product of A and $[BCD]$, of $[AB]$ and $[CD]$, of A, B, C and D etc. Hence by definition and the properties of determinants.

$$(ABCD) = (A \cdot BCD) = (AB \cdot CD) = -(ABDC), \text{ etc.}$$

It is to be noted that the sign of $(ABCD)$ is changed when two of the points A, B, C, D are interchanged. These products are called progressive because every additional factor increases the dimension of the product.

If any of these products vanish it shows that the points lie in a space of lower dimension than is determined by a like number of independent points. For example if

$$[ABC] = 0$$

then A, B, C lie on a line as can easily be verified by expressing the matrix in terms of coordinates.

3. **Regressive Matrices and products.** We can consider space as generated by planes as well as by points. If its coordinates are α_i, a plane α is represented by the matrix

$$\alpha = \left\| \alpha_1 \ \alpha_2 \ \alpha_3 \ \alpha_4 \right\|.$$

The same plane may be represented by the matrix $[ABC]$ of any three noncollinear points lying in it. If α_i is equal to the coefficient of x_i in the expansion of the determinant $(ABCX)$, we shall write

$$\alpha = [ABC].$$

The line of intersection of two planes α and β can be represented by the matrix

$$[\alpha\beta] = \left\| q_{34} \ q_{42} \ q_{23} \ q_{14} \ q_{31} \ q_{12} \right\|, \tag{13}$$

where

$$q_{ik} = \begin{vmatrix} \alpha_i & \alpha_k \\ \beta_i & \beta_k \end{vmatrix}.$$

If the same line is the join of two points A and B, we know from line geometry that the coordinates q_{ik} are proportional to the coefficients of the minors $\begin{vmatrix} x_i & x_k \\ y_i & y_k \end{vmatrix}$ in the determinant $(ABxy)$. If q_{ik} is *equal* to the coefficient of $| \, x_i \ y_k \, |$ in that determinant we shall write

$$[\alpha\beta] = [AB].$$

Three planes α, β, γ intersect in a point A. The coordinates a_i of this point are proportional to the coefficients of ξ_i in the determinant [8] $(\xi\alpha\beta\gamma)$. In particular, if a_i is equal to the coefficient of ξ_i in that determinant, we write

$$A = [\alpha\beta\gamma].$$

There is a determinant $(\alpha\beta\gamma\delta)$ of four planes just as of four points. The matrices $[\alpha\beta]$, $[\alpha\beta\gamma]$, $[\alpha\beta\gamma\delta]$ can be regarded as products. They

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8 It is to be observed that the variable ξ is put in the first row of this determinant while in §1 we wrote for points $(ABCX)$. This change is made in order to make the reduction formulas agree in sign with the ones Grassmann gave.

obey the same laws as the corresponding products of points. These products of matrices expressed in plane coordinates we shall call *regressive* because each additional factor decreases the dimension of the product.

If a regressive product vanishes it shows that the planes determine a space of higher dimension than a like number of independent planes determine. For example if

$$(\alpha\beta\gamma\delta) = 0$$

the four planes $\alpha, \beta, \gamma, \delta$ intersect in a point as is easily shown by writing the matrix in terms of coordinates.

4. **Mixed products and reduction formulas.** If the total number of points in a set of progressive matrices is equal to or less than four, the matrices are multiplied together as already explained. If the total number of planes in a set of regressive matrices is equal to or less than four, they are multiplied together in a similar manner. In both cases the product is associative. If the total number of points or planes in two matrices is greater than four,[9] we have not defined the product. In that case we replace each of the matrices by its equivalent in complementary elements. We shall say that points and planes are complementary elements and that lines are complementary to lines. For example, we could replace $[AB]$ by $[\alpha\beta]$ where

$$[AB] = [\alpha\beta],$$

$[ABC]$ by α where

$$[ABC] = \alpha,$$

etc. The total number of elements (points or planes) in the new matrices will then be less than four and the product can be formed as before. If the total number of elements is equal to four, the product will be the same whether the matrices are expressed in points or planes. If the matrices are of different kinds (one progressive, the other regressive) we express one of them by its complementary form. Thus in every case of the product of two factors there is a definite result that has a meaning. We call this the *outer* product of the two factors.

The product of a line $[AB]$ and a plane γ is the point of intersection of the line and plane considered as having a certain magnitude. For,

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9 It is assumed here that the number of elements (points or planes) in either factor is not greater than four.

to obtain this product we replace $[AB]$ by its complementary form $[\alpha\beta]$. Then

$$[AB]\cdot\gamma = [\alpha\beta\gamma].$$

The result is the point in which α, β, γ intersect. Since α and β are planes passing through $[AB]$, this is the point in which $[AB]$ intersects γ.

This method of obtaining the product is simple in conception but not analytically convenient. We shall therefore give a set of reduction formulas by which the same results can be obtained in more useful form. The proof of these formulas is not essential for our purposes. Hence we give them without proof.[10] The roman letters represent points, the greek letters planes.

$$\begin{aligned}
[ABC\cdot DEF] &= (ABCF)[DE] - (ABCE)[DF] + (ABCD)[EF] \\
&= (ADEF)[BC] - (BDEF)[AC] + (CDEF)[AB]. && (14)\\
[ABC\cdot DE] &= (ABCE)D - (ABCD)E \\
&= (ABDE)C - (ACDE)B + (BCDE)A. && (15)\\
[\alpha\cdot ABC] &= (\alpha C)[AB] - (\alpha B)[AC] + (\alpha A)[BC]. && (16)\\
[\alpha\cdot AB] &= (\alpha B)A - (\alpha A)B. && (17)
\end{aligned}$$

Similar formulas can be obtained by replacing points by planes and planes by points. The following formula

$$(ABCD)E = (ABCE)D - (ABDE)C + (ACDE)B - (BCDE)A \qquad (18)$$

and the one that results by replacing points by planes are also sometimes found useful.

5. **The complex.** Let A, B, C, D be four points not in a plane. Any two points P_1, P_2 of space can be expressed as linear functions of A, B, C, D.

$$\begin{aligned}
P_1 &= \lambda_1 A + \mu_1 B + \sigma_1 C + \rho_1 D,\\
P_2 &= \lambda_2 A + \mu_2 B + \sigma_2 C + \rho_2 D.
\end{aligned}$$

Hence

$$\begin{aligned}
[P_1P_2] &= [(\lambda_1 A + \mu_1 B + \sigma_1 C + \rho_1 D)(\lambda_2 A + \mu_2 B + \sigma_2 C + \rho_2 D)]\\
&= (\lambda_1\mu_2 - \lambda_2\mu_1)[AB] + (\lambda_1\sigma_2 - \lambda_2\sigma_1)[AC] + [\lambda_1\rho_2 - \lambda_2\rho_1)[AD]\\
&\quad + (\mu_1\sigma_2 - \mu_2\sigma_1)[BC] + (\mu_1\rho_2 - \mu_2\rho_1)[BD] + (\sigma_1\rho_2 - \sigma_2\rho_1)[CD].
\end{aligned}$$

This shows that any line is a linear function of the six edges of a tetrahedron. The sum of any number of lines is then obviously a linear

10 See Linear distance and angle or any of the works mentioned in note 6.

function of the six edges. These edges can be divided into two sets, those through the point A and those in the plane $[BCD]$. The lines through a point all intersect and so their sum is a line. For the same reason the sum of any number of lines in a plane is a line. Therefore *the sum of any number of lines can be expressed as a sum of two lines, one through an arbitrary point A, the other in an arbitrary plane $[BCD]$ not passing through A.*

We have said that a matrix

$$p = \| c_{12} \; c_{13} \; c_{14} \; c_{23} \; c_{24} \; c_{34} \|$$

represents a complex line if the elements c_{ik} are not the Plücker coordinates of a line. It can be expressed as the sum of six matrices

$$\| c_{12} \; 0 \; 0 \; 0 \; 0 \; 0 \|, \quad \| 0 \; c_{13} \; 0 \; 0 \; 0 \; 0 \|, \text{ etc.}$$

Each of these represents a line. Hence *any complex line can be represented as the sum of six lines and consequently as the sum of two lines.*

Any complex p can then be expressed in the form

$$p = [AB] + [CD].$$

By the product of p and any element Γ (point, line, plane or complex) we mean the sum

$$[p\Gamma] = [AB\Gamma] + [CD\Gamma].$$

If p is expressed in a different form

$$p = [A'B'] + [C'D']$$

it is clear that $[p\Gamma]$ will have the same value as before. For example, if Γ is a point the coordinates of the plane $[AB\Gamma] + [CD\Gamma]$ are definite linear functions of the sums

$$\begin{vmatrix} a_i & b_i \\ a_k & b_k \end{vmatrix} + \begin{vmatrix} c_i & d_i \\ c_k & d_k \end{vmatrix}$$

and the coordinates of $[A'B'\Gamma] + [C'D'\Gamma]$ are the same functions of the sums

$$\begin{vmatrix} a_i' & b_i' \\ a_k' & b_k' \end{vmatrix} + \begin{vmatrix} c_i' & d_i' \\ c_k' & d_k' \end{vmatrix}.$$

Since $[AB] + [CD] = [A'B'] + [C'D']$ those sums are by definition equal.

If the sum of $[AB]$ and $[CD]$ is a line, AB and CD intersect. For, if

$$[AB] + [CD] = [PQ],$$

then

$$[ABP] + [CDP] = [PQP] = 0.$$

This shows that $[ABP]$ and $[CDP]$ are the same plane and hence AB and CD lie in a plane and so intersect.

The product of p by itself is

$$[pp] = [(AB + CD)(AB + CD)] = 2(AB\,CD).$$

If p is a complex line $[AB]$ and $[CD]$ do not intersect and so $(AB\,CD)$ is not zero. If, however, p is a line $[AB]$

$$(pp) = (AB \cdot AB) = 0. \tag{19}$$

Hence *the necessary and sufficient condition that a matrix*

$$p = \| c_{ik} \|$$

represent a simple line is

$$(pp) = 0.$$

Let

$$p = [AB] + [CD]$$

be a complex line and

$$l = [XY]$$

be a line. The equation

$$(pl) = (ABXY) + (CDXY) = 0$$

is a linear equation in the coordinates

$$\begin{vmatrix} x_i & x_k \\ y_i & y_k \end{vmatrix}$$

of the line l. Hence the lines satisfying this equation constitute a linear complex. This complex is the totality of lines l satisfying the equation

$$(pl) = 0. \tag{20}$$

This is a different thing from p which in a sense is the envelope of the lines just as a point in a plane is different from the set of lines passing through it. For this reason we call p a complex line to distinguish it from a linear complex. Where no ambiguity results we shall use the word complex for either the complex line or the linear complex.

A complex p can be represented as a linear function of two lines of which one, l, can be any line not belonging to the linear complex,

$$(pl) = 0.$$

For a number λ can be found satisfying the equation.

$$[(p - \lambda l)(p - \lambda l)] = (pp) - 2\lambda(pl) + \lambda^2(ll) = 0. \tag{21}$$

Since l is a line, by (19), $(ll) = 0$. Also by assumption (pl) is not zero. Hence if

$$\lambda = \frac{(pp)}{(pl)},$$

$p - \lambda l$ is a line l' and so

$$p = \lambda l + l'.$$

The two lines l and l' are said to be *polar with respect to the complex.* Any line of the complex that intersects one of them will intersect the other also. For, if q is a line of the complex cutting l,

$$(pq) = 0, \qquad (lq) = 0.$$

Hence from the equation

$$(pq) = \lambda(lq) + (l'q)$$

it is seen that $(l'q) = 0$ and so q intersects l.

Let P be any point and

$$p = [AB] + [CD]$$

a complex. Then

$$[Pp] = [PAB] + [PCD] \tag{22}$$

is a plane. If Q is any point in this plane

$$(PpQ) = (p \cdot PQ) = 0.$$

Hence $[PQ]$ is a line of the complex. All lines passing through P and lying in the plane $[Pp]$ therefore belong to the complex. Hence $[Pp]$ is what is known as the *polar plane of P with respect to the complex.* Similarly, if α is any plane

$$[\alpha p]$$

is what is called the pole of α with respect to the complex. All the lines of the complex, lying in the plane α, pass through the point $[\alpha p]$.

If l and l' are polar lines with respect to p,

$$p = \lambda l + \mu l'.$$

If then X is a point on l, $[Xl] = 0$ and so

$$[Xp] = \mu[Xl']$$

which shows that the polar plane of X with respect to p contains the line l'.

If the product (pq) of two complexes p and q is zero, the complexes are said to be in involution. In this case we shall say that the two complexes intersect from analogy with the case of two lines which intersect if their product is zero.

If two lines l_1, l_2 satisfy a linear relation

$$\lambda_1\ l_1 + \lambda_2\ l_2 = 0, \qquad \lambda_1,\ \lambda_2 \neq 0$$

they coincide in position. If three lines satisfy a linear relation

$$\lambda_1 l_1 + \lambda_2 l_2 + \lambda_3 l_3 = 0 \qquad \lambda_1, \lambda_2, \text{ or } \lambda_3 \neq 0$$

any line cutting two of them cuts the third and so they belong to a plane pencil. If four lines satisfy a linear relation

$$\lambda_1 l_1 + \lambda_2 l_2 + \lambda_3 l_3 + \lambda_4 l_4 = 0 \qquad \lambda_1 \lambda_2, \lambda_3, \text{ or } \lambda_4 \neq 0$$

any line cutting three cuts the fourth also. Hence they belong to the same system of generators on a quadric. If five lines satisfy a linear relation, the two lines cutting four of them will cut the fifth also and so they belong to a linear congruence. If six lines satisfy a linear relation they belong to a linear complex.

Similarly if two complex lines satisfy a linear relation the linear complexes represented by them are identical.

If three complex lines satisfy a linear relation, the linear complexes have a common congruence. If four complex lines satisfy a linear relation, the complexes have one system of generators on a quadric surface in common. If five satisfy a linear relation, the complexes have two lines in common. If six complex lines satisfy a linear relation the complexes are in involution with a fixed complex.

II. Dyadics.

6. **The indeterminate product.** Grassmann[11] showed that there are four kinds of products characterized by laws which are the same for units and for any linear functions of the units. These are the algebraic, $AB = BA$, combinatory $AB = -BA$, that in which all products are zero, and that in which there is no relation between the products of independent units. Grassmann discussed the first two in detail, but it was left to the genius of Willard Gibbs to recognize the importance of the last. Because of the indefinite character of the result he called it the *indeterminate product.*

We represent the indeterminate product of A and B by the notation AB. By definition this product obeys the following laws.

$$\begin{aligned} AB + CD &= CD + AB, \\ (AB + CD) + EF &= AB + (CD + EF), \\ \lambda AB + \mu AB &= (\lambda + \mu)AB, \\ A(B + C) &= AB + AC, \\ (A + B)C &= AC + BC, \\ \lambda AB = (\lambda A)B &= A(\lambda B), \\ 0 \cdot AB &= 0, \end{aligned}$$

where A and B are extensive quantities (points, lines, planes or complexes) and λ, μ numbers. If the factors A and B of AB are replaced by equivalent expressions, and the product expanded by the above laws the sum of terms obtained is said to be equal to AB.

Gibbs called the product AB a *dyad.* If A_1, A_2, $A_3, \ldots . A_n$ are extensive quantities of the same kind (points, lines, complexes, or planes) and B_1, B_2, $B_3, \ldots B_n$ extensive quantities of the same kind, the sum

$$\Phi = A_1B_1 + A_2B_2 + \ldots . A_nB_n$$

is called a *dyadic.* The A's are called the antecedents and the B's the consequents of the dyadic.

There are two products of a dyad AB and an extensive quantity C. These are

$$\begin{aligned} AB \cdot C &= A[BC], \\ C \cdot AB &= [CA]B. \end{aligned}$$

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11 Ausdehnungslehre, chapter 2, page 33.

Similarly there are two products $C\Phi$ and ΦC of C and a dyadic Φ. These are obtained by multiplying C and each dyad of Φ as above and adding the results.

If X is complementary to the consequents

$$\Phi X = A_1(B_1 X) + A_2(B_2 X) + \ldots + A_n(B_n X),$$

is an extensive quantity of the same kind (dimensions) as the antecedents. Hence

$$Y = \Phi X$$

is a linear transformation in which to each element X corresponds an element Y of the same kind as the antecedents. It can be shown that the most general linear transformation of these elements can be expressed in this way. Similarly if X is complementary to the antecedents

$$Y = X\Phi$$

is a transformation of elements X into elements Y of the same kind as the consequents.

In this paper we shall consider the following types of dyadics.

(a) The one-one dyadic, in which the antecedents and consequents are both points.

(b) The three-three dyadic, in which the antecedents and consequents are both planes.

(c) The one-three dyadics, in which the antecedents are points and the consequents are planes.

(d) The two-two dyadics, in which the antecedents and consequents are both lines or complexes.

(e) The one-two and two-one dyadics.

(f) The two-three and three-two dyadics.

7. **Idemfactors.** A dyadic I such that

$$X = IX \tag{24}$$

for all elements X of a given kind, is called an *idemfactor.* In this case the antecedents and consequents must be complementary in kind. Therefore there are three idemfactors, a one-three, a three-one and a two-two.

There is only one idemfactor of each of these types, For, if I_1 and I_2 are dyadics such that

$$X = I_1 X, \qquad X = I_2 X,$$

then

$$(I_1 - I_2)X = 0.$$

Since this is true for all elements X of the same kind, that is, of the same dimension it is easy to show that

$$I_1 - I_2 = 0,$$

which shows that I_1 and I_2 are identical.

If ξ is complementary to X, the idemfactor I in (24) satifies the equation

$$\xi = \xi I.$$

For, if we multiply each side of (24) by ξ we get

$$(\xi X) = (\xi \cdot IX) = (\xi I \cdot X).$$

Hence

$$[(\xi - \xi I)X] = 0$$

for all elements X and so

$$\xi - \xi I = 0.$$

8. **Conjugate, self-conjugate and anti-self-conjugate dyadics.** The dyadic Φ_c obtained by interchanging the antecedents and consequents of Φ is called the *conjugate* of Φ. Thus if

$$\Phi\ = A_1B_1 + A_2B_2 + \ldots . + A_nB_n,$$
$$\Phi_c = B_1A_1 + B_2A_2 + \ldots . + B_nA_n.$$

If X is complementary to the consequents, it is clear that

$$\Phi X = \pm X\Phi_c.$$

The sign is plus or minus according as $[XB_i]$ is equal to $[B_iX]$ or to its negative. Similarly if γ is complementary to the antecedents

$$\gamma\Phi = \pm \Phi_c\gamma.$$

A dyadic Φ is called self-conjugate if

$$\Phi = \Phi_c$$

and anti-self-conjugate if

$$\Phi = - \Phi_c.$$

In each case the antecedents and consequents must be quantities of the same kind. *Any dyadic whose antecedents and consequents are quantities of the same kind can be expressed as the sum of a self-conjugate and of an anti-self-conjugate dyadic.* For.

$$\Phi = \tfrac{1}{2}(\Phi + \Phi_c) + \tfrac{1}{2}(\Phi - \Phi_c)$$

and it is clear that $\frac{1}{2}(\Phi + \Phi_c)$ is self-conjugate and $\frac{1}{2}(\Phi - \Phi_c)$ anti-self-conjugate.

The one-three idemfactor is minus the conjugate of the three-one and vice versa, because if Φ is the three-one idemfactor $\alpha\Phi = \alpha$, or $\alpha = -\Phi_c\alpha$, since $[\alpha A_i] = -[A_i\alpha]$. The two-two idemfactor is self-conjugate.

9. **Products of two dyadics.** By the product $AB\cdot CD$ of two dyads AB and CD is meant the indeterminate product $A[BC]D$ obtained by taking the outer product (see §4) of the adjacent factors B, C. In case $[BC]$ is not a number, the result is an indeterminate product of three factors or a triad. If $[BC]$ is a number, it is commutative with A and the result is the dyad $(BC)AD$. Similarly the product of three dyads AB, CD, EF is defined as

$$AB\cdot CD\cdot EF = A[BC][DE]F$$

and the product of two dyads and an extensive quantity E is

$$AB\cdot CD\cdot E = A[BC][DE]$$

etc. In each case it is clear that the product is associative so far as dyads or dyads and extensive quantities are concerned.

The product $\Phi\Psi$ of two dyadics is defined as the result of multiplying each dyad of Φ by each dyad of Ψ and adding the results. Similarly the product of three or more dyadics is obtained by multiplying them distributively. Since the product of dyads is associative, the product of dyadics is associative.

We have seen that the dyadic Ψ as an operator transforms extensive quantities X complementary to the consequents into extensive quantities ΨX of the same dimension as the antecedents. *If the consequents of Φ are complementary to the antecedents of Ψ, $\Phi\Psi$ is a dyadic which as an operator is equivalent to the operator Ψ followed by the operator Φ.* For if

$$Y = \Psi X, \qquad Z = \Phi Y,$$

by the associative law

$$Z = \Phi\cdot\Psi X = \Phi\Psi\cdot X.$$

In the same way, if X is complementary to the antecedents of Φ, $X\Phi\Psi$ is equivalent to the transformation $X\Phi$ followed by Ψ as postfactor.

If the consequents of Φ are complementary to the antecedents of an idemfactor I,

$$\Phi I = \Phi.$$

For, if

$$\Phi = A_1B_1 + A_2B_2 + \ldots + A_nB_n$$

by the definition of an idemfactor

$$B_iI = B_i,$$

and so

$$\begin{aligned}\Phi I &= A_1B_1I + A_2B_2I + \ldots + A_nB_nI \\ &= A_1B_1 + A_2B_2 + \ldots A_nB_n = \Phi.\end{aligned}$$

Similarly if the consequents of I are complementary to the antecedents of Φ,

$$I\Phi = \Phi.$$

If there exists a dyadic Ψ such that

$$\Phi\Psi = I$$

or

$$\Psi\Phi = I$$

Φ and Ψ are said to be inverse dyadics. In many cases these two relations of Ψ and Φ will be equivalent, but there are some cases in which they are not.

10. **Symbolic Notation.** If we write a dyadic as

(A)* $$A_1B_1 + A_2B_2 + \ldots + A_nB_n = \Sigma A_iB_i,$$

the products of the dyadic with an extensive quantity X are

(B) $$A_1[B_1X] + A_2[B_2X] + \ldots + A_n[B_nX] = \Sigma A_i[B_iX],$$
(C) $$[XA_1]B_1 + [XA_2]B_2 + \ldots + [XA_n]B_n = \Sigma[XA_i]B_i.$$

Similarly if

(D) $$C_1D_1 + C_2D_2 + \ldots + C_nD_n = \Sigma C_iD_i$$

is a second dyadic, the products of the two dyadics are

(E) $$\Sigma_{ik}A_i[B_iC_k]D_k, \qquad \Sigma_{ik}C_i[D_iA_k]B_k.$$

With a dyadic is associated a number or extensive quantity

(F) $$[A_1B_1] + [A_2B_2] + \dots + [A_nB_n] = \Sigma[A_iB_i]$$

and the product of this with an extensive quantity α is

(G) $$[A_1B_1\cdot\alpha] + [A_2B_2\cdot\alpha] + \dots + [A_nB_n\cdot\alpha] = \Sigma[A_iB_i\cdot\alpha].$$

Now if we observe the above relations (A) to (G) we will see that a similarity runs throughout which can be made the basis of a symbolic notation. This consists in replacing ΣA_iB_i by a symbolic dyad AB and ΣC_iD_i by a symbolic dyad CD. We then have

$$\begin{aligned} AB &= \Sigma A_iB_i, \\ A[BX] &= \Sigma A_i[B_iX], \\ [XA]B &= \Sigma[XA_i]B_i, \\ CD &= \Sigma C_iD_i, \\ AB\cdot CD &= \Sigma A_i[B_iC_k]D_k, \\ CD\cdot AB &= \Sigma C_i[D_iA_k]B_k, \\ [AB] &= \Sigma[A_iB_i], \\ [AB\cdot\alpha] &= \Sigma[A_iB_i\cdot\alpha]. \end{aligned}$$

The symbolism consists in each case in omitting the summation sign and the subscripts. Conversely each symbolic expression is equivalent to the non-symbolic form obtained by introducing summation signs and attaching subscripts to the proper letters.

By this notation operations on dyadics appear like operations with simple dyads and the results can be expanded and handled much the same as ordinary extensive quantities. Thus if A_i and B_i are points and α a plane, the last expression can be expanded in the form

$$[AB\cdot\alpha] = \Sigma[A_iB_i\cdot\alpha] = \Sigma(A_i\alpha)B_i - \Sigma(B_i\alpha)A_i,$$

and if we put $\Sigma(A_i\alpha)B_i = (A\alpha)B$, $\Sigma(B_i\alpha)A_i = (B\alpha)A$, we have

$$[AB\cdot\alpha] = (A\alpha)B - (B\alpha)A,$$

which follows the ordinary Grassmann formula for expansion of a product.

Two dyadics AB and CD have a double product defined by

$$AB{:}CD = [AC]\,[BD].$$

The significance and properties of these double products will be discussed later.

It is clear that these symbolic forms will not be ambiguous if each of the letters A, B, C, D does not occur more than once in a product. If the same dyadic occurs more than once in a product, we represent it in each of its positions by a different pair of letters. Thus to obtain the product of AB with itself, we let $AB = A'B'$ and so write the result in the form

$$A[BA']B' = \Sigma A_i[B_iA_k]B_k$$

If we write it in the form $A[BA]B$ it is not clear whether this means $A[BA']B'$ or $A[B'A']B$. It is evident also that a product containing one of the letters A or B without the other, such as

$$[AC]D$$

has no significance.

11. **The one-three ond three-one dyadics.** These dyadics have been investigated quite extensively by Gibbs,[2] Wilson[3] and Phillips.[4] We shall therefore state only a few facts about them.

A one-three dyadic has the form

$$B\beta = B_1\beta_1 + B_2\beta_2 + \ldots . + B_n\beta_n$$

where the B's are points and the β's planes. Since the planes can be expressed as linear functions of any four not passing through a point, the dyadic can be expressed in the simpler form,

$$B\beta = B_1\beta_1 + B_2\beta_2 + B_3\beta_3 + B_4\beta_4,$$

where β_1, β_2, β_3, β_4 are any four planes not passing through a point. In the same way instead of the four planes, the four points B_1, B_2 B_3, B_4 could be assigned arbitrarily.

As an operator on points X, this dyadic gives a collineation

$$Y = B(\beta X) = B_1(\beta_1 X) + B_2(\beta_2 X) + B_3(\beta_3 X) + B_4(\beta_4 X).$$

If X is the intersection of the planes β_2, β_3, β_4

$$X = [\beta_2\beta_3\beta_4], \qquad (\beta_2 X) = (\beta_3 X) = (\beta_4 X) = 0,$$

and

$$Y = B_1(\beta_1\beta_2\beta_3\beta_4).$$

Hence the vertices of the tetrahedron β_1, β_2, β_3, β_4 pass by the collineation into the points B_1, B_2, B_3, B_4.

Let A_1, A_2, A_3, A_4, be four points, not in a plane, with magnitudes so chosen that

$$(A_1A_2A_3A_4) = 1.$$

Let

$$[A_1A_2A_3] = \alpha_4, \qquad [A_1A_2A_4] = -\alpha_3,$$
$$[A_1A_3A_4] = \alpha_2, \qquad [A_2A_3A_4] = -\alpha_1.$$

It is then easily seen that

$$[\alpha_i\ A_i] = 1, \qquad i = 1,\ 2,\ 3,\ 4 \tag{25}$$
$$[\alpha_i\ A_j] = 0, \qquad i \neq j. \tag{26}$$

Four points A_i and four planes α_i satisfying these equations are said to form a *reciprocal system*.[12]

If the points A_i and the planes α_i form a reciprocal system, the dyadic

$$I = A_1\alpha_1 + A_2\alpha_2 + A_3\alpha_3 + A_4\alpha_4 \tag{27}$$

is an idemfactor. For equations (25), (26) show that

$$IA_i = A_i.$$

Since any point X can be expressed in the form

$$X = x_1A_1 + x_2A_2 + x_3A_3 + x_4A_4,$$

it follows that

$$IX = x_1A_1 + x_2A_2 + x_3A_3 + x_4A_4 = X.$$

If the antecedents are points lying in a plane or the consequents are planes passing through a point, the dyadic is called *singular*. Suppose B_1, B_2, B_3, B_4 lie in a plane. Then P_4 can be expressed as a linear function of P_1, P_2, P_3. Hence the dyadic

$$B\beta = B_1\beta_1 + B_2\beta_2 + B_3\beta_3 + B_4\beta_4$$

can be written in the form

$$B\gamma_1 = B_1\gamma_1 + B_2\gamma_2 + B_3\gamma_3. \tag{28}$$

12 The reciprocal system was fundamental in Gibbs' work on dyadics. See Gibbs-Wilson Vector Analysis. Also the paper by Wilson mentioned in note 3.

A similar result will be obtained if the planes β_i pass through a point. Hence any singular dyadic can always be expressed as the sum of three dyads. Conversely if the dyadic can be expressed in this form, it is evidently singular.

If X is the point of intersection of the planes $\gamma_1, \gamma_2, \gamma_3$ in (28)

$$B(\beta X) = 0.$$

If a one-three dyadic is singular there is then a point X such that $B\ (\beta X)$ is zero. Conversely, if there is such a point the dyadic is singular. For, if

$$B(\beta X) = B_1(\beta_1 X) + B_2(\beta_2 X) + B_3(\beta_3 X) + B_4(\beta_4 X) = 0$$

either $(\beta_1 X) = (\beta_2 X) = (\beta_3 X) = (\beta_4 X) = 0$ and the four planes pass through the point X, or the four points B_i satisfy a linear relation and so lie in a plane.

If a one-three dyadic Φ is not singular it has an inverse Φ^{-1} such that

$$\Phi\Phi^{-1} = I = \Phi^{-1}\Phi \tag{29}$$

is the one-three idemfactor. To show this, let

$$\Phi = B_1\beta_1 + B_2\beta_2 + B_3\beta_3 + B_4\beta_4.$$

Since B_1, B_2, B_3, B_4 do not lie in a plane, we can associate with them four planes $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ such that the points and planes form a reciprocal system. Similarly let C_1, C_2, C_3, C_4 form with $\beta_1, \beta_2, \beta_3, \beta_4$ a reciprocal system. Then

$$\begin{aligned} (\gamma_i B_i) &= (\beta_i C_i) = 1, \\ (\gamma_i B_j) &= (\beta_i C_j) = 0, \qquad i \neq j. \end{aligned} \tag{30}$$

Using these equations it is easy to show that

$$\Phi^{-1} = C_1\gamma_1 + C_2\gamma_2 + C_3\gamma_3 + C_4\gamma_4$$

has the required property. Also

$$\Phi^{-1}\Phi = I = \Phi\Phi^{-1}. \tag{31}$$

The quantity

$$(B\beta) = (B_1\beta_1) + (B_2\beta_2) + (B_3\beta_3) + (B_4\beta_4)$$

is called the *scalar* of the dyadic. It is evidently independent of the form in which the dyadic is written. For, if the B's and β's are expressed as linear functions of new elements B'_i and β'_i and so the dyadic is expressed in a new form, by the distributive law of outer multiplication, the scalar of the dyadic will at the same time be transformed into the scalar of the dyadic in the new form. The same conclusion follows also from the fact that the laws of the indeterminate multiplication are included among those of any distributive multiplication whose operations are commutative with multiplication by a scalar. Hence if an equation is satisfied by dyads, the equation will still be satisfied, if the indeterminate products are replaced by any such distributive products.

A function of a dyadic independent of the form in which the dyadic is written will be called an invariant if it is a scalar, a covariant if it is an extensive quantity or dyadic. In a similar way we define invariants and covariants of two or more dyadics.

If the scalar of the dyadic is zero it was shown by Pasch [13] that there exist certain tetrahedra such that each vertex passes, by the collineation, set up by the dyadic, into a point of the opposite plane and, conversely, if any such tetrahedron exists the scalar of the dyadic is zero.

The discussion of the three-one dyadic runs exactly similar to the one-three of which it is the conjugate. As an operator it gives also a collineation but in this case it is a collineation in planes instead of in points. If the antecedents α_i and the consequents A_i form a reciprocal system, the dyadic

$$\alpha A = -[\alpha_1 A_1 + \alpha_2 A_2 + \alpha_3 A_3 + \alpha_4 A_4] \tag{32}$$

is the three-one idemfactor.

The scalar of a three-one dyadic is the negative of the scalar of its conjugate (which is one-three) and consequently the vanishing of this scalar has the same signification.

12. **One-one and three-three dyadics.** A one-one dyadic has the form

$$BC = B_1C_1 + B_2C_2 + \ldots . + B_nC_n.$$

Since the points $B_1, B_2, \ldots . B_n$ can be expressed as linear functions of four, the dyadic can always be reduced to the form

$$BC = B_1C_1 + B_2C_2 + B_3C_3 + B_4C_4. \tag{33}$$

[13] Vollkommene Invariante, Math. Ann. Vol. 52, page 128.

Any four points not lying in a plane can be taken as antecedents or as consequents.

As an operator on planes the dyadic gives a correlation which transforms each plane ξ into a point

$$X = B(C\xi) = B_1(C_1\xi) + B_2(C_2\xi) + B_3(C_3\xi) + B_4(C_4\xi).$$

If ξ is the plane $[C_2C_3C_4]$,

$$(B_2\xi) = (B_3\xi) = (B_4\xi) = 0,$$

and

$$X = B_1(C_1C_2C_3C_4).$$

If then the consequents do not lie in a plane, the correlation transforms the planes of the tetrahedron $C_1\, C_2\, C_3\, C_4$ into the points B_1, B_2, B_3, B_4.

Since the antecedents and consequents of the one-one dyadic are extensive quantities of the same dimension it can be expressed as the sum of a self-conjugate and an anti-self-conjugate dyadic.

$$\Phi = \tfrac{1}{2}(\Phi + \Phi_c) + \tfrac{1}{2}(\Phi - \Phi_c). \tag{34}$$

We therefore consider these two types of dyadics first.

A self-conjugate one-one dyadic can be expressed in the form

$$BB = B_1B_1 + B_2B_2 + B_3B_3 + B_4B_4. \tag{35}$$

To show this, express the antecedents and consequents in terms of four points, A_1, A_2, A_3, A_4, not lying in a plane. The dyadic will then take the form

$$\Sigma\lambda_{ik}A_iA_k, \qquad i, k = 1, 2, 3, 4.$$

Since the dyadic is self conjugate

$$\Sigma\lambda_{ik}A_iA_k = \Sigma\lambda_{ik}A_kA_i.$$

Hence

$$\lambda_{ik} = \lambda_{ki}. \tag{A}$$

Consider the quadratic form

$$\Sigma\lambda_{ik}x_ix_k \tag{B}$$

where the x's are numbers. Four linear functions

$$y_n = \Sigma\mu_{nm}x_m \tag{C}$$

can be found such that

$$\Sigma\lambda_{ik}x_ix_k = \Sigma y_n^2. \tag{D}$$

Let

$$B_n = \Sigma \mu_{nm} A_m. \qquad \text{(E)}$$

Using these values, let

$$\Sigma B_n B_n = \Sigma \nu_{ik} A_i A_k. \qquad \text{(F)}$$

Since (F) is obtained from (E) in the same way that (D) is from (C) except that $A_i A_k$ is not equal to $A_k A_i$ we must have

$$\nu_{ik} + \nu_{ki} = \lambda_{ik} + \lambda_{ki} = 2\lambda_{ik}. \qquad \text{(G)}$$

Also, since the left side of (F) is symmetric

$$\nu_{ik} = \nu_{ki}. \qquad \text{(H)}$$

From (G) and (H) we get

$$\nu_{ik} = \lambda_{ik}.$$

Therefore (F) is equivalent to

$$BB = \Sigma B_n B_n = \Sigma \lambda_{ik} A_i A_k.$$

A self-conjugate dyadic represents a polarity. For the transform of a plane ξ is the point

$$X = B(B\xi) = B_1(B_1\xi) + B_2(B_2\xi) + B_3(B_3\xi) + B_4(B_4\xi). \quad (36)$$

This point is the pole of ξ with respect to the quadric surface

$$(B_1\xi)^2 + (B_2\xi)^2 + (B_3\xi)^2 + (B_4\xi)^2 = 0.$$

The points B_1, B_2, B_3, B_4 form a self-polar tetrahedron with respect to the quadric. For, the pole of the plane $[B_1 B_2 B_3]$, from (36), is

$$B_1(B_1B_1B_2B_3) + B_2(B_2B_1B_2B_3) + B_3(B_3B_1B_2B_3) + B_4(B_4B_1B_2B_3) = -B_4(B_1B_2B_3B_4).$$

Thus the pole of $[B_1B_2B_3]$ is the point B_4 and similarly with the other faces of the tetrahedron.

An anti-self-conjugate dyadic represents a null-system. For if,

$$BC = B_1C_1 + B_2C_2 + B_3C_3 + B_4C_4$$

is anti-self-conjugate,

$$\Sigma B_i C_i = -\Sigma C_i B_i = \tfrac{1}{2}\Sigma(B_i C_i - C_i B_i).$$

Hence

$$(\xi B)(C\xi) = \tfrac{1}{2}\Sigma\{(\xi B_i)(C_i\xi) - (\xi C_i)(B_i\xi)\} = 0.$$

For $(\xi B_i) = -(B_i\xi)$, $(\xi C_i) = -(C_i\xi)$ and since these products are numbers they are commutative. Since $(\xi B)(C\xi) = [\xi \cdot B(C\xi)]$, this shows that $B(C\xi)$ is a point in the plane ξ. Every plane ξ therefore passes by the correlation

$$X = B(C\xi)$$

into a point lying on ξ. The correlation is therefore a null-system.

As an operator on planes the anti-self-conjugate dyadic gives the same result as finding the poles of the planes with respect to the complex

$$p = \tfrac{1}{2}\{[B_1C_1] + [B_2C_2] + [B_3C_3] + [B_4C_4]\}$$

For

$$\begin{aligned}[p\xi] = \tfrac{1}{2}\Sigma[B_iC_i\xi] &= \tfrac{1}{2}\Sigma\{(\xi B_i)C_i - (\xi C_i)B_i\} = \\ &= \tfrac{1}{2}\{(\xi B)C - (\xi C)B\} \\ &= \tfrac{1}{2}\Sigma(B_iC_i - C_iB_i)\xi = \tfrac{1}{2}(BC - CB)\xi.\end{aligned}$$

This transformation therefore transforms each plane into its pole with respect to the complex p.

We have seen that any dyadic is the sum of two, one of which is self-conjugate representing a polarity, the other anti-self-conjugate representing a null system. The dyadic transforms any plane ξ into a point

$$B(C\xi) = \tfrac{1}{2}\{B(C\xi) + C(B\xi)\} + \tfrac{1}{2}\{B(C\xi) - C(B\xi)\}$$

on the line joining the points into which it is transformed by the polarity $\frac{1}{2}(BC + CB)$ and by the null-system $\frac{1}{2}(BC - CB)$.

With a one-one dyadic is associated a complex (or line)

$$p = [BC] = [B_1C_1) + [B_2C_2] + [B_3C_3] + [B_4C_4].$$

This is a covariant of BC as can be shown by the same argument used to show that the scalar of the one-three dyadic is an invariant. We shall call this the complex of the dyadic.

If BC transforms ξ into a point of η and η into a point on ξ, the intersection of ξ and η is a line of the complex p. For, if

$$(B(C\xi)\eta) = \Sigma(B_i\eta)(C_i\xi) = 0, \qquad \text{(A)}$$
$$(B(C\cdot\eta)\xi) = \Sigma(B_i\xi)(C_i\eta) = 0, \qquad \text{(B)}$$

then

$$(p\cdot\xi\eta) = \Sigma(B_iC_i\cdot\xi\eta) = \Sigma\{(B_i\xi)(C_i\eta) - (C_i\xi)(B_i\eta)\} = 0. \qquad \text{(C)}$$

Conversely, through each line of the complex pass pairs of planes that are transformed in this way. For, if $[\xi\eta]$ is a line of the complex and the transform of ξ is on η, (A) and (C) are satisfied and so (B) must be satisfied.

If
$$p = [BC] = \Sigma[B_iC_i] = 0, \tag{D}$$

the transform of η will always lie on ξ if that of ξ lies on η. This indicates a polarity. In fact, if $p = 0$, $(p\xi) = 0$ and so

$$\tfrac{1}{2}(BC - CB)\xi = 0$$

where ξ is any plane, since the dyadic $\frac{1}{2}$ $(BC - CB)$ gives the same transformation as the null system set up by p. Then it is easy to see

that
$$BC - CB = 0 \quad \text{or}$$
$$BC = CB.$$

The dyadic being self conjugate represents a polarity. In this case equation (D) shows that the four lines $[B_iC_i]$ belong to the same system of generators on a quadric. For it is a linear relation between four lines. *A polarity thus transforms the planes of any tetrahedron into the vertices of a second tetrahedron such that the lines joining corresponding vertices of the two tetrahedrons belong to the same set of generators on a quadric.*

In general two sets of four points B_i, and C_i can be found such that two one-one dyadics Φ and Ψ can be written in the form

$$\begin{aligned}\Phi &= B_1C_1 + B_2C_2 + B_3C_3 + B_4C_4,\\ \Psi &= \lambda_1B_1C_1 + \lambda_2B_2C_2 + \lambda_3B_3C_3 + \lambda_4B_4C_4,\end{aligned} \tag{36}$$

where the λ's are numbers. For, in general, there exists a set of four independent planes α_i which transform by both dyadics into the same set of four independent points B_i. If we take the C's as the vertices of the tetrahedron formed by the α's and properly choose the magnitudes of the B's, the dyadics will take the above forms.

If the planes of a tetrahedron C_1, C_2, C_3, C_4 transform into points B_1, B_2, B_3, B_4 such that the lines $[B_iC_i]$ belong to one system of generators of a quadric, the other system of generators of that quadric belong to p. For, if l is a generator of that second system, $(l\,B_iC_i) = 0$. Hence

$$(lp) = \Sigma(lB_iC_i) = 0,$$

and consequently l belongs to the complex p. We shall now show that such points B_i,C_i exist. We have just seen that two dyadics Φ, Ψ can be reduced to the form (36). This form shows that Φ

transforms the planes of the tetrahedron $C_1C_2C_3C_4$ into the points B_1, B_2, B_3, B_4. Now let Ψ represent a polarity. Then the lines $[B_iC_i]$ belong to a quadric. This shows that B_iC_i have the required property.

The three-three dyadic is the dual of the one-one. It transforms points into planes and can be expressed as a sum of four terms exactly dual to the one-one. Associated with each three-three dyadic

$$\alpha\beta = \alpha_1\beta_1 + \alpha_2\beta_2 + \alpha_3\beta_3 + \alpha_4\beta_4$$

is a covariant complex

$$p = [\alpha_1\beta_1] + [\alpha_2\beta_2] + [\alpha_3\beta_3) + [\alpha_4\beta_4].$$

As in case of the one-one dyadic it can be shown that if $\alpha\beta$ transforms a point A into a plane passing through B and the point B into a plane passing through A, then the line joining A and B is a line of the complex p.

13. **Two-three and two-one dyadics.** A two-three dyadic has the form

$$q\beta = \Sigma q_i\beta_i,$$

where the β's are planes and the q's are either lines or complexes. Since the planes can be expressed as linear functions of four not through a point, the dyadic can be written

$$q\beta = q_1\beta_1 + q_2\beta_2 + q_3\beta_3 + q_4\beta_4.$$

The consequents can be any four planes not passing through a point. The antecedents cannot, however, be assigned arbitrarily. For, the four complexes q_i in general have two lines l_1 and l_2 in common. We call these the singular lines of the dyadic. It is clear that $(l_1q)\beta = (l_2q)\beta = 0$.

As an operator on points the dyadic determines a transformation of points X into lines or complexes

$$p = q(\beta X) = \Sigma q_i(\beta_i X).$$

If the transform of X is a line,

$$(pp) = \Sigma(q_iq_k)(\beta_i X)(\beta_k X) = 0.$$

The points that are transformed into lines therefore lie on the quadric Q, whose equation is

$$\Sigma(q_i q_k)(\beta_i X)(\beta_k X) = 0.$$

Points on a generator of the quadric transform into lines any one of which is a linear function of any two others. Such a system of lines is a flat pencil. Hence the points of a generator transform into the lines of a flat pencil. If the quadric is not singular, take a skew quadrilateral on it and let β_1, β_2, β_3, β_4 be the planes determined by consecutive sides. Then q_1, q_2, q_3, q_4 will be lines for they correspond to the vertices of the quadrilateral (which are points of Q). Furthermore, q_1 and q_2 belong to a pencil and so intersect. Similarly q_2 intersects q_3 etc. The four lines therefore form a quadrilateral. If l is a diagonal of the quadrilateral it cuts all the lines q_i. Hence

$$(lq)\beta = 0.$$

The diagonals are therefore the same (being the singular lines of the dyadic) whatever quadrilateral β_1, β_2, β_3, β_4 is taken on the quadric Q. The flat pencils corresponding to points on a generator have their vertices on one of those diagonals and their planes pass through the other. All the generators of one system of Q give pencils with vertices on one diagonal, all those of the other system give pencils with vertices on the other diagonal.

Points of a plane transform into complexes with one system of generators on a quadric R in common. Points on the intersection of the plane with Q transform into the other system of generators of R. If the plane is tangent to Q, points on the intersection transform into lines of two plane pencils.

If Q degenerates into a cone, points on a generator still transform into the lines of a pencil. In case of the general quadric, the pencils corresponding to one system of generators have vertices on one line, those corresponding to the other system have vertices on another. In case of the cone, the two systems of generators coincide. Hence, the two lines on which the vertices lie, coincide. This line belongs to all the pencils and so is the transform of the vertex of the cone. In this case the four complexes q_1, q_2, q_3, q_4 have only one line in common.

Two points X, Y are harmonic with respect to Q if

$$\Sigma(q_i q_k)[(\beta_i X)(\beta_k Y) + (\beta_i Y)(\beta_k X)] = 0.$$

Since

$$\Sigma q_i \beta_i = \Sigma q_k \beta_k = \Phi = q\beta$$

this is equivalent to

$$[\Phi X \cdot \Phi Y] + [\Phi Y \cdot \Phi X] = 2[\Phi X \cdot \Phi Y] = 0.$$

This expresses that the complexes ΦX and ΦY that correspond to points harmonic with respect to the quadric Q are in involution. And conversely, if the complexes are in involution, the points are harmonic with respect to Q.

With a two-three dyadic

$$q\beta = \Sigma q_i\beta_i$$

is associated a point

$$P = \Sigma[q_i\beta_i].$$

This is a covariant of the dyadic. In order to obtain a geometrical interpretation for it suppose $\beta_1, \beta_2, \beta_3, \beta_4$ so chosen that the four points $[q_i\beta_i]$ lie in a plane. Then P (being a linear function of the points $[q_i\beta_i]$) lies in the same plane. That is, *if the vertices of a tetrahedron transform into four complexes such that the polar points of the opposite planes are four points in a plane, that plane passes through the point* P. That such tetrahedra $\beta_1, \beta_2, \beta_3, \beta_4$ exist can be shown as follows. Let

$$q\beta = q_1\beta_1 + q_2\beta_2 + q_3\beta_3 + q_3\beta_4.$$

If the points $[q_i\beta_i]$ satisfy a linear relation, the planes β_i have the required property. If not, at least one of the products $[q_i\beta_k]$, $i \neq k$, must be different from zero. Let $[q_4\beta_3]$ be different from zero. The dyadic can be written

$$q\beta = q_1\beta_1 + q_2\beta_2 + (q_3 - \lambda q_4)\beta_3 + q_4(\beta_4 + \lambda\beta_3).$$

Let α be the plane passing through $[q_1\beta_1]$, $[q_2\beta_2]$ and P. Since $[q_3\beta_3]$ and $[q_4\beta_4]$ are not equal $[q_4\beta_3]$ cannot equal both of them. Suppose $[q_3\beta_4]$ and $[q_4\beta_3]$ are different points. Then λ can be chosen such that $[q_1\beta_1]$, $[q_2\beta_2]$, $[(q_3 - \lambda q_4)B_3]$ and P lie in a plane. Since.

$$P = [q_1\beta_1] + [q_2\beta_2] + [q_3 - \lambda q_4)\beta_3] + [q_4(\beta_4 + \lambda\beta_3)]$$

this plane must pass through $[q_4(\beta_4 + \lambda\beta_3)]$. Hence $\beta_1, \beta_2, \beta_3, \beta_4 + \lambda\beta_3$ have the required property.

The discussion of the two-one dyadic can be taken by duality from the discussion of the two-three. The dyadic can be written in the form

$$qB = q_1B_1 + q_2B_2 + q_3B_3 + q_4B_4.$$

where the B's are any four independent points. The q's are not any four complexes but four that have two given lines in common. This dyadic transforms planes into lines or complexes. The planes which are transformed into lines envelope a quadric whose equation is

$$(q_i q_k)(B_i a)(B_k a) = 0.$$

Associated with the two-one dyadic is a covariant plane whose property is the dual of the covariant point of the two-three.

14. **Two-two dyadics.** A two-two dyadic has the form

$$rs = r_1 s_1 + r_2 s_2 + \ldots . r_n s_n,$$

the r's and s's being complexes (or lines). Since any complex can be expressed as a linear function of six that are linearly independent, the dyadic can be reduced to the form

$$rs = r_1 s_1 + r_2 s_2 + r_3 s_3 + r_4 s_4 + r_5 s_5 + r_6 s_6,$$

in which any six linearly independent complexes (or lines) can be taken as antecedents or consequents.

As an operator, the dyadic determines a transformation of complexes p into complexes

$$p' = r(sp) = \Sigma r_i(s_i p).$$

The lines that transform into lines belong to a quadratic complex g, consisting of lines p satisfying the equation

$$[r(sp) \cdot r(sp)] = 0.$$

Similarly, the complexes that transform into lines are the complexes p satisfying this quadratic equation.

The lines of the quadratic complex g transform into the lines of another quadratic complex g'. If two lines p and q of g intersect, the pencil of lines $p + \lambda q$ will, in general, transform into the pencil of complexes $p' + \lambda q'$. If, however, $p + \lambda q$ is the pencil of lines of g which lie in a singular [14] plane, $p' + \lambda q'$ will, for all values of λ, represent a line. Hence the lines in the singular planes of g transform into the lines in the singular planes of g'. It is to be noticed that the

14 In general the lines of a quadratic line complex which lie in a given plane envelope a conic. There are however ∞^2 planes in which these conics degenerate. These planes are called singular planes. See Jessop, page 89.

dyadic does not, in general, set up a contact transformation, i. e., intersecting lines do not, in general, go into intersecting lines. What we have shown is that the contact of pairs of lines in the singular pencils of g is preserved.

The lines of a pencil $p + \lambda q$, in general, transform into a pencil of complexes $p' + \lambda q'$. In this pencil are two special complexes that are lines. These correspond to the two lines of the pencil $p + \lambda q$ that belong to g. The lines of a plane transform into a two parameter linear system of complexes. The special complexes of this system are one system of generators on a quadric. These correspond to the lines of g which lie in the plane (and so envelope a conic). Similarly, the lines through a point go into a two parameter linear system of complexes whose quadric of singular elements corresponds to the cone of lines passing through the point and belonging to g.

Any two-two dyadic can be expressed as the sum of a self-conjugate and an anti-self-conjugate dyadic. For

$$rs = \Sigma r_i s_i = \tfrac{1}{2}\Sigma(r_i s_i + s_i r_i) + \tfrac{1}{2}\Sigma(r_i s_i - s_i r_i) = \tfrac{1}{2}(rs + sr) + \tfrac{1}{2}(rs - sr).$$

The first term is seen to be self-conjugate and the second term anti-self-conjugate.

A self-conjugate two-two dyadic is analogous to a polarity. For such a dyadic rs we have the relation

$$r(sp) = (pr)s.$$

Hence, if

$$(qr)(sp) = 0,$$

then

$$(pr)(sq) = 0,$$

that is, if p transforms into a complex (or line) in involution with q, then q transforms into a complex (or line) in involution with p.

Express rs in terms of six linearly independent complexes $q_1, q_2, \ldots q_6$,

$$rs = \Sigma a_{ik} q_i q_k.$$

If the dyadic is self-conjugate

$$\Sigma a_{ik} q_i q_k = \Sigma a_{ik} q_k q_i.$$

Hence

$$a_{ik} = a_{ki}.$$

Such a dyadic can always be reduced to the form

$$\lambda_1 p_1 p_1 + \lambda_2 p_2 p_2 + \ldots + \lambda_6 p_6 p_6$$

the p's being complexes or lines and the λ's numbers. This reduction can be accomplished by the same transformation that reduces the quadratic form

$$\Sigma a_{ik} x_i x_k \tag{A}$$

to a sum of squares. Suppose, in fact, the transformation

$$y_i = \Sigma \mu_{ik} x_k \tag{B}$$

reduces (A) to the form

$$\lambda_1 y_1^2 + \lambda_2 y_2^2 + \ldots . + \lambda_6 y_6^2. \tag{C}$$

When we replace the y's in (C) by the values from (B) and expand, the coefficient of $x_i x_k$ will be

$$a_{ik} + a_{ki}$$

as in (A). Now let

$$p_i = \Sigma \mu_{ik} q_k \tag{D}$$

Then

$$\lambda_1 p_1 p_1 + \lambda_2 p_2 p_2 + \ldots . + \lambda_6 p_6 q_6 \tag{E}$$

will be equal to rs. For when we replace the p's in (E) by their values from (D) and expand, the sum of the coefficients of $p_i p_k$ and $p_k p_i$ in the result (as in the case of the quadratic form) will be

$$a_{ki} + a_{ik} = 2a_{ik}.$$

Also from the symmetry of (E) it is clear that the coefficients of $p_i p_k$ and $p_k p_i$ will be equal. Hence each is equal to a_{ik} and so (E) is equal to rs. In the manipulation of the dyadic and the quadratic form the principal difference is that $x_i x_k = x_k x_i$ while $p_i p_k$ and $p_k p_i$ need not be equal. The above discussion shows that the reduction to the sum of squares does not require that the individual products be commutative but merely that the whole dyadic be self conjugate.

Any self-conjugate two-two dyadic can be expressed in the form

$$rs = \lambda(p_1 p_4 + p_4 p_1) + \mu(p_2 p_5 + p_5 p_2) + \nu(p_3 p_6 + p_6 p_3)$$

where $p_1, p_2 \ldots p_6$ are complexes (or lines) and λ, μ, ν numbers. To show this, first reduce rs to the form

$$rs = \lambda_1 q_1 q_1 + \lambda_2 q_2 q_2 + \ldots . + \lambda_6 q_6 q_6.$$

Then let

$$\begin{aligned} p_1 &= \sqrt{\lambda_1}q_1 + \sqrt{-\lambda_4}q_4 \\ p_4 &= \sqrt{\lambda_1}q_1 - \sqrt{-\lambda_4}q_4 \\ p_2 &= \sqrt{\lambda_2}q_2 + \sqrt{-\lambda_5}q_5 \\ p_5 &= \sqrt{\lambda_2}q_2 - \sqrt{-\lambda_5}q_5 \\ p_3 &= \sqrt{\lambda_3}q_3 + \sqrt{-\lambda_6}q_6 \\ p_6 &= \sqrt{\lambda_3}q_3 - \sqrt{-\lambda_6}q_6 \end{aligned}$$

Using these values it is readily seen that

$$rs = \tfrac{1}{2}(p_1p_4 + p_4p_1) + \tfrac{1}{2}(p_2p_5 + p_5p_2) + \tfrac{1}{2}(p_3p_6 + p_6p_3).$$

If none of the quantities $q_1, q_2, \ldots, q_6$ are zero this has the form required. If p_1 is zero we can replace it by any complex and let λ be zero in the expression

$$rs = \lambda(p_1p_4 + p_4p_1) + \ldots.$$

Hence every self-conjugate two-two dyadic can be reduced to this form, $p_1, p_2, \ldots p_6$ being complexes.

Every self-conjugate two-two dyadic can be expressed as the product of a dyadic and its conjugate. That is, if Ψ is any such dyadic, a dyadic $\Phi = rs$ can be found such that

$$\Phi_c\Phi = \Psi.$$

To show this reduce Ψ to the form

$$\Psi = \lambda(p_1p_4 + p_4p_1) + \mu(p_2p_5 + p_5p_2) + \nu(p_3p_6 + p_6p_3). \qquad \text{(A)}$$

Let $q_1, q_2 \ldots q_6$ be the edges of a tetrahedron, q_1 and q_4, q_2 and q_5, q_3 and q_6 being the pairs of non-intersecting edges. Choose the magnitudes of the q's such that

$$[q_1q_4] = [q_2q_5) = [q_3q_6] = 1.$$

Now let

$$\Phi = \mu_1q_1p_1 + \mu_2q_2p_2 + \ldots \mu_6q_6p_6.$$

Then

$$\Phi_c\Phi = \mu_1\mu_4(p_1p_4 + p_4p_1) + \mu_2\mu_5(p_2p_5 + p_5p_2) + \mu_3\mu_6(p_3p_6 + p_6p_3).$$

Comparison of this with (A) shows that we can make $\Phi_c\Phi = \Psi$ by choosing $\mu_1, \mu_2 \ldots \mu_6$ such that

$$\mu_1\mu_4 = \lambda, \qquad \mu_2\mu_5 = \mu, \qquad \mu_3\mu_6 = \nu.$$

By using the theorem just proved we can show that *the complex g of lines which are transformed into lines is a general quadratic complex,*

i. e. any quadratic complex consists of the lines thus transformed by some two-two dyadic. In fact q consists of all lines p satisfying the equation

$$[\Phi p \cdot \Phi p] = [p \Phi_c \cdot \Phi p] = [p \Psi p] = 0.$$

We have just shown that Φ can be determined such that Ψ is any self-conjugate two-two dyadic. Now any homogeneous quadratic equation in the Plücker coordinates of a line p can be written in the form

$$[p \, \Psi \, p] = 0$$

where Ψ *is a self-conjugate two-two dyadic.* Hence *any quadratic complex is the complex q of some two-two dyadic* Φ.

Suppose next, that Φ is an anti-self-conjugate two-two dyadic. Let $q_1, q_2 \ldots . q_6$ be six linearly independent complexes. Then Φ can be written

$$\Phi = \Sigma a_{ik} q_i q_k.$$

Since

$$\Phi = -\Phi_c$$

$$\Sigma a_{ik} q_i q_k = -\Sigma a_{ik} q_k q_i$$

whence

$$a_{ik} = -a_{ki}.$$

The dyadic can therefore be written

$$\Phi = a_{12}(q_1 q_2 - q_2 q_1) + a_{13}(q_1 q_3 - q_3 q_1) + a_{14}(q_1 q_4 - q_4 q_1) + \ldots$$

Suppose one of the coefficients a_{ik}, say a_{14}, is not zero. Let

$$\lambda_{14} p_4 = a_{12} q_2 + a_{13} q_3 + a_{14} q_4 + a_{15} q_5 + a_{16} q_6,$$

λ_{14} being an arbitrarily assigned number which is zero if the right side of the equation is zero. By using this equation eliminate q_4 from Φ and so reduce it to the form

$$\Phi = \lambda_{14}(q_1 p_4 - p_4 q_1) + \ldots .$$

In this form q_1 appears only in the term $q_1 p_4 - q_4 p_1$. The others contain q_2, q_3, q_4, q_5, q_6. Similarly, if q_2 occurs in more than one of the combinations $q_i q_k - q_k q_i$ a new complex can be introduced such that q_2 will appear in only one combination. Finally q_3 can be treated in the same way. The dyadic will then have the form

$$\Phi = \lambda_{14}(q_1 p_4 - p_4 q_1) + \lambda_{25}(q_2 p_5 - p_5 q_2) + \lambda_{36}(q_3 p_6 - p_6 q_3) + . \; .$$

Each of the remaining terms contains p_4, p_5, or p_6. A sum of terms

$$\lambda_{14}(q_1p_4 - q_4p_1) + \lambda_{24}(q_2p_4 - q_4p_2) + \ldots .$$

can be combined into a single term

$$\lambda_{14}(p_1p_4 - p_4p_1)$$

where

$$\lambda_{14}p_1 = \lambda_{14}q_1 + \lambda_{24}q_2 + \ldots . .$$

Hence the dyadic can be reduced to the form

$$\Phi = \lambda_{14}(p_1p_4 - p_4p_1) + \lambda_{25}(p_2p_5 - p_5p_2) + \lambda_{36}(p_3p_6 - p_6p_3).$$

The complexes $p_1, p_2 \ldots p_6$ can be taken linearly independent. If, for example, p_6 were a linear function of the others it could be replaced by this linear function and the dyadic would then be expressed in terms of 5 complexes, $p_1, p_2 \ldots p_5$. The above process would then reduce Φ to two terms instead of three. This is a special case in which one of the coefficients λ_{14}, λ_{25}, λ_{36} is zero.

An anti-self-conjugate dyadic Φ transforms any complex p into a complex in involution with p. For

$$\Phi p = p\Phi_c = - p\Phi.$$

Hence

$$[p\Phi p] = - [p\Phi p] = 0.$$

This expresses that Φp and p are in involution.

A very important type of two-two dyadic is that which gives the same transformation of lines and complexes as a point collineation or a point-plane correlation. The peculiarity of such a transformation is that it preserves contact, that is, it transforms intersecting lines into intersecting lines and complexes in involution into complexes in involution. If Φ is such a dyadic

$$\Phi p_1 \cdot \Phi p_2 = p_1\Phi_c\Phi p_2 = 0$$

whenever

$$p_1p_2 = 0.$$

These are linear equations in the coordinates of p_1 and p_2 such that the first is always satisfied when the second is. *Hence there must be a constant λ such that*

$$p_1\Phi_c\Phi p_2 = \lambda p_1p_2.$$

If I is the two-two idemfactor this is equivalent to

$$p_1[\Phi_c\Phi - \lambda I]p_2 = 0.$$

Hence

$$\Phi_c\Phi = \lambda I.$$

Conversely, if this condition is satisfied the dyadic determines a collineation or correlation.

If a collineation or correlation is set up by either a self-conjugate or an anti-self-conjugate dyadic, the transformation is an involution. For then

$$\Phi = \pm \Phi_c$$
$$\Phi_c\Phi = \lambda I.$$

Hence

$$\Phi^2 = \pm \lambda I$$

which shows that two applications of the transformation Φ gives identity. Hence Φ determines an involution.

II. Double Products.

15. The double product [15] of two dyads AB and CD is defined as

$$[AC]\ [BD].$$

In general this is a new dyad. If one of the factors $[AC]$, $[BD]$ is a scalar, it is however an extensive quantity. If both factors are scalars, the double product is a scalar.

The double product of two dyadics

$$AB = \Sigma A_iB_i$$
$$CD = \Sigma C_iD_i$$

is the sum of terms

$$AB : CD = \Sigma[A_iC_k]\ [B_iD_k] = [AC]\ [BD]$$

obtained by multiplying the two dyadics distributively. Since the products $[A_i C_k]$ and $[B_i D_k]$ are distributive, if the antecedents or the consequents of either dyadic are replaced by their values as linear

15 Gibbs-Wilson, Vector Analysis, page 306. Wilson's paper quoted above.

functions of other extensive quantities; the double product of the dyadics in the new form will be equal to that in the old. The double product is thus independent of the form in which the dyadics are expressed. Hence it is a covariant of the two dyadics.

The geometrical interpretation of the double product $[AC]$ $[BD]$ depends on whether $[BD]$, that is $[B_iD_k]$, is a progressive or a regressive product. Suppose $[BD]$ is progressive and X a space complementary to $[BD]$. Express X as a product of planes ξ_i,

$$X = [\xi_1\xi_2 \ldots \xi_m].$$

Divide the planes into two sets. Call the product of the planes in one set α_i and the product of the planes in the other set β_i and arrange the planes in the sets so that

$$X = [\alpha_i\beta_i].$$

If the sets are so chosen that β_i is complementary to D, the reduction formulas (§4) give

$$[DX] = \Sigma\alpha_i(D\beta_i),$$

the summation being for all combinations of the planes, $\xi_1\xi_2 \ldots \xi_m$ in sets α_i, β_i. Therefore

$$[AC]\,[BDX] = [AC]\,[B \cdot DX] = [AC]\Sigma(B\alpha_i)\,(D\beta_i).$$

This result can be written

$$[AC]\,[BDX] = \Sigma[A(B\alpha_i)C(D\beta_i)].$$

This shows that if α_i is transformed by AB and β_i by CD and if the transforms are then joined, $[AC]$ $[BDX]$ will be a linear function of the joins. This is true in whatever way X is expressed as a product of planes.

If $[BD]$ is regressive we proceed as before except that X is expressed as a product of points instead of planes. If B and D are of complementary dimensions, either points or planes may be used.

Suppose, for example,

$$AB = \Sigma A_iB_i, \qquad CD = \Sigma C_iD_i$$

A_i, B_i, C_i, D_i being points. Let L be any line and ξ_1, ξ_2, two planes through it. Transform ξ_1, by AB and ξ_2 by CD. The result is two points whose join is a line p. Transform ξ_2 by AB and ξ_1 by CD. Let the join of the corresponding points be q. Then $[AC]$ $[BD]$ transforms

L into a line or complex r such that r is a linear function of p and q. Hence p and q are polar with respect to r (see §5). This is true for every pair of planes ξ_1 and ξ_2 passing through L. *To find the complex or line into which* $[AC]$ $[BD]$ *transforms* L, *we therefore find the complex or line with respect to which* p *and* q *are polar whatever pair of planes are taken through* L.

As a second case consider a correlation AB and collineation $C\gamma$, A_i, B_i, C_i being points and γ a plane. The double product

$$[AC]\ (B\gamma)$$

is a complex or line. In this case $(B\gamma)$ is a number and so X must be a number. If P_1, P_2, P_3, P_4 are the four vertices of a tetrahedron we may take

$$X = (P_1P_2P_3P_4).$$

Transform P_1 by the collineation $C\gamma$ and the opposite plane $[P_2P_3P_4]$ by AB. Let the join of the resulting points be p_1. Proceed in the same way with the other vertices of the tetrahedron and the planes opposite them. *The above general discussion shows that* $[AC](B\gamma)X$, *and so,* $[AC](B\gamma)$ *is a complex or line belonging to the congruence determined by the four lines thus obtained. This is true for every tetrahedron* P_1, P_2, P_3, P_4.

As a final illustration consider the case of a one-one dyadic AB and a two-two dyadic pq, The double product

$$[Ap]\ [Bq]$$

is a three-three dyadic. Let X be any point and ξ_1, ξ_2, ξ_3 three planes through it. Let

$$R_1 = A(B\xi_1), \qquad r_1 = p(q_1\xi_2\xi_3).$$

The join of R_1 and r_1 is a plane $[R_1r_1]$. Permuting ξ_1, ξ_2, ξ_3 we get three such planes. The three planes intersect in a point. *By the above general discussion that point is on the plane into which* $[Ap]$ $[Bq]$ *transforms* X. *This is true for every set of three planes through* X.

16. **Double products with idemfactors.** In particular the double product of a dyadic Φ and an idemfactor is an invariant or covariant of Φ. This is a special case of the preceding general discussion. For example let $A\alpha$ be the dyadic determining the identical point collineation and let

$$\Phi = B\beta$$

represent any other point collineation. Then the double product

$$[AB]\ [\alpha\beta]$$

transforms any line L into a line or complex

$$L' = [AB](\alpha\beta\cdot L) = -[BA](\alpha\cdot\beta L).$$

Since $(\alpha\beta L)$ is a pure regressive product. Furthermore, this is equivalent to

$$-B\cdot A\alpha\cdot[BL] = -[B\cdot\beta L] = [BL\cdot\beta]$$

since $A\alpha$ is the idemfactor. This complex is determined as follows. Let X, Y be two points on L and X', Y' their transforms by Φ. Join X to Y' and Y to X'. Then by the general theorem of the preceding section L' is a linear function of the two lines thus obtained. That is, these lines are polar lines with respect to L'. This is true whatever pair of points X, Y are taken on L. This proves the following geometrical theorem. Let X, Y, Z be any three distinct points on L and X', Y' Z', three distinct points on any other line. A dyadic $B\beta$ can be found which will transform X, Y, Z into X', Y', Z'. Therefore the three pairs of lines XY', YX'; XZ', ZX'; YZ', ZY' are pairs of polar lines with respect to a complex, namely, the complex into which $[AB]$ $[\alpha\beta]$ transforms $[XY]$. This is the generalization of the theorem of Pappus for the hexagon inscribed in two lines in a plane.

The dyadic $[AB]$ $[\alpha\beta]$ will represent a collineation if and only if every line XY transforms into a line $X'Y'$ cutting it. The collineation $B\beta$ then gives a transformation of lines which is a null system. By §14 $B\beta$ then determines an involution.

We can write $B\beta$ in the form

$$B\beta = B[CDE] = B_1[C_1D_1E_1] + B_2[C_2D_2E_2] + B_3[C_3D_3E_3] + B_4[C_4D_4E_4].$$

Then

$$\begin{aligned}[AB]\ [\alpha\beta] &= [AB]\ [\alpha\cdot CDE].\\ &= [AB]\{(\alpha E)[CD] - (\alpha D)[CE] + (\alpha C)[DE]\}\\ &= -B\cdot A\alpha\cdot\{E[CD] - D[CE] + C[DE]\}\\ &= -[BE]\ [CD] + [BD]\ [CE] - [BC]\ [DE].\end{aligned}$$

This gives the dyadic in a form that does not involve the idemfactor. The result can be obtained from

$$B[CDE]$$

by a symbolic multiplication of B and CDE analogous to the outer product.

Again, let pq be the two-two idemfactor. Then

$$[Bp]\,[\alpha q]$$

is a three-three dyadic which transforms any plane ξ into a plane

$$\xi' = [Bp]\,(\beta q \cdot \xi) = B \cdot pq \cdot \beta\xi = [B \cdot \beta\xi]$$

To interpret this let X, Y, Z be any three non-collinear points on ξ and X', Y', Z' their transforms by $B\beta$. Join X' to YZ, Y' to XZ, Z' to XY. By the general theorem of the preceding section these planes intersect in a point on ξ'. This is true, whatever points X, Y, Z are taken on ξ. This involves the following geometrical theorem. Take four points X, Y, Z, W in a plane, no three of which are collinear, and four points X', Y', Z', W' in a second plane. A dyadic $B\beta$ can be found which will transform X, Y, Z, W, into X', Y', Z', W'. Joining the points X, Y, Z and X', Y', Z', W' as above we get a point. Similarly, Y, Z, W and Y', Z', W' determine a second point etc. In this way we get four points which lie in a plane, namely, in the plane into which $[Bp]\,[\beta q]$ transforms $[XYZ]$.

If we write $B\beta$ in the form

$$B\beta = B[CDE],$$

$$\begin{aligned}[Bp]\,[\cdot\beta q] &= [Bp]\{(qCD)E - (qCE)D + (qDE)C\}\\ &= B \cdot pq \cdot \{[CD]E - [CE]D + [DE]C\}\\ &= [BCD]E - [BCE]D + (BDE)C.\end{aligned}$$

This can be regarded as a symbolic product of B and $[CDE]$ analogous to the outer product.

Finally let αA be the three-one idemfactor. The double product of this and the dyadic $B\beta$ is

$$(b\alpha)\,(\beta A) = -\,b \cdot \alpha A \cdot \beta = -\,(b\beta).$$

When this is zero the scalar, or linear invariant, of the dyadic vanishes. When the double product of two dyadics vanishes, we shall call them *apolar*. To interpret this let A_1, A_2, A_3, A_4 be the vertices of a tetrahedron and α_1, α_2, α_3, α_4 the opposite planes. Let $B\beta$ transform A_1, A_2, A_3, A_4 into the points A_1'. A_2', A_3', A_4'. The general theorem states that $(A_1'\alpha_1)$, $(A_2'\alpha_2)$, $(A_3'\alpha_3)$, $(A_4'\alpha_4)$ will satisfy a linear relation.

If then three of these numbers are zero the fourth will be zero also. This is Pasch's theorem [16] that if a collineation represented by $B\beta$, with scalar invariant zero, transforms each of three vertices of a tetrahedron into a point of the opposite plane, it will transform the fourth vertex into a point of its opposite plane.

Let $A\alpha$ and $B\beta$ both be idemfactors and let $L = (XY)$ be any line. Then

$$\begin{aligned}[AB](\alpha\beta\cdot L) &= [AB](\alpha\beta\cdot XY)\\ &= [AB]\{(\alpha X)(\beta Y) - (\alpha Y)(\beta X)\}\\ &= A(\alpha X)\cdot B\beta\cdot Y + B(\beta X)\cdot A\alpha\cdot Y\\ &= [XY] + [XY] = 2L.\end{aligned}$$

Hence

$$[AB](\alpha\beta\cdot L) = 2L$$

and so

$$[AB]\,[\alpha\beta] = 2pq$$

where pq is the two-two idemfactor. *The double product of the one-three idemfactor with itself is thus twice the two-two idemfactor.*

The double product of the idemfactor $A\alpha$ and a one-one dyadic CD is the line or complex

$$[CA]\,[D\alpha] = -\,C\cdot A\alpha\cdot D = -\,[CD].$$

We have called this the complex of the dyadic. The general theorem states that if CD transforms the planes of the tetrahedron X_1, X_2, X_3, X_4 into the points Y_1, Y_2, Y_3, Y_4, the complex $[CD]$ is a linear function of the four lines $[X_1Y_1]$, $[X_2Y_2]$, $[X_3Y_3]$, $[X_4Y_4]$, that is, the two lines cutting these four lines belong to the complex $[CD]$.

The double product of the three-one idemfactor αA and a dyadic CD is

$$(C\alpha)[DA] = DC\cdot\alpha A = [DC] = -\,[CD].$$

The interpretation of this coincides with that given in §12.

If $[CD]$ is zero, the one-one dyadic CD represents a polarity. Thus the condition that a one-one dyadic represent a polarity *is that it be apolar with the one-three or three-one idemfactor.*

The double product of CD and the two-two idemfactor pq is the three-three dyadic

$$\Phi = [Cp]\,[Dq].$$

16 Loc. cit.

As an operator this determines a point plane correlation,

$$\xi = \Phi X = [Cp]\,[DqX] = C\cdot pq\cdot DX = [CDX].$$

This is the correlation which transforms each point X into its polar plane with respect to the complex $[CD]$. If CD represents a polarity $[CD]$ is zero and so the double product of CD and pq is zero. Hence *the condition that a correlation represent ,a polarity is that it be apolar with the two-two idemfactor.*

Let rs be any two-two dyadic. Symbolically we may write this

$$rs = [CD]\,[EF].$$

The double product of rs and the idemfactor $A\alpha$ is

$$\begin{aligned}[rA]\,[s\alpha] &= [CDA]\,[EF\cdot\alpha] \\ &= [CDA]\,[(E\alpha)F - (F\alpha)E] \\ &= CD\cdot A\alpha\cdot\{FE - EF\} \\ &= CD\cdot\{FE - EF\} \\ &= [CDF]E - [CDE]F.\end{aligned}$$

This result has the same form as the product $[CD\cdot EF]$ where C, D, E, F, are points in a plane. The dyadic determines a collineation which transforms a plane ξ into the plane

$$\eta = [rA](s\alpha\xi) = -\,[r\cdot s\xi].$$

To interpret this collineation geometrically let rs transform the sides $[A_2A_3]$, $[A_3A_1]$, $[A_1A_2]$ of a triangle in ξ into the complexes p_1, p_2, p_3 respectively. Let

$$\alpha_1 = [A_1p_1]$$

be the polar plane of A, with respect to p_1 and similarly let

$$\alpha_2 = [A_2p_2],\ \ \alpha_3 = [A_3p_3].$$

The general theorem states that $\alpha_1, \alpha_2, \alpha_3$, will intersect on η. The fact that this is true whatever points A_1, A_2, A_3, A_4 are taken on ξ proves a geometrical theorem. Suppose for example rs represents a collineation. By such a collineation four non collinear points A_i of one plane could be transformed into any four non-collinear points B_i of another plane. Join A_1 to $B_2\,B_3$, A_2 to $B_3\,B_1$, and A_3 to $B_1\,B_2$. The three planes intersect in a point. Similarly A_2, A_3, A_4 and

B_2, B_3, B_4 determine a second point, etc. The four points thus obtained lie in a plane.

The double product of the one-two dyadic $B[CD]$ and the three-one idemfactor $A\alpha$ is the two-one dyadic

$$\begin{aligned}\Phi &= [BA]\,[CD\cdot\alpha]\\ &= [BA]\{(C\alpha)D - (D\alpha)C\}\\ &= B\cdot A\alpha\cdot\{DC - CD\}\\ &= [BD]C - [BC]D.\end{aligned}$$

To interpret this let $B[CD]$ transform the lines YZ, ZX, XY of a plane ξ into the points X', Y', Z' respectively. Then Φ will transform the plane ξ into a complex

$$[BD](C\xi) - [BC](D\xi)$$

which is a linear function of the three lines XX', YY', ZZ'. Hence the complex contains the quadric of these lines. If we take four points X, Y, Z, W of ξ four quadrics will thus be determined which all belong to the same complex. In this case the lines of the four point will transform into points of a four line in another plane. Since the dyadic can be so determined that this four line is arbitrary, this shows that if the corresponding triangles of a four point in one plane and a four line in another plane are joined as above the four quadrics determined will belong to a complex.

If

$$[BCD] = 0,$$
$$[CD](B\xi) + [DB](C\xi) + [BC](D\xi) = 0$$

for every plane ξ. Hence

$$[CD]B = [BD]C - [BC]D$$

which shows that in that case the dyadic Φ is the conjugate of $B[CD]$.

The double product of $B[CD]$ and αA is the plane of the dyadic

$$(B\alpha)[CDA] = [BCD].$$

Let p_1, p_2, p_3 be three lines intersecting in a point of this plane. If p_3 transforms into a point of the plane $p_1\,p_2$ and p_2 into a point of p_3, p_1, the general theorem shows that p_1 will transform into a point of the plane p_2p_3. If $[BCD] = 0$ this will be true of any three lines intersecting in a point.

The double product of $B[CD]$ and the two-two idemfactor pq is

$$[Bp][CDq] = [BCD].$$

17. **Dyadics apolar to all the idemfactors.** If the double product of rs and $A\alpha$ is zero, we may consider rs as analogous to a polarity. In that case, if

$$\begin{aligned} rs &= [CD][EF] \\ [rA][\alpha s] &= [CDF]E - [CDE]F = 0 \end{aligned}$$

and hence

$$[CDF|E = [DCE|F, \tag{A}$$

Let X, Y be any two points. Then by direct expansion we get

$$\begin{aligned} (XYEF)[CD] = (XYCD)[EF] &+ (CDEF)[XY] \\ - (XCDE)[YF] &- (YCDF)[XE) \\ + (XCDF)[YE] &+ (YCDE)[XF]. \end{aligned}$$

But from (A) we have

$$(CDFE) = (CDEF) = 0,$$

Also

$$\begin{aligned} (XCDF)[YE] &= (XCDE)[YF], \\ (YCDF)[XE] &= (YCDE)[XF]. \end{aligned}$$

Hence

$$(XYEF)[CD] = (XYCD)[EF].$$

Since this is true for all value of X and Y

$$[EF][CD] = [CD][EF].$$

The dyadic is therefore self conjugate and its scalar vanishes. Conversely, if these conditions are satisfied it is easy to show that rs is apolar to the one-three, the three-one and the two-two idemfactors. It is thus apolar to all the idemfactors.

The double product of two polarities is apolar to all the idemfactors. For let CD and $C'D'$ be two polarities. Then

$$[CD] = [C'D'] = 0.$$

Hence, if $A\alpha$ is the one-three idemfactor

$$\begin{aligned} [CC' \cdot A][DD' \cdot \alpha] &= [CC'A]\{(D\alpha)D' - (D'\alpha)D\} \\ &= - [CC'D]D' + [CC'D']D = 0, \end{aligned}$$

which shows that $[CC'] [DD']$ is apolar to $A\alpha$. It follows that it is also apolar to αA and pq.

We have already noted that a one-one dyadic which represents a polarity is apolar to all the idemfactors. The same is true of a three-three dyadic.

If rs is apolar to the idemfactors, the double product of rs and a one-one polarity CD is apolar to the idemfactors. For

$$[Cr \cdot Ds] = [(Cr \cdot s)D] - (Cr \cdot D)S = 0$$

Similarly we can show that the double product of rs and a three-three polarity is apolar to the idemfactors.

If rs is apolar to the two-two idemfactor pq, its scalar

$$(rp)(sq) = (rs) = 0.$$

In this case the general theorem states that if rs transforms each of five edges of a tetrahedron into a complex to which the opposite edge belongs, the same will be true of the sixth.

We have thus shown that *if any dyadic is apolar to the one-three or three-one idemfactor, it is apolar to all the idemfactors and, excepting the case of the two-two apolar to the two-two idemfactor, if a dyadic is apolar to any idemfactor it is apolar to all. Furthermore, if two dyadics are apolar to all the idemfactors their double product (if it is a dyadic) is also.*

18. **Dyadics symbolically derived from a given dyadic.** If we write a one-three dyadic symbolically in the form

$$B[CDE]$$

we have seen that its double product with the one-three and the two-two idemfactors are

$$-[BC][DE] + [BD][CE] - [BE][CD]$$

and

$$[BCD]E - [BCE]D + [BDE]C$$

respectively. These can be considered as obtained by a sort of symbolic multiplication of B and CDE analogous (except for a possible change of sign) to the outer multiplication.

Similarly, from any dyadic a series of dyadics are obtained. These are all double products of the original dyadic with the various idemfactors.

In a somewhat similar way from a line $[BC]$ we get a dyadic

$$CB - BC.$$

This is the product

$$\begin{aligned} A[\alpha \cdot BC] &= A\{(\alpha C)B - (\alpha B)C\} \\ &= A\alpha \cdot C \cdot B - A\alpha \cdot B \cdot C = CB - BC. \end{aligned}$$

This shows that if

$$[BC] = [DE]$$

then

$$BC - CB = DE - ED.$$

In this discussion $[BC]$ and $[DE]$ may be complex lines or simple lines. If $[BC]$ is a complex, the dyadic $BC - CB$ gives the plane-point polar transformation with respect to the complex.

Similarly, from a plane $[BCD]$ we get two dyadics

$$A[\alpha \cdot BCD] = B[CD] - C[BD] + D[BC]$$

and

$$[BCD \cdot \alpha]A = [CD]B - [BD]C + [BC]D.$$

The first of these as an operator on lines gives the point in which the line cuts the plane. The second as an operator on planes gives the line in which $[BCD]$ cuts the plane.

Those same dyadics are also obtained by multiplying the plane $[BCD]$ with the idemfactor pq.

In the same way by considering a point as the product of three planes, two dyadics can be determined.

19. **Double products of dyadic with themselves.** The double product of a one-three dyadic

$$B\beta = B'\beta'$$

with itself is a two-two dyadic

$$[BB'] [\beta\beta']$$

which gives the transformation of lines determined by the transformation $X' = b(\beta X)$ of points. For, if $b\beta$ transforms X, Y into X', Y', then $[BB'] [\beta\beta']$ transforms the line $[XY]$ into a linear function of $[X'Y']$ and $[Y'X']$, that is, into the line $[X'Y']$.

Similarly, the triple product

$$[BB'B''] [\beta\beta'\beta'']$$

of $B\beta$ with itself represents the same transformation as an operator on planes. For, if $B\beta$ transforms three points X, Y, Z into X', Y', Z', then

$$[BB'B''] [\beta\beta'\beta''] = B\beta : [B'B''] [\beta'\beta'']$$

transforms the plane $[XYZ]$ into a linear function of the planes $[X'Y'Z']$, $[Y'Z'X']$, etc., that is into the plane $[X'Y'Z']$.

In the same way it is easily shown that the double and the triple product of a one-one dyadic with itself determine the same transformation in lines and in points.

The double product of a one-two dyadic with itself is zero. For, if $Ap = A'p'$,

$$[AA'](pp') = [A'A](p'p) = -[AA'](pp').$$

Since the double product is equal to its negative, it is zero. The same is true of the double product of a two-three dyadic with itself.

20. **Hamilton-Cayley equations.** It has been shown by various writers that a one-three or a three-one dyadic in three dimensions satisfies an algebraic equation of the fourth degree called the Hamilton-Cayley equation [17] of the dyadic.

That the two-two dyadic satisfies an equation of the sixth degree might be inferred from the fact that the transformation set up by a two-two dyadic in three dimensions can be interpreted as a transformation of points in a space of five dimensions. In general, there will then be six linearly independent complexes left invariant by the dyadic. Taking these as prefactors, the dyadic can be written

$$\Phi = rs = \lambda_1 p_1 q_1 + \lambda_2 p_2 q_2 + \ldots + \lambda_6 p_6 q_6.$$

Since

$$r(sp_1) = \mu p_1,$$

where μ is constant, it follows that

$$(p_1 q_2) = (p_1 q_3) = \ldots = (p_1 q_6) = 0.$$

Thus each p is in involution with all the q's except the one associated with it. If the p's and q's are lines, this is the configuration called a double six. In general we may call it a double six of complexes.

17 Whitehead's Universal Algebra, page 261. Bôcher's Introduction to Higher Algebra, Chapter XXII.

If I is the two-two idemfactor, it is easily seen that

$$\{\Phi - \lambda_1(p_1q_1)I\} \cdot p_1 = 0.$$

Similarly,

$$\{\Phi - \lambda_2(p_2q_2)I\} \cdot p_2 = 0,$$

etc. Consider the product

$$\Psi = \{\Phi - \lambda_1(p_1q_1)I\}\{\Phi - \lambda_2(p_2q_2)I\} \ldots \{\Phi - \lambda_6(p_6q_6)I\}.$$

It is clear that

$$\Psi p_6 = 0.$$

Since Ψ and I are commutative, any factor could be put last. Hence

$$\Psi p_1 = \Psi p_2 = \ldots = \Psi p_6 = 0.$$

Since $p_1 \ldots p_6$ on assumed linearly indepedent,

$$\Psi \equiv 0.$$

When expanded this has the form

$$A_0\Phi^6 + A_1\Phi^5 + \ldots + A_3 - \Phi + A_6 I = 0.$$

This is the Hamilton-Cayley equation satisfied by the dyadic.

That a polynomial equation is satisfied by any dyadic whose prefactors and postfactors on dual may be shown in the following way. Let R_i and S_k be dual. Let $R_i \ldots R_n$ be linearly independent and let $S_1 \ldots S_n$ be linearly independent. Suppose

$$\Phi = \Sigma A_{ik} R_i S_k,$$
$$\Psi = \Sigma b_{ik} R_i S_k$$

are commutative. Then

$$\Phi\Psi - \Psi\Phi = \Sigma b_{ik}(\Phi R_i)S_k - A_{ik}(\Psi R_i)S_k = 0.$$

Since the S'^s are linearly independent, the coefficient of S_k in this equation is zero. That is,

$$\begin{aligned} &b_{1k}(\Phi R_1) - a_{1k}(\Phi R_1) + \ldots + b_{nk}(\Phi Rn) - A_{nk}(\Psi R_n) \\ &= (b_{1k}\Phi - A_{1k}\Psi) \cdot R_1 + \ldots + (b_{nk}\Phi - A_{nk}\Psi) \cdot R_n = 0. \end{aligned}$$

There on n such equations. Eliminating $R_2 \ldots R_n$ as in solving algebraic equations, we get

$$0 = \Delta \cdot R_1 = \begin{vmatrix} b_{11}\Phi - a_{11}\Psi, & b_{21}\Phi - a_{21}\Psi, & \ldots, & b_{n1}\Phi - a_{n1}\Psi \\ b_{12}\Phi - a_{12}\Psi, & b_{22}\Phi - a_{22}\Psi, & \ldots, & b_{n2}\Phi - a_{n2}\Psi \\ \ldots & \ldots & \ldots & \ldots \\ b_{1n}\Phi - a_{1n}\Psi, & \ldots & \ldots & b_{nn}\Phi - a_{nn}\Psi \end{vmatrix}.$$

Similarly,

$$\Delta \cdot R_2 = \Delta \cdot R_3 = \ldots = \Delta \cdot R_n = 0.$$

Since $R_1, \ldots R_n$ on linearly independent,

$$\Delta = 0.$$

when expanded this has the form

$$A_0\Phi^n + A_1\Phi^{n-1}\Psi + \ldots + A_{n-1}\Phi\Psi^{n-1} + A_n\Psi^n = 0.$$

The coefficient A_0 is the discriminant of Ψ, and A_n that of Ψ. Hence, if either of the dyadics is non-singular, the coefficients do not all vanish. In particular, if Ψ is an idemfactor, the equation becomes

$$A_0\Phi^n + A_1\Phi^{n-1} + \ldots + A_{n-1}\Phi + A_nI = 0.$$

This is the Hamilton-Cayley equation satisfied by Φ.

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POST-GLACIAL HISTORY OF BOSTON.

By Hervey W. Shimer.

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CONTENTS.

Introduction.

The time from the close of the Glacial Period, from the melting back of the glaciers which lately covered this region, to the present, is full of interest. For it is this post-glacial time which tells us of our own immediate past; it tells us of the recovery by organisms of the uninhabited glacier-covered lands. It gives us the history of these organisms and through them of the topography and climate of the region. The records of these organisms, in the Boston area, are mainly preserved in the mud deposited here during this time. This mud was partly laid down in shallow fresh-water swamps but mostly in sea-water, in inlets from the ocean. Naturally the majority of these records consist of the remnants of plants, and especially of shells, though there are also one or two records of early man.

One of the earliest persons to make a broad study of the post-glacial fossil shells of Boston was Miss D. L. Bryant (1). This subject formed the theme of her graduating thesis in geology in 1891 at the Massachusetts Institute of Technology; it was pursued under the efficient help of Professor W. O. Crosby. Unfortunately it was never published. Later on during the same year, however, Mr. Warren Upham (3) used Miss Bryant's principal facts and conclusions (for which he gave full credit) in the preparation of a paper on the "Recent fossils of the Harbor and Back Bay, Boston." This is an excellent little pamphlet full of information concerning these Post-Pleistocene fossils. In 1903 Professor W. O. Crosby (2) discussed the bed rock of this area with reference to the pre-glacial drainage, the deposition and subsequent erosion of the blue glacial clay and the deposition of the silt.

In the preparation of the present paper we have drawn freely from these three pamphlets. The notes and the additions here made to the lists of species from Muddy River, Charles River and City Point, as published by Warren Upham, are based on specimens in the Boston Society of Natural History and the Massachusetts Institute of Technology, unless otherwise stated; these were largely collected by the late Professor Henry W. Haynes. The principal original contribution in this paper, however, regards the Back Bay region of Boston. The recent excavation of the Boylston Street Subway* of the Boston Elevated Railway Company gave many sections down through the Post-Glacial mud to the Glacial clay. These sections and their included organic remains proved so interesting that this record of them was kept.

I wish to express my indebtedness to the following,— to the various officers in charge of the Boylston Street Subway excavations, who were always most courteous and helpful, especially to Messrs. L. S. Stone, J. H. O'Connor, J. T. Frame, and F. H. Eichorn; to Mr. C. W. Johnson, Curator of the Boston Society of Natural History, for giving me opportunity to study the Muddy River, Charles River and City Point fossils in the Society's collection, as well as for identification of some species and aid in the revision of the nomenclature; to Mr. F. N. Balch for permission to make use of his notes upon early colonial records of shell-fish; to Rev. H. W. Winkley for his kindness in comparing our specimens of the Pyramidellidae with those in his large private collection; to Mr. Wm. F. Clapp of the Museum of Comparative Zoölogy for his helpful criticism, and especially for his discovery and description of the minute new species of Vitrinella; to Mr. G. B. Reed of Harvard University for examination of the peat; to Dr. Willoughby, Curator of Peabody Museum, Harvard University, for information concerning the fishweir found in the Boylston Street Subway and for suggestions on the comparison of this wood with that used by early man elsewhere; and to the Bostonian Society for permission to make a copy of the DeCosta map (1775) of Boston and vicinity, now in the Old State House.

The sections are arranged in order from that of Muddy River (section 1) at the west to that of City Point (section 7) at the east (see map).

Description of Sections.

1. **Muddy River,** from Brookline northeastward. The collections here were made mostly from a trench, averaging 16 feet in depth, extending along Muddy River from Brookline to Longwood and then

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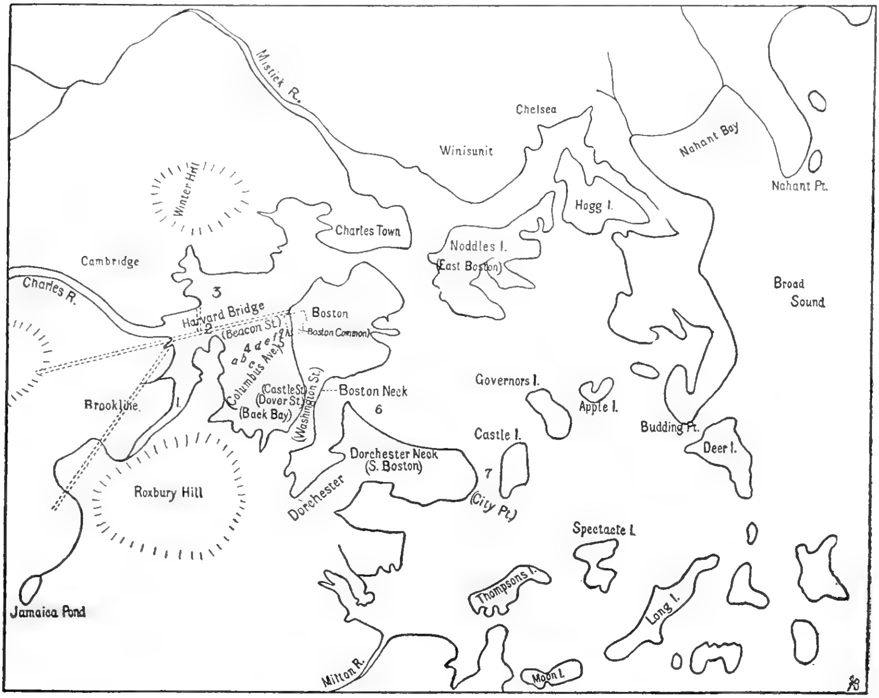
* Completed in 1914.

northeast to Charles River. The generalized section in this region from above downwards is as follows *:—

1. Alluvium, — 5 feet at the Longwood Bridge to 12 feet elsewhere.
2. Peat,— averaging one-foot in thickness, containing stalks



Boston and vicinity in colonial time. The De Costa map, 1775, (reproduced by permission of the Bostonian Society) forms the basis of the above sketch map. The dotted parallel lines, exclusive of those showing Harvard (Technology) Bridge, indicate the dams built by the Boston and Roxbury mill corporation. The numbers 1 to 7 refer to the sections described in this paper.

of swamp plants, leaves of deciduous trees, and some shells,— mostly Modiolus demissus var. plicatulus, embedded in some sand and much mud.

3. Silt,— (no thickness given). Most of the shells noted in the table below occur in this stratum immediately beneath the

* Arranged from Miss Bryant's thesis.

peat bed, crowded thickly together. The shells range almost to the Boston and Albany Railroad station in Brookline; there are none to the southwest of this.

4. Eroded sand plain (a glacial deposit). At the Longwood Bridge the sand plain had been eroded to a depth of 37 feet before the deposition of the five feet of alluvium.

2. **Charles River,** directly east of the Harvard (Technology) Bridge extending between Back Bay and Cambridge. During the dredging here to fill in the shallows on the Cambridge side between the newly constructed wall along the river and the railroad tracks, many shells were found. These shells occurred mostly in the sands and not in the superficial muds. These sands were some ten feet below mean low tide. The height of the tide here, before its obliteration by the dam, was ten feet.

The most conspicuous species are the large and abundant forms of oyster (Ostrea virginica), short-neck clam (Venus mercenaria), long-neck clam (Mya arenaria) and scallop (Pecten gibbus borealis). A small oyster shell is unusual, the average size being 8 by 2.5 inches; one figured by Miss Bryant had a length of 10.5 inches.

During early colonial days (middle of the seventeenth century) an extensive oyster-bank existed here, preventing large boats from going farther up the Charles. (See p. 451).

3. **New Tech Site.** The new site for the Massachusetts Institute of Technology occupies the northeastern angle between Charles River and Massachusetts Avenue. The many bore-holes put down here while the foundations of the new buildings were being planned showed that the solid rock bottom varied much in depth. The following is one of the deeper sections,—

1. Fine and coarse sand, much of it colored green; 35 feet. Unidentifiable fragments of fossils were present in the material brought up by the wash-drill.
2. Soft to stiff blue clay (a glacial deposit); 83 feet.
3. Decomposed bed-rock of slate; 14 feet. The boring stopped in the slate at a depth of 132 feet.

4. **Boylston Street Subway** localities. The sections were made at or very near the junction with the following streets:

a. Fairfield Street. The top of the peat is 18 feet below mean low tide; the peat is 5 feet thick.

b. Exeter Street.— The surface of the street here is 16.5 feet above mean low tide, while the bottom of the peat bed is 15.5 feet below mean low tide.

		Feet
1.	Fill, in blotting out the Back Bay This fill has taken place mostly since 1868.	16
2.	Gravelly black silt. Few fossils	6
3.	Fine black silt. Many fossils The middle portion is very full of fossils; the uppermost two feet and the lowest foot contain but few. This silt is a dark-grey (when dry) argillaceous sand with a considerable number of mica scales. The compound microscope shows that very minute sand particles made up fully nine-tenths of the mass; there is merely sufficient clay and carbon particles to give consistency and a dark-grey color to the sediment.	5
4.	Sandy, fresh-water peat	5
5.	Blue sandy clay with some peat This is the upper edge of the glacial deposit.	1

c. Copley Plaza Hotel, on Copley Square at corner of Dartmouth Street and Huntington Avenue. During the excavations for the foundations Mr. C. W. Johnson obtained, at a depth of 25 to 30 feet below the street surface, Mya arenaria and Macoma balthica, both similar to the Exeter Street forms. The silt in which they occurred was similar in color and composition to that of Exeter Street,— 4b3.

At Dartmouth Street in the Subway the upper ten feet of blue clay (beneath the black silt) was so hard that a pickax could penetrate it only with difficulty; below that it gradually became quite soft. This hardening was probably due to the oxidation of the surface and the deposition of iron as cement upon exposure to air. The presence of ancient gullies in the surface of the clay encountered at various places in the subway also points to this subaerial exposure.

d. Clarendon Street. At a depth of 25 feet below the surface of the street were found,—

Mulinia lateralis c
Macoma balthica c
Gemma gemma c
Ilyanassa obsoleta c

These forms are all like those from the Exeter Street locality and occur in a similar silt.

e. Berkeley Street. Surface of street is about 16 feet above low tide.

		Feet
1.	Fill, blotting out the Back Bay	19
2.	Dark grey loamy silt, prominently stratified	12

a. Upper 8 feet contained

Mya arenaria c. Large.
Ensis directus C.
Mulinia lateralis
Gemma gemma
Modiolus demissus, var. plicatulus r.
Ostrea virginica c, but comparatively small, including both current and quiet water forms. These were noted directly beneath the fill. On account of the absence of oysters between this and the stratum of large current oysters below, it is believed that these smaller oysters did not grow here but are due to man's agency.
Mytilis edulis r
Ilyanassa obsoleta r
Balanus cf. balanoides r

b. Lower 4 feet contained

Ostrea virginica C; similar to the very large current forms so common at the Charles River locality.
Venus mercenaria c
Mulinia lateralis C
Gemma gemma C
Littorina palliata c
Ilyanassa obsoleta C
Nassa trivittata r
Polinices heros r
Crepidula plana r
C. fornicata r
Cliona sulphurea r. Noted on oyster shells.
Crab claws r
Fish vertebra R

Besides these, Macoma balthica was abundant, but its exact position in 2 was not noted.

3. Blue glacial clay, at a depth of 31 feet. No unconformity was observed in the ten foot wide section studied.

To the west of Berkeley Street, nearly in front of the Rogers Building (M. I. T.) occurred sticks in both vertical and horizontal positions, apparently a portion of an old fish-weir. The length of the vertical ones varied according to different observers from four to seven feet. They usually penetrated the blue clay, one to a depth of eighteen inches. Taking Mr. L. S. Stone's estimate of the greater length of seven feet, there would be from six to seven feet of silt above the sticks. For a consideration of their age there must be added to this the thickness deposited between the driving of the sticks and the deposition of sediment over their decaying ends. The wood testifies to its great age in being exceedingly brittle and very heavy, showing that a certain amount of petrifaction had occurred. Its very dark, almost black, color indicates, likewise, considerable carbonization.

f. Arlington Street.

		Feet
1.	Fill	16
2.	Black silt	5
	A few shells are reported from near the top of this.	
3.	Boulder clay	17
	The boulders are well rounded, and are more numerous at the bottom of the section, where they make up fully one-half of the sediment. The boulders are usually two to three inches in diameter; the largest noted had a diameter of three feet, with corners all well rounded. This clay was not penetrated farther up Boylston Street.	

g. Church Street. At some thirty feet below the surface of the street (which is here fifteen feet above low tide) a tree stump was excavated from near the top of a peat bed. The peat continued eighteen feet below the stump. The stump was reported as uncarbonized. Apparently another tree was encountered in a wash-boring near here.

h. Charles Street. At the Public Garden side of Charles and Boylston streets a boring penetrated a peat bed 27.5 feet thick. The bottom of the peat is 42 feet below the surface of the street, which is here 15 feet above low tide.

5. **Site of Old Providence Depot.** The following were found while excavating Providence Street:*

Mya arenaria r. Small
Ilyanassa obsoleta C.
Littorina rudis r.

6. **Commonwealth Flats, South Boston.** Peat was encountered here 20 feet below low tide.†

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* Collected by Mr. E. L. Green.
† Communicated by Mr. R. W. Sayles.

7. **City Point, South Boston.** To form the Marine Park here mud was dredged from midway between Castle Island and the old City Point shore, being dumped at the edge of the latter. In this mud occurred the shells noted in the table below. The dead appearance of most shells leaves no doubt as to their fossil condition, though the excavation went to a depth of only a few feet.

List of Species.

The following list includes all post-glacial fossils noted, or listed by previous observers, from Brookline through Back Bay, Boston, to City Point.

	Species x — Present C — Very common c — Common r — Rare R — Very rare	Muddy River	Charles River	Exeter Street	Berkeley Street	City Point
1.	Plants (unrecognizable fragments)	x		x		
	Foraminifera *					
2.	Polystomella striatopunctata			x		
3.	P. sp.			x		
4.	Trochammina inflata			x		
	Spongia					
5.	Cliona sulphurea			r	r	R
	Bryozoa					
6.	Membranipora pilosa			r		
	Pelecypoda					
7.	Yoldia limatula					x
8.	Ostrea virginica	x	C	R	c	C
9.	Pecten gibbus borealis	R	C			C
10.	P. magellanicus					x
11.	Anomia simplex					c
12.	Mytilus edulis					x
13.	Modiolus modiolus			R		x
14.	M. demissus var. plicatulus	x	x	r	r	x
15.	Clidophora trilineata					x
16.	Arctica islandica					x
17.	Cyclocardia borealis					x
18.	Astarte undata					x
19.	A. elliptica					x
20.	Lucina filosa					x
21.	Kellia planulata					x
22.	Laevicardium mortoni					x
23.	Venus mercenaria	x	C		c	C
24.	Gemma gemma			C	C	x
25.	Petricola pholadiformis					x
26.	Macoma balthica	C	x	C	c	x

* Identified by J. A. Cushman.

Species x — Present C — Very common c — Common r — Rare R — Very rare	Muddy River	Charles River	Exeter Street	Berkeley Street	City Point
27. Tagelus gibbus					x
28. Ensis directus			r	C	x
29. Angulus tener					x
30. Mactra solidissima					x
31. Mulinia lateralis	C	x	C	x	c
32. Mya arenaria	x	C	C	c	C
Gastropoda					
33. Acmaea testudinalis					x
34. A. testudinalis var. alveus					x
35. Vitrinella shimeri Clapp			r		
36. Turbonilla winkleyi			c	R	x
37. Odostomia trifida			R		
38. O. fusca			c		x
39. O. bisuturalis			c	r	
40. Littorina rudis	x		r		x
41. L. rudis tenebrosa	R		r		
42. L. palliata			r		x
43. L. littorea *					c
44. Lacuna vincta					x
45. Crepidula fornicata			r	r	c
46. C. plana			R	r	x
47. C. convexa			R		x
48. Polinices heros	c	x		r	x
49. P. triseriata	x	x			c
50. Neverita duplicata					x
51. Paludestrina minuta			C		
52. Bittium alternatum			R		x
53. Triforis nigrocinctus			R		x
54. Columbella lunata				R	x
55. Cingula carinata				R	
56. Buccinum undatum					x
57. Nassa trivittata	x	x	c	r	x
58. Ilyanassa obsoleta	C	x	C	C	c
59. Urosalpinx cinereus	r	x	R		x
60. Thais lapillus					c
61. Anachis avara		x			
62. Tornatina canaliculata	x		C	r	x
63. Melampus lineatus	c				x
Crustacea					
64. A copepod			x		
65. Balanus balanoides	x			r	
66. B. crenatus			R		
67. B. porcatus			x		
68. Crab claws			r	r	
Vertebrata					
69. Fish				R	

* This species was doubtless introduced into the fossil shells by the dredge, since nowhere else upon the American coast is this shell reported earlier than 1855 (Gulf of St. Lawrence). It is apparently a late migrant from Europe.

Notes on Species.

Plants.

The peat encountered in the various sections is probably entirely of fresh water origin. After an examination of the peat from the subway at Exeter Street, Mr. G. B. Reed of Harvard University writes:

"I find no plants or remains of plants such as now grow on salt marshes or anywhere below high tide level. But what species have entered into the formation of the peat I can not determine beyond the presence of grasses and sedges, probably both tops and roots, woody roots probably of some Ericaceous plants, and fragments of wood. A large part, however, is made up of much decomposed material now unrecognizable. It has apparently, too, undergone considerable compression as all the stems are flattened."

The peat at Church Street, the deepest encountered, was also of fresh water origin, and occurred similarly beneath the black silt.

Spongia.

Cliona sulphurea.— The specimens noted at the Berkeley Street locality were almost entirely in oyster shells.

Bryozoa.

Membranipora pilosa.— This form is comparatively abundant at Exeter Street upon the larger shells of Mya arenaria, less so upon Modiolus demissus, var. plicatulus.

Pelecypoda.

Ostrea virginica.— This, our only species of oyster, is very rare at Exeter Street, being represented by but three specimens, the largest of which is only 85 mm. long by 70 mm. broad. At Charles River this shell is exceedingly abundant including both the long, narrow or so-called "current" form and the short, broad "quiet-water" form. The most usual size of the former is 230 mm. in length and 55 mm. in breadth; of the latter the length is 130 mm. and the breadth 70 mm. At Berkeley Street the very large current form is common at a depth of 27 to 31 feet. A valve of one of these, an old individual, with a length of 140 mm. has a maximum thickness of 50 mm. At City Point the specimens are similar in size and abundance to those from Charles River. Miss Bryant figures one from here 265 mm. by 80 mm.

This oyster, as native, is now absent from Massachusetts Bay; during early colonial days it occurred only locally and then, on account of the cold air at such depths as to be exposed only at the low spring tides. A large oyster-bank was situated at the mouth of the Charles River, another at the mouth of the Mystic and probably one on the Noddles Island, now East Boston, flats.

That the large current forms flourished in Back Bay as late as the middle of the seventeenth century is shown by the following quotations (5):

"The Oisters be great ones in forme of a shoo horne, some be a foote long, these breed on certain bankes that are bare every spring tide. This fish without the shell is so big that it must admit of a division before you can well get it into your mouth." . . . "Towards the southwest in the middle of this Bay" (i. e., Back Bay, at mouth of Charles River) "is a great Oyster-banke" . . . "The Oyster-bankes" (referring to the same) "doe barre out the bigger ships."

In the first edition (1841) of the "Invertebrata of Massachusetts," Dr. Gould says (p. 357) "old men relate that they were accustomed to go up Mystic River and Charles River, and gather oysters of great size, before it was the custom to bring them from New York. And even now individuals of enormous size are occasionally brought from both these places, and probably might be found by special search, at any time."

The cause of this great numerical reduction since colonial days is said to be a very severe cold spell about 1780 in which the sea bottom was covered with ice, thus preventing the oysters from getting air. Another factor which aided in the destruction of some of these species, especially the oyster, from the Back Bay region was the gradual obliteration of Boston as an island by the formation of a neck uniting it with the mainland to the south. Even during late colonial days heavy seas washed over this neck into the Back Bay. Oysters need a clean substratum, such as gravel, or other shells, to which the young, the spat, may attach themselves, otherwise they will perish; and the opening across Boston neck would give the tidal currents extra strength with which to cleanse this partially enclosed region from the river muds; but that this was never so exposed to the action of waves as at City Point is shown by the occurrence of the surf-clam (Mactra solidissima) at the latter place only.

Many plantings of the oyster spat in its old home in the Charles River during recent years have resulted merely in the death of the spat.

Pecten gibbus borealis.— (This is our common scallop, the Pecten irradians of authors.) The single specimen seen from Muddy River is 26 mm. long by 25 mm. high. It is one of the common forms at the Charles River locality.

Mytilus edulis.— The edible mussel is present though apparently rare at Berkeley Street and City Point.

This species, occurring from about half tide down into comparatively deep water, was very abundant during early colonial times and was largely eaten by the colonists. Since it is a rather open coast form its rarity at the Back Bay localities is not surprising.

Modiolus modiolus.— This deep water inhabitant is represented in our Exeter Street collections by but one valve, 3 mm. long.

Modiolus demissus, var. *plicatulus.*— This is the coarse horse-mussel. It is very abundant in the superficial sediment at Muddy River. This mud was formed after the typical marine shells had been deposited and is hence comparatively recent. This species of Modiolus continued to thrive here until the completion of the dam across the tidal portion of the Charles River in 1911. Only a few, but characteristic, pieces of this shell were noted at Exeter Street.

Venus mercenaria.— The Muddy River forms are normal in size and weight; the concentric growth lines are quite strong. The Charles River and Berkeley Street specimens are similar to these and are very abundant.

The quahog, little-neck, round or hard clam, is now rare north of Cape Cod, as it apparently was during the early colonial days.

Gemma gemma.— This is the most abundant form found at Exeter Street; a specimen of average size measures 3+ mm. in length by 3+ mm. in height. It is likewise very abundant and of a similar size at Clarendon and Berkeley Streets.

The average of 10 specimens from Exeter Street gives a proportion of height to length of 1 to 1.06. The average of a similar number from Provincetown, Massachusetts is 1 to 1.15.

This greater height of the subway forms may be interpreted either as an evolution toward greater length since that time or as evidence of a slightly more unfavorable environment in the Back Bay area. This latter hypothesis is partly corroborated by the specimens of the same species from Buttonwoods, Rhode Island. Here, far up the Narragansett Bay, the average of height to length is 1 to 1.

*Macoma balthica.**— The Exeter Street shells are very abundant; they are normal in size and shape, an average sized specimen measuring 25 mm. long by 20 mm. high. Those specimens preserving the epidermis are usually bluish-black in color.

The Muddy River forms are very similar to the Exeter Street specimens, as are also the ones from beneath the Copley Plaza Hotel, and from Berkeley Street.

The average of ten specimens from Exeter Street gave 1 to 1.20 as the proportion of height to length, as against a proportion of 1 to 1.23 in specimens from Eastham, Massachusetts, the recent shell thus showing a similar lengthening to that noted in Gemma gemma.

Ensis directus.— The razor-clam, though now but little used as food, was highly esteemed by the early settlers. It is much more abundant at the Berkeley Street than at the Exeter Street locality.

Mulinia lateralis.— In the specimens from Exeter Street the average proportion of height to length was 1 to 1.17, while the larger recent shells from Woods Hole are in the proportion of 1 to 1.22.

Mya arenaria.— The common sand clam, soft clam or long-neck clam. Among specimens of this very abundant species at Exeter Street are some large ones with a length of 100 mm. and height of 55 mm. The Muddy River forms are normal in shape and size. The Charles River specimens seen average 110 mm. long by 65 mm. high; there are some 128 mm. by 80 mm. Those seen from the Copley Plaza and the numerous forms from Berkeley Street are similar to those from Exeter Street. The City Point forms are in size and abundance similar to those from Charles River.

That the long-neck clam was very abundant here during the early colonial days is shown by the following quotation (6):—

"Clames is a shell fish, which I have seene sold in Westminster for 12 pe. the skore. These our swine feeds upon, and of them there is no want; every shore is full; it makes the swine proove exceedingly, they will not faile at low water to be with them. The Salvages are much taken with the delight of this fishe, and are not cloyed, not-withstanding the plenty: for our swine we find it a good commodity."

Odostomia trifida.— A single, small (3 mm. long), well preserved specimen was noted at Exeter Street.

Odostomia bisuturalis.— The specimens from Exeter Street are small, averaging 3+ mm. in length and with a proportion of width to length of 1 to 2.

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* Dall, after a careful comparison, considers the American specimens referable to the European species M. balthica.

Odostomia fusca.— The specimens from Exeter Street are small, averaging 3 mm. in length.

Turbonilla winkleyi.— An average specimen from Exeter Street measured 5 mm. long by 1.5 mm. wide at the large whorl. Its proportionate length and breadth are the same as those of some recent forms from Buzzards Bay.

Littorina rudis.— The Exeter Street forms are small; the largest is 9 mm. long. A normal young individual 10 mm. long was noted from Muddy River.

Littorina rudis tenebrosa.— The Exeter Street forms are small; the largest is 5 mm. long; two specimens retain the peculiar mottled checking so characteristic of this variety.

Littorina palliata.— Two specimens were noted from Exeter Street, the larger of which has a length of 9 mm. and a width of 8 mm.

Crepidula fornicata.— The Exeter Street specimens of this, the common Decker, vary from thin to heavy; are whitish without and within and moderately convex, with white platform. The shells noted are small; one has a length of 14 mm., a breadth of 11 mm., a height of 4 mm. with a depth of platform of 2 mm. Those from Berkeley Street and City Point are normal both in size and shape.

Crepidula plana.— Very probably this Flat Decker form is C. fornicata modified by its position. The Exeter Street shells are thin, white without and within, and flat, with white platform. The shells noted are small; one has length 10 mm., breadth 8 mm., height 1.5 mm., with depth of platform .2 mm. The Berkeley Street specimens are of normal size. Only two specimens were noted from City Point, the larger one of which had a length of 25 mm.

Crepidula convexa.— The Exeter Street specimens of the Convex Decker are small and very convex. The color outside is ashen brown, within reddish brown; the deeply seated platform is similar in color to the inside of the shell in very young (4 mm. long) specimens, lighter brown in older (11 mm. long) ones. One specimen has length 11 mm., breadth 8 mm., height 5 mm., depth of platform 2.5 mm. Another has length, 4 mm., breadth, 3 mm., height, 2 mm., depth of platform, 1 mm.

Polinices heros.— (Polinices is Montfort's original (1810) spelling of the genus.) The Muddy River specimens average 19 mm. in length by 17 mm. in width. From City Point two specimens were noted, considerably larger than those from Muddy River.

Polinices triseriata.— The single specimen noted from Muddy River was small but well preserved. Those from City Point had an average length of 23 mm.

Paludestrina minuta.— The Exeter Street specimens are small; a common form has a length of about 2.5 mm. and a width of 1.5 mm. The average of five specimens from here gives a proportion of greatest breadth to length of 1 to 1.78; of five from Danvers, Massachusetts, 1 to 1.68, an increase in breadth of the living individuals.

Bittium alternatum.— One individual was noted at Exeter Street; this is 6 mm. long and retains a few patches of its original slate color.

Triforis nigrocinctus.— Only one example, 3 mm. long, of this sinistral, granulated shell was noted at Exeter Street; it has become an ashy gray except where between the ridges it still retains some of the original dark red color.

Nassa trivittata.— The specimens from Exeter Street average 8.3 mm. in length by 4.8 mm. in width. Recent specimens from Ipswich Beach, Massachusetts, average 25 mm. by 9 mm. Living forms have thus attained a larger size and a greater proportionate width, averaging 1 to 2.8 as against 1 to 1.73 in the Exeter Street forms.

Ilyanassa obsoleta.— The forms from Exeter Street are about half the size of the normal species of this coast, averaging 12 mm. in length. The costae are likewise stronger than on the normal shell, approaching Urosalpinx cinereus in this respect; there are 10 to 17 costae present. They are most similar in every respect to the ones living at Buttonwoods, west of Warwick Lighthouse, far up the western side of Narragansett Bay, both probably owing their small size to the freshened condition of the water. The Muddy River forms are much larger, averaging in length 22 mm.

The following list of average measurements compares in size and proportion specimens of this species from several fossil and recent localities:—

Locality	Length mm.	Width mm.	Proportion of width to length
Subway, Exeter Street Post Pleistocene (brackish) *	12.4	7.9	1:1.57
Marblehead shell heap Post Pleistocene	18	12	1:1.5
Sankaty Head, Pleistocene	24.5	14	1:1.75
Buttonwoods, recent (brackish)	12	8	1:1.5
Dorchester Bay Recent (salt)	17	10	1:1.7
Marblehead Recent (salt)	18.5	10.5	1:1.76

* Collected by Professor E. S. Morse.

It is seen from the above tabulation that it is the brackish water environment which produces the narrow species. This is true, at least, for Buttonwoods and Exeter Street; we have no data for the Marblehead shell heap. The recent specimens from Marblehead and Dorchester Bay are from normal sea water, as was probably, judging from the associated fauna, also true of the Pleistocene of Sankaty Head, Nantucket. The difference is thus apparently due to environment and is not a permanent change of form due to evolution in time.

Urosalpinx cinereus.— This species is represented by one individual from Exeter Street, 6 mm. long. The average length of the Muddy River forms is 20 mm., which is likewise the length of those noted from City Point. It was not noted at Berkeley Street.

Thais lapillus.— The specimens noted from City Point have an average length of 30 mm. The revolving ridges are coarse.

Tornatina canaliculata.— An average sized specimen from Exeter Street is 2.5 mm. long by 1.5 mm. wide.

Conclusions.

The history of Boston from the closing stages of the great continental glaciers covering all of this region to the present day may be summed up in the following five stages:

1. Deposition in fresh water of mud and sand from the melting glacier; 2. Erosion by streams of some of this material after the disappearance of the glacier; 3. Growth of peat in swampy areas (2 and 3 were probably taking place at the same time as nowhere was peat noted in an erosion channel); 4. Partial submergence of the land beneath the ocean with the accumulation of mud and dead shells upon the peat beds. This record of submergence contains two distinct elements. (a) In the earlier or lower beds the marine shells indicate a warm climate similar to that off the Virginia coast at present. (b) The upper beds, and continuing to the present, where still beneath the sea, contain a marine fauna indicative of a colder climate, that of today. 5. In certain areas, as Back Bay, the raising of the land again from its ocean bed by artificial filling.

The conclusions bearing upon these five stages are noted below.

1. The deposition of the blue glacial clay, forming the base of the majority of the sections discussed above, took place probably in a body or bodies, of fresh water, since no remains of animal life are apparent in it. The clay itself, derived from a nearby melting glacier, is the

so-called glacial flour,— the material ground from its rocky floor by the stones held firmly in the base of the advancing ice. A few unidentified pieces of wood were noted in this clay.

2. After the glacier had melted away from this region, the earth was exposed to the air so that the upper layers of the clay were hardened through oxidation. During this time the region was subjected to erosion by running water as evidenced, in Back Bay, by the gullies in the surface of the clay. At the Longwood Bridge, Brookline, a sand-plain (a fossil delta deposited by glacial streams) was eroded to a depth of 37 feet.

3. During this erosive period, or at least during the latter part of it, fresh-water peat was broadly developed. The majority of sections, deep enough to penetrate the glacial clay or sands, encounter this peat immediately above the glacial sediment.

4. Subsequent to the deposition of a variable thickness of peat the land sank with reference to sea-level and a large portion of this region was submerged beneath the ocean. This period of submergence has extended to the present except where man has willed otherwise. During this time occurred the deposition of the black mud, in which were enclosed the shells and other records of the life then living in these waters.

The evidence that the peat in Back Bay furnishes in regard to the extent of this downward movement of the land is as follows: The bottom of the peat at Fairfield Street is 23 feet below low tide, at Exeter Street 15.5 feet, at Church Street 33 feet, and at Charles Street it is 27 feet. With a height of tide of 10 feet, as it was in Charles River before the construction of the tide-water dam, it would mean a submergence of this region of at least 33 plus 10, or 43 feet; and if the peat was formed far above sea-level it would mean a so much greater submergence.

The shells enclosed in the mud deposited upon the peat since its submergence beneath the sea give evidence of two climatic periods,— an earlier period (4a) warmer than the present and a later colder period (4b) extending to the present. In the Back Bay region, where alone our sections were sufficiently detailed to give exact information upon this point, the warmer period ends suddenly. In 4a the shells are very abundant, making up, in places, one-half of the deposited mass. In 4b the shells are comparatively rare. Yet there is little, if any, gradation between the two.

4a. The majority of the fossils noted in the Tabular List of Species are from this lower bed. A comparison of these, especially the shells, with those most abundant along the entire Massachusetts coast north of Cape Cod today, shows that the climate of this region has become somewhat colder since the time this earlier fauna flourished so abundantly. This fauna, representatives of which are rare or altogether wanting off our coast today, is now dominant off the coast of Virginia, though it ranges from Cape Cod to Cape Hatteras. Of the sixty some species noted in our list, about half no longer occur north of Cape Cod, or only rarely in sheltered places, but find their perfect environment farther south. Ganong (7) mentions nine such sheltered areas, including the Gulf of St. Lawrence, Oak Bay, New Brunswick, Casco Bay, Maine, and Massachusetts Bay. Between the retreat of the glaciers from this coast and the present time a period must have occurred during which these waters were as warm as those from Cape Cod to Cape Hatteras today, and during which this Virginian fauna migrated northward.

4b. This was followed by a refrigeration of these northern waters sufficient to prevent the breeding of many of the species except within a few areas protected enough to raise the temperature of the air and water sufficiently during the summer, or breeding season, for the development of the young. (The adult can stand a much greater degree of cold than the young). Though Massachusetts Bay is one of the places in which the Virginian fauna has persisted longer than upon the less protected coast, yet even in Back Bay the shells living after the beginning of this colder period (4b) show a most remarkable decrease in both the number of individuals and the number of species of this southern fauna. Though such typical southern forms as the oyster and Mulinia lateralis persisted into 4b yet the vast majority of the Virginian fauna, including Venus mercenaria, Pecten gibbus borealis, Laevicardium mortoni, Triforis nigrocinctus and Vitrinella, had ceased to exist in the Back Bay region.

If we may judge from the Back Bay sections, this change from a warm water fauna to one characteristic of colder waters, was abrupt and was due to a corresponding alteration in climate. It is not probable that a refrigeration of the ocean waters alone could have made its influences felt so very decidedly as far inland as Back Bay. It is not likely, either, that all the differences between the more fossiliferous lower portion (4a) with its warm water fauna and the upper portion (4b), with its few fossils indicative of colder water, are due to the partial closure of Back Bay by the tidal building of Boston neck. This partial closure, bringing about a reduction in tidal scour, would, of course, cause a more rapid accumulation of sediment within the

Bay and hence relatively fewer fossils. The very great change, however, in the species represented, especially in the reduction both in number of individuals and species, would seem to imply an accompanying climatic change. That this refrigeration continued during colonial days to the present is indicated by the disappearance of oyster banks from the vicinity of Boston (Charles River, Mystic River and East Boston flats) and by the inability of planted oysters to grow here now.

5. A small thickness of sediment just beneath the "fill" may be due to the presence of dam walls built in the early part of the 19th century. In 1814 a corporation, "The Boston and Roxbury Mill Corporation," led by Uriah Coting, obtained a charter from the General Court empowering them to build a dam from the end of Beacon Street (at Charles Street) to Sewell's Point in the uplands of Brookline, with a cross dam to Gravelly Point in Roxbury (see dotted lines on map); also to made a roadway of each dam and to levy tolls for its use. It could confine tide water within this area and run mills by the water power thus created. At this time there was nothing but water and salt marsh from the foot of the Common to the uplands of Brookline. The mill dam was finished in 1821. But the tidal power, rather insufficient at the beginning for the running of the mills, was soon encroached upon, first, by the owners of bordering property filling in their land, thus restricting the area of the dam; and, especially, secondly by the building of the Boston and Providence and the Boston and Worcester Railroads across the water basin (these were incorporated in 1831). With this restriction of the tide and the increase in population this basin soon became a public nuisance and in 1852 a commission of the state legislature recommended that the property be abandoned for mill dam purposes and be filled in for building purposes. This was finally done, giving as a result the topmost 15 to 20 feet in the above Back Bay sections.

Man.— That man lived in this Boston region during the warmer climatic period following the retreat of the glaciers is evidenced by the excavation of the remnants of a fish-weir from these older sediments. This was found in the subway excavation on Boylston Street between Clarendon and Berkeley Streets, nearly opposite Rogers Building of the Massachusetts Institute of Technology. This weir consisted of interlaced vertical and horizontal sticks. The former were much the thicker; one, when wet, had a diameter of over two inches, while the latter in the same condition measured about a half inch. Some, if not all, of the vertical rods penetrated the glacial clay, one to a depth of eighteen inches. The lowest horizontal sticks preserved were about a foot and a half above the glacial clay, and hence between two and three feet below the top of the four-foot bed containing the warm-water fauna. The vertical rods would naturally not have been driven deeper than to allow the horizontal sticks to rest upon the surface of the mud.

It is possible that there were horizontal sticks lower than this which were destroyed before they were covered by the preserving mud or had left their impress upon the vertical rods. Possibly, also, the horizontal withes were not driven deep enough to rest upon the mud surface. It would seem that one or both of these suppositions might be true. The forcing of two inch rods, bluntly and roughly sharpened by a stone ax, as the Harvard specimen shows, into the stiff glacial clay to a depth of eighteen inches, would be a difficult thing to do. Moreover a penetration of the clay to a depth of eighteen inches would suffice to support the weir. These probabilities would add, however, only about a foot and a half to the thickness of the sediment deposited since the weir was erected.

If we consider the lowest preserved horizontal sticks as originally the lowest and as resting upon the surface of the mud when erected, then about thirteen feet of shells and mud had been deposited between the time when man planted the fish-weir and when he blotted out the Bay. If we consider the probability that there was practically no silt present when the weir was erected it would mean the deposition of fourteen feet, eight inches of sediment between that time and the artificial filling of the Bay. The top of the vertical rods preserved was ten to twelve feet below the junction of the silt and fill.

How long a time was consumed in the deposition of these thirteen to fifteen feet of silt and shells is largely a matter of conjecture. It has been estimated that the Mississippi River deposits a foot of mud in two hundred years. A similar rate here would have required 2500 to 3000 years for the accumulation of this thickness. The streams in the Boston area would have carried annually much less sediment than the Mississippi. The amount retained in the Back Bay, however, would be a balance between the amount of mud delivered into this inland bay protected by many islands and the strength of the tidal scour. That the tidal scour was stronger during the existence of the warmer climatic fauna is shown by the presence in this Back Bay area of an abundance of oysters. These need a bottom free from mud or slime. A stronger tidal scour during the formation of this lower bed is also indicated by the fact that this sediment is half composed of shells, while the upper, colder fauna bed contains much more mud in proportion to the number of shells. On the whole it may be considered as probable that the accumulation of silt here had been at least no faster than that by the Mississippi at present. This great age for the fish-weir finds corroboration in the preservation of the wood itself. It is considerably carbonized; its surface is almost black, and either wet or dry, is very brittle. Fragments of this fish-weir are preserved in a wet condition in Peabody Museum of Harvard University and in a dry state in the offices of the Boston Transit Company. Its preservation seems poorer than that of wood, 1500 years old, from a sacrificial well in Yucatan, and every bit as poor as that of wood from the ancient pile dwellings of Lake Neuchatel, Switzerland. The Swiss dwellings had practically disappeared before Roman times, 2000 years ago.

Yet other factors must enter into our consideration of the age of this fish-weir. At present a wooden pile exposed above the mud or sand is cut off within a few years, by the borings of mollusks. We must suppose, however, that the accumulation of the lower three or four feet of sediments, one-half of the mass of which consists of shells, must have been a slow process requiring more than a few years. Possibly such boring forms were absent from the Bay at that time, for none have been noted in the collections. It is usually held, too, that marine waters cause a more rapid decomposition of wood than fresh waters, not only "by reason of the abundance and variety of the attacking animal types, but also, it is said (Challenger reports: Deep-sea deposits, p. 256) on account of the greater amounts of sulphates and carbonates in sea-water, which by decomposition in the presence of organic acids facilitate the oxidation (destruction) of the plant tissue." This is corroborated by the fact that the deep sea dredgings yield vegetable remains in quantity only comparatively near lands; also that limestones (usually deposited far from land) contain slight or no records of land vegetation (8). These are, however, records of the open ocean, not of a partially enclosed bay, where the water would be brackish, the preservative powers of which would be still further increased by the flow and ebb of the tides. The preservation of wood in fossil deposits of a brackish water origin is exceedingly common; but all such wood is supposed to have been buried within a comparatively few years. In the case of the fish-weir the fossil shells indicate that parts of it extended above the encroaching sediment during the time necessary to deposit three or four feet of shells and mud, next to suffer a striking climatic change and finally to deposit another foot or two of sediment. We can not conceive of this as taking place in a comparatively few years.

Still another factor has a bearing upon the age of the fish-weir. The surface of the street where the fish-weir was found is sixteen feet above mean low tide. Since the fill here is nineteen feet and the lowest preserved horizontal portion of the weir thirteen feet below this, the weir must have been driven into water sixteen feet deep at low tide or twenty-six feet at high tide. That is, to reach the surface of the water at high tide, at the present relation of land to ocean, and penetrate the clay eighteen inches, would require sticks twenty-nine feet long, at the least, and these sticks had a diameter of only two inches at base. Since the construction of a fish-weir under such conditions is practically impossible we must suppose that its erection took place before the land had become submerged to its present depth. If we may judge from the practice of today, the weir was erected when the region was exposed at low tide, or almost so, and covered at high tide. If so, the land has sunk sixteen to eighteen feet since man placed here his fish-weir.

While none of the above considerations yield anything definite as to years, yet they strongly indicate that the weir is old, very old.

To briefly summarize,— The remnants of the fish-weir, excavated on Boylston Street, give evidence of man in the Back Bay region of Boston, probably 2000 to 3000 years ago. He built this weir during a climatic period as warm as off the Virginia Coast at present, and upon a sinking coast. Since its erection the region has sunk sixteen to eighteen feet and suffered a refrigeration to its present climate.

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ANCIENT CHINESE PAPER MONEY AS DESCRIBED IN A CHINESE WORK ON NUMISMATICS.

By Andrew McF. Davis.

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CONTENTS.

On the 10th of February, 1915, I presented a paper to the Academy entitled "Certain Old Chinese Notes." The same was published separately with the additional sub-title "Or Chinese Paper Money." The notes which furnished the title of my paper are now deposited in the Museum of Fine Arts, Boston, but were at that time in my possession and were on that occasion submitted to the inspection of the members present. The oldest of the notes was emitted under the Emperor Wu-tsung, of the T'ang Dynasty, who reigned from 841–847 A.D. or 840–846 according to another system of stating the chronology. The Chinese Emperors were accustomed to break up their reigns into periods and the particular period in which this note was emitted was designated as Hwei-Chang or Hui-ch'ang according to the manner which the translator adopted for the phonetic transliteration of the Chinese characters.

In that paper the notes themselves were described and an attempt was made to place on record not only what is now known concerning them but also what knowledge was at command of European students of economics and finance, at any given time, from the days of Marco Polo to the present time. This examination disclosed the existence of a Chinese numismatical work entitled Ch'üan Pu T'ung Chih, which included in its study of coinage a description of this ancient paper money, so far as it was known to the author, and also furnished illustrations of the notes described, covering a period from about 650 A.D. to 1425, A.D., that is to say nearly eight centuries, all prior to the first voyage of Columbus. The illustrations are evidently intended to be of the same size as the original notes. The existence of a number of the notes themselves permits comparison and while there are slight variations in the dimensions, the intention of the illustrator to repeat in black and white outline drawing, the original in its general features, including size, is evident.

The impressions of the notes given herewith are necessarily reduced to meet the exigencies of the pages on which they appear. This reduction is not made strictly on any given scale. The longest of the notes measures upwards of twelve inches in length by six and three-quarters in width. The smallest is five and one-eighth inches by two and three-quarters. To reproduce the larger of these notes on these pages it must be reduced about one-half in size. If the smaller were reduced in the same proportion, the characters thereon, already quite small, would become difficult to decipher. Nevertheless a reduction in size of the smaller was made, enough in amount to call attention to the fact that the note is a very small note. Furthermore, the dimensions of all the notes are stated to the nearest eighth of an inch, the measurements being taken from the photostats of the notes, which were intended to be of full size. A comparison of those measurements with those given in "Certain old Chinese notes" will show that the photostats were as a rule slightly smaller than the actual notes. This may be accounted for in several ways, but in the case of the one kwan Ming note where the actual note measured was three-quarters of an inch longer and one-quarter of an inch wider than the photostat of the drawing in the Chinese book, it must be remembered that we have abundant evidence that various officials emitted these notes and consequently there were undoubtedly many woodcuts from which they were impressed. The mechanical demands of the time did not call for any great delicacy in the measurement of the impressions on the notes. It would have been possible to have given the measurements of between twenty and thirty actual notes, but it was thought better to pursue a uniform policy, especially as the statement of the measurements furnishes a means of estimating the actual size of the notes.

There are said to be in existence several old Chinese numismatical works which are illustrated in a similar way to the one which we have under consideration. Our author says, in speaking of certain notes emitted during the Chin Dynasty, of which he had knowledge only through some historical publication, "as I was not able to discover the notes thus referred to in the history, I could not print them in this book." Without knowledge that the history in question was illustrated, this statement does not amount to proof that the illustrations in Ch'üan Pu T'ung Chih were all of them derived from existing notes, but the probability is that such was the case.

There are eighty-one of these designs of faces of notes. While those of the different dynasties are not fashioned precisely alike it may be asserted that they have a common model. We should expect to find at the top of the note a heading announcing in a horizontal inscription, written in all probability in seal characters, that the note belongs to an emission of a certain dynasty. Below, enclosed within an ornamental border, there would probably be two panels, the upper divided into two parts, and headed by a horizontal inscription denoting the denominational value of the note, beneath which a pictorial representation of this value would be found, either in silver ingots or in strings of copper cash. This panel also frequently has at each side a vertical inscription generally written in seal characters, which sets forth the purpose of the note and the intent that it shall circulate throughout the kingdom.

The lower panel of the note will be found to contain in vertical columns a statement setting forth the department of the government which has been authorized to make the emission, an assertion of the value at which the note was to be received in trade, a reference to the law against counterfeiting and a declaration of the reward which will be given to informers. The last column to the left is invariably headed with the characters representing the dynastic era or period of the emission, below which appear a year character, a month character and a day character, so arranged as to leave space for inserting the specific date of the note, the intention obviously being to fill in the blanks with a brush so that each note should bear the date of the day of its issue. If, however, such was the case, the existing specimens no longer bear these brush inscriptions the marks having disappeared under the wear of use.

Besides the eighty-one pictorial representations of faces of notes, there are also represented the official seals which were stamped on the face of the notes of the different dynasties, one on the upper panel and one on the lower panel of each note. Some of the notes also bore a seal stamped on the reverse and in a few instances representations of animals were impressed on the backs of the notes. Of these seals and animals we have reproductions. In a single instance a note, the one kwan Ming, had a special design for the back. This also is given.

The seals were stamped upon the face or back of the note as the case might be and the color used was almost invariably red, the only exception to this so far as appears, being those on the Posterior Chou notes which are said to have been impressed in yellow. They appear herein as if printed in black, but it must be remembered that they were superimposed in a different color after the note was printed. Marco Polo described the process of stamping the seals on the notes, as follows: "The principal officer, deputed by his majesty, having dipped into vermilion the royal seal, committed to his custody, stamps with it the piece of paper, so that the form of the seal tinged with vermilion remains impressed upon it, by which it receives full authority as current money...."

The author of Ch'üan Pu T'ung Chih apparently devoted about sixteen years of his life, during the first half of the nineteenth century to the preparation of his work for publication and to running it through the press. In connection with his description of the T'ang notes, 825–826 A.D., he states that paper money first appeared in China in the period 806–820 A.D. It may be inferred that when he wrote this he had not seen the Kao-tsung, Yung-hui notes, 650–655 A.D. It is indeed probable that he met with these latter notes while running his book through the press, and inserted designs of them without disturbing the pagination of the portion of the book already prepared, but actually disarranging the sequence of the page numbers by duplicating those containing the descriptive text, the notes themselves being put in without the numbers essential to designate their position. At all events, he states that paper money first appeared in China between 806 and 820 A.D. and in the same work describes in detail notes issued 650–655 A.D.

The author, either on the authority of Chinese historical works, or from knowledge derived from the notes themselves, gives the denominations of about two hundred and fifty-nine notes emitted during twenty-six eras or periods in the reigns of different emperors of ten dynasties, or if the Sung dynasty is divided into the Northern Sung and Southern Sung, the number of dynasties should be eleven. Of these notes it would seem from what he says that he himself had in his collection about two hundred and twenty-five specimens of different varieties. In the case of the total number of notes referred to as well as in the statement as to the number of different varieties in his possession, the precise numbers cannot be positively asserted owing to the vagueness and incongruity of expression in the text. He gives for instance under the period covering 860–873 A.D., two illustrations and says in his text that in the year 1833, "some notes of this era were acquired." The only thing positively to be ascertained from this is that there were two varieties, those of which illustrations were given in the book, and perhaps more. He states that during the reign of

Kao-Tsung 1127–1162 A.D., there were three varieties issued, of which he gives the denominations. He publishes three illustrations purporting to represent these notes, but as a matter of fact two of these illustrations are of denominations not mentioned by him in his list of three. There are numerous other incongruities of this sort and some of a similar nature are to be found when one attempts to determine whether the notes mentioned or depicted are from his collection or from that of some other collector. The only thing that seems to be fairly well established is that whether from his collection or from elsewhere the designs of the notes were drawn from actual specimens.

It will be remembered that when the stock of Law's Company of the Indies was first increased, the right to subscribe to new stock was made dependent on the ownership of four shares of the old. The different shares were then christened *mères* and *filles* and at a later date the next succeeding emission was called *petites filles*. It is certainly very remarkable that this humorous technology of the French stock market at the beginning of the eighteenth century should have been anticipated four hundred and fifty years in China, but it is recorded that in the period 1264–1294 A.D. of the Yüan dynasty, notes were emitted on the basis of five for one in specie and these notes were called the Mother while the equivalent specie for any note was called the Child.

It has already been stated that the various notes described in the Chinese work which we are considering were practically framed after the same model. The Chinese dynastic historians allude to emissions which were evidently intended to be retired within a given time, to others whose circulation was intended to be confined to a certain district, and there are statements made which indicate that specific preparation was made for the redemption of certain of the notes. There is, however, no illustration furnished by the author of Ch'üan Pu T'ung Chih in which there is any indication through inscriptions on the face of the note or elsewhere, that provision had been made for its redemption, nor of any limitation of either time or space for the circulation of the note. We are not however limited to this work for knowledge of these old Chinese notes, and although the main purpose of this translation is to furnish a key to the knowledge contained in this particular book, it is desirable to add thereto something about other sources of information.

There is, in the first place, in the Museum of Fine Arts, Boston, a complete set of photographs of the twenty emissions, of Chao-tsung, Lung-chi, 889–890 A.D., of the T'ang dynasty. The original notes from which the photographs were taken have disappeared, but the inscriptions on the photographs are probably quite as legible as they were on the notes themselves.

In addition to the illustrations reproduced from the pages of Ch'üan Pu T'ung Chih there are also included herewith five reproductions from the pages of a work recently published in Japan entitled Ssŭ Chao Ch'ao Pi T'u Lu, a title which is rendered into English as follows: "Illustrated Record of the Paper-money of the Four Dynasties"; and two illustrations taken from the third volume of the Journal of the Peking Oriental Society. Some of these illustrations were taken from the notes themselves and are lacking in the precision of the Chinese characters shown in the reproductions in black and white of the drawings of the notes made for Ch'üan Pu T'ung Chih. They illustrate certain features of these emissions which are not covered by the notes included in that work, and have especial value in their bearing upon the point heretofore referred to that the notes in that work contained in their inscriptions no limitations of time or place for their circulation and no indication that they were subject to redemption. In the examples taken from Ssŭ Chao Ch'ao Pi T'u Lu we can see the method by which provision was made for designating on the face of the note that it was intended for local circulation. We find also provisions for redemptions and for the reception of the notes in payment for taxes. The depreciation of some of these notes is recognized in the inscriptions on their face.

The description of one of them seems to be based upon an impression taken from a fragment of a wood-block of the note, which was in possession of a Chinese collector. Dr. S. W. Bushell gives the following description of it, in the Journal of the Peking Oriental Society, Volume III, Number 4, pp. 309–310:

> The border is filled with a floral design of lotus flowers and leaves. Above the border are three large characters *yi shih kuan*, ten strings, equal to 10,000 cash, the nominal value. Within the border, the vertical column in the middle reads *yi shih kuan pa shih*, below which we may supply *tsu pai*, indicating the real value to be 8000 cash, eighty being reckoned as a full hundred. On the left are two characters *tzu hao*, a space being left above for the insertion of the number of each note in manuscript. On the right and left sides close to the border are two columns of antique (seal) characters, worn and indistinct, but decipherable with the aid of contemporary records, reading on the right, *wei tsao chiao ch'ao chê chan*, "Whoever counterfeits this note shall be beheaded"; on the left *shang ch'ien san pai kuan* "Reward 300 strings of copper cash."

The characters on the right are partly completed by conjecture.

Those on the left in large script indicate the three provinces in which the notes were to circulate.

Dr. Bushell in the article already quoted from gives the text of a note emitted A.D. 1214 as follows:

....The full text of a note issued in the second year, (A. D. 1214) of the reign of the Emperor Hsüan Tsung of the same Chin dynasty. It is taken from the collection of antiquities of Chien Ta-hin, a famous scholar, published early in this century. It is quoted from the same source by the author of the *Chin shih ts'ui pien*, a well known work in 160 books on ancient inscriptions, where it is described as 12 inches broad, 15 inches long. The accompanying figure is smaller than the original and the floral border surrounding it is omitted from want of space. The value, five strings, half that of the preceding note, is also written in large characters at the top outside the border. On the left, also outside and encroaching on the floral border, are two panels indicating that the note was current in Ching Chao Fu and P'ing Liang Fu which were both in the province of Shensi. The heading written horizontally reads *Chên yu pao chüan*, "Precious note of the Chên Yu period" (A. D. 1213–1216). Below: "Five Strings, eighty cash equal to a full hundred" with columns on either side for the class and number. Underneath in nine columns, "This precious note issued by Imperial decree shall circulate together with ready money and shall be redeemable at any time at the government treasuries of Ching Chao and P'ing Liang." "Whoever counterfeits it shall be beheaded. The reward shall be 300 strings of these notes, as well as the property of the criminal." The middle column is for the date, the other five are filled with the titles of the officials of the Board of Revenue and Paper Money-Bureaux, blanks being left for the insertion of their names and signs manual.

Several of these reproductions bear upon their face inscriptions to the effect that their circulation is for an unlimited time. On some of them offices were designated where they would be redeemed and on one at least, the statement is made that the note will be received in payment of certain taxes.

Marco Polo stated that new notes would be issued for old ones on payment of a charge for printing. On one of these notes we find a provision covering that point.

The last illustration of a note in our series is taken from the third volume, Number 4, of the Journal of the Peking Oriental Society. Whether the original is what Dr. S. W. Bushell, the author of the following extract thinks, a copper note, or a plate from which notes were to be printed, will depend upon the judgment of the reader. Here is what Dr. Bushell says:

The third figure is the copy of a copper note of the last reign of the Ming dynasty. It is a curious example of an attempt to stem the rapid depreciation of the notes by making these of real intrinsic value. I was inclined, at first view, to think it was a copper plate for printing paper notes but the inscription shews this idea to be untenable. The figure is the same size as the original and must have weighed nearly, if not quite, as much as the 200 cash it represented. I have extracted it from *Chi chin eo chien lu*, a numismatic work, the learned author of which describing it says: At the beginning of the Ming dynasty, they issued notes after the fashion of the Yuan and Chin dynasties, these notes being all made of paper. Near the end of the twelfth year of the reign Ts'ung Chên, (A. D. 1239), Chang Chü of the Hamlin College presented a memorial recommending notes to be cast from copper. This is one of these copper notes. It is of the value of 200 cash, and in the centre there is a picture of two strings of cash, just as in the large paper notes of the period, of which the value was 1000 cash, there are figured ten such strings. The remainder of the inscription is the same as that of the said paper money, with the addition in the middle of the lower part, of seven characters meaning 'Moulded in changed form in the cyclical year *chi mao* (A. D. 1239); of the period Ts'ung Chên.' On the reverse three square seals are moulded in relief, each smaller than the one above: *Ta Ming Pao chih chih yin*, 'Seal of the Money note Department of the great Ming'; *Pao ch'ao Ti chu ssu yin*, 'Seal of the Inspectorate of Money Notes'; *Chu tsao pao ch'ao chü yin*, 'Seal of the Bureau for casting money notes'. Near the upper border of the plate, there is a small round hole. The original date of Hung Wu, the founder of the dynasty, was retained all through on the notes and we find it here at the end of the inscription. This is the only specimen of a copper note that has been, as far as I know, preserved. At the time it was cast, the Ming dynasty was near its fall and probably very few of these metallic notes were circulated.

A typographical error in the article from which we have quoted has converted the "cyclical year *chi mao*" from A.D. 1639 into 1239. The date 1639 is indeed used in connection with this note or plate by Dr. Bushell himself in opening this very article. This correction probably carries with it the correction of the date of the twelfth year of the reign of Ts'ung Chên, (A.D. 1239) a few lines above, to 1639.

It is not within the purview of this communication to discuss seriously the question whether Dr. Bushell was right when he abandoned the idea that this copper plate was for printing notes and concluded that the language of the inscription made clear that it was cast in that form for use as money, this particular example being the only known specimen preserved. It is clear however that if the casting is unmistakably a coin, it has no right to be considered in a paper that deals exclusively with paper money. The plate or note is a reproduction in its general appearance of a note of the emission of the Hung-wu period, 1368–1398 A.D., the characters used being identical with the exception that seven new characters are inserted in the inscription which are translated by Dr. Bushell, "Moulded in changed form in the cyclical year *chi mao*" (A.D. 1639), and which Mr. Tomita, the translator of Ch'üan Pu T'ung Chih, interprets as reading, "Cast anew in the year of *chi mao*." Neither of these renderings is inconsistent with the casting being a plate for printing notes. When we come to the reading of the seals on the reverse of the casting, Dr. Bushell's reading of the lower seal would at first glance seem to cut us off from any choice between note and plate. He interprets that seal as reading, "Seal of the Bureau for casting money notes." Mr. Tomita gives the following reading for this seal: "Seal of the Bureau of the Cast Treasure-Note"; which is nearly equivalent. Refuge from the apparent inference that the casting was a "money note" and not a plate from which currency could be printed may perhaps be found in different interpretations of these characters by students who shall devote attention to their study. Meantime it would seem incredible that any ruler should have attempted to supersede the convenient and easily portable Chinese string of copper coins by an equivalent weight, rectangular in form, with sharp corners and with delicate inscriptions thereon in raised characters. Until this interpretation shall be proved to be correct, believers in Chinese intelligence will, harbor doubt of its possibility.

Dr. Bushell was obviously impressed by the fact that the inscriptions on the casting, while they indicated that they were made in 1639 still bore the characters which showed that the note or plate was a reproduction of the design for a note in the days of Hung-wu, (1368–1398). There were, however, precedents for double dates of this sort. In the period Hsien-ching (1136–1141) of the Western Liao, an emission called Great Liao Treasure notes was put forth with an inscription stating that the Great Hsia Treasure note was issued under imperial authority for the use of the people. In the days of the Hsia dynasty, notes were emitted which were called Ta-Tê Treasure notes, and which bore the characters denoting that they were emitted during the Yüan-tê period (1119–1126). The name Ta-Tê was not adopted till nine years after the end of the Yüan-Tê period. It seems reasonable to suppose that in each of these instances, the official having charge of the emission, in his effort to make use of a note of previous issue as a model, neglected to correct his copy so as to eliminate all the previous dates. A similar confusion in the case of the casting may perhaps be explained the same way. The difficulties encountered in translating the new characters inserted in the inscription and in the seal for the reverse may have their foundation in a similar cause.

In an article in the same number of the Journal of the Peking Oriental Society as that from which we have already quoted so freely,* a writer makes the statement that in 1651 A.D., notes were issued and that annually for eighteen years a fixed amount was emitted. Then the attempt to make use of paper money was abandoned. If this be so, it would not be surprising if the "money note" might be found to be connected with this emission. The difference in time is not great.

The translation which follows is the work of Mr. Kojiro Tomita, a native of Japan, and Assistant Curator of Chinese and Japanese Art at the Museum of Fine Arts of Boston. He has by preference adhered to a nearly literal method, rather than attempt to express the meaning in well phrased English periods. He has given the underlying meaning of the Chinese characters. The reader can shape this meaning into more readable phrases at will. His scholarly philological attainments and his complete mastery of English furnish a guarantee of the accuracy of his work.

Andrew McF. Davis.

* The Origin of the Paper Currency of China by Shioda Saburo. Journal of the Peking Oriental Society. Volume III, Number 4, page 278.

INTRODUCTION BY THE TRANSLATOR.

The reign of a Chinese emperor is designated as such and such an era, and all notes bear the name of the era in which they were issued. In some cases, during one reign, the name of the era is changed many times. To give corresponding dates in the Christian era is sometimes a difficult task, as books on the subject often disagree. However, in each case the best authorities have been followed.

The dates that appear after the names of emperors in parentheses denote the periods of their reigns.

In the transliteration of Chinese proper names, Giles' system has been followed.

In translating the inscriptions on the various notes, the original wording has been followed as closely as possible, with the purpose of bringing out such distinctions as, for example, the following:

"Shall be *rewarded*".	"Shall be *given*".
"The *informant*".	"*To him who informs*".

Much difficulty has been experienced in rendering the Chinese into English because of the absolute lack of kinship between the two languages. To give the general meaning or to translate the Chinese freely, as many writers have done, would have been simpler, but by this method the slight, yet important, distinctions in the text of each issue could not be brought out.

No doubt many of the English words chosen might be replaced by more appropriate ones; for instance, the word "informer" might be preferred by some to the word "informant", etc., etc.

It will be noted that the text accompanying the different issues varies in length. In some cases the inscriptions on the notes have been incorporated in the text, and the designs are described, while in others they have been ignored. Inconsistencies are noticeable features of this book, and of typographical errors there are not a few. Wherever an inconsistency or an error has been discovered, an endeavor has been made to mention it in a footnote.

In the phrase "....note to be used *as* cash (or *as* silver), the word "*as*" is the equivalent of "*together with*", "*on the same footing*", or "*jointly*".

"*To be used side by side*". In the original, four characters which literally mean "*parallel-going-use-employ*" are frequently used, as well as two characters literally meaning "*parallel use*" (an abridged form of the four characters previously mentioned). In translating, the phrase "*to be used side by side*" has been adopted, and no distinction has been made between the two forms.

The phrases at the end of the inscriptions indicating the punishment for concealing, in spite of being aware of the guilt of another, differ. In many cases the translations are awkward, but an attempt has been made to retain the original meaning.

"*Public Convenience*". Though the literal translation is "*convenient (use) of people*", the phrase "*Public Convenience*" has been adopted as a better form for a title.

"*Issuance*". Though the literal translation is "*issue-circulaiing*" or "*distribute-circulating,*" the word "*Issuance*" has been adopted.

"*Imperial authorization decree*". Whether or not such an expression is allowable is doubtful; however, it has been used to distinguish it from others which simply mean "*decree*" or "*sanction*".

Chinese vs. *English*. The absence of even fairly exhaustive Chinese-English dictionaries has made the rendering of the Chinese into English doubly difficult, as each character has many different meanings and, further, when used in combination with one or more characters, takes on a new meaning. No dictionary, even in the original language, gives enough examples of these combinations, which amount to thousands and thousands. Since generally all Chinese-English dictionaries deal with the modern Chinese language, and the authors themselves intended to make the dictionaries of general, not technical, use, many words that were found on the notes had to be rendered according to my best judgment. Of course the titles of officials, etc., may or may not have English equivalents; but since there is no standard to follow, the most appropriate renderings that could be thought of have been supplied. In order to make correct renderings of the titles of officials, one must be a deep professional student of the political economy or governmental organization of Chinese of the various dynasties and the various provinces. In the present case, as many reference books in Chinese as were at command have been consulted.

In translating the text, points not essential, as for instance, repetitions of chronology or the author's poetic eulogies concerning great discoveries, have been omitted.

KOJIRO TOMITA.

TRANSLATION OF THE CH'ÜAN PU T'UNG CHIH.

EXTRACTS FROM THE INTRODUCTION TO THE "CH'ÜAN PU T'UNG CHIH".

The compilation of the "Ch'üan Pu T'ung Chih" was begun in 1816; in the winter of 1832 it had been printed; and in the spring of 1833 * the binding was completed.

As there are many hundreds of varieties of paper money, they could not be enumerated even on a hundred pages.

The following are some of the notes which I acquired:

From Mr. T'ao's collection, in the autumn of 1832, notes of the Sung Dynasty (Chien-lung Era, 960–962); of the Yüan Dynasty (Chih-yüan Era, 1264–1294); and of the Ming Dynasty (Hung-wu Era, 1368–1398) — twenty-three in all.

In the summer of the following year, from Mr. Chu, notes of the Sung Dynasty (Ching-k'ang Era, 1126, and the Chien-yen Era, 1127–1130); of the Western Hsia Dynasty (Yüan-tê Era, 1119–1126); of the Chin Dynasty (Tien-hui Era, 1123–1137); of the Liao Dynasty (K'ang-kuo Era, 1127–1135, and the Hsien-ch'ing Era, 1136–1141) — thirty-one in all.

And in the spring of 1834, † from the Tung Collection, notes of the T'ang Dynasty (Hui-ch'ang Era, 841–846, the Ta-chung Era, 847–859, the Hsien-t'ung Era, 860–873, the Lung-chi Era, 889, and the T'ien-yu Era, 904–922); of the Sung Dynasty (Shao-hsing Era, 1131–1162), the Ch'ien-tao Era, 1165–1173); of the Yüan Dynasty (T'ien-li Era, 1328–1329, and the Chih-chêng Era, 1341–1367); of the Ming Dynasty (Yung-lê Era, 1403–1424, and the Hung-hsi Era, 1425 ‡) — one hundred and sixty-seven in all.

NOTES OF EMPEROR KAO-TSUNG (650–683 A. D.) OF THE T'ANG DYNASTY.

In 650 A. D. Kao-tsung ascended the throne, establishing the era called Yung-hui (650–655 A. D.); and during his rule, which extended in all over a period of thirty-three years, the name of the era underwent fourteen changes.

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* This must be the date of the first edition. K. T.

† This date falls one year after the completion of the book. K. T.

‡ These dates are all A.D.— K. T.

Notes of ten different denominations were issued in the Yung-hui Era of Kao-tsung, all of them yellow in color. At the top of each is inscribed "Great T'ang Treasure-Note"; in the middle, the denomination of the note, e. g., 1 kwan, 5 kwan, 10 kwan, etc.; and directly below appears a picture representing (a string of) ch'ien (cash) proportionate in value to the denomination of the note, e. g., 1 kwan, 1000 ch'ien; 5 kwan, 5000 ch'ien, etc., etc. At the bottom is inscribed: "The Board of Revenue,* having received the Imperial Decree, prints the Treasure-Note to be used as cash, etc........., on the........day,........month,........year of Yung-hui." On the surrounding border is a design of dragons and clouds. Each of the ten notes is stamped similarly above with a square seal with the characters "Printed Treasure Note", and below with another square seal which reads: "The Seal of Yung-hui of the Great T'ang". On the back of these notes there is neither pattern nor seal.

These Kao-tsung notes came, with the subsequent issues of different eras — seven in all — from the collection of the Tung Family. How fortunate it was to have acquired them! The excellence of their workmanship, so distinguishable from the rest, surpasses that of all other paper money. Whether or not there were any notes emitted in the time previous to the Kao-tsung is not known.

Plate 1. Yung-hui (650–655 A. D.) Note.

Translation of the inscriptions.

First line: "*Great T'ang Treasure-Note.*"

Second line: "*One Kwan.*"

Illustration: (Pictorial representation of 1000 ch'ien in one string).

The vertical columns in the lower panel:

"*The Civil Board, having received the Imperial Decree, prints and issues under the heavens* † *the Great T'ang Treasure-Note to be used as cash. The counterfeiter shall be decapitated summarily in punishment for the crime; the first informant shall be given 12 taels in silver.*

Yung-hui,....year,....month,....day, emitted." ‡

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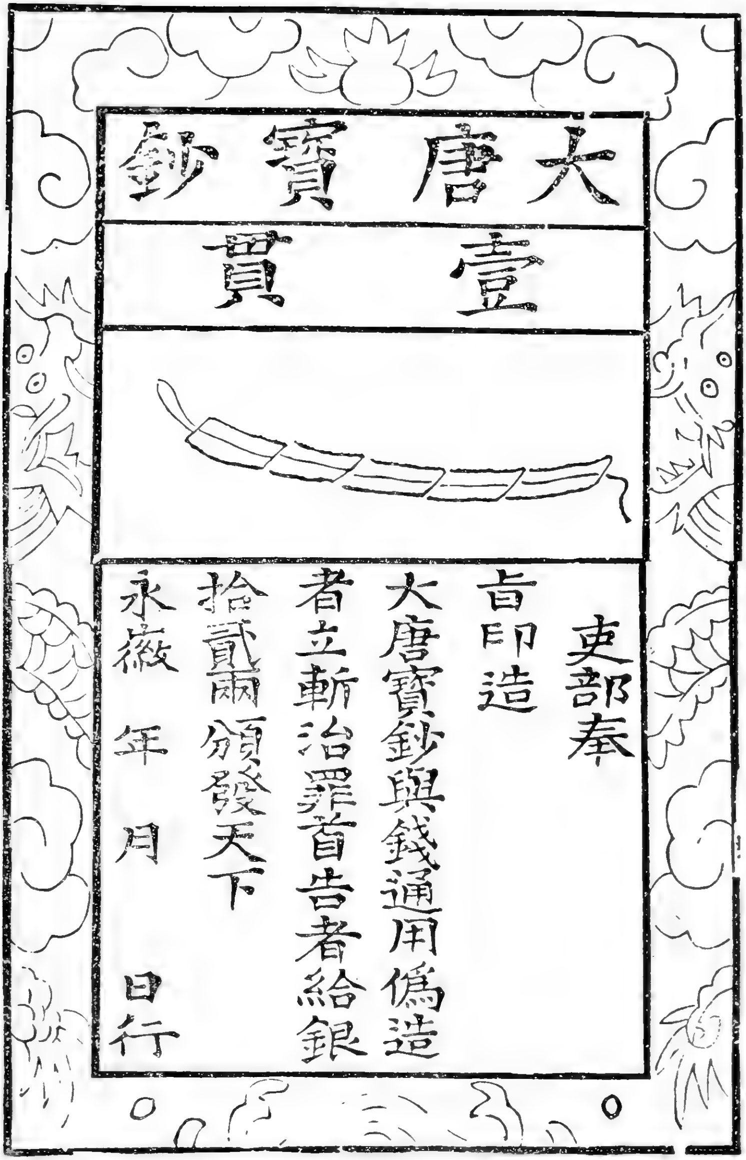
* On the actual note it says "Civil Board" instead of "Board of Revenue," hence the latter must be a misprint. The Chinese characters for "civil" and for "revenue" are somewhat alike. K. T.

† In the actual inscription this phrase "issues under the heavens" comes after the word "silver" at the very end of the sentence. K. T.

‡ The word here used literally means "act". K. T.

PLATE 1.



T'ANG DYNASTY
KAO-TSUNG 650–683 A.D.
YUNG-HUI 650–655 A.D.
ONE KWAN

DIMENSIONS
$5\frac{5}{8} \times 8\frac{7}{8}$ INCHES

PLATE 2.

T'ANG DYNASTY
KAO-TSUNG 650-683 A.D.
YUNG-HUI 650-655 A.D.
10 KWAN

DIMENSIONS
$5\frac{5}{8} \times 8\frac{7}{8}$ INCHES

Plate 2. Yung-hui (650–655 A. D.) Note.

The inscription is the same as that on Plate 1, with the exception of the denomination which is 10 kwan, and the reward to the informant, which is 30 taels. The illustration represents 10 strings of 1000 ch'ien each.

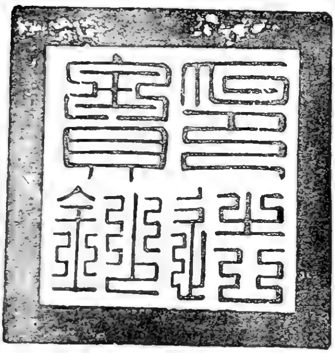
Plate 3. Upper Seal on the Yung-hui Notes.

Four characters, arranged as follows:

Treasure	Print
Note	Made

Translation: "*Printed Treasure-Note.*"

PLATE 3.



DIMENSIONS
$2\frac{1}{2} \times 2\frac{1}{2}$ INCHES

PLATE 4.

DIMENSIONS
$3 \times 3\frac{1}{8}$ INCHES

Plate 4. Lower Seal on the Yung-hui Notes.

Six characters arranged as follows:

of	Yung-	Great
Seal	hui	T'ang

Translation: "*The Seal of the Yung-hui Era of the Great T'ang Dynasty.*"

Notes of Emperor Ching-tsung (825–826 A. D.) of the T'ang Dynasty.

Paper money first appeared in the time of the Emperor Hsien-tsung * (806–820 A. D.) and was called "fei-ch'üan" † or "flying certificate".

There are ten varieties of the Pao-li notes of the Emperor Ching-tsung.‡ Their color is yellow, and each bears at the top the inscription "Great T'ang Treasure-Note"; directly below is written the denomination of the note, e. g., 10 kwan in writing with an illustration of one ingot of yüan-pao, (a standard silver bar); 20 kwan, with 2 ingots of yüan-pao, etc., the number of the bars varying according to the value of the note. In the lower part is inscribed: "The Board of Rites, having received the Imperial Decree, prints the Great T'ang Treasure-Note which is to circulate as money, etc." On the two sides respectively is written in the chuan (seal) style of writing: "To be current under the Heavens" and "To circulate as cash". The surrounding border shows a design of dragons and clouds. Each of the ten notes is similarly stamped; in the upper part is a square seal which reads: "Print-made Treasure-Note", and in the lower part another square seal which reads: "The Seal of Pao-li of the Great T'ang". On the reverse of each there is neither pattern nor seal. Some of the notes are illustrated herewith in order to record their existence.

Plate 5. Pao-li (825–826 A. D.) Note.

Translation of the inscriptions.

First line: "*Great T'ang Treasure-Note.*"
Second line: "*Ten Kwan.*" §
Illustration: (Pictorial representation of one yüan-pao).
At the right of the illustration, written vertically in the chuan (seal) style:

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* Compare this statement with the text concerning the Kao-tsung Notes. K. T.

† The book "T'ang-shu", from which presumably this information is drawn, mentions the "ho-ch'üan" or "identification certificate (coupon, check, billet or note)" which was also called "fei-ch'ien" or "flying money". Fei-ch'üan may therefore be the abridged combination of these two terms. K. T.

‡ This must mean notes proceeding by tens from 10 kwan to 100 kwan. K. T.

§ Literally, *one* ten Kwan. K. T.

PLATE 5.

T'ANG DYNASTY

CHING-TSUNG 825-826 A.D.

PAO-LI 825-826 A.D.

10 KWAN

DIMENSIONS

$5\frac{1}{2} \times 8\frac{7}{8}$ INCHES

"*To be current under the heavens.*"

At the left of the illustration, written vertically in the chuan (seal) style:

"*To circulate as cash.*"

The vertical columns in the lower panel:

The Board of Rites, having received the Imperial Decree, prints and issues under the heavens the Great T'ang Treasure-Note to be used as cash. The counterfeiter shall be decapitated summarily in punishment or the crime; the first informant shall be given 10 taels in silver.*

Pao-li,. . . .year,. . . .month,. . . .day,. .emitted." †

Plate 6. Pao-li (825–826 A.D.) Notes.

The inscription is the same as that on the 10 kwan note with the exception of the denomination, which is 100 kwan, and the reward to the informant which is 100 taels. The illustration represents 10 yüan-pao.

Plate 7. Upper Seal on the Pao-li Notes.

Four characters arranged as follows:

Treasure	Print
Note	Made

Translation: "*Printed Treasure-Note.*"

Plate 8. Lower Seal on the Pao-li Notes.

Six characters arranged as follows:

of	Pao-	Great
Seal	li	T'ang

Translation: "*The Seal of the Pao-li Era of the Great T'ang Dynasty.*

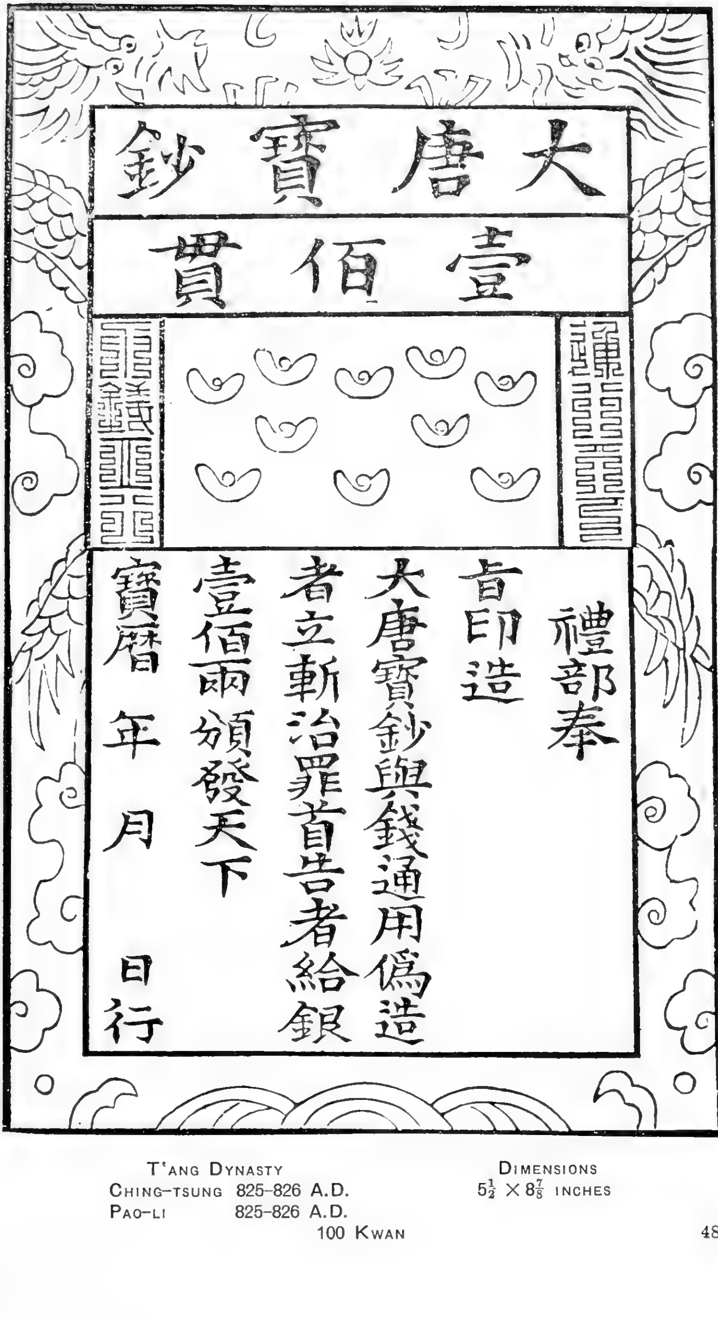
Notes of Emperor Wu-tsung (841–846 A.D.) of the T'ang Dynasty.

There are ten varieties of notes that were issued during the era of Hui-ch'ang (841–846 A.D.), in the reign of Wu-tsung. The note of

* In the actual inscription this phrase "issues under the heavens" comes after the word "silver" at the very end of the sentence. K. T.

† The word here used literally means "act". K. T.

PLATE 6.

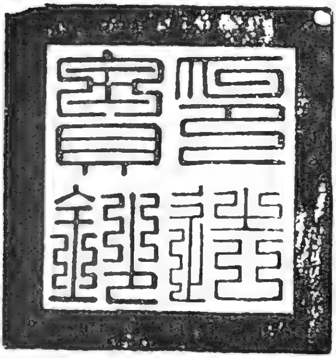


T'ANG DYNASTY
CHING-TSUNG 825-826 A.D.
PAO-LI 825-826 A.D.
100 KWAN

DIMENSIONS
$5\frac{1}{2} \times 8\frac{7}{8}$ INCHES

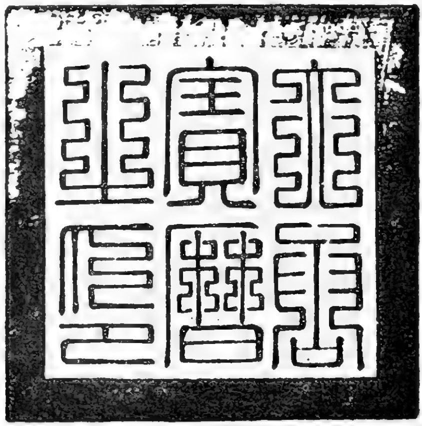
the value of one kwan bears a picture of one yüan-pao; that of 2 kwan, 2 yüan-pao; 3 kwan, 3 yüan-pao, and so on up to 10 kwan, each bearing a corresponding number of yüan-pao. On the border of these notes there appear two dragons tossing a jewel. The color of the paper is yellow, and all the inscriptions except the uppermost are written in the style of the great calligraphers Han Yü and Liu Tsung-yüan of the T'ang Period. Herewith two notes, one of maximum, and the other of minimum value are illustrated.

PLATE 7.



DIMENSIONS
$2\frac{1}{2} \times 2\frac{5}{8}$ INCHES

PLATE 8.



DIMENSIONS
$3\frac{1}{2} \times 3\frac{1}{2}$ INCHES

PLATE 9. HUI-CH'ANG (841–846 A.D.) NOTE.

Translation of the inscriptions.

First line: "*Great T'ang Issuance Treasure-Note.*" (Written in seal characters.)
Second line: "*One Kwan.*"
Illustration: (Pictorial representation of one yüan-pao).
In the right hand border, written vertically:
"*Issued to the world.*" Literally "*Distributed under the heavens.*"
In the left-hand border written vertically:
"*To be universally accepted.*"

PLATE 9.

T'ANG DYNASTY
WU-TSUNG 841-846 A.D.
HUI-CH'ANG 841-846 A.D.

DIMENSIONS
$5 \times 8\frac{7}{8}$ INCHES

ONE KWAN

Lower panel:

"*The Cabinet, having received the Imperial decree, prints and distributes the Great T'ang General Circulation Treasure-Note to be used side by side with silver, which is emitted under the heavens for the convenient use of the people. The counterfeiter shall be decapitated; for informing and arresting the reward shall be 260 taels in silver; and for concealing and not reporting (such guilt) the punishment shall be the same.**

Hui-ch'ang, ... year, ... month, ... day."

Plate 10.

The inscription is the same as that on the one kwan note with the exception of the denomination, which is 10 kwan, and the reward to the informant and captor which is 820 taels. The illustration represents 10 yüan-pao.

Plate 11. Upper Seal on the Hui-ch'ang Notes.

Four characters arranged as follows:

of	Hui-
Imperial Seal	ch'ang

Translation: "*Imperial Seal of the Hui-ch'ang Era.*"

Plate 12. Lower Seal on the Hui-ch'ang Notes.

Six characters arranged as follows:

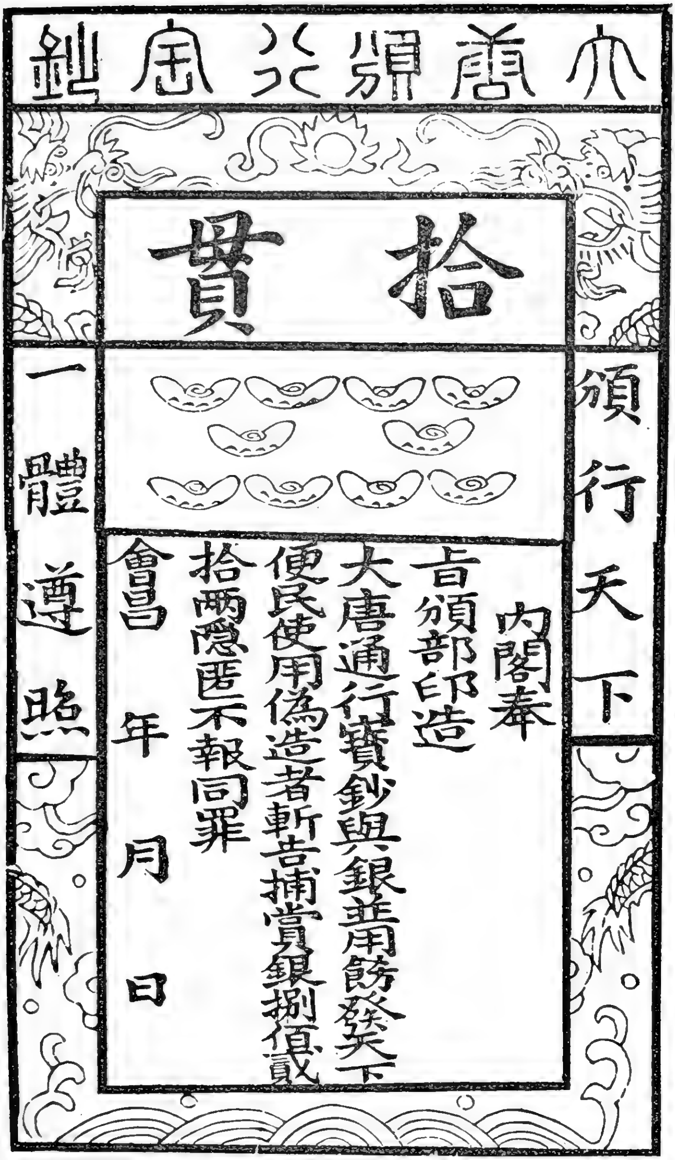
Treasure	Print	Great
Note	Made	T'ang

Translation: "*Printed Treasure-Note of the Great T'ang Dynasty.*"

Notes of Emperor Hsüan-tsung (847–859 A.D.) of the T'ang Dynasty.

The Emperor Hsüan-tsung came to the throne in 847, and the era of his rule became known as Ta-chung. There are twenty varieties of the Ta-chung notes, of which those ranging in denomination from 10 to 100 wên bear on the border a dragon design; while those rang-

* As in the case of counterfeiting. K. T.



T'ang Dynasty
Wu-tsung 841-846 A.D.
Hui-ch'ang 841-846 A.D.
10 Kwan

Dimensions
5 × $8\frac{7}{8}$ inches

ing from 100 to 1000 wên have a border design consisting of four ch'ih.* All are small military notes and their color is yellow.

PLATE 13. TA-CHUNG (847–859 A.D.) NOTE.

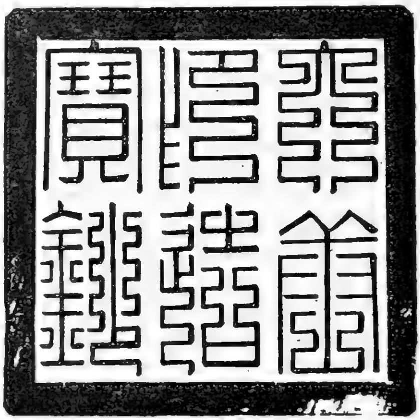
Translation of the Inscriptions.

First line: *"Great T'ang Military Administration Treasure-Note."*†
Second line: *"Ten Wên."*
Illustration: (Pictorial representation of 10 wên in one string).

PLATE 11.

DIMENSIONS
$2\frac{1}{2} \times 2\frac{1}{2}$ INCHES

PLATE 12.



DIMENSIONS
$3\frac{1}{4} \times 3\frac{1}{8}$ INCHES

Lower panel: *"The Board of War, having received the Imperial Decree, prints and issues to the Military barracks* ‡ *in every province, for the convenient use of the people, the Great T'ang Circulating Treasure-Note, to be employed as silver coin.* (*He who*) *prints a facsimile* § *shall*

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* Dragons without horns. K. T.

† By some this is translated as "*War Period* Treasure-Note"; but it seems to be a misinterpretation. K. T.

‡ Though literally "Military Barracks or Camps," the word "Army" would be a correct rendering. K. T.

§ Meaning "counterfeit". K. T.

PLATE 13.

T'ANG DYNASTY
HSÜAN-TSUNG 847–859 A.D.
TA-CHUNG 847–859 A.D.
10 WÊN

DIMENSIONS
$3\frac{1}{8} \times 8\frac{1}{2}$ INCHES

be executed summarily. The first informant shall be rewarded with ten taels in silver. The government soldier who conceals such guilt shall be punished accordingly.

"*Ta-chung,. . . .year,. . . .month,. . . .day, sanctioned.*" *

Plate 14.

The inscription is the same as that on the 10 wên note with the exception of the denomination, which is 100 wên, and the reward to the informant which is 100 taels. The illustration represents 100 cash in one string.

Plate 15.

The inscription is the same as that on the 10 wên note with the exception of the denomination, which is one kwan, and the reward to the informant which is 100 taels. The illustration represents 10 strings of 100 cash each.

Plate 16. Upper Seal on the Ta-chung Notes.

Four characters arranged as follows:

of	Ta-
Imperial Seal	chung

Translation: "*Imperial Seal of the Ta-chung Era.*"

Plate 17. Lower Seal on the Ta-chung Notes.

Four characters arranged as follows:

Treasure	Military
Note	Barracks

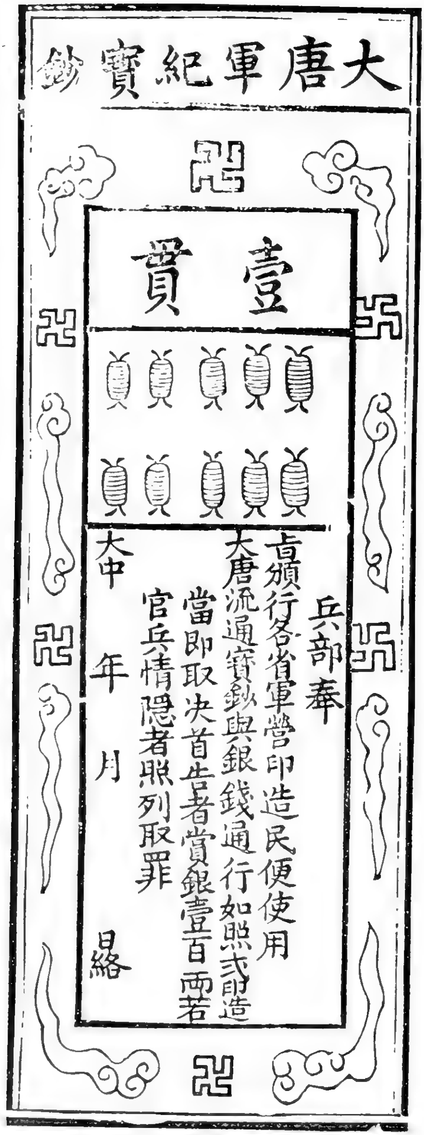
Translation: "*Treasure-Note of the Army.*"

* The sense of the character employed is not clear, as it has the meaning "bound, tied, wound, joined, continued", etc. There is no authority for translating it "sanctioned". K. T.

PLATE 14.

T'ANG DYNASTY
HSÜAN-TSUNG 847–859 A.D.
TA-CHUNG 847–859 A.D.
100 WÊN

DIMENSIONS
$3\frac{1}{8} \times 8\frac{1}{2}$ INCHES



T'ANG DYNASTY
HSÜAN-TSUNG 847-859 A.D.
TA-CHUNG 847-859 A.D.
ONE KWAN

DIMENSIONS
$3\frac{1}{8} \times 8\frac{1}{2}$ INCHES

Notes of Emperor I-tsung (860–873 A.D.) of the T'ang Dynasty.

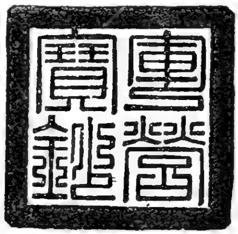
During his reign of fifteen years (806–820 A.D.) the Emperor Hsien-tsung caused to be enacted a merchants' monetary deposit law by which "identification certificates" were issued for the convenience of travelling traders, the same being convertible into cash on presentation. These "identification certificates" were known as "flying money" (fei-ch'ien) or "flying certificates" (fei-ch'üan).

In 860 A.D., I-tsung ascended the throne, and his era came to be known as "Hsien-t'ung". Though there was a financial readjustment under his rule on account of the scarcity of cash, there is no known record of the issuance of paper money at this period. Nevertheless, some notes of this era were acquired in the year 1833 from Tung Yung-jui, which once formed a part of the valuable collection of his ances-

PLATE 16.

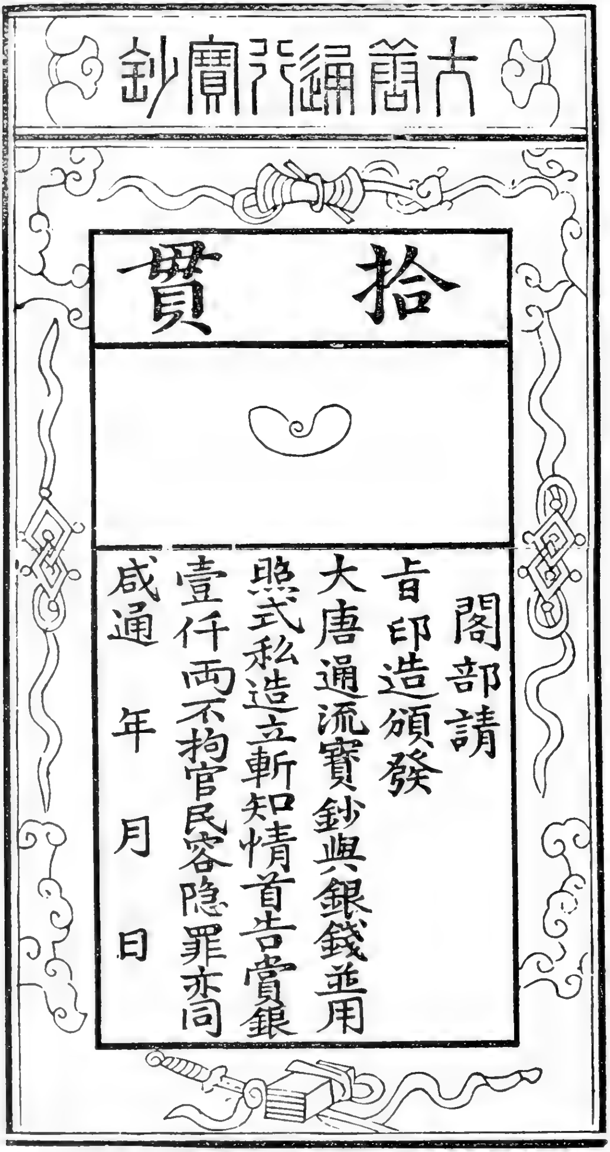
DIMENSIONS
$1\frac{3}{8} \times 1\frac{3}{8}$ INCHES

PLATE 17.



DIMENSIONS
$1\frac{3}{4} \times 1\frac{3}{4}$ INCHES

tor, Tung Piao Kung. Of the sixty odd varieties of notes of the successive dynasties published in the present work, these T'ang notes were discovered last. Their color is golden yellow, and they have a distinctive beauty. The arrangement of the various parts is as follows: at the top is written horizontally in the lesser chuan style, "Great T'ang General Circulation Treasure-Note"; directly below is inscribed, for example, "100 kwan", with a picture of 10 ingots of yüan-pao; in the lower panel appears the inscription: "The Cabinet, having petitioned the Imperial Decree, prints and issues the Great T'ang Circulating Treasure-Note to be used side by side with silver coin. He who privately makes a facsimile shall be decapitated summarily; he who first informs in the matter shall be rewarded with



T'ang Dynasty
I tsung 860–873 A.D.
Hsien t'ung 860–873 A.D.
10 Kwan

Dimensions
$5\frac{3}{8} \times 10\frac{1}{4}$ inches

4000 taels in silver. To official and civilian alike the punishment for conniving at (such an offence) shall also be the same. On the surrounding border two dragons appear on either side, with a jewel on the upper border and water on the lower. A square seal which reads "Great T'ang Issuance" appears above, and below is another square seal reading "Hsien-t'ung Circulating Treasure-Note". The latter seal is repeated on the back of each note.

Plate 18. Hsien-t'ung (860–873 A.D.) Note.

Translation of the inscriptions.

First line: *"Great T'ang General Circulation Treasure-Note."*
Second line: *"Ten Kwan."*
Illustration: (Pictorial representation of one yüan-pao).
Lower panel: *"The Cabinet, having petitioned the Imperial decree, prints and issues the Great T'ang Circulating Treasure-Note to be used side by side with silver coin. (He who) first privately makes a facsimile shall be decapitated summarily upon learning of (such guilt); (he who) first informs in the matter shall be rewarded with 1000 taels in silver. To official and civilian alike the punishment for conniving at (such an offence) shall also be the same.*
Hsien-t'ung,....year,....month,....day."

Plate 19.

The inscription is the same as that on the 10 kwan note with the exception of the denomination, which is 100 kwan, and the reward to the informant which is 4000 taels. The illustration represents 10 yüan pao.

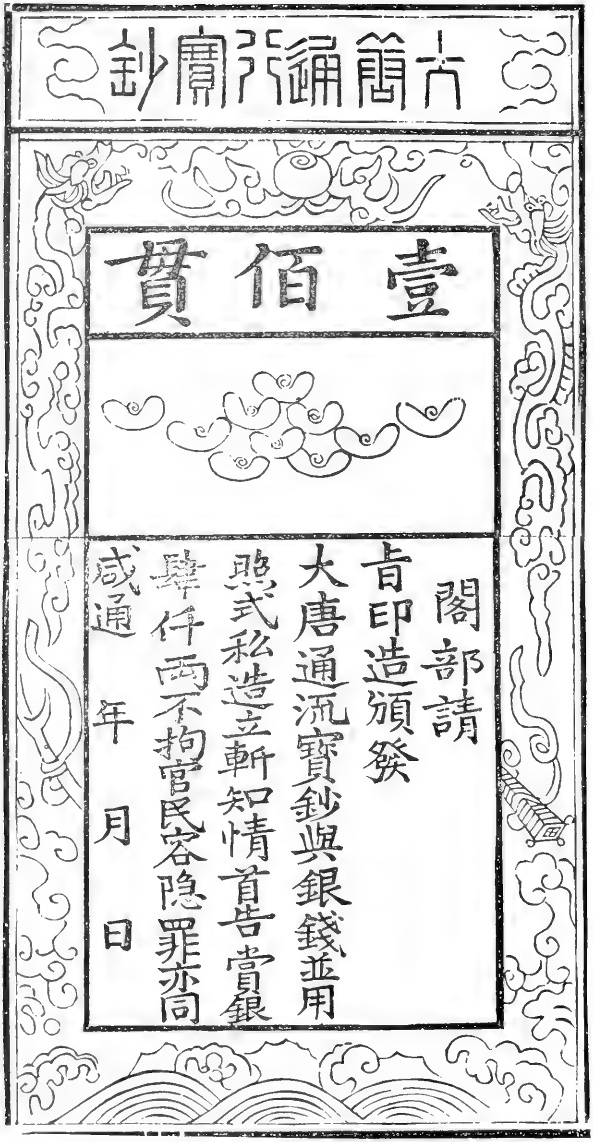
Plate 20. Upper Seal on the Hsien-t'ung Notes.

Four characters arranged as follows:

Distributing	Great
Issuing	T'ang

Translation: *"Issuance of the Great T'ang Dynasty."*

PLATE 19.



T'ang Dynasty
I-tsung 860-873 A.D.
Hsien-t'ung 860-873 A.D.
100 Kwan

Dimensions
$5\frac{1}{8} \times 10\frac{1}{8}$ inches

Plate 21. Lower Seal on the Hsien-t'ung Notes.

Six characters arranged as follows:

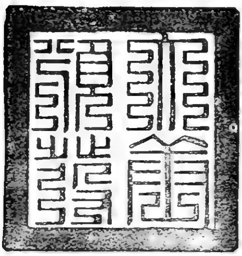
Treasure	Through	Hsien-
Note	Current	t'ung

Translation: "*Circulating Treasure-Note of the Hsien-t'ung Era.*"

Seal Appearing on the Back of the Hsien-t'ung Notes.

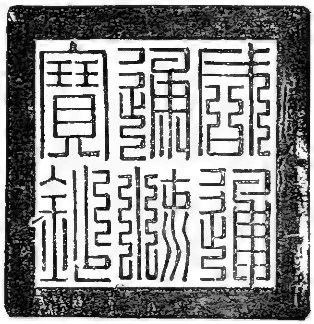
The inscription is the same as that on the lower seal of which it is a replica. See Plate 21.

PLATE 20.



DIMENSIONS
$2\frac{1}{8} \times 2\frac{1}{8}$ INCHES

PLATE 21.



DIMENSIONS
$2\frac{3}{4} \times 2\frac{3}{4}$ INCHES

Notes of Emperor Chao-tsung (889–903 A.D.) of the T'ang Dynasty.

Chao-tsung became Emperor in 889 A.D. and established the era called Lung-chi, which lasted only a year; and during this short period he issued twenty varieties of notes. The designs on the borders of the respective notes are: for the one kwan note, clouds and flowers; for the 10 kwan, clouds and chrysanthemums; for the 15 kwan, the Hsi-fan lotus (Passiflora cœrulea); for the 20 kwan, the Wan-shou * vine; and for the 25 kwan....†

* "Wan-shou" means "ten thousand years". K. T.
† The design for the 25 kwan note is not mentioned. K. T.

PLATE 22.

T'ang Dynasty
Chao tsung 889-903 A.D.
Lung chi 889 A.D.

Dimensions
$4\frac{3}{4} \times 9\frac{1}{4}$ inches

5 Kwan

Plate 22. Lung-chi (889 A.D.) Note.

Translation of the inscriptions.

First line: "*Great T'ang General Circulation Treasure-Note.*"
Second line: "*Five Kwan.*"
Illustration: (Pictorial representation of one cash).
Lower panel "*The Cabinet, having received the Imperial decree, prints and issues the Great T'ang Circulating Treasure-Note to be used side by side with silver coin. (He who) prints a facsimile shall be decapitated summarily. The first informant shall be rewarded with 650 taels in silver. To the concealer — military man and civilian alike — the same punishment * shall apply.*
Lung-chi, ... year, ... month, ... day."

Plate 23.

The inscription on the 50 kwan note is the same as that on the 5 kwan note with the exception of the denomination, and the reward to the informant which is 1500 taels. The illustration represents ten cash.

Plate 24.

The inscription on the 55 kwan note is the same as that on the 5 kwan note with the exception of the denomination, and the reward to the informant which 850 taels. The illustration represents eleven cash.

Plate 25.

The inscription on the 100 kwan note is the same as that on the 5 kwan note with the exception of the denomination, and the reward to the informant which is 940 taels. The illustration represents twenty cash.

---

* As in the case of counterfeiting. K. T.

PLATE 23.

T'ang Dynasty
Chao-tsung 889-903 A.D.
Lung chi 889 A.D.

Dimensions
$4\frac{3}{4} \times 9\frac{1}{4}$ inches

50 Kwan

PLATE 24.

T'ANG DYNASTY
CHAO-TSUNG 889-903 A.D.
LUNG-CHI 889 A.D.

DIMENSIONS
$4\frac{3}{4} \times 9\frac{1}{4}$ INCHES

55 KWAN

PLATE 25.

T'ANG DYNASTY
CHAO-TSUNG 889-903 A.D
LUNG-CHI 889 A.D.

DIMENSIONS
$4\frac{3}{4} \times 9\frac{1}{4}$ INCHES

100 KWAN

PLATE 26. UPPER SEAL ON THE LUNG-CHI NOTES.

Four characters arranged as follows:

of	Lung-
Imperial Seal	chi

Translation: "*The Imperial Seal of the Lung-chi Era.*"

PLATE 27. LOWER SEAL ON THE LUNG-CHI NOTES.

Six characters arranged as follows:

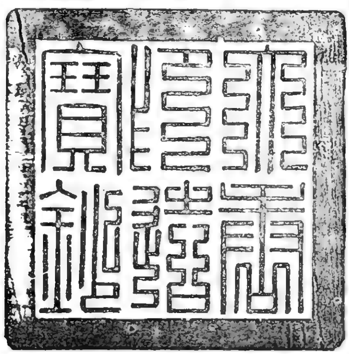
Treasure	Print	Great
Note	Made	T'ang

Translation: "*Printed Treasure-Note of the Great T'ang Dynasty.*"

PLATE 26.

DIMENSIONS
2 × $1\frac{7}{8}$ INCHES

PLATE 27.



DIMENSIONS
$2\frac{3}{4}$ × $2\frac{3}{4}$ INCHES

THE T'IEN-YU (904–922 A.D.) NOTES OF THE T'ANG DYNASTY.

In 904 A.D., the first year of the T'ien-yu Era, the reigning emperor, Chao-tsung, was assassinated by Chu Ch'üan-chung, and a young boy twelve years of age was placed on the throne as his successor. He became known as Chao-hsüan-ti, and remained the nominal head of the empire until 907 A.D., when he transferred his imperial power to Chu Ch'üan-chung, marking the end of the T'ang Dynasty * and the establishment of the Hou Liang or the Posterior Liang Dynasty.

During this T'ien-yu Era,† ten varieties of notes were issued. Their color is yellow, and in denomination they range from one to ten kwan. At the top is written horizontally "Great T'ang Public Convenience Treasure-Note". Directly below is written the value with a pictorial representation of a proportionate number of strings of cash, i. e., for 1 kwan, 1 string of cash. Beneath appears an inscription which reads: "The Cabinet, having petitioned the Throne, prints and issues the Great T'ang Treasure-Note to be current under the heavens and to be used as cash. The counterfeiter of the same shall be decapitated; the informant and captor will be rewarded with 120 taels in silver (this amount in the case of the one kwan note). To the conniver (at such an offence) the punishment shall be the same. T'ien-yu,.......year,.......month,.......day." On the border appear two dragons tossing a jewel, and below them, waves. The upper portion bears a square seal with the characters "Imperial Seal of the Great T'ang Dynasty." The lower seal which is also square reads: "Printed Treasure-Note of the T'ien-yu Era". The latter seal is stamped on the back of the note, which is otherwise undecorated.

Plate 28. T'ien-yu (904–922 A.D.) Note.

Translation of the inscriptions.

First line: "*Great T'ang Public Convenience Treasure-Note.*"

Second line: "*One Kwan.*"

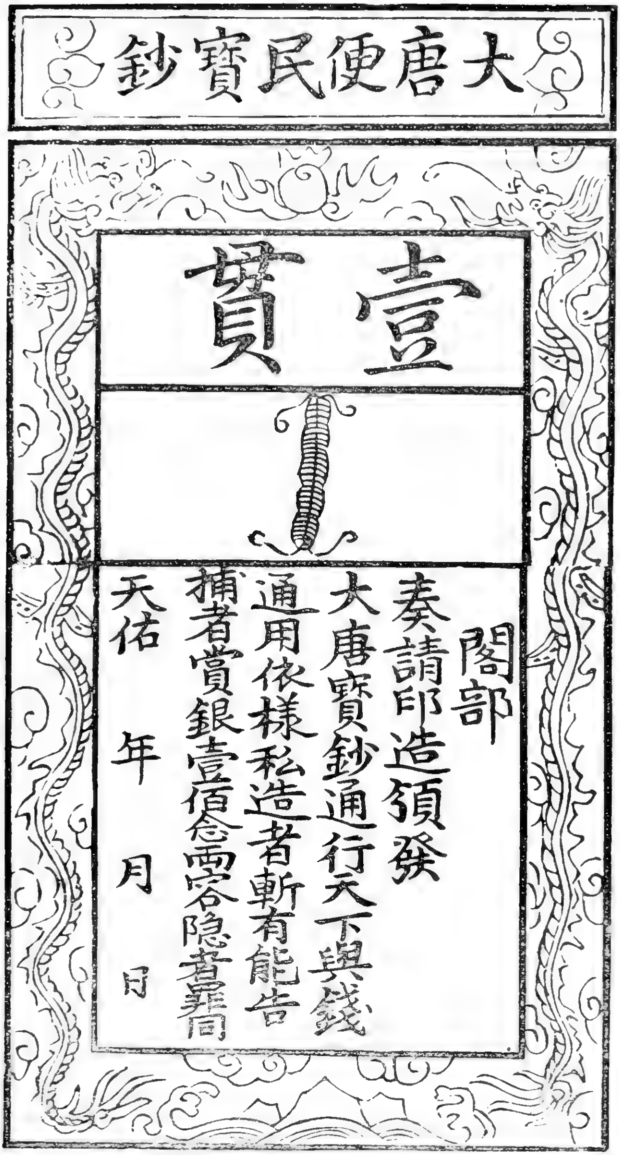
Illustration: (Pictorial representation of one string of cash).

Lower panel: "*The Cabinet, having petitioned the Throne, prints and issues the Great T'ang Treasure-Note to be current under the heavens and to be used as cash. The counterfeiter of the same form shall be decapitated;*

---

* According to history the name T'ien-yu was retained until 922, as the boy emperor, after abdicating the Imperial throne, was made king of a certain territory. K. T.

† By "T'ien-yu Era" in this particular case, it seems that the author means the period of about four years commencing with the last year of the Emperor Chao-tsung's reign and ending with the year of the transfer of the Imperial power by Chao-hsüan-ti to Chu Ch'üan-chung. The author says that after the accession of Chu Ch'üan-chung, which marked the end of the T'ang Dynasty, for three years the country was in a chaotic state, with constant fighting, and that as a temporary expedient, notes modelled after those of the Emperor I-tsung were issued to meet the financial situation. K. T.



T'ANG DYNASTY
CHAO-HSÜAN-TI 904-907 A.D.
T'IEN-YU 904-922 A.D.
ONE KWAN

DIMENSIONS
$4\frac{3}{8} \times 8\frac{3}{8}$ INCHES

*he who daringly informs (about) and captures (such a criminal) shall be rewarded with 120 taels in silver. To the conniver (at such an offence) the punishment shall be the same.**

"T'ien-yu,....year,....month,....day."

Plate 29.

The inscription is the same as that on the one kwan note with the exception of the denomination, which is 10 kwan, and the reward to the informant and captor which is 710 taels. The illustration represents 10 strings of cash.

Plate 30.

The inscription is the same as that on the one kwan note with the exception of the denomination, which is 100 kwan, and the reward to the informant and captor which is 5000 taels. The illustration represents 10 groups of cash of 10 strings each.

Plate 31. Upper Seal on the T'ien-yu Notes.

Four characters arranged as follows:

of	Great
Imperial Seal	T'ang

Translation: "*Imperial Seal of the Great T'ang Dynasty.*

Plate 32. Lower Seal on the T'ien-yu Notes.

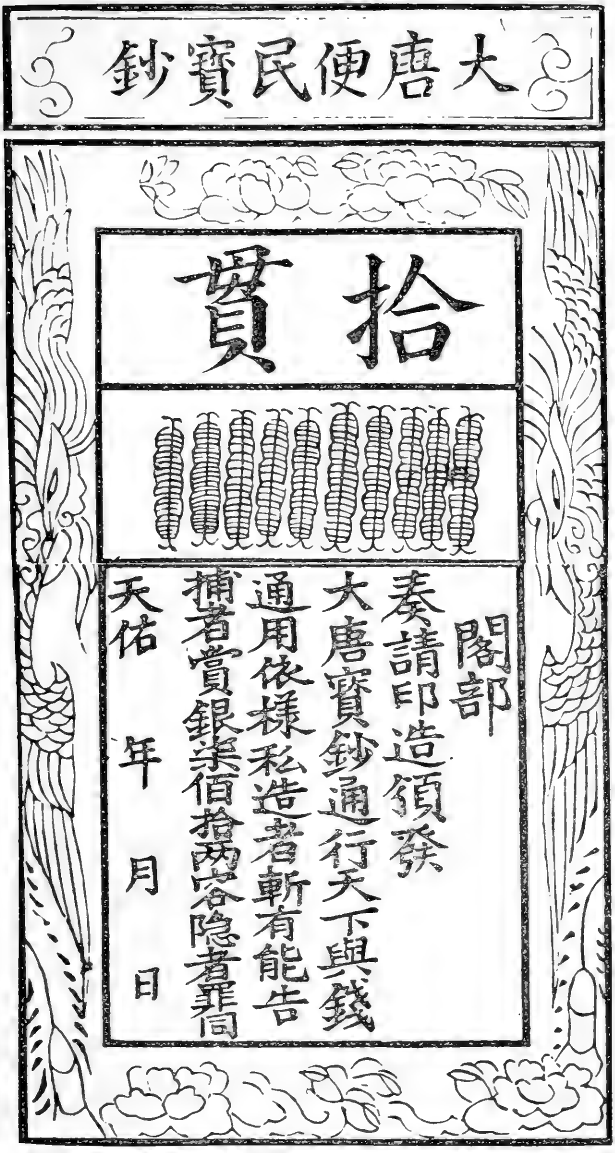
Six characters arranged as follows:

Treasure	Print	T'ien
Note	Made	yu

Translation: "*Printed Treasure-Note of the T'ien-yu Era.*"

---

* As in the case of counterfeiting. K. T.



T'ANG DYNASTY
CHAO-HSÜAN-TI 904–907 A.D.
T'IEN-YU 904–922 A.D.
10 KWAN

DIMENSIONS
$4\frac{3}{8} \times 8\frac{3}{8}$ INCHES

PLATE 30.

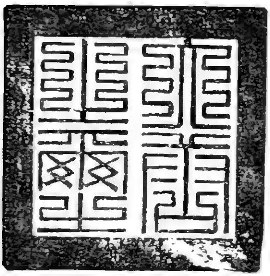
T'ANG DYNASTY
CHAO-HSÜAN-LI 904–907 A.D.
T'IEN-YU 905–922 A.D.
100 KWAN

DIMENSIONS
$4\frac{3}{8} \times 8\frac{3}{8}$ INCHES

Seal Appearing on the Reverse of the T'ien-yu Notes.

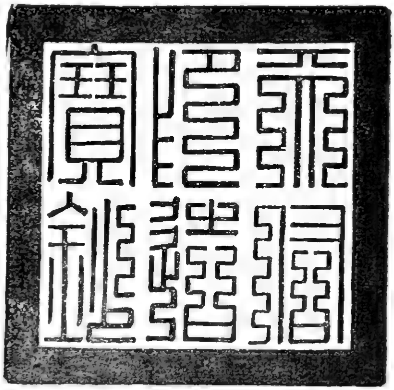
The inscription is the same as that on the Lower Seal, of which it is a replica. See Plate 32.

PLATE 31.



DIMENSIONS
$1\frac{7}{8} \times 1\frac{7}{8}$ INCHES

PLATE 32.



DIMENSIONS
$2\frac{3}{4} \times 2\frac{3}{4}$ INCHES

Notes of Emperor T'ai-tsu (951–953 A.D.) of the Hou (Posterior) Chou Dynasty.

In January of the first year of the Kuang-shun Era (951–953 A.D.), T'ai-tsu came to the throne. This era covered three years during which time notes were issued. The remaining specimens of these notes are very scarce, but ten varieties of the following denominations have been acquired: 1 [10?] * 20, 30, 40, 50, 60, 70, 80, 90 and 100 taels. The color of the paper is "lake" (the blue of the waters of a lake). The figures which denote the value of the notes are undecipherable, while the designs on the borders and the signs indicating the value have been defaced.

---

* In the text of the book this figure is distinctly 1, but it may possibly be a typographical error and have been intended for 10. K. T.

Plate 33. Kuang-shun (951–953 A.D.) Note.*

Translation of the inscriptions.

Above: "*Great Chou General Circulation Treasure-Note.*"
At the right, in the seal style:
"*To be current under the Heavens.*"
At the left, in the seal style:
"*For the convenient use of the people.*"
In the lower panel: "*The Great Chou General Circulation Treasure-Note is purposed for the convenient use of all the people.*

The Civil Board, having received the Imperial authorization decree, designs this note to represent 30 taels in official silver, which value cannot be altered. The counterfeiter of this model — principal or conspirator irrespectively — shall be executed summarily and exposed to public view. He who discovers a counterfeiter and reports his name to the District authorities shall receive immediately a reward of 8 taels in silver from the District authorities. This shall be current in all provinces.

Great Chou, Kuang-shun,. . . .year,. . . .month,. . . .day, issued."

Plate 34.

The inscription is the same as that on the 30 tael note with the exception of the denomination, which is 40 taels, and the reward to the informant which is 10 taels.

Plate 35. Upper Seal on the Kuang-shun Notes.

Four characters arranged as follows:

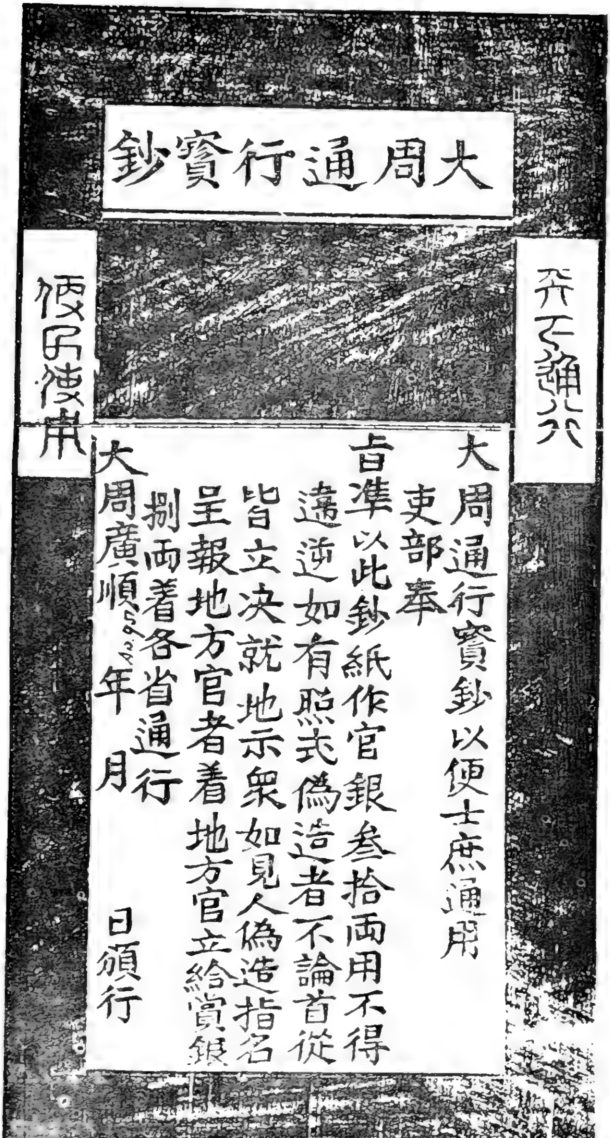
Private	Kuang
Seal	shun

Translation: "*Private † Seal of the Kuang-shun Era.*"

---

* The panel in which the representation of the value of the note should appear and the border of the note are in black, since they were unrecognizable in the original. K. T.

† The word "private" is used presumably to distinguish it from the Imperial Seal. K. T.

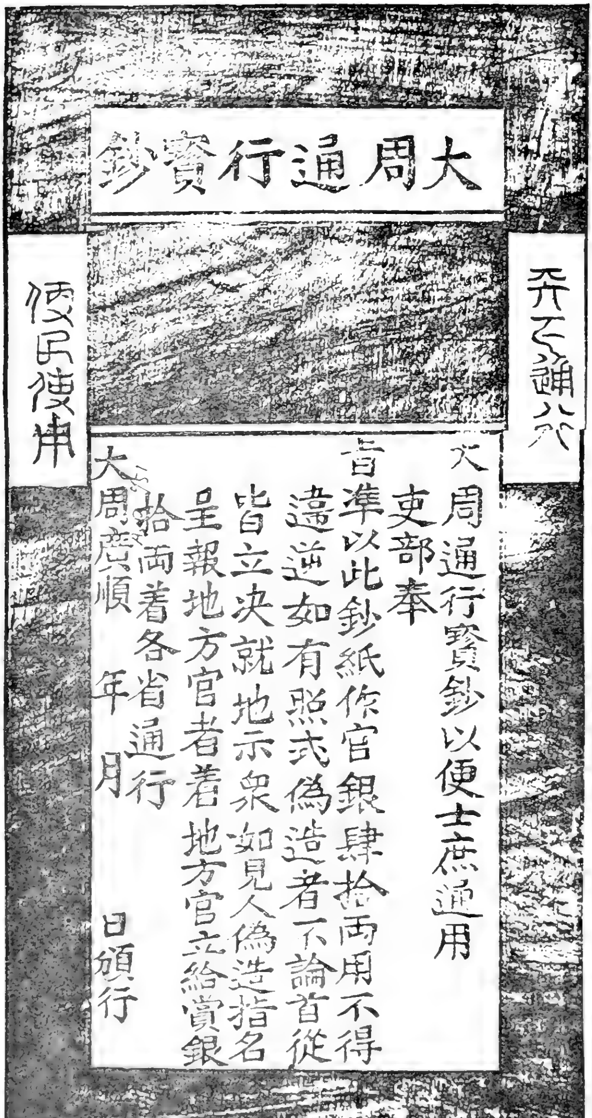


POSTERIOR CHOU DYNASTY
T'AI-TSU 951-953 A.D.
KUANG-SHUN 951-953 A.D.

DIMENSIONS
$4\frac{1}{4} \times 8\frac{3}{8}$ INCHES

30 TAELS

PLATE 34.



POSTERIOR CHOU DYNASTY
T'AI-TSU 951-953 A.D.
KUANG-SHUN 951-953 A.D.

DIMENSIONS
$4\frac{1}{4} \times 8\frac{3}{8}$ INCHES

40 TAELS

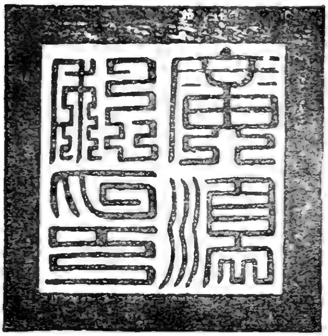
Plate 36. Lower Seal on the Kuang-shun Notes.

Six characters arranged as follows:

Treasure	Through	Great
Note	Circulating	Chou

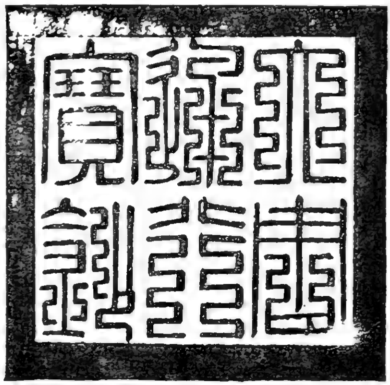
Translation: "*General Circulation Treasure-Note of the Great Chou Dynasty.*"

PLATE 35.



DIMENSIONS
$2\frac{3}{8} \times 2\frac{3}{8}$ INCHES

PLATE 36.



DIMENSIONS
$2\frac{3}{4} \times 2\frac{3}{4}$ INCHES

Notes of Emperor Shih-tsung (954–959 A.D.) of the Hou (Posterior) Chou Dynasty.

In 954 A.D. Shih-tsung came to the throne and established the era called Hsien-tê (954–959 A.D.). During his reign he caused notes to be emitted. Ten varieties of these have been acquired. At the top of each is written horizontally "Great Chou General Circulation Treasure-Note". In the right and left-hand borders respectively appear the inscriptions "To circulate as cash" and "Not to be used without authority", in the lesser seal style; and a floral design fills the remaining space in the border. On the back of the note appear a picture of a horse and a man, and two characters which read "P'ing-an" (Peace). The same mark appears on the Western Liao notes which are modelled after those of the Hou Chou Dynasty. On the face of the notes there are two seals whose impressions are not made in red mixed with oil, but in yellow pigment mixed with sizing. The color of the paper is blue-black,* the forerunner of the dark notes of the Sung and Yüan and Ming Dynasties, a fact which proves that it was in this period (the Posterior Chou) that blue-black* paper was substituted in the notes for the yellow used in the T'ang Dynasty.

Plate 37. Hsien-tê (954–959 A.D.) Note.

Translation of the inscriptions:

Above: "*Great Chou General Circulation Treasure-Note.*"
Illustration: (Pictorial representation of one ingot).
At the right, in the lesser seal style:
"*To circulate as cash.*"
At the left, in the lesser seal style:
"*Not to be used without authority.*"
In the lower panel: "*The Great Chou General Circulation Treasure-Note is purposed for the convenient use of all the people. The Board of Rites, having received the Imperial authorization decree, designs this note to represent 1 tael in official silver, which value cannot be altered. The counterfeiter of this model — principal or conspirator — shall be immediately executed by the authorities of the district concerned. (He who) reports to the District authorities the name of an offender by counterfeiting shall be rewarded with 14 taels in silver. This shall be current in all provinces.*
Great Chou, Hsien-tê,. . . .year,. . . .month,. . . .day, issued."

Plate 38.

The inscription is the same as that on the one tael note with the exception of the denomination, which is 10 taels, and the reward to the informant which is 60 taels. The illustration represents 10 ingots.

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* Dark gray (?). K. T.

PLATE 37.

POSTERIOR CHOU DYNASTY
SHIH-TSUNG 954-959 A.D.
HSIEN-TÊ 954-959 A.D.

DIMENSIONS
$4\frac{1}{4} \times 8\frac{1}{4}$ INCHES

ONE TAEL

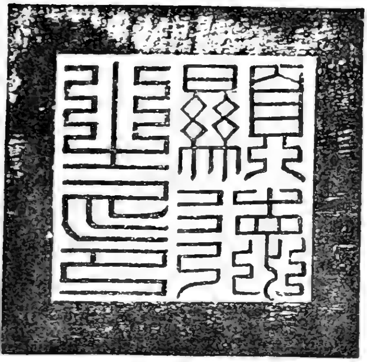
PLATE 38.

POSTERIOR CHOU DYNASTY
SHIH TSUNG 954 959 A.D.
HSIEN TÊ 954 959 A.D.

DIMENSIONS
$4\frac{3}{5} \times 8\frac{3}{5}$ INCHES

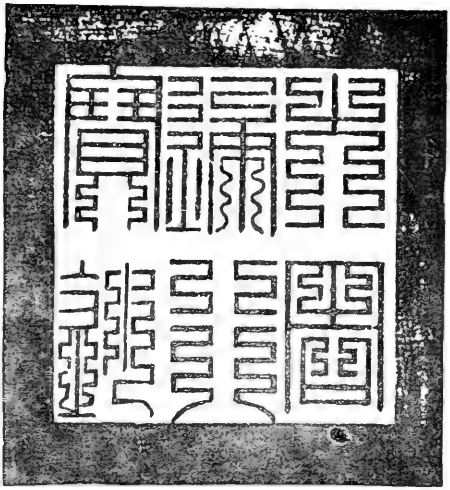
10 TAELS

PLATE 39.



DIMENSIONS
$2\frac{5}{8} \times 2\frac{1}{2}$ INCHES

PLATE 40.



DIMENSIONS
$3\frac{1}{4} \times 3\frac{1}{2}$ INCHES

PLATE 41.

Plate 39. Upper Seal on the Hsien-tê Notes.

Four characters arranged as follows:

of	Hsien-
Seal	tê

Translation: "*Seal of the Hsien-tê Era.*"

Plate 40. Lower Seal on the Hsien-tê Note.

Six characters arranged as follows:

Treasure	Through	Great
Note	Circulating	Chou

Translation: *General Circulation Treasure-Note of the Great Chou Dynasty.*"

Plate 41. Illustration on the Reverse of the Hsien-tê Note.

Man with a horse and two characters "P'ing-an" (*Peace*).

Notes of Emperor T'ai-tsu (960–975 A.D.) of the Northern Sung Dynasty.

The first emperor of the Sung, T'ai-tsu, ascended the throne in 960 A.D., establishing the era called Chien-lung (960–962 A.D.). In its fourth year the name of the era was changed to Ch'ien-tê. Two kinds of notes — large and small — bearing the name of the former era have been found, though history itself does not record their emission. At the top of each, written horizontally, appears the inscription "Great Sung General Circulation Treasure Note"; on the right and left-hand borders respectively, in an ancient style of writing, is inscribed "To be current under the heavens" and "For the convenient use of the people". In the center is given the value of the note, for instance, 100 kwan, and directly below a pictorial representation of a number of yüan-pao (14 in five horizontal rows in the case of a 100 kwan note). Within the panel containing the pictorial representation appears, at the right, "As cash", and at the left, "To circulate". In the lower part is inscribed: "The Board of Revenue, having received the Imperial Decree, prints and issues under the heavens the

Great Sung Treasure-Note, to be used as cash. The counterfeiter shall be decapitated summarily; the first informant shall be given 400 taels in silver. Chien-lung,......year,......month,......day, emitted." There is a design of dragons on the border. The upper seal, which is square, reads: "The Seal of the Chien-lung Era", while the lower, which is also square, reads: "Great Sung Chien-lung Treasure-Note." This latter seal appears again on the back of the note with an ornamental figure which consists of a brush, an ingot of money and a jui (scepter symbolizing good luck) and a flower. The color of the paper is gray, and in quality it is the same as that used for the Yüan and Ming notes.

Plate 42. Chien-lung (960–962 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Sung General Circulation Treasure-Note.*"
Second line: "*Fifty Kwan.*"
Illustration: (Pictorial representation of seven ingots of yüan-pao).
At the left and right of the picture, within the upper panel:
"*To circulate as cash.*"
In the right-hand border, in an ancient style of writing:
"*To be current under the heavens.*"
In the left-hand border, in an ancient style of writing:
"*For the convenient use of the people.*"
In the lower panel: "*The Board of Revenue, having received the Imperial Decree, prints and issues under the heavens* the Great Sung Treasure-Note, to be used as cash. The counterfeiter shall be decapitated summarily; the first informant shall be given 400 taels in silver.*
Chien-lung,....year,....month,....day, emitted." †

Plate 43.

The inscription is the same as that on the 50 kwan note with the exception of the denomination which is 100 kwan. The reward to the informant is the same as in the case of the 50 kwan note, i. e., 400 taels. The illustration represents 14 ingots of yüan-pao.

---

* In the actual inscription this phrase "issues under the heavens" comes after the word "taels" at the very end of the sentence. K. T.
† The word here used literally means "act". K. T.

PLATE 42.

SUNG DYNASTY
T'AI-TSU 960-975 A.D
CHIEN-LUNG 960-962 A.D.

DIMENSIONS
$6\frac{5}{8} \times 12\frac{5}{8}$ INCHES

50 KWAN

Sung Dynasty
T'ai-tsu 960–975 A.D.
Chien-lung 960–962 A.D.

Dimensions
$6\frac{3}{4} \times 12\frac{1}{2}$ inches

100 Kwan

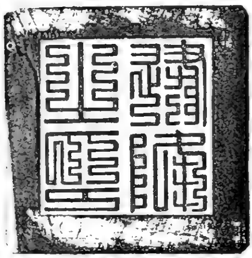
Plate 44. Upper Seal on the Chien-lung Notes.

Four characters arranged as follows:

of	Chien-
Seal	lung

Translation: "*Seal of the Chien-lung Era.*"

PLATE 44.



Dimensions
$2\frac{3}{4} \times 2\frac{3}{4}$ inches

PLATE 45.

Dimensions
$3 \times 3\frac{1}{8}$ inches

PLATE 46.

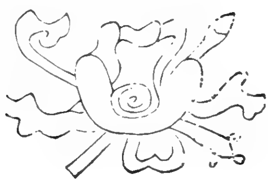


Plate 45. Lower Seal on the Chien-lung Notes.

Six characters arranged as follows:

Treasure	Chien-	Great
Note	lung	Sung

Translation: "*Treasure-Note of the Chien-lung Era of the Great Sung Dynasty.*"

Plate 46. Seal and Floral Pattern on the Reverse of the Chien-lung Notes.

Picture:

An ornamental figure consisting of a brush, an ingot of money, a jui (scepter) and a flower.

Seal:

The inscription on this seal is the same as that on the lower seal of which it is a replica. See Plate 45.

Notes of Emperor Shên-tsung (1067–1085 A.D.) of the Northern Sung Dynasty.

There are in all more than two hundred varieties of notes which were issued during the period beginning with the T'ang and ending with the Ming Dynasty. Among them, the notes emitted during the reign of the Emperor T'ai-tsu of the Sung alone bear the character "act" * (meaning "emitted") after the date of emission. The same character is also found on the Hsi-ning (1068–1077 A.D.) notes of Shên-tsung,† which were modelled after those above-mentioned. No design and no seal appear on the back of these notes, unlike those of T'ai-tsu.

Plate 47. Hsi-ning (1068–1077 A.D.) Note.

Translation of the inscriptions.

First line: "*Hsi-ning Treasure-Note.*"

Second line: "*Fifty Kwan.*"

Illustration: (Pictorial representation of five ingots).

In the lower panel: "*The Boards of Rites and Revenue, having received the Imperial Decree, print this paper-note to be used parallel with silver coin. The counterfeiter shall be decapitated. The captor of the criminal shall be rewarded with 400 taels in silver. The conniver — district official and civilian alike — shall be decapitated summarily.*

Hsi-ning, ... year, ... month, ... day emitted."

---

* It will be noted that this character appeared on the notes of Kao-tsung and Ching-tsung, of the T'ang Dynasty. K. T.

† Compare the preceding statement. K. T.

PLATE 47.

SUNG DYNASTY
SHÊN-TSUNG 1067-1085 A.D.
HSI-NING 1068-1077 A.D.
50 KWAN

DIMENSIONS
$6\frac{3}{4} \times 12\frac{5}{8}$ INCHES

Plate 48. Upper Seal on the Hsi-ning Note.

Four characters arranged as follows:

of	Hsi-
Treasure	ning

Translation: "*The Treasure of the Hsi-ning Era.*"

Plate 49. Lower Seal on the Hsi-ning Note.

Six characters arranged as follows:

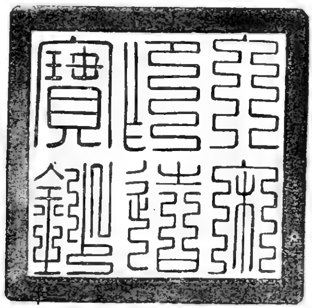
Treasure	Print	Great
Note	Made	Sung

Translation: "*Printed Treasure-Note of the Great Sung Dynasty.*"

PLATE 48.

DIMENSIONS
$2\frac{5}{8} \times 2\frac{5}{8}$ INCHES

PLATE 49.



DIMENSIONS
$3\frac{1}{4} \times 3\frac{1}{4}$ INCHES

Notes of Ch'in-tsung (1126 A.D.) of the Northern Sung Dynasty.

Ten varieties of notes were issued in the Ching-k'ang Era (1126 A.D.) during the reign of the Emperor Ch'in-tsung.

The first is the 5 kwan note with a pictorial representation of one silver ingot, having as a border design the eight treasure-emblems; on the right and left-hand borders respectively appear the inscriptions "Great Sung Treasure-Note" and "For the convenient use of the people", both in seal characters. On the reverse of the note there is a mark consisting of a scroll, bearing the four characters which mean "To open the scroll is to benefit". A like mark is found on each note of the ten varieties. The second is the 10 kwan note with an illustration of two ingots and a border design consisting of four dragons with a jewel. Then comes the 15 kwan note with three ingots and a border design of the lotus plant; * the 25 kwan note has a pictorial representation of five ingots and a border design consisting of four dragons and a jewel; on the 30 kwan note appear six ingots and a border design of the An-pa-hsien; † on the 35 kwan note, seven ingots and a border design of the Hsi-fan plant (Passiflora cœrulea); on the 40 kwan note, eight ingots and a border design consisting of two dragons, clouds and a jewel; on the 45 kwan note, nine ingots and a border design consisting of five dragons and a jewel; and finally, the 50 kwan note with ten ingots and a border design of the eight treasure emblems.

Plate 50. Ching-k'ang (1126 A.D.) Note.

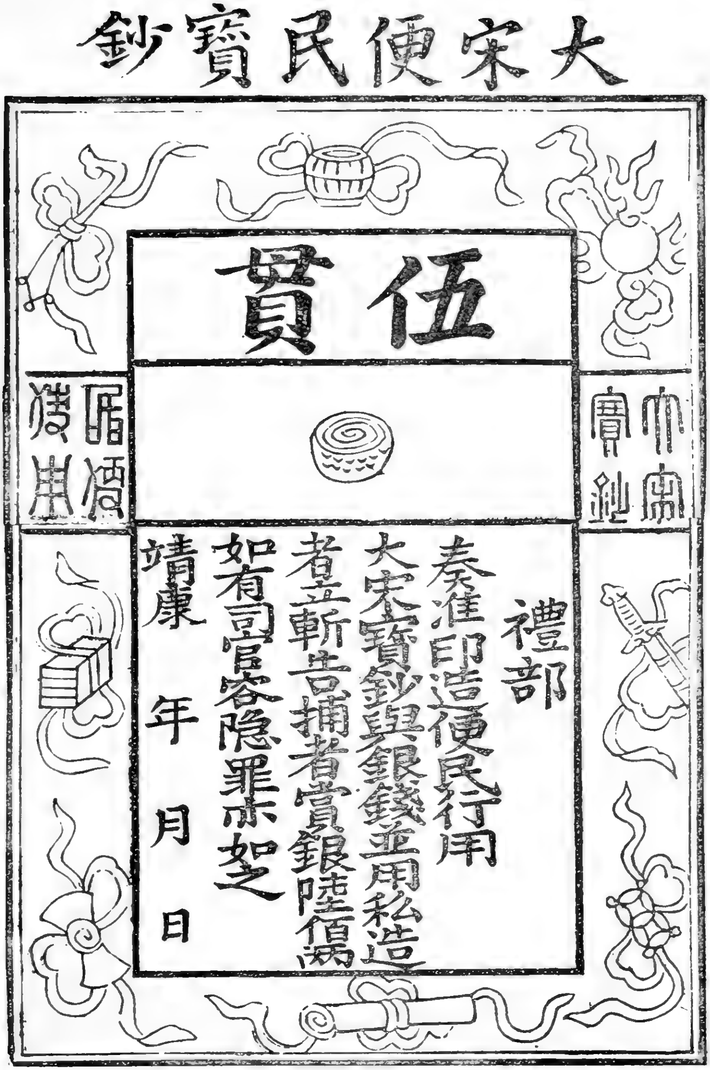
Translation of the inscriptions.

Heading: "*Great Sung Public Convenience Treasure-Note.*"
Top of panel: "*Five Kwan.*"
Illustration: (Pictorial representation of one ingot of silver).
Right-hand border, in seal style:
"*Great Sung Treasure-Note.*"
Left-hand border, in seal style:
"*For the Convenient Use of the People.*"
In the lower panel: "*The Board of Rites, having petitioned the Imperial sanction, prints for the convenient use of the people the Great Sung Treasure-Note, to be used side by side with silver coin. The counterfeiter shall be decapitated summarily; the informant or captor shall be rewarded with 600 taels in silver. If any official connives at (such guilt) the punishment shall be the same as this (the case of the counterfeiter).*
Ching-k'ang,....year,....month,....day."

---

* Directly after the 15 kwan note in the text comes the 25 kwan note. The writer no doubt omitted the 20 kwan note. K. T.
† Probably a kind of hydrangea. K. T.

PLATE 50.



SUNG DYNASTY
C'HIN-TSUNG 1126 A.D.
CHING-K'ANG 1126 A.D.

DIMENSIONS
$5\frac{1}{3} \times 8\frac{1}{2}$ INCHES

5 KWAN

Plate 51.

The inscription is the same as that on the 5 kwan note with the exception of the denomination, which is 30 kwan and the reward to the informant and captor which is 1000 taels. The illustration represents six ingots.

Plate 52.

The inscription is the same as that on the 5 kwan note with the exception of the denomination, which is 50 kwan, and the reward to the informant and captor which is 1000 taels. The illustration represents ten ingots.

Plate 53. Upper Seal on the Ching-k'ang Notes.

Four characters arranged as follows:

of Ching-
Seal k'ang

Translation: "*The Seal of the Ching-k'ang Era.*"

Plate 54. Illustration and Upper Seal on the Reverse of the Ching-k'ang Notes.

Four characters written vertically on the scroll:

Open
Scroll
is
Benefit

Translation: "*To open the scroll is to benefit.*"
Four characters on the seal:

of Ching-
Seal k'ang

Translation: "*The Seal of the Ching-k'ang Era,*" the seal being a replica of the upper seal.— See Plate 53.

Sung Dynasty
C'hin-tsung 1126 A.D.
Ching-k'ang 1126 A.D.

Dimensions
$5\frac{1}{2} \times 8\frac{5}{8}$ inches

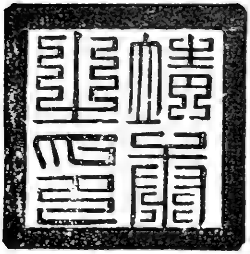
30 Kwan

SUNG DYNASTY
C'HIN-TSUNG 1126 A.D.
CHING-K'ANG 1126 A.D.

DIMENSIONS
$7\frac{3}{4} \times 5\frac{1}{2}$ INCHES

50 KWAN

PLATE 53.



DIMENSIONS
$1\frac{7}{8} \times 2\frac{1}{8}$ INCHES

PLATE 54.

PLATE 55.

DIMENSIONS
$2\frac{7}{8} \times 2\frac{7}{8}$ INCHES

Plate 55. Lower Seal on the Ching-k'ang Notes.

Six characters arranged as follows:

Treasure	Convenience	Great
Note	Public (People)	Sung

Translation: "*Public Convenience Treasure-Note of the Great Sung Dynasty.*"

Notes of Emperor Kao-tsung (1127–1162 A.D.) of the Southern Sung Dynasty.

In 1127 A.D. Kao-tsung ascended the throne and established the era called Chien-yen, which lasted through 1130 A.D., when its name was changed to Shao-hsing (1131–1162 A.D.). Five varieties of notes bearing the former name are in the possession of the Chu Family. They are somewhat similar to the notes of the Hsia and Chin Dynasties. Each has ornamental borders with the dragon-and-cloud design; at the top are six characters which read: "Great Sung General Circulation Treasure-Note"; below is the denomination,— 10, 20, 30, 40 and 50 kwan respectively, and a pictorial representation of cash (1, 2, 3, 4 and 5 respectively). On either side the pictorial representation are four characters in an ancient style of writing, which read: "Great Sung Metal Cash" (the first two words at the right and the last two at the left). Below is the inscription: "The Board of Revenue, having petitioned", etc., ending with "Chien-yen, ...year,........month,........day". On the reverse of each note appears a figure: for ten kwan, a tiger; for 20 kwan a Ssŭ; for 30 kwan, an elephant; for 40 kwan, a rabbit; and for fifty kwan, a lion.*

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* In the beginning of this text, the author discusses the issuance of hui-tzŭ which may be translated as "bonds" or "agreements". He quotes from two books, in one of which the hui-tzŭ is referred to as "paper-money", while in the other it is not considered paper-money, and is classed as chiao-tzu, or "bills of exchange". After thus presenting the two opposite views, it is to be inferred that the author is inclined to agree with the first and that he considers the notes published in Kao-tsung's time hui-tzŭ. However, in the following chapter of his book the author makes it clear that hui-tzŭ are bronze tablets which were issued as certificates representing money. K. T.

PLATE 56. CHIEN-YEN (1127–1130 A.D.) NOTE.

Translation of the inscriptions.

First line: "*Great Sung General Circulation Treasure-Note.*"
Second line: "*Ten Kwan.*"
Illustration: (Pictorial representation of one cash with ribbon).
At the right of the picture in an ancient style of writing:
"*Great Sung.*"
At the left of the picture in an ancient style of writing:
"*Metal Cash.*"
In the panel: "*The Board of Revenue, having petitioned the Imperial Sanction, prints the currency paper-money, the Great Sung Treasure-Note, to be current and to be used as copper cash. The counterfeiter shall be arrested and decapitated summarily. The informant and the captor shall be rewarded with 1150 taels in silver, and in addition shall be given the property of the criminal.*
Chien-yen,....year,....month,....day."

PLATE 57.

The inscription is the same as that on the 10 kwan note with the exception of the denomination, which is 20 kwan, and the reward to the informant and captor which is 750 taels, in addition to the property of the criminal. The illustration represents two cash joined.

PLATE 58.

The inscription is the same as that on the 10 kwan note, with the exception of the denomination, which is 30 kwan, and the reward to the informant and captor which is 850 taels, in addition to the property of the criminal. The illustration represents three cash joined with a ribbon.

PLATE 59.

The inscription is the same as that on the 10 kwan note, with the exception of the denomination, which is 40 kwan, and the reward to the informant and captor which is 950 taels, in addition to the property of the criminal. The illustration represents four cash in a string.

PLATE 56.

SUNG DYNASTY
KAO-TSUNG 1127–1162 A.D.
CHIEN-YEN 1127–1130 A.D.
10 KWAN

DIMENSIONS
$4\frac{7}{8} \times 9$ INCHES

PLATE 57.

SUNG DYNASTY
KAO-TSUNG 1127–1162 A.D.
CHIEN-YEN 1127–1130 A.D.
20 KWAN

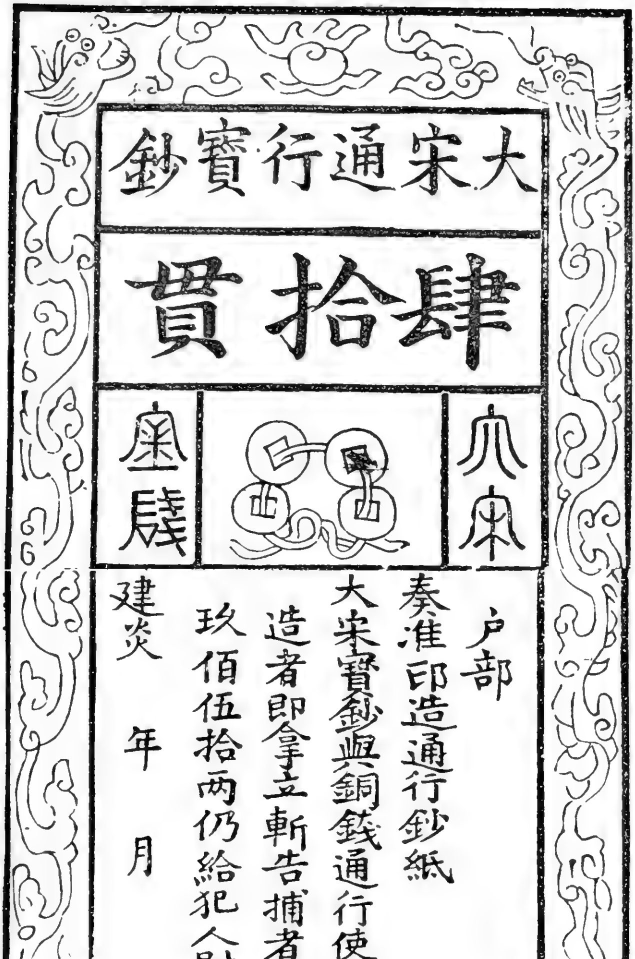
DIMENSIONS
$4\frac{7}{8} \times 9$ INCHES

PLATE 58.

SUNG DYNASTY
KAO TSUNG 1127–1162 A.D.
CHIEN YEN 1127–1130 A.D.
30 KWAN

DIMENSIONS
$4\frac{7}{8} \times 9$ INCHES

PLATE 59.



Kao-tsung 1127–1162 A.D.
Chien-yen 1127–1130 A.D.
40 Kwan

Dimensions
$4\frac{7}{8} \times 9$ inches

Plate 60.

The inscription is the same as that on the 10 kwan note, with the exception of the denomination, which is 50 kwan, and the reward to the informant and captor which is 450 taels, in addition to the property of the criminal. The illustration represents five cash grouped two and two with one above, all joined with a ribbon.

Plate 61. Upper Seal on the Chien-yen Notes.

Four characters arranged as follows:

of	Chien-
Seal	yen

Translation: "*The Seal of the Chien-yen Era.*"

Plate 62. Lower Seal on the Chien-yen Notes.

Six characters arranged as follows:

Treasure	Through	Great
Note	Circulating	Sung

Translation: "*General Circulation Treasure-Note of the Great Sung Dynasty.*"

Seal on the Reverse of the Chien-yen Note.

The inscription is the same as that on the upper seal, of which it is a replica.— See Plate 61.

Pictures on the Reverse of the Chien-yen Notes.

Plate 63. A tiger, which appears on the 10 kwan note.
Plate 64. A ssŭ, which appears on the 20 kwan note.
Plate 65. An elephant, which appears on the 30 kwan note.
Plate 66. A rabbit, which appears on the 40 kwan note.
Plate 67. A lion, which appears on the 50 kwan note.

PLATE 60.

SUNG DYNASTY
KAO-TSUNG 1127-1162 A.D.
CHIEN-YEN 1127-1130 A.D.

DIMENSIONS
$4\frac{7}{8} \times 9$ INCHES

50 KWAN

PLATE 61.

DIMENSIONS
2 × 2 INCHES

PLATE 62.

DIMENSIONS
3 × 3 INCHES

PLATE 63.

PLATE 64.

PLATE 65.

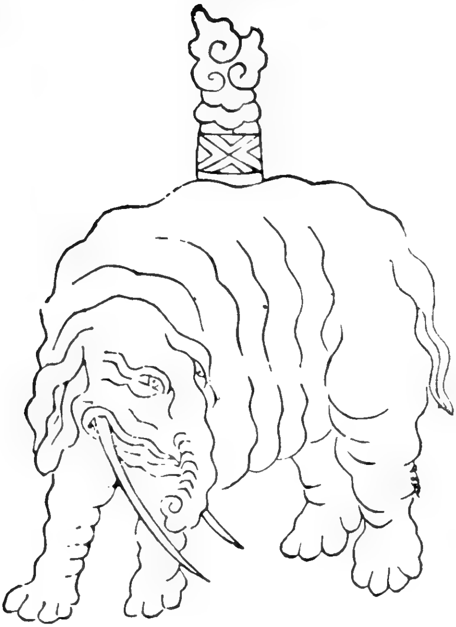


PLATE 66.

PLATE 67.

Notes of Kao-tsung (1127–1162 A.D.) of the Southern Sung Dynasty.

The five varieties of notes which were emitted during the Chien-yen Era have already been printed. As has been said, in 1131 A.D. the name of the reign was changed to Shao-hsing, during which period three varieties * of notes were issued. The form of these notes differs little from those of the preceding era. On the one kwan note appears a pictorial representation of one cash, and on the 5 kwan note, 5 cash, and on the 10 kwan note, 10 cash, all decorated with figured borders. On either side of the pictorial representation on each note are the inscriptions, in the seal style of writing, "To circulate under the heavens" (at the right) and "To be current and to be used" (at the left). Below is the inscription: "The Board of Revenue, having petitioned", etc., ending with "Shao-hsing,. . . .year,. . . .month,. . . .day". Two square seals appear on the notes. The upper reads: "Seal of the Shao-hsing Era", and the lower, "Printed Treasure-Note of the Great Sung Dynasty". On the back of these notes no figure or seal appears.

Plate 68. Shao-hsing (1131–1162 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Sung Current Use Treasure-Note.*"
Second line: "*Two Kwan.*"
Illustration: (Pictorial representation of two cash).
At the right of the picture in the seal style:
"*To circulate under the heavens.*"
At the left of the picture in the seal style:
"*To be current and to be used.*"
In the lower panel: "*The Board of Revenue, having petitioned the Imperial Sanction, prints for the general public use the Great Sung Treasure-Note, to be used side by side with cash. (He who) counterfeits shall be decapitated summarily; (he who) first informs shall be rewarded with 300*

---

* After referring thus to the three varieties, the text mentions a little later, as will be noted, the three notes, namely, the one, five and ten kwan notes. Nevertheless, the illustrations that follow the text are two, five and eight kwan notes. K. T.

SUNG DYNASTY
KAO-TSUNG 1127–1162 A.D.
SHAO-HSING 1131–1162 A.D.

DIMENSIONS
$5\frac{1}{2} \times 8\frac{3}{4}$ INCHES

2 KWAN

taels in silver. To the official who conceals (such guilt) the punishment shall be the same (as the counterfeiter).

Shao-hsing, ... year, ... month, ... day."

Plate 69.

The inscription is the same as that on the 2 kwan note, with the exception of the denomination, which is 5 kwan, and the reward to the informant which is 600 taels. The illustration represents five cash.

Plate 70.

The inscription is the same as that on the two kwan note, with the exception of the denomination, which is 8 kwan, and the reward to the informant which is 900 taels. The illustration represents eight cash.

Plate 71. Upper Seal on the Shao-hsing Notes.

Four characters arranged as follows:

of	Shao-
Seal	hsing

Translation: "*Seal of the Shao-hsing Era.*"

Plate 72. Lower Seal on the Shao-hsing Notes.

Six characters arranged as follows:

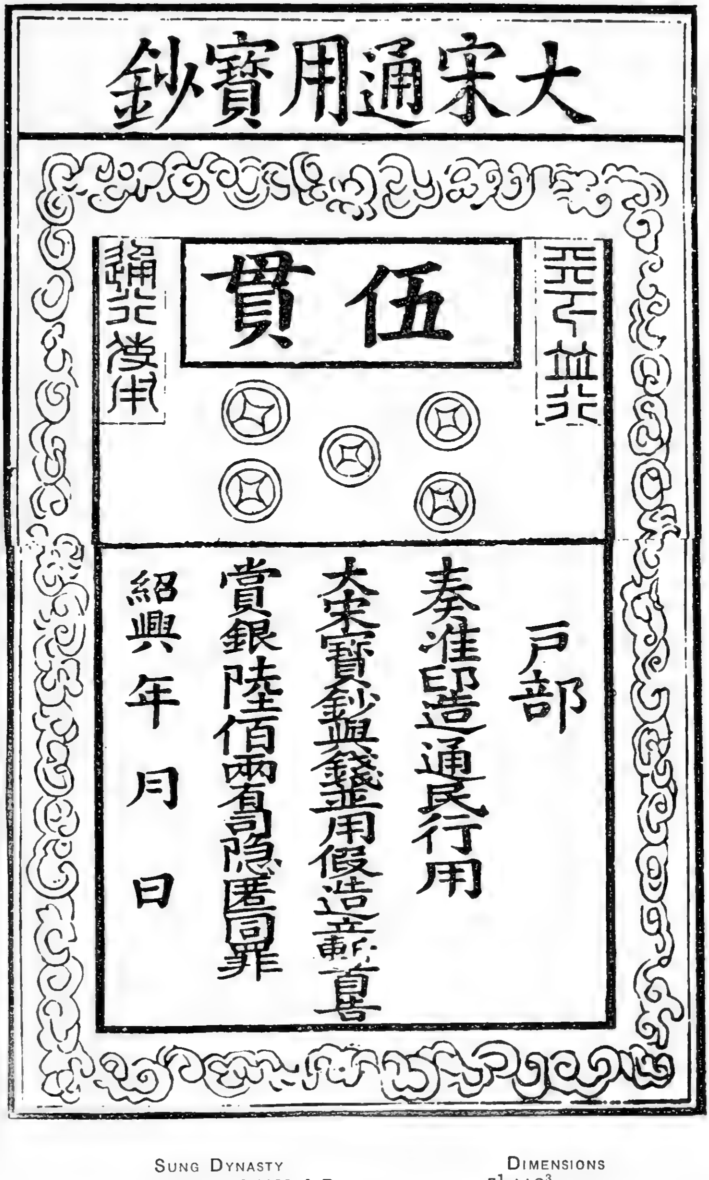
Treasure	Print	Great
Note	Made	Sung

Translation: "*Printed Treasure-Note of the Great Sung Dynasty.*"

Notes of Hsiao-tsung (1163–1189 A.D.) of the Southern Sung Dynasty.

In the third year of the Lung-hsing Era of the reign of the Emperor Hsiao-tsung, the name of the era was changed to Ch'ien-tao (1165–1173 A.D). During this latter era paper money was emitted to meet the national need. The form of the notes is somewhat like that of the

PLATE 69.



SUNG DYNASTY
KAO-TSUNG 1127-1162 A.D.
SHAO-HSING 1131-1162 A.D
5 KWAN

DIMENSIONS
$5\frac{1}{2} \times 8\frac{3}{4}$ INCHES

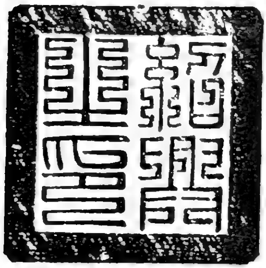
SUNG DYNASTY
KAO TSUNG 1127–1162 A.D.
SHAO HSING 1131–1162 A.D.

DIMENSIONS
$5\frac{1}{2} \times 8\frac{3}{4}$ INCHES

8 KWAN

Shao-hsing notes. The denominations are as follow: the 10 kwan note with one ingot of silver; the 20 kwan note, with two ingots; the 30 kwan with three ingots; and the 40, 50, 60, 70, 80, 90 and 100 kwan notes with a corresponding number of ingots. The borders are decorated with figures of dragons and clouds, and the color of the paper is gray.

PLATE 71.



DIMENSIONS
2 × 2 INCHES

PLATE 72.

DIMENSIONS
$2\frac{7}{8} \times 2\frac{7}{8}$ INCHES

PLATE 73. TRANSLATION OF THE INSCRIPTIONS ON THE CH'IEN-TAO (1165–1173 A.D.) NOTE.

Translation of the inscriptions.

First line: "*Great Sung General Circulation Treasure-Note.*"
Second line: "*Ten Kwan.*"
Illustration: (Pictorial representation of one yüan-pao).
In the lower panel: "*The Civil Board, having petitioned the Imperial sanction, prints, to be current and to be employed, the Great Sung Treasure-Note, to be used as cash. The counterfeiter shall be decapitated summarily; (he who) informs and arrests shall be rewarded with 550 taels in silver. If a District official be the conniver (at such guilt) he shall be punished.*
Ch'ien-tao,. . . .year,. . . .month,. . . .day."

PLATE 73.

SUNG DYNASTY
HSIAO-TSUNG 1163–1189 A.D.
CH'IEN-TAO 1165–1173 A.D.
10 KWAN

DIMENSIONS
$5\frac{1}{8} \times 8\frac{5}{8}$ INCHES

PLATE 74.

SUNG DYNASTY
HSIAO-TSUNG 1163–1189 A.D.
CH'IEN-TAO 1165–1173 A.D.
100 KWAN

DIMENSIONS
$5\frac{1}{8} \times 8\frac{5}{8}$ INCHES

PLATE 74.

The inscription is the same as that on the 10 kwan note, with the exception of the denomination, which is 100 kwan, and the reward to the informant and captor which is 1,400 taels. The illustration represents 10 yüan-po.

PLATE 75. UPPER SEAL ON THE CH'IEN-TAO NOTES.

Four characters arranged as follows:

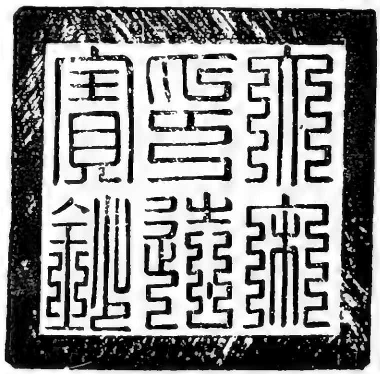
of	Ch'ien-
Seal	tao

Translation: "*Seal of the Ch'ien-tao Era.*"

PLATE 75.

DIMENSIONS
2 × 2 INCHES

PLATE 76.



DIMENSIONS
$2\frac{7}{8} \times 2\frac{7}{8}$ INCHES

PLATE 76. LOWER SEAL ON THE CH'IEN-TAO NOTES.

Six characters arranged as follows:

Treasure	Print	Great
Note	made	Sung

Translation: "*Printed Treasure-Note of the Great Sung Dynasty.*"

Notes of Kung-tsung (1275 A.D.) of the Sung Dynasty.

In the fifth month of the year 1275, during the reign of Kung-tsung of the Southern Sung Dynasty, notes were used in place of silver money. Though they were in circulation not quite a year, the Tung Piao Family owned the complete ten varieties in spite of their rarity. Herewith the notes of minimum and maximum denominations are illustrated.

Plate 77. Tê-yu (1275 A.D) Notes.

Translation of the inscriptions.

First line: "*Great Sung General Circulation Treasure-Note.*"
Illustration: (Pictorial representation of one yüan-pao).
In the right hand border written vertically:
"*Issued under the heavens.*
In the left-hand border written vertically:
"*To enrich the State and satisfy the people.*"
In the lower panel: "*The Great Sung General Circulation Treasure-Note is purposed for the convenient use of all the people.*

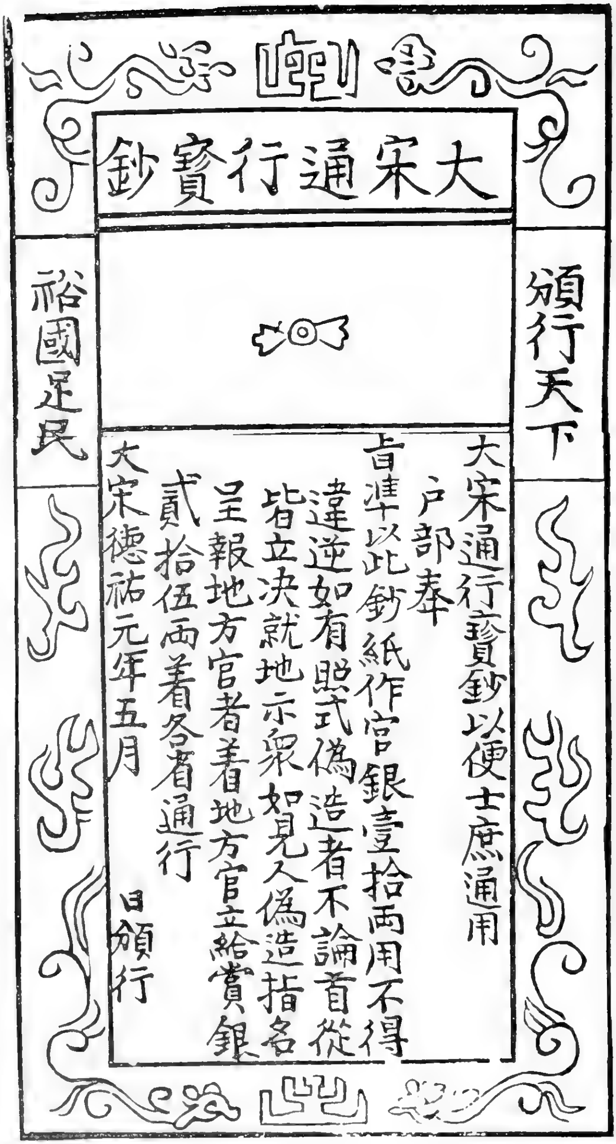
The Board of Revenue, having received the Imperial sanction, designs this note to represent 10 taels in official silver, which value cannot be altered. The counterfeiter of this model — principal or conspirator — shall be executed summarily and exposed to public view. He who discovers a counterfeiter and reports his name to the District authorities shall receive immediately a reward of 25 taels in silver from the District authorities. This shall be current in all provinces.

Great Sung, Tê-yu, ... year, ... month, ... day, issued."

Plate 78.

The inscription is the same as that on the 10 tael note, with the exception of the denomination, which is 100 taels, and the reward to the informant which is 115 taels. The illustration represents ten yüan-pao.

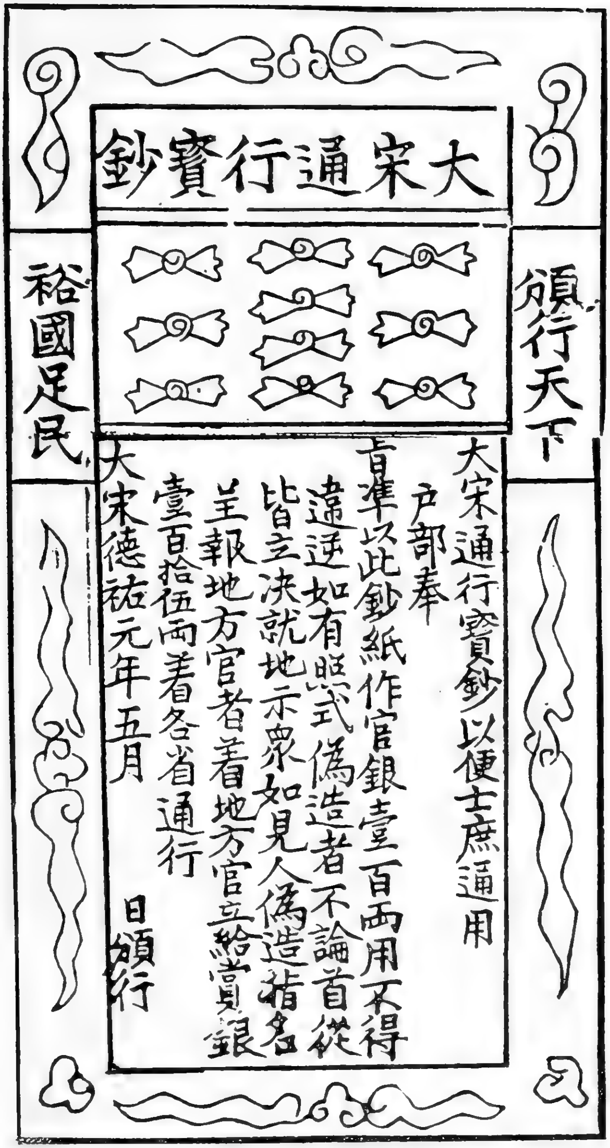
PLATE 77.



Sung Dynasty
Kung-tsung 1275 A.D.
Tê-yu 1275 A.D.

Dimensions
$4\frac{3}{8} \times 8\frac{1}{4}$ inches

10 Taels



SUNG DYNASTY
KUNG-TSUNG 1275 A.D.
TÊ-YU 1275 A.D.

DIMENSIONS
$4\frac{3}{8} \times 8\frac{1}{4}$ INCHES

100 TAELS

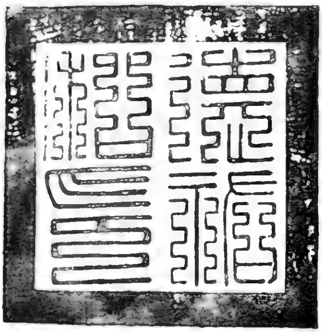
Plate 79. Upper Seal on the Tê-yu Notes.

Four characters as follows:

Private	Tê-
Seal	yu

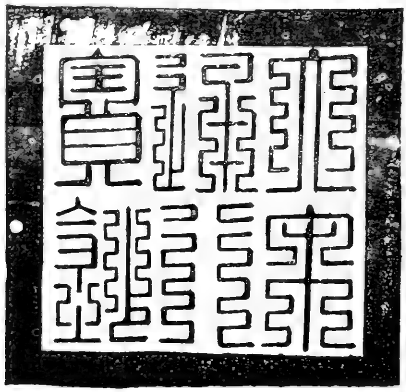
Translation: "*Private Seal of the Tê-yu Era.*"

PLATE 79.



Dimensions
$2\frac{1}{4} \times 2\frac{1}{4}$ inches

PLATE 80.



Dimensions
$2\frac{7}{8} \times 2\frac{3}{4}$ inches

Plate 80. Lower Seal on the Tê-yu Notes.

Six characters arranged as follows:

Treasure	Through	Great
Note	Circulating	Sung

Translation: "*General Circulation Treasure-Note of the Great Sung Dynasty.*"

Notes of Emperor T'ai-tsung (1123–1134 A.D.) of the Chin Dynasty.

In 1123 A.D. T'ai-tsung of the Chin Dynasty ascended the throne and established the era known as T'ien-hui (1123–1137 A.D.). According to the annals of the Sung Dynasty, the Nü-chen, or Nü-chih,* in the twenty-fourth year of Shao-hsing (1154 A.D.) instituted the bill of exchange system modelled after that of the Sung and emitted notes of two sizes, large and small, which were used side by side with the old coins. This year corresponds to the second year of the Ch'en-yüan Era in the reign of Liang (Hai-ling Wang) of the Chin Dynasty. As I was not able to discover the notes thus referred to in the history, I could not print them in this book. However, I acquired the 10 kwan note of T'ai-tsung of the Chin Dynasty. The quality of the paper resembles the Kao-li variety, but is thicker as the sheets are doubled. The form follows that of the T'ai-tsu notes of the Sung Dynasty.† The color is gray; the borders are decorated with clouds and bats. At the top appears the inscription: "Great Chin Issuance Treasure-Note". In the middle is written: "Ten Kwan" and a pictorial representation of five ingots. At the two sides are characters in the "dropping dew" seal style which read respectively: "Great Chin Treasure-Note" and "To be issued to the world".‡ Below appears the inscription beginning with the words "The Civil Board having", etc., and ending with "T'ien-hui, ...year,......month, ...day". The emission of the notes took place in 1124 A.D.

There is another note of which I am the possessor. It is a 5 kwan note with a border decoration of the Hsi-fan lotus (Passiflora cœrulea). At the top is inscribed "Great Chin Army Treasure-Note"; in the middle is written "Five Kwan" with a picture of one yüan-pao. Below appears the inscription: "Great Chin Treasure-Note to be used as the yellow flag. If District officials..... the same punishment shall apply to all." It would appear that the two characters which together mean "conceal" are left out. Next follows "......year,......day" without the character "month".

---

* The name of a tribe which later established the Chin State. K. T.

† Does this refer to the regulations concerning the notes? The form of the notes of T'ai-tsu's reign is quite different from that of the note herein referred to. K. T.

‡ Literally "distributed under the heavens." K. T.

PLATE 81. T'IEN-HUI (1123–1137 A.D.) NOTE.

Translation of the inscriptions.

First line: "*Great Chin Army Treasure-Note.*"
Second line: "*Five Kwan.*"
Illustration: (Pictorial representation of one yüan-pao).
In the lower panel: "*The Civil Board, having petitioned and received the Imperial sanction, prints for the convenient use of the people the Great Chin Treasure-Note to be used as the yellow flag.* The counterfeiter — if (discovered)† — shall be decapitated summarily. The informant and the captor shall be rewarded with 600 taels in silver. If District officials . . . .‡ the same punishment shall apply to all.*
T'ien-hui, ... year, ... day." §

PLATE 82. T'IEN-HUI (1123–1137 A.D) NOTE.

Translation of the inscriptions.

First line: "*Great Chin Issuance Treasure-Note.*"
Second line: "*Ten Kwan.*"
Illustration: (Pictorial representation of 5 ingots).
At the right of the picture in the "dropping dew" seal style:
"*Great Chin Treasure-Note.*"
At the left of the picture in the "dropping dew" seal style:
"*To be issued to the world.*" Literally "*distributed under the heavens.*"
In the lower panel: "*The Civil Board, having petitioned and received the Imperial sanction, prints for the convenient use of the people the Great Chin Treasure-Note to be distributed and used as cash. The counter-*

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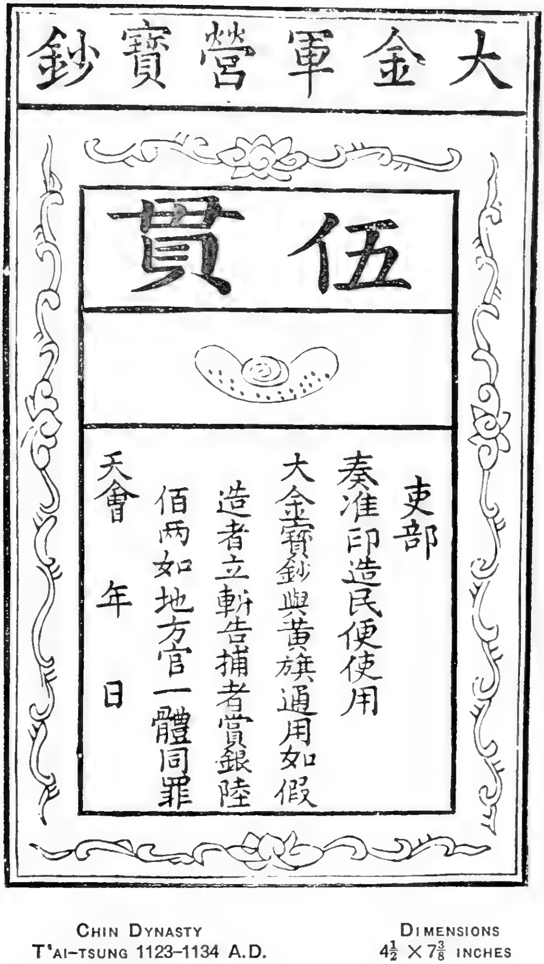
* I have failed to discover in any authoritative books a reference to the "yellow flag" as having anything to do with currency or the monetary system. Some authorities define the term as the "Imperial flag", and others more commonly speak of it as the "standard" of a particular army division. There is a very remote possibility, however, that it was the name given to a particular kind of certificate or bond issued in place of money. Again, it is possible that it refers to a military body for whose convenience the note was emitted, as the note is known as the "Army Treasure-Note". K. T.

† As the word which corresponds to "if" appears in this sentence, it was found necessary to insert a word like "discovered" to make the meaning clear. K. T.

‡ As already noted in the text, the two characters which together mean "conceal" have been omitted. K. T.

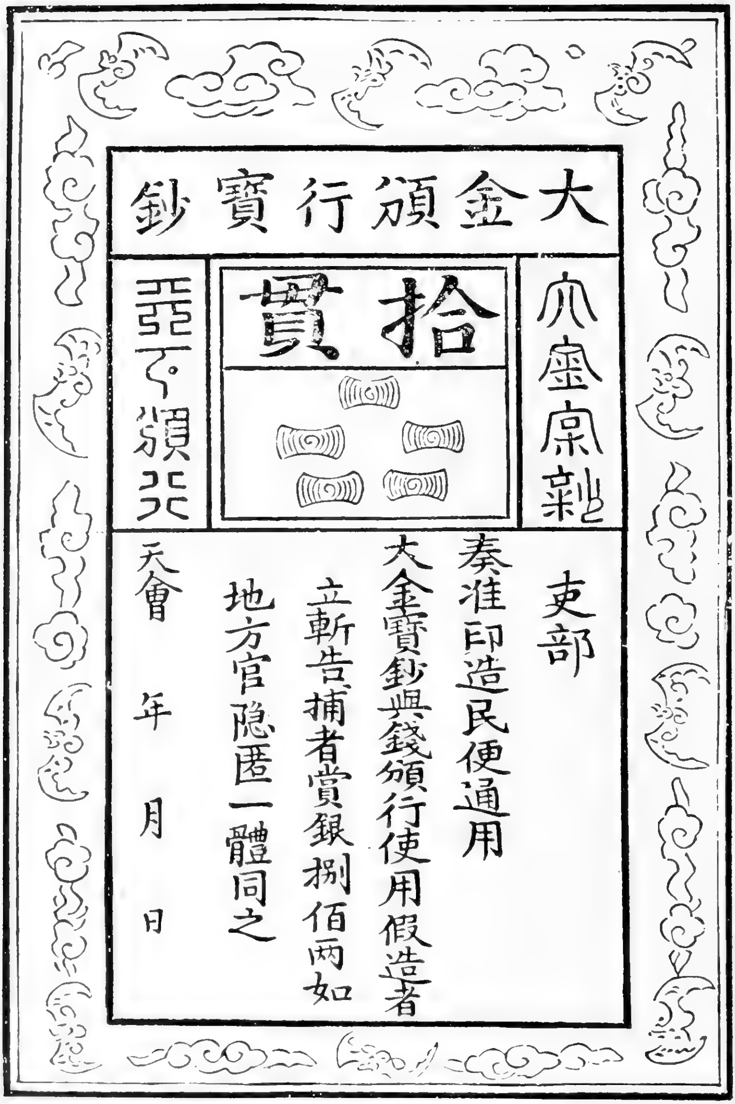
§ As indicated in the text, the word "month" does not appear. K. T.

PLATE 81.



CHIN DYNASTY
T'AI-TSUNG 1123–1134 A.D.
T'IEN-HUI 1123–1137 A.D.
5 KWAN

DIMENSIONS
$4\frac{1}{2} \times 7\frac{3}{8}$ INCHES



Chin Dynasty
T'ai-tsung 1123-1134 A.D.
T'ien-hui 1123-1137 A.D.
10 Kwan

Dimensions
6 × 9⅛ inches

*feiter shall be decapitated summarily; the informant and captor shall be rewarded with 800 taels in silver. If District officials conceal (such guilt), the same as this shall apply to all.**

T'ien-hui,....year,....month,....day."

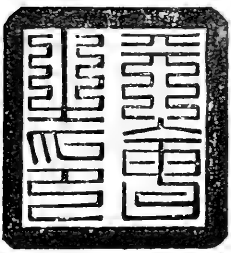
PLATE 83. UPPER SEAL ON THE T'IEN-HUI NOTES.

Four characters arranged as follows:

of	T'ien-
Seal	hui

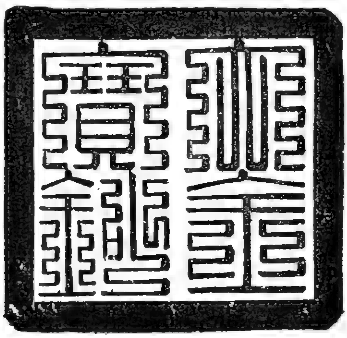
Translation: "*Seal of the T'ien-hui Era.*"

PLATE 83.



DIMENSIONS
$1\frac{7}{8} \times 2$ INCHES

PLATE 84.



DIMENSIONS
$2\frac{3}{4} \times 2\frac{3}{4}$ INCHES

PLATE 84. LOWER SEAL ON THE T'IEN-HUI NOTES.

Four characters arranged as follows:

Treasure	Great
Note	Chin

Translation: "*Treasure-Note of the Great Chin Dynasty.*"

SEAL ON THE REVERSE OF THE T'IEN-HUI NOTES.

The inscription is the same as that on the lower seal, of which it is a replica. See Plate 84.

* A very incomplete expression! It obviously means that the punishment shall be the same as in the case of the counterfeiter. K. T.

Notes of Yeh-lu (1125–1135 A.D.) of the Western Liao Dynasty.

In 1125 A.D., Yeh-lü * established the Western Liao Dynasty. The era of his reign was first known as Yen-ch'ing, but two years later the name was changed to K'ang-kuo (1127–1135 A.D.). In 1127 A.D., notes were emitted. Today, in the collection of the Chu Family, there are ten notes of that issue. Each bears the denomination. On the one kwan note a string of cash is illustrated, and on the border is a pair of dragons tossing a jewel. On the 2 kwan note are two strings of cash and a border design of two dragons. On the 3 kwan note appear three strings of cash and a border design of two dragons. On the 4 kwan are four strings of cash and a border design of two cash and dragons; on the 5 kwan note, five strings of cash and a border design of a phoenix carrying [?] a peony blossom; on the 6 kwan note, six strings of cash and a border design of a floral motive; on the 7 kwan note, seven strings of cash and a border design of floating clouds; on the 8 kwan note, eight strings of cash and a border design of clouds and bats; on the 9 kwan note, nine strings of cash and a border design of flames; and on the 10 kwan note, ten strings of cash and a border design of narcissus and swastika. The inscription on the lower part of each note reads: "The Board of War, having petitioned the Imperial sanction,..................................to be used as silver for military supplies † .... K'ang-kuo,......year, ...month,........day." A square seal with the characters "K'ang-kuo Army" is stamped on the upper portion of the note, and another square seal with the characters "Great Liao Printed Treasure-Note" appears in the lower portion. On the reverse appears a picture of a horse and four characters which read: "Peace be unto men and horses".

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* Yeh-lü was Emperor Tê-tsung, later known as T'ien-yu Huang-ti. K. T.

† "Military supplies" is not a satisfactory translation. Broadly, the two Chinese characters employed in the inscription mean "Military" or "Commissary". The term should be accepted as meaning "silver coin intended for the use of the army." K. T.

Plate 85. K'ang-kuo (1127–1135 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Liao Army Treasure-Note.*"
Second line: "*Three Kwan.*"
Illustration: (Pictorial representation of three strings of cash).
In the lower panel: "*The Board of War, having petitioned and received the Imperial sanction, prints for the convenient use of the Army the Great Liao Treasure-Note to be used as silver for military supplies. The counterfeiter shall be decapitated summarily; the informant and captor shall be rewarded with 400 taels in silver.*
K'ang-kuo,....year,....month,....day."

Plate 86.

The inscription is the same as that on the 3 kwan note, with the exception of the denomination which is 6 kwan, and the reward to the informant and captor which is 200 taels. The illustration represents six strings of cash.

Plate 87.

The inscription is the same as that on the 3 kwan note, with the exception of the denomination, which is 9 kwan, and the reward to the informant and captor which is 1000 taels. The illustration represents nine strings of cash.

Plate 88. Upper Seal on the K'ang-Kuo Notes.

Four characters arranged as follows:

Military Barracks	K'ang-kuo

Translation: "*Army of the K'ang-kuo Era.*"

Plate 89. Lower Seal on the K'ang-kuo Notes.

Six characters arranged as follows:

Treasure Note	Print Made	Great Liao

Translation: "*Printed Treasure-Note of the Great Liao Dynasty.*"

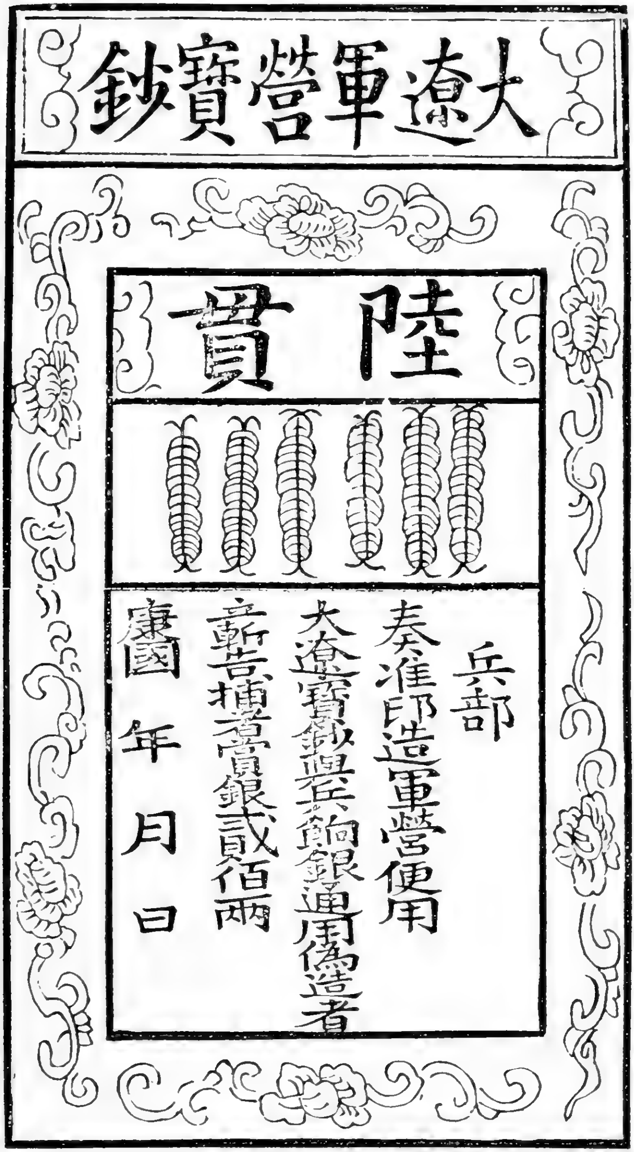
PLATE 85.

Western Liao Dynasty
Tê-tsung 1125–1135 A.D.
K'ang kuo 1127–1135 A.D.

Dimensions
$5\frac{1}{8} \times 9\frac{1}{4}$ inches

3 Kwan

PLATE 86.



WESTERN LIAO DYNASTY
TÊ-TSUNG 1125–1135 A.D.
K'ANG-KUO 1127–1135 A.D.

DIMENSIONS
$5\frac{1}{8} \times 9\frac{1}{2}$ INCHES

6 KWAN

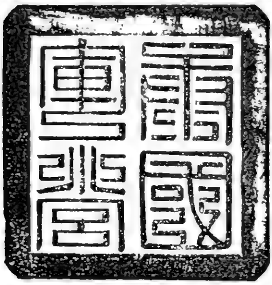
PLATE 87.

WESTERN LIAO DYNASTY
TÊ-TSUNG 1125-1135 A.D.
K'ANG-KUO 1127-1135 A.D.

DIMENSIONS
$5\frac{1}{4} \times 9\frac{3}{8}$ INCHES

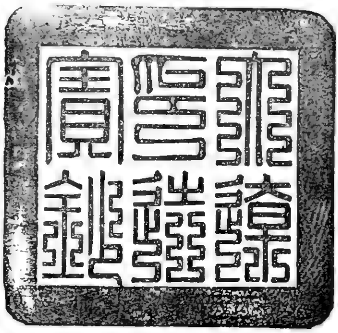
9 KWAN

PLATE 88.



DIMENSIONS
$2\frac{1}{4} \times 2\frac{1}{4}$ INCHES

PLATE 89.



DIMENSIONS
$2\frac{3}{4} \times 2\frac{5}{8}$ INCHES

PLATE 90.

Plate 90. Picture and Seal on the Reverse of the K'ang-kuo Notes.

Picture of a horse and four characters which read:

"*Peace be unto men and horses.*" *

Seal.

The inscription is the same as that on the lower seal of which it is a replica. See Plate 89.

Notes of (the Empress) Kan-t'ien-hou (1136–1141 A.D.) of the Western Liao Dynasty.

In 1136 A.D., the Empress Kan-t'ien-hou ascended the throne and named her reign Hsien-ch'ing (1136–1141 A.D.). Though the books of history do not record the emission of notes during this reign, I acquired two notes of this era from the collection of the Chu Family. They are illustrated herewith. The smaller note is of 3 kwan. The border-decoration is a floral motive. At the top is horizontally inscribed: "Great Liao Army Treasure-Note". Below the inscription reads: "........to be used by the Army........ If District officials......the same punishment shall apply to all." It appears that the two characters which together mean "conceal" have been omitted. The inscription ends "Hsien-ch'ing,......year, ...day", without the word "month". The larger note has a border decoration of ch'ih dragons.† At the top is horizontally inscribed: "Great Liao Issuance Treasure-Note", and in the middle appears the denomination, "10 Kwan", and a pictorial representation of five ingots. At the right and left respectively is written: "Great Liao Treasure-Note" and "To be current in the world". Below appears the inscription: "The Board of Revenue, having petitioned and received the Imperial sanction, prints for the convenient use of the people the Great Hsia Treasure-Note, to be distributed and used as cash", etc., ending with "Hsien-ch'ing,......year,...... month,......day." Why the character "Hsia" (of "the Great Hsia") appears in this inscription is puzzling.‡

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* "Men and horses" probably means "army". T. K.

† Dragons whose horns have not grown. K. T.

‡ The author thus confesses his bewilderment and elsewhere in the book expresses his hope that the mystery may later be solved. K. T.

Plate 91. Hsien-ch'ing (1136–1141 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Liao Army Treasure-Note.*"
Second line: "*Three Kwan.*"
Illustration: (Pictorial representation of thirty strings of cash).
In the lower panel: "*The Board of Revenue, having petitioned and received the Imperial sanction, prints for the convenient use of the people the Great Liao Treasure-Note to be used with the Army.* The counterfeiter — if (discovered †) — shall be decapitated summarily. The informant and captor shall be rewarded with 500 taels in silver. If District officials ‡ . . . ., the same punishment shall apply to all.*
Hsien-ch'ing, ... year, ... day." §

Plate 92. Hsien-ch'ing (1136–1141 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Liao Issuance Treasure-Note.*"
Second line: "*Ten Kwan.*"
Illustration: (Pictorial representation of five ingots).
At the right of the illustration in the "sharp forked style":
"*Great Liao Treasure-Note.*"
At the left of the illustration in the "sharp forked style":
"*To be current in the world.*"
In the lower panel: "*The Board of Revenue, having petitioned and received the Imperial sanction, prints for the convenient use of the people the Great Hsia ** Treasure-Note to be distributed and used as cash. The counterfeiter shall be decapitated summarily; the informant and captor shall be rewarded with 800 taels in silver. If a District official conceals (such guilt), the same punishment shall apply to all.*
Hsien-ch'ing, ... year, ... month, ... day."

---

* This probably means "to be used *by* the army. K. T.

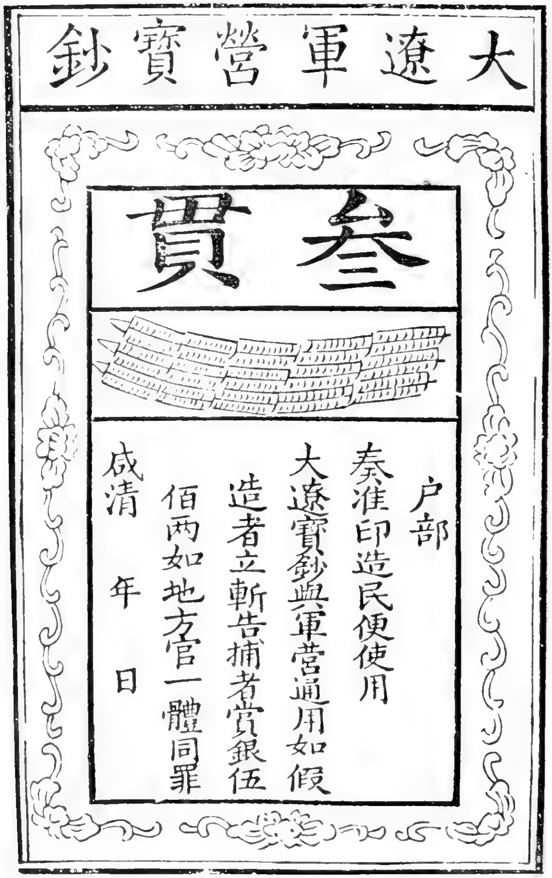
† As the word which corresponds to "if" appears in this sentence, it was found necessary to insert a word like "discovered" to make the meaning clear. K. T.

‡ As already noted in the text, the two characters which together mean "conceal" have been omitted. K. T.

§ As noted in the text, the word "month" does not appear. K. T.

** See the text that accompanies this issue. K. T.

PLATE 91.



WESTERN LIAO DYNASTY
KAN-T'IEN-HOU 1136–1141 A.D.
HSIEN-CH'ING 1136–1141 A.D.
3 KWAN

DIMENSIONS
$4\frac{1}{2} \times 7\frac{1}{4}$ INCHES

PLATE 92.

WESTERN LIAO DYNASTY
KAN-T'IEN-HOU 1136–1141 A.D.
HSIEN-CH'ING 1136–1141 A.D.
10 KWAN

DIMENSIONS
6 × 9 INCHES

Plate 93. Upper Seal on the Hsien-ch'ing Notes.

Four characters arranged as follows:

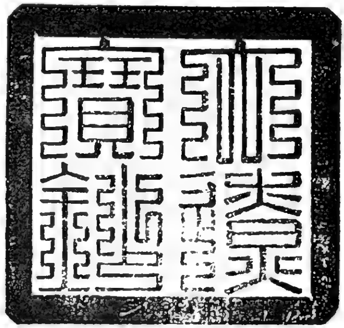
of	Hsien-
Seal	ch'ing

Translation: "*Seal of the Hsien-ch'ing Era.*"

PLATE 93.

Dimensions
$1\frac{7}{8} \times 2$ inches

PLATE 94.



Dimensions
$2\frac{3}{4} \times 2\frac{5}{8}$ inches

Plate 94. Lower Seal on the Hsien-ch'ing Notes.

Four characters arranged as follows:

Treasure	Great
Note	Liao

Translation: "*Treasure-Note of the Great Liao Dynasty.*"

Seal on the Reverse of the Hsien-ch'ing Notes.

The inscription is the same as that on the upper seal, of which it is a replica. See Plate 93.

Notes of Ch'ung-tsung (1087–1138 A.D.) of the Western Hsia Dynasty.

Ch'ung-tsung of the Western Hsia Dynasty came to the throne in 1087 A.D. During his reign of fifty-three years, he changed the name of the era nine times, of which Yüan-tê (1119–1126 A.D.) and Ta-tê (1135–1139 A.D.) are those with which we are concerned. Though the books of history do not record the issuance of notes in his reign, such notes have been in the possession of the Chu Family. They are one kwan and five kwan in denomination. Their color is gray, and the border-decoration consists of clouds and bats. On one of them at the top appears horizontally: "Great Hsia Issuance Treasure-Note", and in the middle is the denomination, "5 Kwan", and the pictorial representation of five ingots. On the two sides of the picture, written in the "jade chopstick" [?] seal style, inscriptions are inserted which read respectively: "Ta-tê Treasure-Note" and "To be current in the world". It is strange that a note issued in the Yüan-tê Era should bear the name "Ta-tê" which was not adopted until nine years after the end of the Yüan-tê Era, i. e., in the forty-ninth year of Ch'ung-tsung's reign. The writing below reads: "The Board of Rites having petitioned", etc., ending with "Yüan-tê,......year,...... month,......day."

The other, which is the one kwan note, has a border decorated with *ch'ih* * dragons. The title on the top reads: "Great Hsia Army Treasure-Note". In the middle appears the denomination, "One Kwan", and the pictorial representation of 1000 cash. Below is an inscription which reads: "........to be used by the Army......" (Though the text of this note is like that of the Military provision note of the Yüan Dynasty, their application differs). The inscription ends: "If District officials...., the same punishment shall apply to all. Yüan-tê,....year,....day." It seems that the two characters which together mean "conceal" and another character for "month" have been omitted.

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* Dragons whose horns have not grown. K. T.

Plate 95. Yüan-tê (1119–1126 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Hsia Army Treasure-Note.*"
Second line: "*One Kwan.*"
Illustration: (Pictorial representation of 1000 cash).
In the lower panel: "*The Board of Rites, having petitioned and received the Imperial sanction, prints for the convenient use of the people the Great Hsia Treasure-Note to be used with the Army.** *The counterfeiter — if (discovered †) — shall be decapitated summarily. The informant and captor shall be rewarded with 200 taels in silver. If District officials . . . . ,‡ the same punishment shall apply to all.*
Yüan-tê, ... year, ... day." §

Plate 96. Yüan-tê (1119–1126 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Hsia Issuance Treasure-Note.*"
Second line: "*Five Kwan.*"
Illustration: (Pictorial representation of five ingots).
At the right of the illustration in the "jade chopstick" seal style: "*Ta-tê* ** *Treasure-Note.*
At the left of the illustration in the "jade chopstick" seal style: "*To be current in the world,*" or literally "*under the heavens.*"
In the lower panel: "*The Board of Rites, having petitioned and received the Imperial sanction, prints for the convenient use of the people the Great Hsia Treasure-Note to be distributed and used as cash. The counterfeiter shall be decapitated summarily; the informant and captor shall be rewarded with 800 taels in silver. If District officials conceal (such guilt), the same punishment shall apply to all.*
Yüan-tê, ... year, ... month, ... day."

---

* This probably means "to be used *by* the army. K. T.

† As the word which corresponds to "if" appears in this sentence, it was found necessary to insert a word like "discovered" to make the meaning clear. K. T.

‡ As already noted in the text, the two characters which together mean "conceal" have been omitted. K. T.

§ As noted in the text, the word "month" does not appear. K. T.

** See the text that accompanies this issue. K. T.

PLATE 95.

HSIA DYNASTY
C'HUNG-TSUNG 1087–1138 A.D.
YÜAN-TÊ 1119–1126 A.D.

DIMENSIONS
$4\frac{1}{2} \times 7\frac{1}{4}$ INCHES

ONE KWAN

PLATE 96.

Hsia Dynasty
C'hung-tsung 1087–1139 A.D.
Yüan-tê 1119–1126 A.D.
5 Kwan

Dimensions
$6\frac{1}{2} \times 9$ inches

Plate 97. Upper Seal on the Yüan-tê Notes.

Four characters arranged as follows:

of	Yüan-
Seal	tê

Translation: "*Seal of the Yüan-tê Era.*"

PLATE 97.

DIMENSIONS
$1\frac{7}{8} \times 1\frac{7}{8}$ INCHES

PLATE 98.

DIMENSIONS
$2\frac{7}{8} \times 2\frac{3}{4}$ INCHES

Plate 98. Lower Seal on the Yüan-tê Notes.

Four characters arranged as follows:

Treasure	Great
Note	Hsia

Translation: "*Treasure-Note of the Great Hsia Dynasty.*"

Seal on the Reverse of the Yüan-tê Notes.

The inscription is the same as that on the upper seal of which it is a replica. See Plate 97.

NOTES OF SHIH-TSU * (1260–1294 A.D.) OF THE YÜAN DYNASTY.

In the twenty-fourth year of the Chih-yüan Era (1287 A.D.), the Chih-yüan Treasure-Notes were emitted. The same were distributed to the world and used side by side with the Ch'üan-ch'ao-ch'ien † of the Chung-tung Era (1260–1263 A.D.). The Chih-yüan Treasure-Note of the denomination one kwan was considered the equivalent of five kwan-worth of Ch'üan-ch'ao-ch'ien, the standard and the subsidiary being interchangeable.‡ Generally, 1000 wên in cash were equal to one kwan, and naturally a note whose face value was one kwan was equivalent to 1000 wên in cash.

There are two sizes of the Chih-yüan note,— the lesser and the greater. Among the former are the denominations 10, 20, 30, 40 and 50 cash, and among the latter 100, 200, 300, 400 and 500. There is beside these a one kwan note, making a total of eleven varieties. The border designs and the size of each sheet vary according to the denomination. The color of the notes is gray.

PLATE 99. CHIH-YÜAN (1264–1294 A.D.) NOTE.

Translation of the inscriptions.

Lesser Note.

First line: "*Great Yüan General Circulation Treasure-Note.*"
Second line: "*Ten Copper* ** *Cash.*"
Illustration: (Pictorial representation of one string of cash).
At the right of the illustration in the seal style:
"*Chih-yüan Treasure-Note.*"

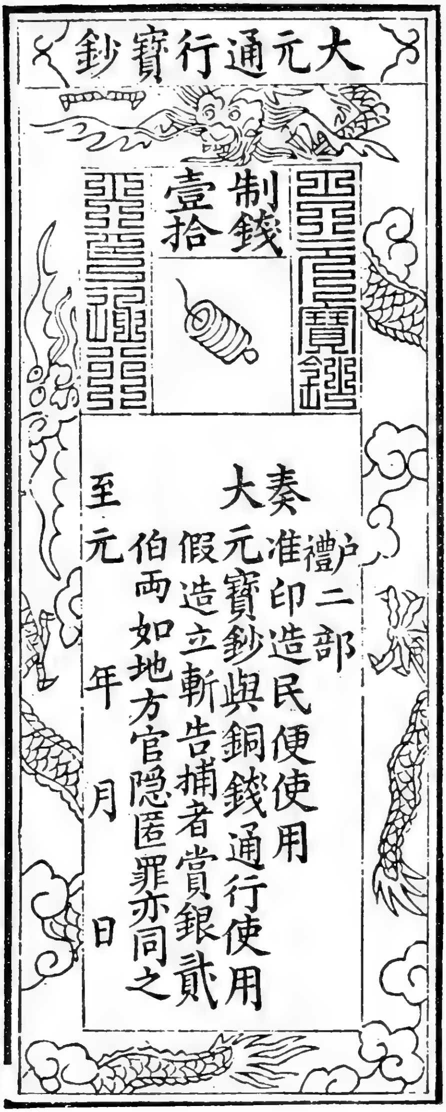
---

* Kublai Khan, who ascended the throne in 1260 and established the Ching-tsung Era, which lasted three years, when the name was changed to Chih-yüan (1264–1294). K. T.

† A substitute money: a medal with a square hole in the center, resembling the regular Chinese coin, and representing various denominations. K. T.

‡ In the original text, this last phrase reads, literally, "equivalence of child and mother". "Mother" (the standard or principal) refers to the notes, while "child" (subsidiary or substitute) refers to specie, as the author explains elsewhere in the original text. At different periods the cases were reversed, i. e., the "Mother" meant specie and the "Child" paper. Whenever one, whether specie or notes, was considered the standard and more valuable than the other, it was referred to as the "Mother". K. T.

** Or "Bronze": a minor coin. K. T.



Yüan Dynasty
Shih-tsu 1260–1294 A.D.
Chih-yüan 1264–1294 A.D.
10 Wên

Dimensions
$2\frac{3}{4} \times 6\frac{7}{8}$ inches

At the left of the illustration in the seal style:
"*To be current in the world.*" Literally, "*under the heavens.*"

In the lower panel: "*The Boards of Revenue and Rites, having petitioned and received the Imperial sanction, print for the convenient use of the people the Great Yüan Treasure-Note, to be current and used as copper cash. (He who) counterfeits shall be decapitated summarily; the informant and captor shall be rewarded with 200 taels* * *in silver. If District officials conceal (such guilt) the punishment shall be the same as this (the case of the counterfeiter).*

Chih-yüan,....year,....month,....day."

Plate 100.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 20 copper coin.

Plate 101.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 30 copper coin.

Plate 102.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 40 copper coin.

Plate 103.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 50 copper coin.

Plate 104. Upper Seal on the Lesser Chih-yüan Notes.

Four characters arranged as follows:

of	A-
Seal	lo

Translation: "*Seal of A-lo.*" †

---

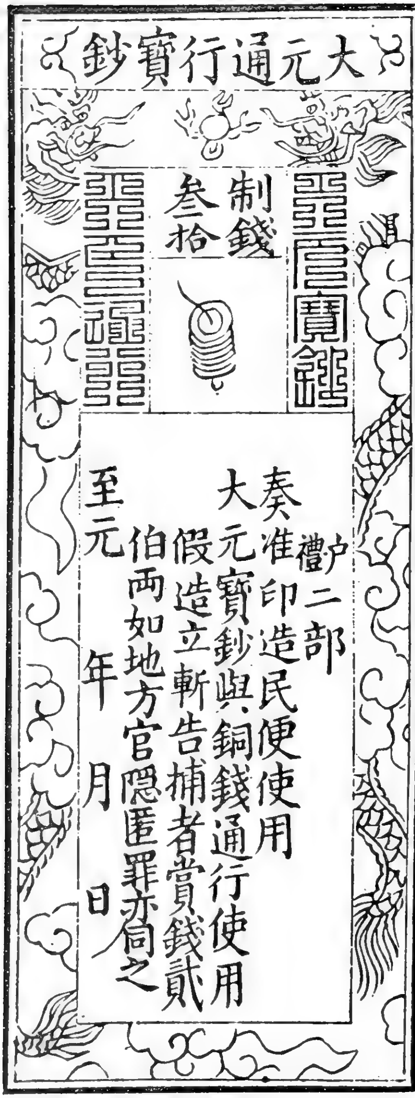
* This amount applies to all notes of the value of 10 to 500 copper coin (inclusive). K. T.

† Is this the personal name of the ruler, or an official? K. T.

YÜAN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH YÜAN 1264–1294 A.D.
20 WÊN

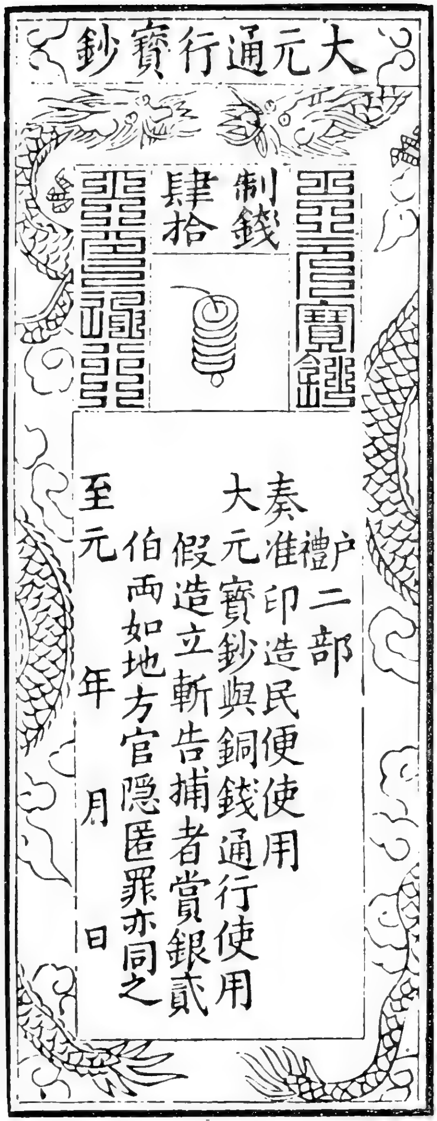
DIMENSIONS
$2\frac{3}{4} \times 6\frac{3}{4}$ INCHES

PLATE 101.



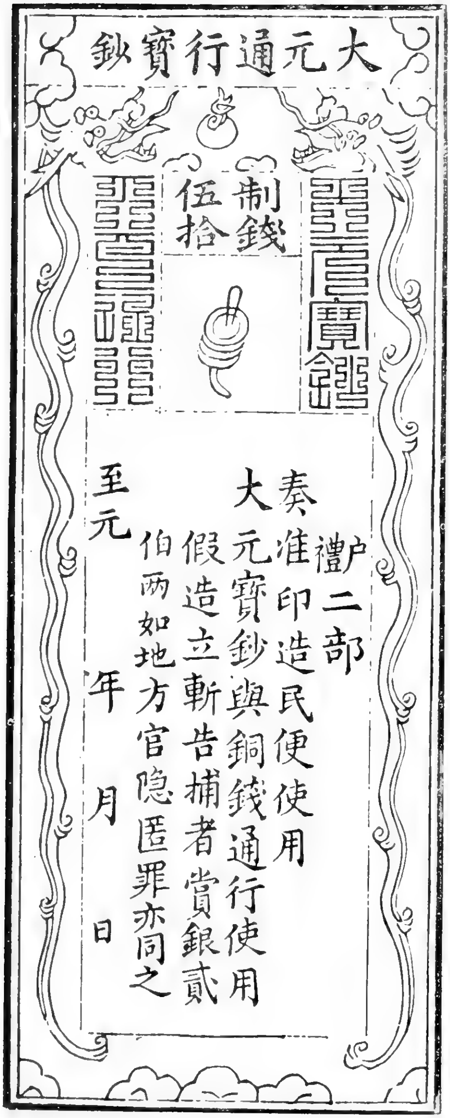
YÜAN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH-YÜAN 1264–1294 A.D.
30 WÊN

DIMENSIONS
$2\frac{5}{8} \times 6\frac{3}{4}$ INCHES



YÜAN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH-YÜAN 1264–1294 A.D.
40 WÊN

DIMENSIONS
$2\frac{3}{4} \times 6\frac{7}{8}$ INCHES



Yüan Dynasty
Shih-tsu 1260–1294 A.D.
Chih-yüan 1264–1294 A.D.
50 Wên

Dimensions
$2\frac{3}{4} \times 6\frac{7}{8}$ inches

PLATE 105. LOWER SEAL ON THE LESSER CHIH-YÜAN NOTES.

Four characters arranged as follows:

Treasure	Chih-
Note	yüan

Translation: "*Treasure-Note of the Chih-yüan Era.*"

PLATE 104.

DIMENSIONS $1\frac{1}{8} \times 1\frac{1}{8}$ INCHES

PLATE 105.

DIMENSIONS $1\frac{1}{8} \times 1\frac{1}{8}$ INCHES

PLATE 106. CHIH-YÜAN (1264–1294 A.D.) NOTE.

Translation of the inscriptions.

Greater Note.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 100 copper coin. The illustration represents one string of cash.

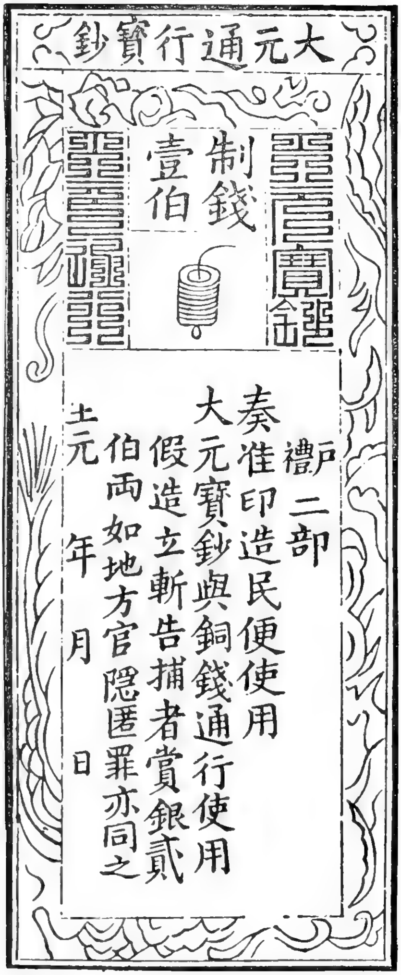
PLATE 107.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 200 copper coin. The illustration represents two strings of cash.

PLATE 108.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 300 copper coin. The illustration represents three strings of cash.

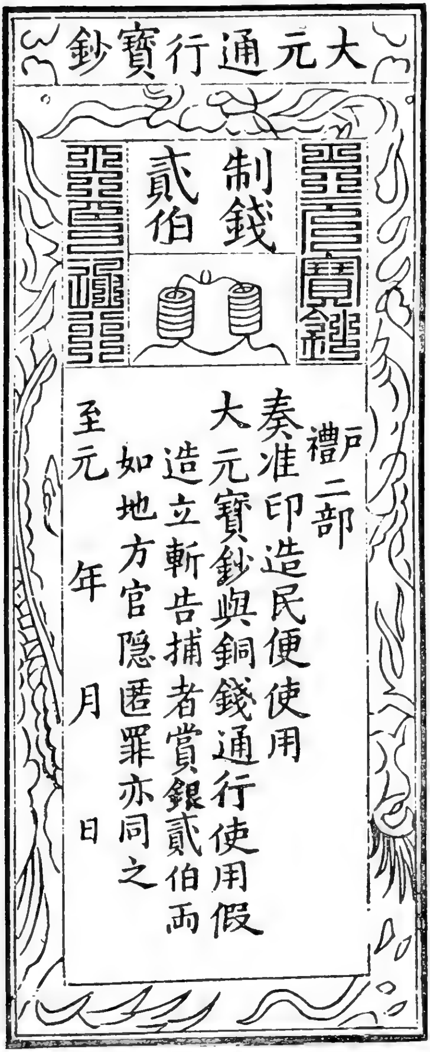
PLATE 106.



Yüan Dynasty
Shih-tsu 1260–1294 A.D.
Chih-yüan 1264–1294 A.D.
100 Copper Coin

Dimensions
$3 \times 7\frac{1}{2}$ inches

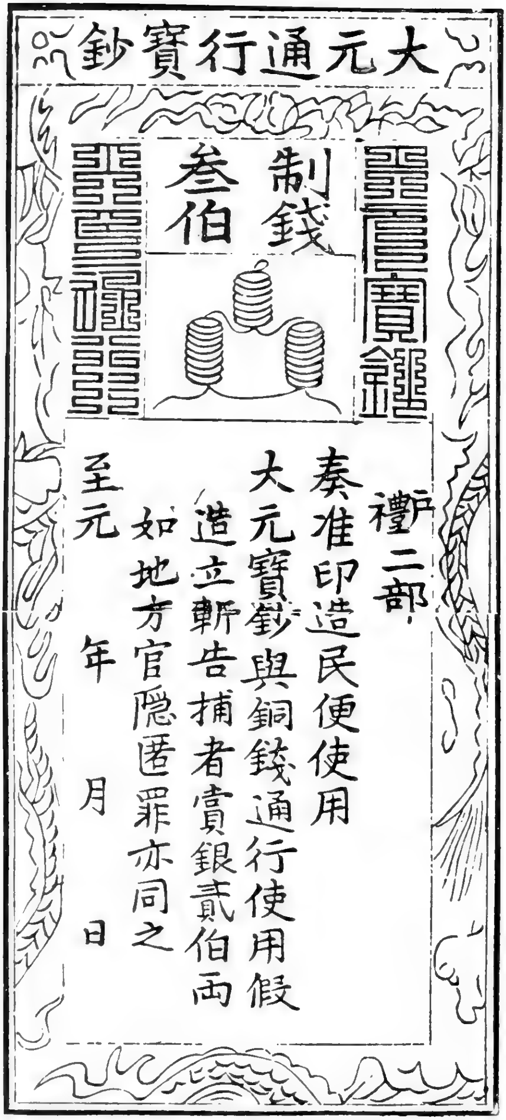
PLATE 107.



Yüan Dynasty
Shih-tsu 1260–1294 A.D.
Chih-yüan 1264–1294 A.D.
200 Copper Coin

Dimensions
$3\frac{1}{4} \times 8$ inches

PLATE 108.



YÜAN DYNASTY
SHIH-TSU 1260-1294 A.D.
CHIH YÜAN 1264-1294 A.D.

DIMENSIONS
$3\frac{3}{4} \times 8\frac{1}{2}$ INCHES

300 COPPER COIN

Plate 109.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 400 copper coin. The illustration represents four strings of cash.*

Plate 110.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 500 copper coin. The illustration represents five strings of cash.

Plate 111. Upper Seal on the Greater Chih-yüan Notes.

Six characters arranged as follows:

Treasure	Chih-	Great
Note	yüan	Yüan

Translation: "*Treasure-Note of the Chih-yüan Era of the Great Yüan Dynasty.*"

Plate 112. Lower Seal on the Greater Chih-yüan Notes.

Six characters arranged as follows:

of	Note (money)	Chih-
Seal	Paper	yüan

Translation: "*Seal of the Paper Money of the Chih-yüan Era.*"

Plate 113. Chih-yüan (1264–1294 A.D.) Military Note of the Yüan Dynasty.

Translation of the inscriptions.

First line: "*Great Yüan Military Supplies Treasure-Note.*"

In the panel: "*The Boards of Revenue and Rites, having received the Imperial decree, print for the use of the soldiers the 100 copper cash note to be current as cash.*

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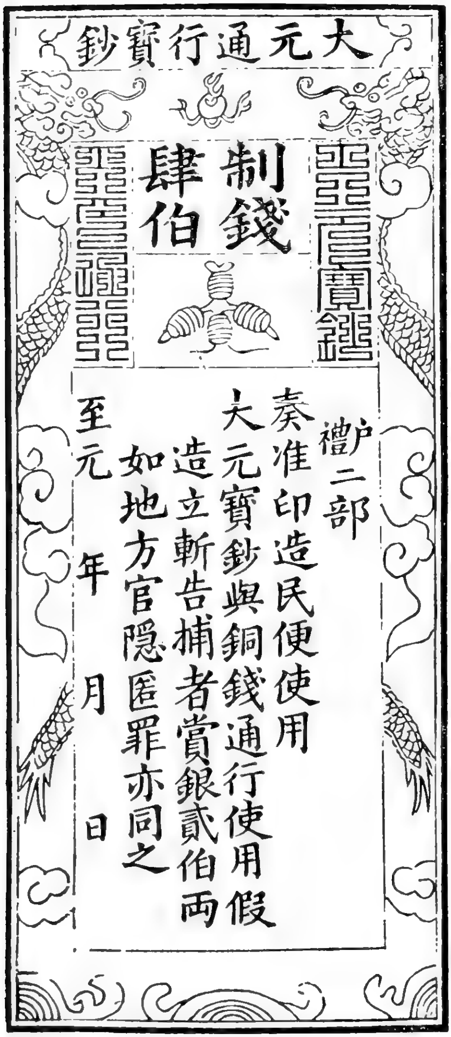
* This note is smaller in dimensions than the 300 kwan note, and the upper and lower seals have been interchanged. K. T.

PLATE 109.



YÜAN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH-YÜAN 1264–1294 A.D.
400 COPPER COIN

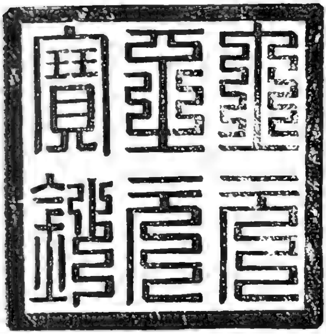
DIMENSIONS
$3\frac{3}{8} \times 7\frac{7}{8}$ INCHES

Yüan Dynasty
Shih-tsu 1260–1294 A.D.
Chih-yüan 1264–1294 A.D.

Dimensions
$5\frac{3}{8} \times 8\frac{5}{8}$ inches

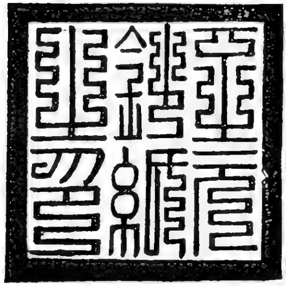
500 Copper Cash

PLATE 111.



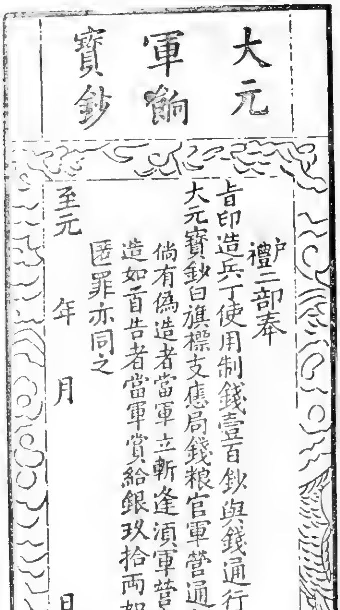
DIMENSIONS
$2\frac{7}{8} \times 2\frac{7}{8}$ INCHES

PLATE 112.



DIMENSIONS
$2\frac{1}{8} \times 2\frac{1}{8}$ INCHES

PLATE 113.



大元
軍餉
寶鈔

户禮二部奉
旨印造兵丁使用制錢壹百鈔與錢通行
大元寶鈔白旗標支應局錢粮官軍營通餉鈔紙
倘有偽造者當軍立斬逢須軍營串糾成
造如首告者當軍賞給銀玖拾両如該軍隱
匿罪亦同之
至元 年 月 日

YÜAN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH-YÜAN 1264–1294 A.D.

DIMENSIONS
$2\frac{7}{8} \times 6\frac{1}{2}$ INCHES

100 COPPER CASH

The Great Yüan Treasure-Note, the Army Mandatory Paper-Money of the Commissariat of the Paymaster's Bureau of the White Banner Division. If a counterfeiter is discovered, (he) shall be decapitated summarily by the Army (authorities). The Army shall have the surveillance of the making (of the notes). To the first informant (of such guilt) shall be given 90 taels in silver at the army camp. The punishment for concealing in the said Army shall be the same as this (the case of the counterfeiter).*

Chih-yüan, ... year, ... month, ... day."

Plate 114.

The inscription is the same as that on the 100 cash note, with the exception of the denomination, which is 200 cash. The reward to the informant is 120 taels in cash.

Plate 115.

The inscription is the same as that on the 100 cash note, with the exception of the denomination, which is 300 cash. The reward to the informant is 140 taels in cash.

Plate 116.

The inscription is the same as that on the 100 cash note, with the exception of the denomination, which is 400 cash. The reward to the informant is 170 taels in silver.

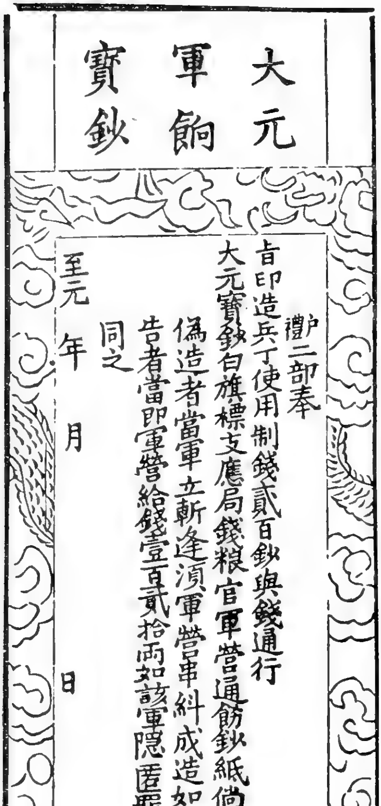
Plate 117.

The inscription is the same as that on the 100 cash note, with the exception of the denomination, which is 500 cash. The reward to the informant is 200 taels in silver.

---

* The original means "Money-Provision Officer." The combination of "Money" and "Provision" is usually rendered as "Taxes in kind and money." In this case it seems more fitting to translate the combination "Commissariat." K. T.

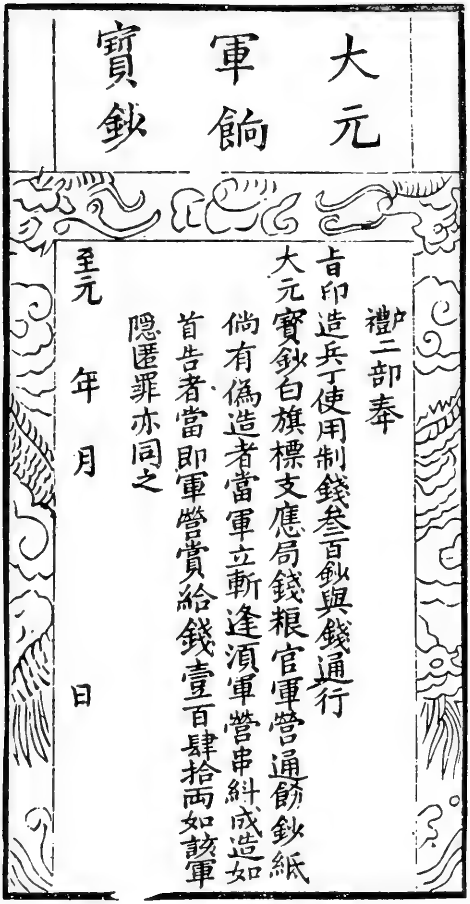
PLATE 114.



YÜAN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH-YÜAN 1264–1294 A.D.
200 COPPER CASH

DIMENSIONS
$3\frac{1}{4} \times 7\frac{1}{2}$ INCHES

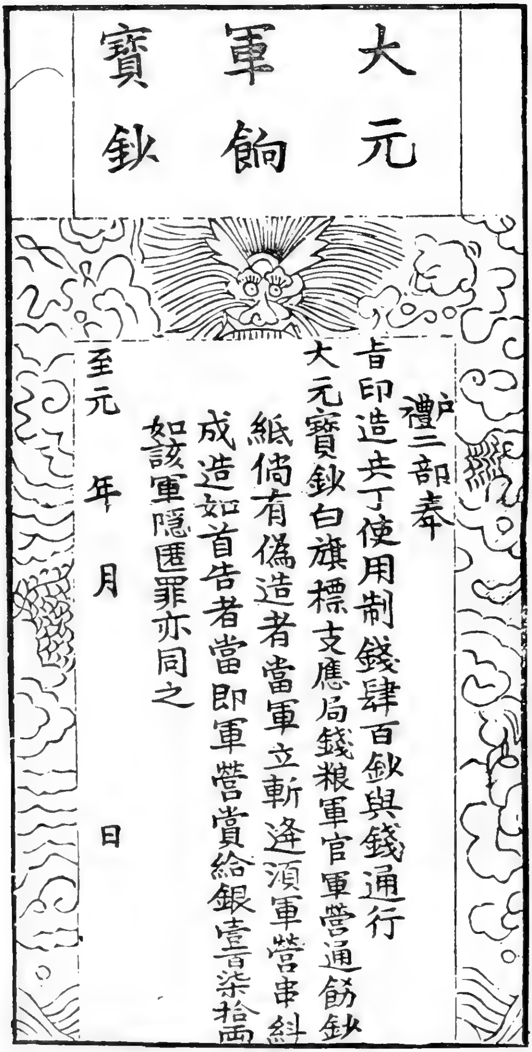
PLATE 115.



Yüan Dynasty
Shih-tsu 1260–1294 A.D.
Chih-yüan 1264–1294 A.D.
300 Cash

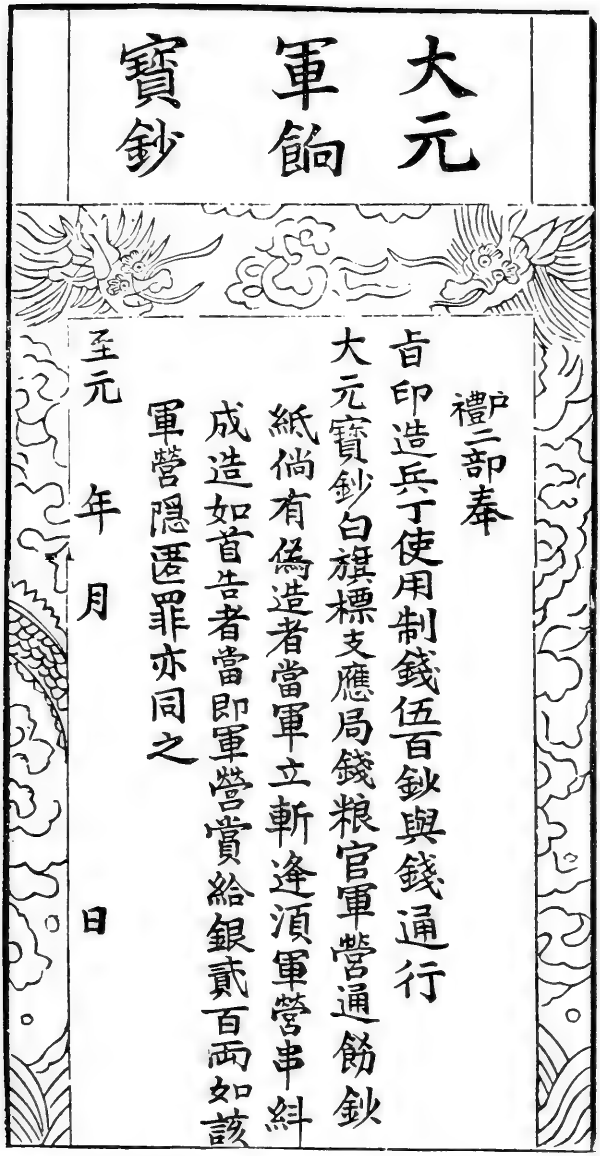
Dimensions
4 × $7\frac{7}{8}$ inches

PLATE 116.



YÜAN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH-YÜAN 1264–1294 A.D.
400 COPPER CASH

DIMENSIONS
$4\frac{5}{8} \times 9\frac{1}{4}$ INCHES



Yüan Dynasty
Shih-tsu 1260–1294 A.D.
Chih-yüan 1264–1294 A.D.

Dimensions
$5\frac{1}{4} \times 10\frac{1}{8}$ inches

500 Copper Cash

PLATE 118. UPPER SEAL ON THE CHIH-YÜAN MILITARY NOTE.

Six characters arranged as follows:

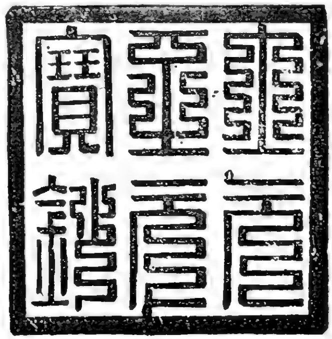
of	A-	Chih-
Seal	lo	yüan

Translation: "*Seal of A-lo* * *of the Chih-yüan Era.*"

PLATE 118.

DIMENSIONS $2\frac{1}{4} \times 2\frac{3}{8}$ INCHES

PLATE 119.



DIMENSIONS $2\frac{3}{4} \times 2\frac{7}{8}$ INCHES

PLATE 119. LOWER SEAL ON THE CHIH-YÜAN MILITARY NOTE.

Six characters arranged as follows:

Treasure	Chih-	Great
Note	yüan	Yüan

Translation: "*Treasure-Note of the Chih-yüan Era of the Great Yüan Dynasty.*"

NOTES OF WÊN-TSUNG (1328–1332 A.D.) OF THE YÜAN DYNASTY.

In July of the year 1328 A.D., Wên-tsung ascended the throne, and the era became known as T'ien-li, lasting until 1330 A.D. Ten varieties of notes from 1 to 10 kwan, issued during these three years, have come down to us. The border decoration consists of clouds only.

* Is this the personal name of a ruler or an official? K. T.

Herewith two notes, of minimum and maximum denominations, are reproduced.

Plate 120. T'ien-li (1328–1330 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Yüan General Circulation Treasure-Note.*"
Second line: "*One Kwan.*"
Illustration: (Pictorial representation of one ingot).
In the lower panel: "*The Board of Rites, having petitioned the throne, prints and issues the Great Yüan Treasure-Note, to be current under the heavens and to be used side by side with cash. The counterfeiter shall be decapitated. He who daringly informs (about) and captures (such a criminal) shall be rewarded with 17 taels in silver. To the concealer (of such guilt) the punishment shall be the same.**
T'ien-li,....year,....month,....day."

Plate 121.

The inscription is the same as that on the one kwan note, with the exception of the denomination, which is 10 kwan. The reward to the informant and captor is 35 taels in silver. The illustration represents ten yüan-pao.

Plate 122. Upper Seal on the T'ien-li Notes.

Four characters arranged as follows:

of	T'ien-
Seal	li

Translation: *Seal of the T'ien-li Era.*

Plate 123. Lower Seal on the T'ien-li Notes.

Six characters arranged as follows:

Treasure	Print	Great
Note	Made	Yüan

Translation: "*Printed Treasure-Note of the Great Yüan Dynasty.*"

* As in the case of counterfeiting. K. T.

PLATE 120.

YÜAN DYNASTY
WÊN-TSUNG 1328–1332 A.D.
T'IEN-LI 1328–1330 A.D.

DIMENSIONS
$4\frac{1}{2} \times 8\frac{1}{4}$ INCHES

ONE KWAN

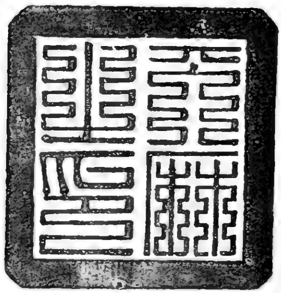
PLATE 121.

YÜAN DYNASTY
WÊN-TSUNG 1328–1332 A.D.
T'IEN-LI 1328–1330 A.D.

DIMENSIONS
$4\frac{3}{8} \times 8\frac{3}{8}$ INCHES

10 KWAN

PLATE 122.



DIMENSIONS
2 × 2 INCHES

PLATE 123.

DIMENSIONS
$2\frac{3}{4} \times 2\frac{7}{8}$ INCHES

Notes of Shun-ti (1333–1367 A.D.) of the Yüan Dynasty.

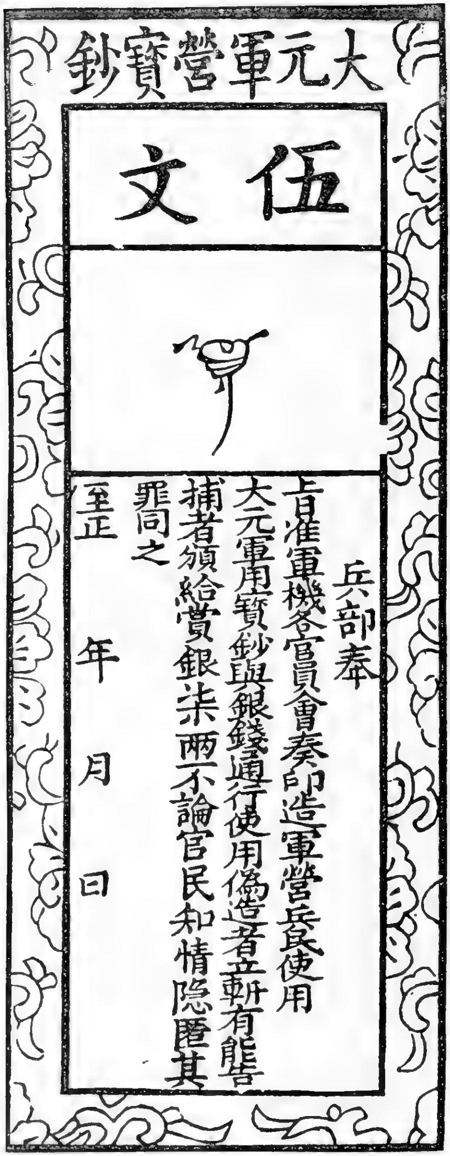
In June of the year 1333 A.D. Shun-ti ascended the throne and established the Yüan-t'ung Era which was changed to Chih-yüan in 1335, and again in 1341 to Chih-chêng, which lasted until 1367. During the Chih-chêng Era the country was in an unsettled state, and the nation was obliged to use "Army" notes. Twenty varieties of these notes have been acquired, among them minor notes of 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 wên, proceeding thence by one hundreds to one kwan (1000 wên). The color is gray. The borders are variously decorated with clouds, bamboos, orchids, plum blossoms, etc. Herewith the minimum, middle and maximum notes are published, omitting the rest.

Plate 124. Chih-chêng (1341–1367 A.D.) Notes.

Translation of the inscriptions.
First line: "*Great Yüan Army Treasure-Note.*"
Second line: "*Five Wên.*"
Illustration: (Pictorial representation of one string of cash).
In the lower panel: "*The Board of War, having received the Imperial authorization decree, upon the petition of the members of the Military Council assembled, prints for the use of the Army and civilians the Great Yüan Military Use Treasure-Note, to circulate and to be used as silver coin. The counterfeiter shall be decapitated summarily. He who daringly informs (about) and captures (such a criminal) shall be given a reward of 7 taels in silver. To official and civilian alike the punishment for being aware of, yet concealing, (such guilt) shall be the same as this (the case of counterfeiting).*
Chih-chêng,....year,....month,....day."

Plate 125.

The inscription is the same as that on the 5 wên note, with the exception of the denomination, which is 90 wên, and the reward to the informant and captor which is 52 taels. The illustration represents nine groups of cash in a string.

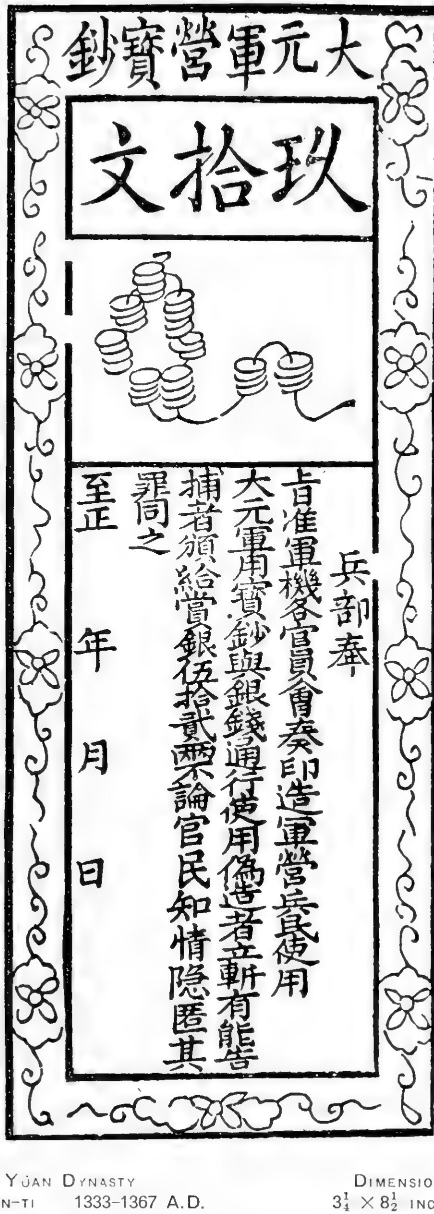


YÜAN DYNASTY
SHUN-TI 1333–1367 A.D.
CHIH-CHÊNG 1341–1367 A.D.

DIMENSIONS
$3\frac{1}{4} \times 8\frac{1}{2}$ INCHES

5 WÊN

PLATE 125.



YÜAN DYNASTY
SHUN-TI 1333–1367 A.D.
CHIH-CHÊNG 1341–1367 A.D.
90 WÊN

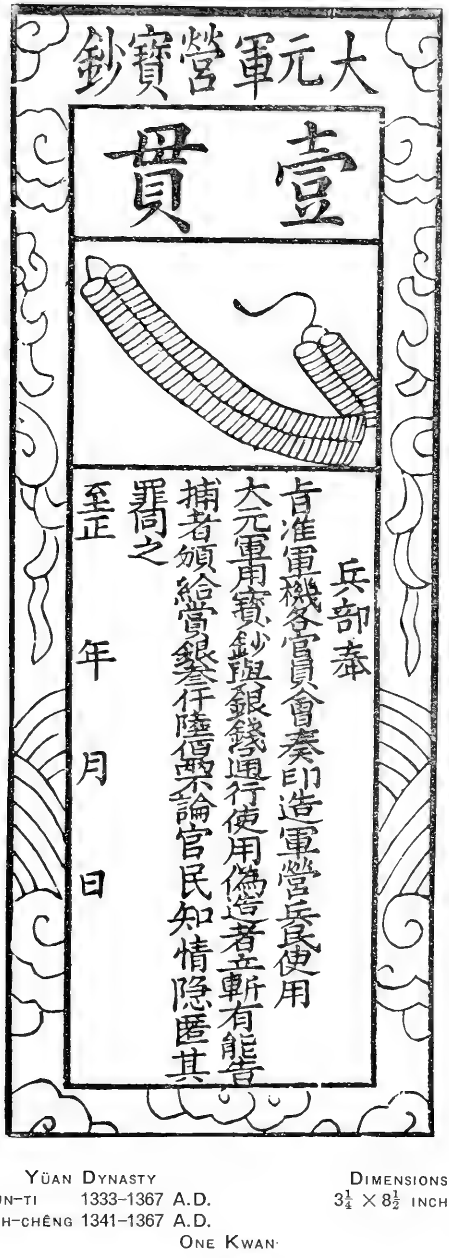
DIMENSIONS
$3\frac{1}{4} \times 8\frac{1}{2}$ INCHES

PLATE 126.

Yüan Dynasty
Shun-ti 1333–1367 A.D
Chih-chêng 1341–1367 A.D.
100 Wên

Dimensions
$3\frac{1}{4} \times 8\frac{1}{2}$ inches

PLATE 127.



YÜAN DYNASTY
SHUN-TI 1333–1367 A.D.
CHIH-CHÊNG 1341–1367 A.D.

DIMENSIONS
$3\frac{1}{4} \times 8\frac{1}{2}$ INCHES

ONE KWAN

Plate 126.

The inscription is the same as that on the 5 wên note, with the exception of the denomination, which is 100 wên, and the reward to the informant and captor which is 57 taels. The illustration represents one string of cash.

Plate 127.

The inscription is the same as that on the 5 wên note, with the exception of the denomination, which is 1 kwan, and the reward to the informant and captor which is 3600 taels. The illustration represents two rows of cash.

Plate 128. Upper Seal on the Chih chêng Notes.

Four characters arranged as follows:

Treasure	Chih-
Note	chêng

Translation: " *Treasure-Note of the Chih-chêng Era.*"

PLATE 128.

Dimensions
$1\frac{1}{4} \times 1\frac{1}{4}$ inches

PLATE 129.

Dimensions
$1\frac{1}{2} \times 1\frac{1}{2}$ inches

Plate 129. Lower Seal on the Chih-chêng Notes.

Six characters arranged as follows:

of	Military	Great
Seal	Barracks	Yüan

Translation: " *Seal of the Army of the Great Yüan Dynasty.*"

NOTES OF T'AI-TSU (1368–1398 A.D.) OF THE MING DYNASTY.

In 1374 the office of the Superintendent (?) of Treasure-Notes was created, and the following year the Executive Department * printed the Great Ming Treasure-Notes, to be current among the people. The material (of paper) was taken from the fibre of the mulberry. The regulation size of the (major) notes was one ch'ih † high and 6 ts'un wide, and the color was blue.‡ They had decorated borders. At the top is written horizontally "Great Ming General Circulation Treasure-Note". At the left and right of the pictorial representation, respectively, are written vertically in the seal style: "Great Ming Treasure Note" and "To be current in the world". In the middle is a pictorial representation of ten string of cash (on the one kwan note) and below is written: "The Executive Department, having petitioned and received the Imperial sanction, prints the Great Ming Treasure-Note to be current and to be used as copper cash. The counterfeiter shall be decapitated." In the case of the 500 wên note, five strings of cash appear, and in the 400, four strings, and the proportion is the same in the case of the notes of 300, 200 and 100 wên.

PLATE 130. HUNG-WU (1368–1398 A.D.) NOTE.

Translation of the inscriptions.

Major.

First line; "*Great Ming General Circulation Treasure-Note.*"
Second line: "*One Kwan.*"
Illustration: (Pictorial representation of ten strings of cash).
At the right of the illustration, in the seal style:
"*Great Ming Treasure-Note.*"

---

* The actual inscription on the notes reads: "The Board of Revenue prints", etc. This board was in the Executive Department. K. T.

† The unit of measurement in China differs in length according to the difference of material, though the term employed is the same; e. g., a ch'ih of fabric is longer than a ch'ih of land. Again, though the same term is employed, the unit differs in various localities. The only way to determine the corresponding dimensions in meters or feet is to get an approximate idea from the illustration, though the latter is somewhat smaller than the same note in the "Shicho Shohei Zuroku" (in Japanese), "Ssŭ Chao Ch'ao T'u Lu", (in Chinese). K. T.

‡ The original text uses the character for "blue" but it should be "gray." K. T.

PLATE 130.

MING DYNASTY
T'AI-TSU 1368-1398 A.D.
HUNG-WU 1368-1398 A.D.

DIMENSIONS
8 × 11¾ INCHES

ONE KWAN

At the left of the illustration, in the seal style:
"To be current under the heavens."

In the lower panel: "*The Board of Revenue, having petitioned and received the Imperial sanction, prints the Great Ming Treasure-Note to be current and to be used as copper cash. The counterfeiter shall be decapitated. The informant and captor shall be rewarded with 250 taels in silver, and in addition shall be given the property of the criminal. Hung-wu,....year,....month,....day.*"

Plate 131. Upper Seal on the One Kwan Note of the Hung-wu Era.

Six characters arranged as follows:

of	Treasure	Great
Seal	Note	Ming

Translation: "*Seal of the Treasure-Note of the Great Ming Dynasty.*"

Plate 132. Lower Seal on the One Kwan Note of the Hung-wu Era.

Six characters arranged as follows:

Office	T'i-	Treasure
Seal	chu *	Note

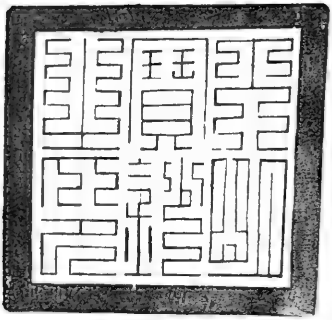
Translation: "*Seal of the Office of Superintendent of Treasure-Notes* (?).

Plate 133. Picture on the Reverse of the One Kwan Note of the Hung-wu Era.

The two characters mean "One Kwan."

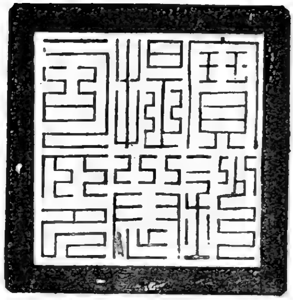
* "T'i-chu" has been translated by some "Inspector" and by Giles "An Inspector of the Salt Department"; however, the duty of a T'i-chu is such that "Superintendent" or "Supervisor" would be more nearly correct. K. T.

PLATE 131.



DIMENSIONS
$3\frac{3}{8} \times 3\frac{1}{4}$ INCHES

PLATE 132.



DIMENSIONS
3×3 INCHES

PLATE 133.

REVERSE OF
1 KWAN MING 1368–1398 A.D.

DIMENSIONS
$3\frac{7}{8} \times 6$ INCHES

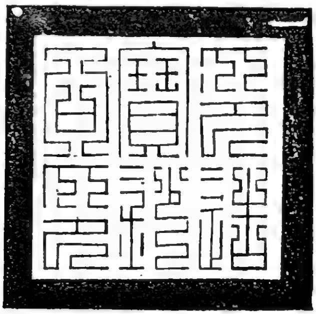
Plate 134. Seal on the Reverse of the One Kwan Note of the Hung-wu Era.

Six characters arranged as follows:

Bureau	Treasure	Print
Seal	Note	Made

Translation: "*Seal of the Bureau of the Printed Treasure-Note.*"

PLATE 134.



DIMENSIONS
$2\frac{3}{8} \times 2\frac{3}{8}$ INCHES

Plate 135. Hung-wu (1368–1398 A.D.) Note.

Translation of the inscriptions.

Minor.

First line: "*Great Ming General Circulation Treasure-Note.*"

Second line: "*Ten Copper Cash.*" Denomination, in panel above picture.

Illustration: (Pictorial representation of one string of cash).

At the right of the illustration in the seal style:

"*Great Ming Treasure-Note.*"

At the left of the illustration in the seal style:

"*To be current under the heavens.*"

In the lower panel: "*The Board of Revenue, having petitioned and received the Imperial sanction, prints the Great Ming Treasure-Note to*

Ming Dynasty
T'ai-tsu 1368–1398 A.D.
Hung-wu 1368–1398 A.D.

Dimensions
$3\frac{1}{4} \times 7\frac{1}{8}$ inches

10 Wên

be current and to be used as copper cash. The counterfeiter shall be decapitated. The informant and captor shall be rewarded with 250 taels in silver, and in addition shall be given the property of the criminal."
Hung-wu,....year,....month,....day."

Plate 136.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 20 wên. The illustration represents two strings of cash.

Plate 137.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 30 wên. The illustration represents one string of cash.

Plate 138.

The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 40 wên. The illustration represents one string of cash.

Plate 139.

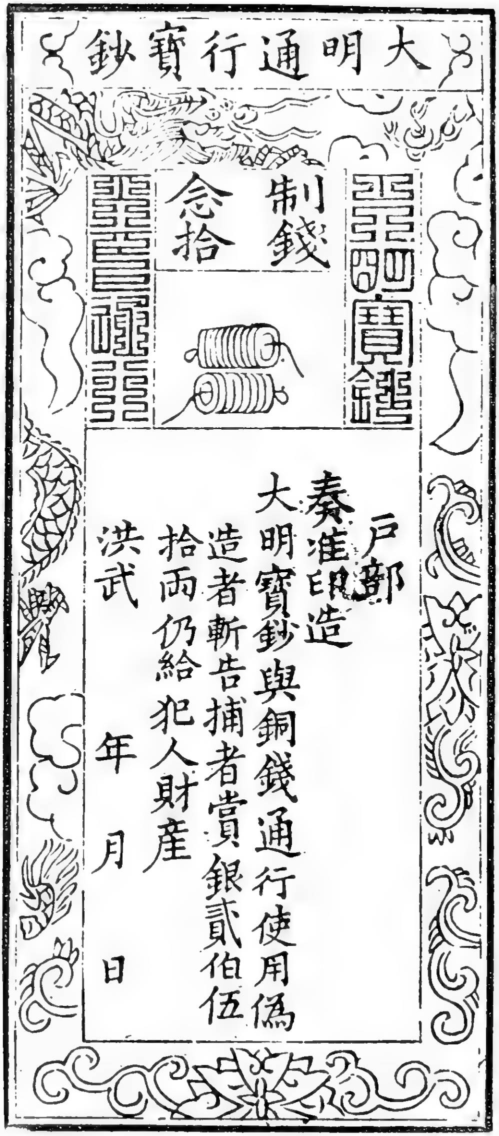
The inscription is the same as that on the 10 wên note, with the exception of the denomination, which is 50 wên. The illustration represents one string of cash.

Plate 140. Upper Seal on the Minor Hung-wu Notes.

Four characters arranged as follows:

Great	Heaven
Peace	under

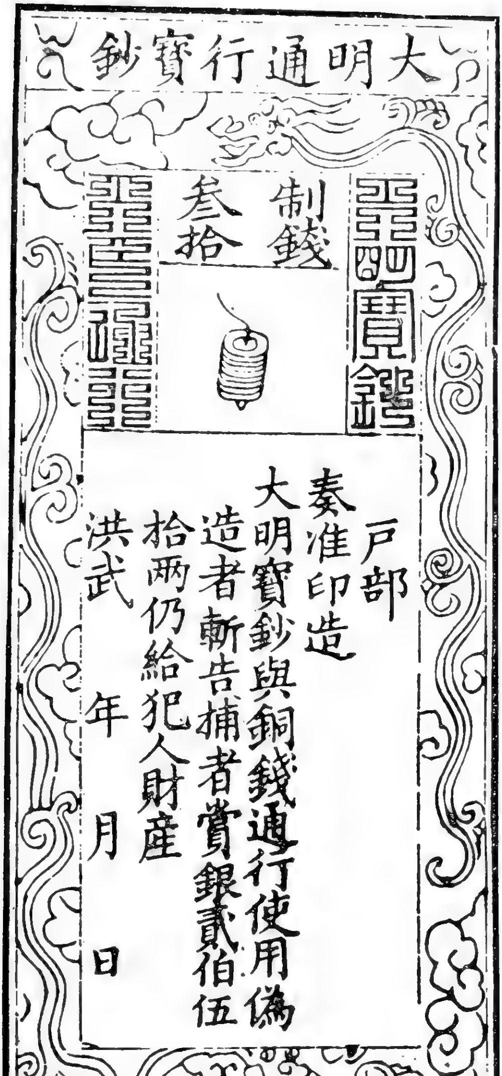
Translation: "*Peace be unto the world.*"



MING DYNASTY
T'AI-TSU 1368-1398 A.D.
HUNG-WU 1368-1398 A.D.

DIMENSIONS
3 × 7 INCHES

20 WÊN



MING DYNASTY
T'AI-TSU 1368–1398 A.D.
HUNG-WU 1368–1398 A.D.

DIMENSIONS
3 × 7 INCHES

30 Wên

PLATE 138.

MING DYNASTY
T'AI-TSU 1368-1398 A.D.
HUNG-WU 1368-1398 A.D.

DIMENSIONS
3 × 7⅛ INCHES

40 WÊN

PLATE 139.

MING DYNASTY
T'AI-TSU 1368-1398 A.D.
HUNG-WU 1368-1398 A.D.

DIMENSIONS
3 × 7 INCHES

50 WÊN

PLATE 141. LOWER SEAL ON THE MINOR HUNG-WU NOTES.

Four characters arranged as follows:

Treasure	Hung-
note	wu

Translation: "*Treasure-Note of the Hung-wu Era.*"

PLATE 140.

DIMENSIONS
1 × 1 INCHES

PLATE 141.

DIMENSIONS
$1\frac{1}{8} \times 1\frac{1}{4}$ INCHES

NOTES OF CH'ÊNG-TSU (1403–1424 A.D.) OF THE MING DYNASTY.

Ch'êng-tsu ascended the throne in 1403 and died in 1424. History does not record the issuance of notes during his reign, which was known as the Yung-lê Era. However, I possess twenty varieties of notes bearing that name. Herewith are printed the minimum, middle and maximum notes. This issue included notes of 1, 2, 3, 4, 6, 7, 8, 9, 11, 12, 13, 14, 16, 17, 18 and 19 kwan, each of which bears a corresponding number of cash. In addition there were issued notes of 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 kwan, each of which bears a pictorial representation of a certain number of cash, each cash representing 5 kwan. Each note has a border decoration of clouds and dragons of varied kinds. The color of the paper is gray. All these notes are major notes.

Plate 142. Yung-lê (1403–1424 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Ming General Circulation Treasure-Note.*"
Second line: "*One Kwan.*"
Illustration: (Pictorial representation of one cash).
At the right of the illustration in the seal style:
"*To be current as cash.*"
At the left of the illustration in the seal style:
"*For the convenient use of the people.*"
In the lower panel: "*The Board of Revenue, having petitioned and received the Imperial sanction, prints the Great Ming Treasure-Note to be used as copper cash. The counterfeiter of the same form shall be decapitated summarily. The punishment to concealers among District officials also shall be the same as this (the case of counterfeiting). The informant and captor shall be given by the authorities a reward of 770 taels in silver, and in addition shall be given the property of the criminal.*
Yung-lê,....year,....month,....day."

Plate 143.

The inscription is the same as that on the one kwan note, with the exception of the denomination which is 50 kwan, and the reward to the informant and captor which is 890 taels. The illustration represents ten cash.

Plate 144. Upper Seal on the Yung-lê Notes.

Four characters arranged as follows:

of	Yung-
Seal	lê

Translation: "*Seal of the Yung-lê Era.*"

PLATE 142.

MING DYNASTY
CH'ÊNG TSU 1403 1424 A.D.
YUNG LÊ 1403 1424 A.D.

DIMENSIONS
$5\frac{1}{4} \times 8\frac{7}{8}$ INCHES

ONE KWAN

PLATE 143.

MING DYNASTY
CH'ÊNG-TSU 1403–1424 A.D.
YUNG-LÊ 1403–1424 A.D.

DIMENSIONS
$5\frac{1}{4} \times 8\frac{7}{8}$ INCHES

50 KWAN

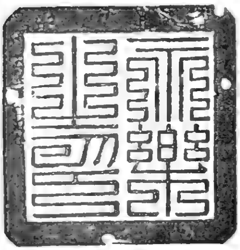
Plate 145. Lower Seal on the Yung-lê Notes.

Six characters arranged as follows:

Treasure	Print	Great
Note	made	Ming

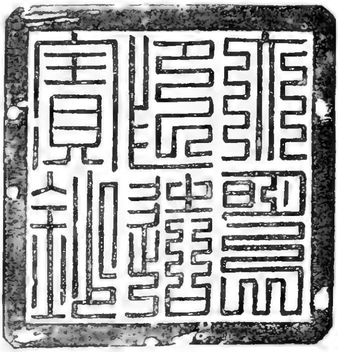
Translation: "*Printed Treasure-Note of the Great Ming Dynasty.*"

PLATE 144.



Dimensions
$1\frac{7}{8} \times 1\frac{7}{8}$ inches

PLATE 145.



Dimensions
$2\frac{1}{2} \times 2\frac{5}{8}$ inches

Notes of Jên-tsung (1425 A.D.) of the Ming Dynasty.

In August of the year 1424, the Emperor Ch'êng-tsu died, whereupon his son succeeded to the throne and became known as Jên-tsung. In the following year he named his reign Hung-hsi. In May of that year he died. During this short reign of about half a year, twenty varieties of notes were emitted. Each is entitled the "Great Ming Military Administration Treasure-Note". Their denominations begin at 10 wên and proceed by tens to 100 and thence by hundreds to 1000 wên. Each note bears a certain number of strings of cash proportionate to its denomination. The designs on the borders of these notes are flowers, plum blossoms on cracked ice, and clouds-and-bats, etc. Herewith are reproduced the minimum, middle and maximum denominations.

Plate 146. Hung-hsi (1425 A.D.) Note.

Translation of the inscriptions.

First line: "*Great Ming Military Administration Treasure-Note.*"
Second line: "*Ten Wên.*"
Illustration: (Pictorial representation of one string of cash).
In the lower panel: "*The Board of War, having received the Imperial authorization decree upon the petition of the Ministers of the Military Council assembled, prints for the use of the Army and for the convenience of the soldiers the Great Ming Military Use Treasure-Note to be used as silver. The counterfeiter of the same form shall be decapitated summarily. He who daringly informs (about) and captures (such a criminal) shall be given by the authorities a reward of 11 taels in silver. To official and civilian alike the punishment for being aware of, yet concealing, (such guilt) shall also be the same (as in the case of counterfeiting).*
Hung-hsi,. . . .year,. . . .month,. . . .day."

Plate 147.

The inscription on the 100 wên note is the same as that on the 10 wên note, except the denomination, and the reward for the informant which is 121 taels. The illustration represents one string of cash.

Plate 148.

The inscription on the 1000 wên note is the same as that on the 10 wên note except the denomination, and the reward for the informant which is 121 taels.* The illustration represents two long strings of cash.

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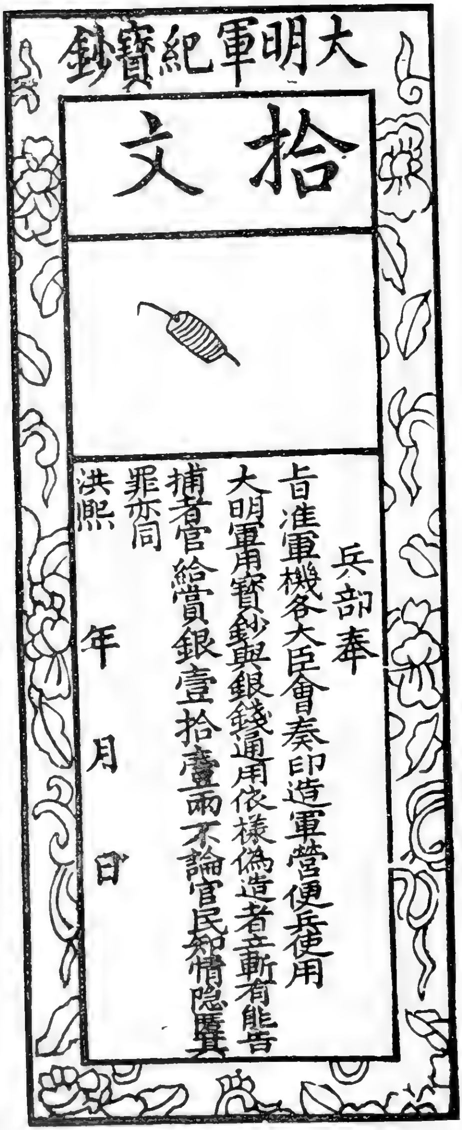
* The following notes agree with the 10 wên note in all respects except those mentioned:

Denomination;	20 wên;	reward,	13 taels.
"	30 wên;	"	15 taels.
"	40 wên;	"	17 taels.
"	60 wên;	"	21 taels.
"	70 wên;	"	23 taels.
"	300 wên;	"	51 taels.
"	400 wên;	"	61 taels.
"	500 wên;	"	71 taels.
"	700 wên;	"	91 taels.
"	800 wên;	"	101 taels.
"	900 wên;	"	111 taels.

K. T.

PLATE 146.



MING DYNASTY
JÊN-TSUNG 1425 A.D.
HUNG-HSI 1425 A.D.

DIMENSIONS
$3\frac{1}{4} \times 8\frac{3}{8}$ INCHES

10 WÊN

PLATE 147.

MING DYNASTY
JÊN-TSUNG 1425 A.D.
HUNG-HSI 1425 A.D.

DIMENSIONS
$3\frac{1}{4} \times 8\frac{3}{8}$ INCHES

100 WÊN

PLATE 148.

MING DYNASTY
JÊN TSUNG 1425 A.D.
HUNG-HSI 1425 A.D.

DIMENSIONS
$3\frac{1}{4} \times 8\frac{3}{8}$ INCHES

1000 WÊN

PLATE 149. UPPER SEAL ON THE HUNG-HSI NOTES.

Four characters arranged as follows:

Treasure	Hung-
Note	hsi

Translation: "*Treasure-Note of the Hung-hsi Era.*"

PLATE 149.

DIMENSIONS
$1\frac{1}{4} \times 1\frac{1}{4}$ INCHES

PLATE 150.

DIMENSIONS
$1\frac{1}{2} \times 1\frac{1}{2}$ INCHES

PLATE 150. LOWER SEAL ON THE HUNG-HSI NOTES.

Six characters arranged as follows:

of	Military	Great
Seal	Order	Ming

Translation: "*Seal of the Military Administration of the Great Ming Dynasty.*"

APPENDIX: TRANSLATIONS FROM OTHER SOURCES.

(Six Reproductions from Ssŭ Chao Ch'ao Pi T'u Lu and two from the Journal of the Peking Oriental Society.)

Plate 151. Remaining Portion of the Tri-Conjunctive Major Note of the Chin Dynasty.

Illustration No. 1 from the "Ssŭ Chao Ch'ao Pi T'u Lu".

(Illustrated Record of the Paper-Money of the Four Dynasties).*

The Tri-Conjunctive† Major Note of the Chin Dynasty.

Although more than half of the lower part of this note is missing, it is clear that this is the Tri-Conjunctive Exchange-Note. In the history of the Chin Dynasty, it is recorded that in 1154 A.D. exchange-notes were issued, the denominations being 1, 2, 3, 5 and 10 kwan, of the major class, and 100, 200, 300, 500 and 700 wên of the minor class. History also refers to the fact that in 1202 A.D. the use of the Tri-Conjunctive Exchange-Notes, which had been in circulation for some years, ceased. This is the only mention of a "Tri-Conjunctive Exchange-Note", but the date of its issuance is lacking.

The note illustrated bears, outside the border, the inscription "Chung-tu (Peking) Conjoined", "Nanking Conjoined" and "P'ing-liang Fu Conjoined", and proves that the treasuries of these three places were associated in its issuance; hence the name "Tri-Conjunctive Exchange-Note". The note must have first been used some time after 1180 A.D., as it was in this year that a regulation was enacted to the effect that 80 wên of cash would be accepted for each 100 wên on a note; and this 10 kwan note bears under the figure "One Ten Kwan" two characters meaning "Eighty", below which there must have been two characters meaning "Sufficient for One Hundred". It is now clear that this Tri-Conjunctive Ten Kwan Note was in circulation between 1180 and 1202 A.D. (Extract from the original text.)

---

* By Lo Chên-yü. K. T.

† The character used contains the idea of a contract, or association, or participation. K. T.

PLATE 151.

10 Kwan Note of the Chin Dynasty
In circulation between 1180–1202 A.D

Translation of the inscriptions.

Outside the top border:
"One Ten Kwan."
Inside the panel, center:
"One Ten Kwan, Eighty. . . . ."
Within the panel, at the right:
"Counterfeit. . . . ."
Within the Panel at the left:
"' . . . .' Mark" or "Number."
Outside the left-hand decorated border:
"Chung-tu Conjoined."
"Nanking Conjoined."
"P'ing-liang Fu Conjoined."

PLATE 152. SHANTUNG TUNG-LU TEN KWAN NOTE.

ILLUSTRATION NO. 2 FROM THE SSŬ CHAO CH'AO PI T'U LU."

The Shantung Tung-lu Ten Kwan Note of the Chin Dynasty.

This note was in circulation in the Eastern District (Tung-lu) of the Shantung Province. About 1216 A.D. the government established in the various Districts treasuries which were allowed to issue notes in place of specie. Up to this time there had been only two Government Printed-Note Offices — one in Peking and the other in Nanking. For the Eastern District of the Shantung Province the treasuries were located in I-tu Fu and Chi-nan Fu. The note herewith illustrated is of this district. History does not mention the exact time of the circulation of this note. However, it could be placed in the period between 1183 and 1197 A.D. The following fact proves this deduction. In 1197 A.D. an official remarked to the Throne that up to 1183 the charge for renewing a note (producing or printing a new note to replace the old or cast away one) was 15 wên for each kwan of the face value of the note, but that since 1183 A.D. the charge for the same had come to be 8 wên for each note, no matter what the face value might be. Whereupon, it was ordered by the Emperor that the charge be 12 wên for each one kwan of the face value of the note. The note in question bears the inscription outside the border "The printing charge for every sheet (is) eight wên." (Extract from the original text.)

PLATE 152.

SHAN–TUNG TUNG–LU
IN CIRCULATION BETWEEN 1183–1197 A.D.
10 KWAN

Translation of the inscriptions.

Outside the border:

"One Ten Kwan."

Upper panel, center, written vertically:

"One Ten Kwan, Eighty is Sufficient for One Hundred."

At the right of "Eighty is Sufficient," etc.:

"' . . . .' Variety" or "Series."

At the left of "Eighty is Sufficient," etc.:

"' . . . .' "Mark" or "Number."

At the right of the upper panel, in the seal style:

"(He who) counterfeits the Exchange-Note shall be decapitated."

At the left of the upper panel, in the seal style:

"The reward shall be 300 kwan in cash."

In the center of the lower panel:

"He who counterfeits the Exchange-Note shall be decapitated. The reward shall be 300 kwan in cash."

At the right of "The counterfeiter," etc., in the lower panel:

"*Shantung Tung-lu*. . . . (23 characters are undecipherable), *Nanking Exchange-Note Treasury, I-tu Fu, Chi-nan Fu*. . . . (one character undecipherable) *Treasuries*. . . . (16 characters undecipherable)."

At the left of "He who counterfeits," etc., in the lower panel:

"The Bureau of Printed-Notes."

"The Commissioner of Printed-Notes."

"*The Board of Revenue in the Executive Department*. . . . (two or three characters undecipherable)."

Outside the right-hand decorated border:

"For the printing of every sheet the charge is 8 cash."

Plate 153. Illustration No. 3 from the "Ssŭ Chao Ch'ao Pi T'u Lu."

Picture on the Reverse of the Two Kwan Note of the Chin Dynasty.

In the upper panel: Two characters meaning "*Two Kwan.*"

This is the picture on the reverse of a "Two Kwan" note whose face is entirely missing. The notes of the Chin Dynasty and also of the Yüan Dynasty included the denomination "Two Kwan." That of the Yüan, however, bore no picture on its reverse. There is no note

PLATE 153.

Reverse of the Two Kwan Note
Probably of the Chin Dynasty

of the denomination "Two Kwan" among the issues of the Ming Dynasty. Hence, I deduce that this note is a two kwan note of the Chin Dynasty. (Extract from the original text).

PLATE 154. CHÊNG-YU (1213–1216 A.D.) NOTE.

ILLUSTRATION NO. 4 FROM THE SSŬ CHAO CH'AO PI T'U LU.

The Five Kwan Note of Chêng-yu (1213–1216 A.D.) *of the Chin Dynasty.*

This five kwan note was issued in 1215 A.D. and was issued conjointly by Ching-chao Fu and P'ing-hang Fu. (Extract from the original text.)

Translation of the inscriptions.

At the top, outside the border decoration:
"*Five Kwan.*"
Written horizontally at the top within the border decoration:
"*Chêng-yu Treasure Bill.*"
In the center of the middle panel:
"*Five Kwan, Eighty is Sufficient for One Hundred.*"
At the right of the figure "Five Kwan," etc.
"'*Yu*' *Variety*" *or* "*Series.*"
At the left of the figure "Five Kwan," etc.:
"'. . . . .' *Mark*" *or* "*Number.*"
At the right of the middle panel, in the seal style:
"*The counterfeiter shall be decapitated; the reward*"
At the left of the middle panel, in the seal style:
"*shall be three hundred kwan in Treasure-Bills.*"
In the center of the lower panel:
"*The counterfeiter shall be decapitated. The reward shall be 300 kwan in Treasure-Bills; in addition, the property of the criminal shall be given.*"
At the right of "The counterfeiter," etc., in the lower panel:
"*The Imperial sanction having been petitioned and received, the Treasure-Bill is printed to be current and to be used equally with the specie. This shall be redeemable for an unlimited period of time at the government treasuries of Ching-chao and P'ing-liang Fu.*" *

* Several characters in this sentence are undecipherable in the illustration. The rendering, therefore, is the best under the circumstances. K. T.

PLATE 154.

CHIN DYNASTY
CHÊNG-YU 1213-1216 A.D
5 KWAN

"*The Treasury Officer in Charge of Printing* (*and his sign-manual*). *The Deputy of the Treasury. The Associate Officer* [*and his sign-manual*]."

At the left of "The counterfeiter," etc., in the lower panel:

"*Chêng-yu, ... year, ... month, ... day.*"

"*The Officer of the Printing Bureau* (*and his sign-manual*). *The Associate Officer* (*and his sign-manual*)."

"*The Director of the Bureau of Treasure-Bills* (*and his sign-manual*). *The Deputy . . . ., Examiner.*"

"*The Director of the Bureau of Printing* (*and his sign-manual*). *The Deputy* (*and his sign-manual*), *Examiner.*"

"*The Chief Auditor of the Board of Revenue in the Executive Department* (*and his sign-manual*)."

Outside the left-hand border:

"*Ching-chao Fu conjoined.*"

"*P'ing-liang Fu conjoined.*"

Plate 155. Hsing-ting (1217–1222 A.D.) Note.

Illustration No. 5 from the "Ssŭ chao Ch'ao Pi T'u Lu".

The Two Kwan Note of the Hsing-ting (1217–1222 A.D.) Era of the Chin Dynasty.

In 1221 A.D., in the reign of Hsüan-tsung (1213–1223 A.D.) this note, called the "Hsing-ting Pao-ch'üan" was issued. The face value of the note — one kwan — was accepted for 400 kwan of tung-pao (Chêng-yu tung-pao, which is paper-money). (Extract from the original text.)

Translation of the inscriptions.

Outside the border:

Pictorial representation of twenty strings of cash.

In the top row, written horizontally:

"*Hsing-ting Treasure-Money.*"

In the second row, written horizontally:

"*Two kwan wên-shêng.*" *

* The first character, "wên", means "to hear, to smell, or news"; the second character, "shêng" means "to reduce, to reflect on one's own conduct, province, the governmental department", etc. The combination of the two characters is unintelligible. K. T.

PLATE 155.

CHIN DYNASTY
HSING-TING 1217–1222 A.D.
2 KWAN

In the middle panel, at the right, written vertically:

"'........' Variety" or "Series."

In the middle panel, at the left, written vertically:

"'........' Mark" or "Number."

In the middle panel, below, written horizontally:

"Nanking District."

At the right of the middle panel, written vertically in the seal style:

"The counterfeiter shall be decapitated."

At the left of the middle panel, written vertically in the seal style:

"The reward shall be 600 kwan."

In the center of the circular panel, written vertically:

"The counterfeiter shall be decapitated; in addition, the property of the criminal shall be given."

At the right of "The counterfeiter," etc., in the circular panel:

"The Imperial sanction having been petitioned and received, the Hsing-ting Treasure Money is printed to be current and to be used equally with the specie. This shall circulate and be current for an unlimited period of time."

"The Officer of the Bureau of Treasure-Money (and his sign-manual). The Associate Officer (and his sign-manual)."

"The Officer of the Bureau of Printing" (and his sign-manual). The Associate Officer (and his sign-manual).

At the left of "The Counterfeiter," etc., in the circular panel:

"Hsing-ting, sixth year, second month,....day."

"The Director of the Bureau of Treasure-Money (and his sign-manual). The Deputy...., examiner (or examined)."

"The Director of the Bureau of Printing (and his sign-manual). The Deputy examiner (or examined)."

"The Accountant of the Board of Revenue (and his sign-manual)."

"The Chief Auditor of the Board of Revenue in the Executive Department (and his sign-manual)."

Plate 156. Chih-yüan (1264–1294 A.D.) Note of the Yüan Dynasty.

Illustration No. 6 from the "Ssŭ chao Ch'ao Pi T'u Lu".

The Chih-yüan Note of the Yüan Dynasty.

At the beginning of the Yüan Dynasty, the Chung-tsung Yüan-pao Note, which was emitted in October of the year 1260 A.D., was in circulation. It remained in use until 1287 A.D. [the twenty-fourth

PLATE 156.

CHIN DYNASTY
SHIH-TSU 1260–1294 A.D.
CHIH-YÜAN 1264–1294 A.D.
TWO KWAN

year of the Chih-yüan Era], when the Chih-yüan Treasure-Notes took its place.* The denominations of the Chih-yüan Treasure-Notes were 2 kwan, 1 kwan, 500, 300, 200, 100, 50, 30, 10 and 5 wên, eleven varieties in all. (Extract from the original text.)

Translation of the inscriptions.

At the top, outside the decorated border, written horizontally:
"Chih-yüan General Circulation Treasure-Note."
In the upper panel:
"*Two Kwan*" [and its pictorial representation].
At the right and left of the upper middle panel respectively:
An inscription in Mongolian.
Below the Mongolian inscription at the right:
"'. . . .' Variety" or "Series."
Below the Mongolian inscription at the left:
"'. . . .' Mark" or "Number."
In the center of the lower panel:
The counterfeiter shall be punished by decapitation. The first informant shall be rewarded with five ingots in silver and in addition shall be given the property of the criminal."
At the right of "The counterfeiter," etc., in the lower panel:
"The Executive Department, having petitioned and received the Imperial sanction, prints the Chih-yüan Treasure-Note to be acceptable for the payment of taxes (in grain) within the jurisdiction of the Rural Tax Office.† This shall be current in all Districts for an unlimited period of time."
"The Officer of the Bureau of Treasure-Notes. The Associate Officer."
"The Officer of the Bureau of Printing. The Associate Officer."
At the left of "The counterfeiter," etc., in the lower panel:
"Chih-yüan, ... year, ... month, ... day."
"The Director of the Bureau of Treasure-Notes. The Deputy."
"The Director of the Bureau of Printing. The Deputy."
"The T'i-chu (Superintendent?) in the Executive Department."

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* The author of the "Ch'üan Pu T'ung Chih" refers to the issuance of the Chih-yüan Treasure-Notes in 1287 and reproduces ten examples. However, they differ completely from those which are illustrated in connection with this text, though both kinds bear the words "Chih-yüan". Which is correct? Because of the source from which the author of the "Ssŭ Chao Ch'ao Pi T'u Lu" drew his information, his remarks are more likely to be correct. See the translation of the text on "Notes of Shih-tsu of the Yüan Dynasty" (page 580).

† The meaning is obscure and the translation subject to correction. K. T.

Plate 157. Hung-wu (1368–1398 A.D.) Note.

From the Journal of the Peking Oriental Society.

Translation of the inscriptions.

First line: "*Great Ming General Circulation Treasure-Note.*"
Second line: "*Two Hundred Wên.*"
Illustration: (Pictorial representation of two strings of cash).
At the right of the illustration in the seal style:
"*Great Ming Treasure-Note.*"
At the left of the illustration in the seal style:
"*To be current under the heavens.*"
In the lower panel: "*The Board of Revenue, having petitioned and received the Imperial sanction, prints the Great Ming Treasure-Note to be current and to be used as copper cash. Cast anew in the year of chi*-mao † of the Ch'ung-chên Era.‡ The counterfeiter shall be decapitated. The informant and captor shall be rewarded with 250 taels in silver, and in addition shall be given the property of the criminal.*"
Hung-wu,....year,....month,....day."

Plate 158. Three Seals on the Hung-wu Copper (?) Note.

From the Journal of the Peking Oriental Society.

Top. The inscription is the same as that on Plate 131.
Middle. The inscription is the same as that on Plate 132.
Bottom. Six characters arranged as follows:

Bureau	Treasure	Cast
Seal	Note	Made

Translation: "*Seal of the Bureau of the Cast Treasure-Note.*"
The inscription is the same as that on the one Kwan, Ming note, Plate 136, with the exception of the denomination, which is 200 wên, with two strings of cash.

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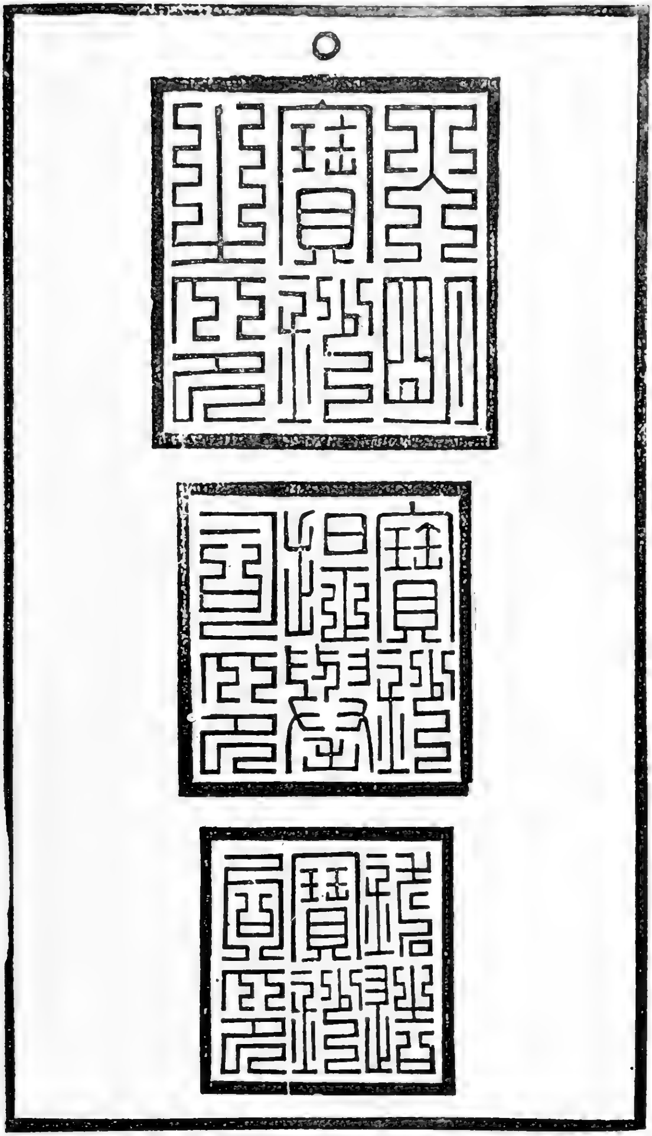
* The sixth of the ten cyclical stems. K. T.
† The rabbit year, the fourth of the twelve zodiacal signs. K. T.
‡ The year of chi-mao in the Ch'ung-chên Era corresponds to the year 1639 A. D. K. T.

PLATE 157.

HUNG-WU 1368–1398 A.D.
TWO HUNDRED WÊN

PLATE 158.



Seals on Hung-wu Note
1368–1398 A.D. Recast 1639 A.D.

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ROTATIONS IN HYPERSPACE.

By C. L. E. Moore.

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In this paper three problems are discussed. First, the resolution of a complex 2-vector M, in space of $2p$ dimensions into the sum of p mutually completely perpendicular simple 2-vectors or planes. It is shown that this can always be done and is in general unique. But if M satisfies certain product relations the resolution can be effected in an infinite number of ways. In four dimensions this relation is equivalent to saying that M is what Whitehead[1] calls self-supplementary. In this case the resolution can be effected in ∞^2 different ways.

Second, the application of the preceding to show that a rotation in a space of $2p$ dimensions leaves p mutually completely perpendicular planes invariant. In general these are the only invariant planes. But in case the rates of rotation in the p invariant planes are the same or differ only in sign there are an infinite number of invariant planes which can be arranged in sets of p which are mutually completely perpendicular. In 4-space in case the rates of rotation in two completely perpendicular invariant planes have the same magnitude there are ∞^2 invariant planes which are completely perpendicular in pairs.

Third, the consideration of the variety V_p left invariant by all the transformations leaving the same set of p planes invariant. It is found that this variety is of order 2^p. The path curves are curves of constant curvature and first torsion and are geodesics on V_p. The centers of curvature of all the path curves that pass through a given point lie on a sphere of p-dimensions having the given point P and the point of intersection O of the p invariant planes as ends of a diameter. Through each point pass 2^p path curves which are circles having O for center and OP for radius. The variety V_p can be developed on a plane space of p dimensions.

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[1] A treatise on Universal Algebra, page 292.

The only papers that I know of bearing on rotations in hyperspace are given below:[2]

1. **Introduction.** In terms of the Gibbs Vector analysis an infinitesimal rotation in three dimensions can be expressed by the formula[3]

$$r' = r + a{\times}r\,dt,$$

where a is a vector along the axis of the rotation and r is any vector through the fixed origin. If the rotation is considered as parallel to a fixed plane determined by the vectors b, c then it can be represented by the formula

$$r' = r + (b{\times}c){\times}r\,dt.$$

By the Gibbs definition of the cross product (a vector perpendicular to the plane of the two vectors and of magnitude equal to the product of the lengths of the two vectors into the sine of the angle between them, so arranged that the three vectors b, c, $b \times c$ for a right handed system) this last expression is equivalent to the first. If we wish to extend this to higher dimensions we cannot have a form equivalent to the first since the cross product of two 1-vectors cannot be considered as a 1-vector as, in that case, two 1-vectors do not uniquely determine a 1-vector. We will then have to start with a new set of definitions of the products. It must be kept in mind that we may have vectors of different dimensions as 1-vectors, 2-vectors, 3-vectors, etc., of one, two, three, etc., dimensions. I shall here use the vector analysis already set up by Wilson and Lewis.[4]

The cross product of two-vectors extending from the same origin is defined as the parallelogram defined by the two vectors. The product is then a 2-vector. The magnitude of the product is equal to the area of the parallelogram. Similar definitions are given for the cross

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[2] F. N. Cole: On rotations in space of four dimensions. American Journal, **12**, 1889, page 191.

P. H. Schoute: Le déplacement le plus général dans l'espace à n dimensions. Annales de l'Ecole Polytechnique de Delft, **7**, 1891.

Bemporad: sui gruppi dei movimenti. Annali della r. scuola normale sup. di Pisa, **8**, 1904.

E. E. Levi: Sui gruppi di movimenti. Atti dei Lincei Series 5, **14**, part 1, 1905.

[3] Gibbs-Wilson Vector Analysis, page 99.

[4] Space-time manifold of relativity. The non-euclidean geometry of mechanics and electromagnetics. These Proceedings, **48,** number 11, 1912.

product of more than two 1-vectors. The dot product of two 1-vectors is defined as the projection of one on the other multiplied by the length of the one on which the projection is made. This agrees with the Gibbs definition of the dot product of two 1-vectors. This product is a scalar. The dot product of two vectors of higher dimension is defined as the vector in the larger space perpendicular to the smaller. The magnitude is equal to the magnitude of the projection of the smaller into the magnitude of the larger. If the two vectors are of equal magnitude this product is again a scalar otherwise it is a vector. This definition differs widely from the usual definition of inner product. This product is commutative while the ordinary inner product is not.

We shall choose unit vectors along mutually perpendicular axes for our reference system. Let these reference vectors be $k_1, k_2, \ldots . k_n$. Then the coordinate planes, 3-spaces, 4-spaces, etc. are

$$\begin{aligned}
&k_{12} = k_1 \times k_2,\ k_{13} = k_1 \times k_3, \ldots . k_{rs} = k_r \times k_s \\
&k_{123} = k_1 \times k_2 \times k_3, \ldots . k_{pqr} = k_p \times k_q \times k_r, \\
&\cdots\cdots\cdots\cdots\cdots\cdots \\
&k_{pq \ldots . r} = k_p \times k_q \times \ldots . \times k_r.
\end{aligned}$$

The dot product of these unit vectors are as follows:

$$\begin{aligned}
&k_i \cdot k_i = 1,\ k_i \cdot k_j = 0,\ (i \neq j), \\
&k_{ij} \cdot k_{ij} = 1,\ k_{ij} \cdot k_{il} = 0,\ (j \neq l),\ k_{ij} \cdot k_{mn} = 0\ (i, j \neq m, n) \\
&k_i \cdot k_{ij} = -k_j,\ k_j \cdot k_{ij} = k_i, \\
&k_i \cdot k_{ijl} = k_{jl},\ k_{ij} \cdot k_{ijl} = k_l \text{ etc.}
\end{aligned}$$

The dot product of two of these unit vectors vanishes if the smaller is not entirely contained in the larger, that is if a subscript appears in the smaller which does not also appear in the larger. If the dot product vanishes the two vectors are perpendicular. This however does not require complete perpendicularity, that is it requires that one vector in one is perpendicular to the other while complete perpendicularity requires that every vector in one is perpendicular to every vector in the other. To obtain a vector completely perpendicular to a given vector we must resort to the complement, which for unit vectors is defined as the vector obtained by taking the dot product of the given vector with the pseudo scalar.[5] Throughout this paper

5 The pseudo scalar is defined as the cross product of all the 1-vectors arranged so that the value is unity. Thus in 4-space the pseudo scalar is $k_1 \times k_2 \times k_3 \times k_4 = k_{1234}$.

the word perpendicular shall be used to mean complete perpendicularity.

The formular for the reduction of the various products of 1- and 2-vectors are,

(1). $a\cdot(b\times c) = (a\cdot c)b - (a\cdot b)c$

(2). $(a\times b)\cdot C = a\cdot(b\cdot C) = -b\cdot(a\cdot C)$

(3). $a\times(b\cdot C) = (a\times C)\cdot b - (a\cdot b)C$

(4). $(b\cdot C)\cdot A = -b(C\cdot A) + C\cdot(b\times A)$

where a, b, c are 1-vectors and A, C are 2-vectors.

Now having these definitions an infinitesimal rotation [6] parallel to a fixed plane M_1 is defined by the equation

$$r' = r + M_1\cdot r\,dt.$$

The length of r' is equal to the length of r. For

$$r'\cdot r' = r\cdot r + 2r\cdot(M_1\cdot r)dt = r\cdot r$$

The product $r\cdot(M_1\cdot r)$ vanishes since $M_1\cdot r$ is defined as a vector in M_1 perpendicular to r. A general rotation can be considered as made up of rotations parallel to a number of independent planes. The equation for such a rotation is

$$r' = r + (M_1 + M_2 + \ldots + M_k)\cdot r\,dt.$$

The sum of k, simple plane vectors is a complex [7] plane vector or 2-vector. Therefore we may write the rotation in the form

$$r' = r + M\cdot r\,dt \tag{5}$$

where M is a complex 2-vector, that is, is not equivalent to a simple 2-vector. The canonical form then which (5) may take depends on the form in which M may be written. Then we shall first show that M can always be resolved into the sum of p mutually perpendicular planes if we are working in a space of 2 p dimensions. We first consider the cases of four dimensions and five dimensions and then generalize to space of any number of dimensions.

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6 A rotation is defined as a rigid motion leaving one point fixed.

7 Plane vectors in 4-space, for example, are analogous to lines in 3-space. We know that the sum of two lines is not a line unless the lines intersect. The same is true of plane vectors, their sum is a complex or complex vector unless the two simple plane vectors have a line in common. We shall use complex as equivalent to complex vector.

II.

2. **Complex 2-vectors in 4-space.** Let k_1, k_2, k_3, k_4 be four mutually perpendicular unit vectors. Then any 1-vector can be expressed as a linear function of these four and any 2-vector (simple or complex) can be represented as a linear function of the six coordinate planes $k_{ij} = k_i \times k_j$. Thus

$$M = a_{12}k_{12} + a_{13}k_{13} + a_{14}k_{14} + a_{23}k_{23} + a_{24}k_{24} + a_{34}k_{34}. \tag{6}$$

From this equation we have at once, *A complex 2-vector can be resolved into the sum of two simple planes* M_1 and M_2, *one passing through an arbitrary 1-vector and the other lying in a 3-space perpendicular to it.* For let

$$M_1 = a_{12}k_{12} + a_{13}k_{13} + a_{14}k_{14}$$

This is a simple plane since it is the sum of three simple 2-vectors having the vector k_1 in common. As we could choose for k_1 a unit vector in any direction, this plane can be made to pass through an arbitrary 1-vector. Then let

$$M_2 = a_{23}k_{23} + a_{24}k_{24} + a_{34}k_{34}.$$

This is a plane since it is the sum of three simple plane vectors which lie in the 3-space determined by k_2, k_3, k_4. This 3-space is evidently perpendicular to k_1 since $k_1 \cdot (k_2 \times k_3 \times k_4) = 0$. (If we did not confine ourselves to a rectangular set of axes this 3-space would not necessarily be perpendicular to k_1). We can then write

$$M = M_1 + M_2.$$

The condition that M be a simple plane vector is

$$M \times M = 0$$

For,

$$M \times M = (M_1 + M_2) \times (M_1 + M_2) = 2M_1 \times M_2.$$

In 4-space the cross product of two 2-vectors is a scalar and if this product vanishes it signifies that M_1 and M_2 lie in a 3-space and consequently $M_1 + M_2$ can be expressed as a simple plane vector.

A complex 2-vector can always be resolved into the sum of two simple

2-vectors, one of which is arbitrary. For, let A be any plane vector, then $M-\lambda A$ will be a simple plane if

$$(M-\lambda A)\times(M-\lambda A) = M\times M-2\lambda\, M\times A = 0$$

or

$$\lambda = \frac{M\times M}{2M\times A}$$

and we can write

$$M = \frac{M\times M}{2M\times A}A + (M - \frac{M\times M}{2M\times A}A)$$

We shall now show that the complex 2-vector can always be resolved in at least one way into the sum of two perpendicular planes. Let

$$M = m_1M_1 + m_2M_2 \tag{8}$$

where M_1 and M_2 are completely perpendicular unit planes and m_1 and m_2 numbers. Then indicating $(M\times M)\cdot M$ by A we can write

$$A = (M\times M)\cdot M = 2m_1m_2(M_1\times M_2)\cdot M = 2m_1m_2(m_2M_1+m_1M_2). \tag{9}$$

Solving (8) and (9) for M_1 and M_2 we have

$$\begin{aligned} M_1 &= \frac{2m_2^2M - A}{2m_2(m_2^2 - m_1^2)} \\ M_2 &= \frac{2m_1^2M - A}{2m_1(m_1^2 - m_2^2)} \end{aligned} \tag{10}$$

The values of m_1 and m_2 can be computed from the relations

$$\begin{aligned} M\cdot M &= m_1^2 + m_2^2 \\ A\cdot M &= 4m_1^2m_2^2 \end{aligned}$$

From which we get

$$\begin{aligned} m_1 &= \tfrac{1}{2}\sqrt{M\cdot M + \sqrt{M\cdot A}} + \tfrac{1}{2}\sqrt{M\cdot M - \sqrt{M\cdot A}} \\ m_2 &= \tfrac{1}{2}\sqrt{M\cdot M + \sqrt{M\cdot A}} - \tfrac{1}{2}\sqrt{M\cdot M - \sqrt{M\cdot A}} \end{aligned}$$

If $m_1 \neq \pm m_2$ the solution (10) is unique.[8] If $m_1 = \pm m_2$ the solutions become infinite. From (9) we see at once that this relation means

[8] For the non-euclidean geometry considered by Wilson and Lewis this resolution was unique since in that case the denominators contained the factor $m_1^2 + m_2^2$ instead of $m_1^2 - m_2^2$.

that $A = \pm M$ or the complement of M is $\pm M$. (From the definition of complement, the complement of M is $m_2M_1 + m_1M_2$). If we indicate complement by * we have the relations for 4-space.

$$k^*_{12} = k_{34},\ k^*_{13} = k_{42},\ k^*_{14} = k_{23},\ k^*_{23} = k_{14},\ k^*_{24} = k_{31},\ k^*_{34} = k_{12}.$$

Then if a complex is such that $M^* = \pm M$ it can be written in the form

$$M = (a_{12}k_{12} + a_{13}k_{13} + a_{14}k_{14}) \pm (a_{13}k_{42} + a_{14}k_{23} + a_{12}k_{34}).$$

The expressions in brackets are completely perpendicular planes and in this case we have a resolution into completely perpendicular planes. Hence: *A complex 2-vector can always be resolved into the sum of two completely perpendicular planes.*

By a proper choice of axes M can be written in the form

$$M = m_1k_{12} + m_2k_{34}$$

and if $M^* = \pm M$ the above resolution is not unique. We shall now proceed to investigate this case. We saw that a complex could always be resolved into the sum of two planes one of which was arbitrary. Let the arbitrary plane be X and write

$$M = X + K.$$

If r is any vector in X, consider the transformation

$$r' = r\cdot M = r\cdot X + r\cdot K.$$

$r\cdot X$ is a vector in X and if r' also lies in X, $r\cdot K$ must vanish since X and K have no vector in common. But since r was any vector in X the vanishing of $r\cdot K$ for all values of r means that K must be completely perpendicular to X. Hence the resolution of M into the sum of two perpendicular planes resolves itself into finding the planes left invariant by the transformation $r' = r\cdot M$. We shall therefore find the planes left invariant by this transformation.

The invariants of this transformation are more easily found by expressing it in the form of a dyadic. From formula (1) we have

$$r\cdot(k_{ij}) = (r\cdot k_j)k_i - (r\cdot k_i)k_j$$

which can be written as the dot product of r into the dyadic $k_jk_i - k_ik_j$. The transformation

$$r' = r\cdot M$$

then takes the form

(12) $$r' = r\cdot[m_1(k_2k_1 - k_1k_2) + m_2(k_4k_3 - k_3k_4)] = r\cdot\Phi$$

where $\Phi = m_1(k_2k_1 - k_1k_2) + m_2(k_4k_3 - k_3k_4)$.

If $m_1 \neq \pm m_2$ the only 1-vectors left invariant [9] are

$$k_1 \pm ik_2, \quad k_3 \pm ik_4.$$

For if
$$r = \lambda_1k_1 + \lambda_2k_2 + \lambda_3k_3 + \lambda_4k_4,$$
$$r' = r\cdot\Phi = -m_1\lambda_1k_2 + m_1\lambda_2k_1 - m_2\lambda_3k_4 + m_2\lambda_4k_3$$

and if this is to be equal to μr

(13) $$m_1\lambda_2 = \mu\lambda_1, - m_1\lambda_1 = \mu\lambda_2, m_2\lambda_4 = \mu\lambda_3, - m_2\lambda_3 = \mu\lambda_4$$

which can be satisfied only for the values

$$\lambda_2 = \pm i\lambda_1, \lambda_3 = 0, \lambda_4 = 0; \quad \lambda_1 = \lambda_2 = 0, \lambda_4 = \pm i\lambda_3$$

If $m_1 = m_2$ we see that (13) is satisfied by any vector of the pencils

$$k_1 + ik_2 + \lambda(k_3 + ik_4), \quad k_1 - ik_2 + \lambda(k_3 - ik_4),$$

that is these vectors are left invariant for all values of λ. If $m_1 = -m_2$, the pencils

$$k_1 + ik_2 + \lambda_3(k_3 - ik_3), \quad k_1 - ik_2 + \lambda(k_3 + ik_4)$$

are left invariant for all values of λ.

If we apply the transformation twice, that is

$$r' = r\cdot\Phi, \quad r'' = r'\cdot\Phi = (r\cdot\Phi)\cdot\Phi$$

assuming the above form for r we have

$$r'' = -m_1^2(\lambda_1k_1 + \lambda_2k_2) - m_2^2(\lambda_3k_3 + \lambda_4k_4).$$

If $m_1 = \pm m_2$ r'' is a multiple of r and if $m_1 = \pm m_2 = 1$, the transformation repeated twice is a reflection through the origin and of course repeated four times is the identical transformation. These are the only conditions under which the transformation will close. Hence *the necessary and sufficient condition that* (12) *be of finite order is* $M_1 = \pm m_2$ *or* $M^* = \pm M$. In this case there are two pencils of invariant vectors while in the general case only four vectors are left invariant.

In order to find the 2-vectors left invariant by the transformation

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[9] Invariant here means that $r' = \mu r$.

we will express Φ in terms of planes (2-vectors). This is done by means of the double product of Gibbs.[10] If $\Phi = \Sigma\ k_i l_i$ is a dyadic which transforms 1-vectors into 1-vectors then $\frac{1}{2}\,\Phi{}^{\times}_{\times}\Phi = \frac{1}{2}\,\Sigma\ (k_i{\times}k_j)(l_i{\times}l_j)$ represents the same transformation expressed in plane coordinates, that is a transformation which transforms planes into planes. To show this let r and s be two 1-vectors. Then the plane $r{\times}s$ is transformed by Φ into $(r\cdot\Phi){\times}(s\cdot\Phi)$ which can be written

$$\begin{aligned} r'{\times}s' &= (r\cdot\Phi){\times}(s\cdot\Phi) = \tfrac{1}{2}[(r\cdot\Phi){\times}(s\cdot\Phi) - (s\cdot\Phi){\times}(r\cdot\Phi)] \\ &= \tfrac{1}{2}\{[\Sigma(r\cdot k_i)l_i]{\times}[\Sigma(s\cdot k_j)l_j] - [\Sigma(s\cdot k_i)l_i]{\times}[\Sigma(r\cdot k_j)l_j]\} \\ &= \tfrac{1}{2}\{\Sigma[(r\cdot k_i)(s\cdot k_j) - (s\cdot k_i)(r\cdot k_j)](l_i{\times}l_j) \\ &= \tfrac{1}{2}\Sigma[(r{\times}s)\cdot(k_i{\times}l_j)](l_i{\times}l_j) \\ &= \tfrac{1}{2}\,(r{\times}s)\cdot[\Phi{}^{\times}_{\times}\Phi]. \end{aligned}$$

If Φ is the dyadic used in (12)

$$\Phi = m_1(k_2k_1 - k_1k_2) + m_2(k_4k_3 - k_3k_4). \tag{14}$$

Then

$$\Psi = \tfrac{1}{2}\Phi{}^{\times}_{\times}\Phi = m_1^2k_{12}k_{12} + m_2^2k_{34}k_{34} + m_1m_2(k_{13}k_{24} + k_{24}k_{13} - k_{14}k_{23} - k_{23}k_{14}). \tag{15}$$

If

$$P = \Sigma a_{ij}\,k_{ij}$$

be any complex 2-vector

$$P\cdot\Psi = m_1^2a_{12}k_{12} + m_1m_2a_{24}k_{13} - m_1m_2a_{23}k_{14} - m_1m_2a_{14}k_{23} + m_1m_2a_{13}k_{24} + m_2^2a_{34}k_{34}$$

and if $P\cdot\Psi = \lambda P$ we see that this is satisfied by the planes k_{12} and k_{34} and by the complexes

$$a_{13}(k_{13} + k_{24}) + a_{14}(k_{14} - k_{23});\ a_{13}(k_{13} - k_{24}) + a_{14}(k_{14} + k_{23}).$$

These complexes satisfy the condition for all values of a_{13} and a_{24}. The invariant planes will then be k_{12} and k_{34} and the planes belonging to either of these pencils of complexes. These last named planes are obtained from the values of $a_{13} : a_{14}$ satisfying either of the relations

$$\begin{aligned} [a_{13}(k_{13} + k_{24}) + a_{14}(k_{14} - k_{23})]{\times}[a_{13}(k_{13} + k_{24}) + a_{14}(k_{14} - k_{23})] &= 0 \\ [a_{13}(k_{13} - k_{24}) + a_{14}(k_{14} + k_{23})]{\times}[a_{13}(k_{13} - k_{24}) + a_{14}(k_{14} + k_{23})] &= 0 \end{aligned}$$

10 See Phillips and Moore, Dyadics occurring in point space of three dimensions. These Proceedings, vol. 53.

These give the values $a_{14} = \pm i a_{13}$. Hence the invariant planes are

(16) $(k_{13} + k_{24}) \pm i(k_{14} - k_{23}), \quad (k_{13} - k_{24}) \pm i(k_{14} + k_{23}).$

Now if $m_1 = \pm m_2$

(17) $\Psi_1 = m_1^2[(k_{12}k_{12} + k_{34}k_{34}) \pm (k_{13}k_{42} + k_{42}k_{13} + k_{14}k_{23} + k_{23}k_{14})]$.

Hence the complex

(18) $P = a_{12}k_{12} + a_{13}(k_{13} \pm k_{42}) + a_{14}(k_{14} \pm k_{23}) + a_{34}k_{34}.$

(Both positive or both negative signs are to be taken together), is left invariant for all values of a_{12}, a_{13}, a_{14}, a_{34}. The planes which belong to this system of complexes are determined by the relation

$$P \times P = a_{12}a_{34} - a_{13}^2 - a_{14}^2 = 0.$$

Substituting in (18) we have for the invariant planes

$$K_1 = (a_{13}^2 + a_{14}^2)k_{12} + a_{13}a_{34}(k_{13} \pm k_{42}) + a_{14}a_{34}(k_{14} \pm k_{23}) + a_{34}^2k_{34}$$

The plane

$$K_2 = a_{34}^2k_{12} - a_{13}a_{34}(k_{13} \pm k_{42}) - a_{14}a_{13}(k_{14} \pm k_{23}) + (a_{13}^2 + a_{14}^2)k_{34}$$

also belongs to (18) and is completely perpendicular to K_1. Hence *the planes left invariant by the transformation $P' = P \cdot \Psi_1$ form a two parameter family and are completely perpendicular in pairs.* The planes belong to a three parameter linear system of complexes and so must cut two fixed planes. It is not difficult to see that these are the planes (16). The first pair when $m_1 = m_2$ and the second pair when $m_1 = -m_2$. We can now write

$$M = m_1(k_{12} + k_{34}) = \frac{m_1}{a_{34}^2 + a_{13}^2 + a_{14}^2}(K_1 + K_2).$$

Hence the theorem may be stated: *Any complex 2-vector can be resolved into the sum of two completely perpendicular planes. If $M^* \neq \pm M$ the resolution is unique. If $M^* = \pm M$ the resolution can be made in ∞^2 ways.*

3. **Complex 2-vectors in 5-space.** In 5-space a complex 2-vector M can be resolved into the sum of two simple plane vectors. For,

if we express the complex in terms of the unit coordinate planes we have

$$M = \sum_{i,j=1}^{5} a_{ij}k_{ij} = \sum_{1}^{5} a_{5j}k_{5j} + \sum_{i,j=1}^{4} a_{ij}k_{ij}.$$

The sum $\Sigma a_{5j} k_{5j}$ represents a simple plane vector since each term in it contains the vector k_{5}.. The sum $\sum_{1}^{4} a_{ij}k_{ij}$ represents a complex 2-vector lying in the 4-space determined by k_1, k_2, k_3, k_4 and hence can be expressed as the sum of two plane vectors in this 4-space, one of which is arbitrary. The plane $A = \Sigma a_5 k_{5j}$ will cut the 4-space $k_1 \times k_2 \times k_3 \times k_4$ in a 1-vector. Now resolve $\sum_{1}^{4} a_{i5}k_{ij}$ into the sum of two simple plane, $B + C$ and choose B so that it will contain the vector in which A cuts the 4-space. Since A and B have a vector in common, $A + B$ will be a simple plane vector D and we have $M = C + D$ where C and D are simple planes. Neither of these planes can be chosen arbitrarily as was the case in 4-space. It follows from the fact that a complex vector is always expressible as the sum of two plane vectors that it must necessarily lie in a 4-space. This 4-space is the same no matter how the complex M is expressed as the sum of two simple planes. For, if

$$M = M_1 + M_2$$

where M_1 and M_2 are simple planes, then

$$M \times M = 2M_1 \times M_2$$

But $M \times M$ is the same however M is expressed hence the 4-space $M_1 \times M_2$ must be the same however M is expressed as the sum of two plane vectors. Since a plane vector in 4-space can be resolved into the sum of two completely perpendicular 2-vectors the same holds true for complex 2-vectors in 5-space. Just as in 4-space if

$$M = \lambda(M_1 + M_2) \text{ or } M = \lambda(M_1 - M_2)$$

where M_1 and M_2 are completely perpendicular unit planes, the resolution into the sum of perpendicular planes can be effected in ∞^2 ways.

Besides leaving the four imaginary vectors found in 4-space invariant, the transformation $r \cdot M$ in 5-space annihilates the real vector perpendicular to $M \times M$. The products of this transformation then with itself can never be equal to the identical transformation. If

$M = M_1 \pm M_2$ where M_1 and M_2 are unit planes, then the transformation repeated four times will be the identical transformation for vectors in $M \times M$.

4. **Complex 2-vectors in space of 2p dimensions.** We shall first show that if a complex 2-vector in a space of $2p$ dimensions can be resolved into the sum of p independent simple plane vectors one of which passes through an arbitrary 1-vector then a complex 2-vector in a space of $2p+1$ dimensions can also be resolved into the sum of p independent simple plane vectors but in this case no one of the simple 2-vectors can be made to pass through an arbitrary 1-vector. To show this it is only necessary to write the complex in $2p+1$ dimensions in terms of unit coordinate planes

$$M = \sum_{1}^{2p+1} a_{1j}k_{1j} + \sum_{2}^{2p+1} a_{ij}k_{ij}.$$

The first sum represents a simple plane vector since each term contains the vector k_1. The second sum represents a complex 2-vector lying in the space of $2p$ dimensions determined by the vectors $k_2, k_3, \ldots k_{2p+1}$ and therefore by the above assumption can be expressed as the sum of p simple plane vectors one of which, A say, passes through the vector in which the plane $B = \sum_{1}^{2p+1} a_{1j}k_{1j}$ cuts the space in which the complex $\sum_{2}^{2p+1} a_{ij}k_{ij}$ lies. Then since A and B have a vector in common, their sum can be expressed as a simple plane vector. The complex M is then expressed as the sum of p independent planes. But p independent simple plane vectors determine a space of $2p$ dimensions and this space of $2p$ dimensions is the same no matter how M is expressed. For if

$$M = M_1 + M_2 + \ldots + M_p.$$

Then

$$M \times M \times M \ldots p \text{ factors} = p! \quad M_1 \times M_2 \times \ldots \times M_p;$$

and since the first member is independent of how the complex is expressed as the sum of p independent planes, the second must be.

Again, if a complex 2-vector in a space of $2p$ dimensions can be resolved into the sum of p independent simple plane vectors one of which passes through an arbitrary 1-vector, then a complex 2-vector in a space of $2p + 2$ dimensions can be resolved into the sum of $p + 1$ independent simple plane vectors one of which passes through an arbitrary 1-vector. For let the complex be expressed in terms of the unit coordinate planes

$$M = \sum_{1}^{2p+2} a_{1j}k_{1j} + \sum_{2}^{2p+2} a_{ij}k_{ij}.$$

The first sum is a simple 2-vector passing through k_1 which can be chosen arbitrarily. The second sum is a complex 2-vector in a space of $2p + 1$ dimensions and consequently can be expressed as the sum of p independent simple plane vectors. Hence the whole complex can be expressed as the sum of $p + 1$ independent planes. We have seen that a complex 2-vector in 4-space can be resolved into the sum of two independent simple plane vectors one of which can be chosen arbitrarily and therefore by induction we have: *a complex 2-vector in $2p$ or $2p + 1$ dimensions can always be resolved into the sum of p independent simple plane vectors.*

The condition that a 2-vector in a space of $2p$ dimensions be simple, is

$$M \times M = 0.$$

For if this condition is satisfied then the following relations are satisfied owing to the associative character of the multiplication when the order of the whole product is equal to or less than $2p$

$$M \times M \times M = 0$$
$$M \times M \times M \times M = 0$$
$$\ldots\ldots\ldots\ldots\ldots\ldots$$
$$M \times M \times M \times \ldots \times p \text{ factors} = 0.$$

The last one shows that the complex must lie in a space of lower dimensions and therefore can be expressed as the sum of $p - 1$ simple plane vectors. By the same argument it can be expressed as the sum of $p - 2$ simple plane vectors and so on until finally it can be expressed as a single simple plane vector. If M is a simple plane, $M \times M = 0$. Hence this is both a necessary and a sufficient condition that a 2-vector be simple.

We shall next show that a complex 2-vector in a space of $2p$ dimensions can be resolved into the sum of p mutually perpendicular simple planes. Let

$$M = \sum_{1}^{p} m_i M_i$$

when M_i are mutually perpendicular unit simple planes and m_i numbers. We can then derive $p-1$ complex 2-vectors as follows

$$
\begin{aligned}
A &= (M\times M)\cdot M = 2\sum_1^p m_i m_j^2 M_i \qquad & i \neq j \\
B &= (M\times M\times M)\cdot(M\times M) = 6\sum_1^p m_i m_j^2 m_k^2 M_i \qquad & i\neq j\neq k. \\
&\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots & \\
P &= (M\times M\times M\dots p \text{ factors})\cdot(M\times M\times M\dots (p-1) \text{ factors}) & \\
&= p!\, m_1 m_2 \dots m_p \sum m_1 m_2 \dots m_{i-1} m_{i+1}\dots m_p M_i. &
\end{aligned} \tag{20}
$$

We have then all together p equations to solve for the p plane M_1, $M_2, \dots M_p$. and the solution will be unique unless these equations prove not to be linearly independent, that is unless the determinant Δ of the system vanishes. If we observe how the columns of this determinant are made up we see that it contains each of the m's as a factor. Also if $m_i = \pm m_j$, $\Delta = 0$. Therefore we can write Δ in the factored form

$$\Delta = \cdot p!(m_1 m_2 \dots m_p)\pi(m_i^2 - m_j^2).$$

Now if $m_1 = \pm m_2$ say, and the other m's are all different then a value of λ can be found so that

$$A + \lambda M$$

will lie in a space of $2p-4$ dimensions and by the above argument this new complex can be resolved into the sum of $p-2$ mutually perpendicular plane vectors. The remaining 4-space will be completely perpendicular to the space in which $A+\lambda M$ lies and that part of M lying in it can be resolved into the sum of two perpendicular planes in ∞^2 ways. Hence the whole complex can be resolved into the sum of p mutually perpendicular planes in ∞^2 ways. The same argument of course applies to any pair of equal roots. If $m_1 = \pm m_2 = \pm m_3$ the other m's being all different and different from m_1; a value of λ can be found so that $A+\lambda M$ will lie in a space of $2p-6$ dimensions and the part of M lying in this space can be resolved into $p-3$ mutually perpendicular planes. The whole complex can then be resolved into the sum of p mutually perpendicular planes provided the complex 2-vector in space of six dimensions such that $(M\times M)\cdot M = \lambda M$ can be resolved into the sum of three mutually perpendicular planes. Continuing the argument we see that the resolution is always possible provided that in a space of $2m$ dimensions in which

$$(M\times M)\cdot M = \lambda M$$

can be resolved into the sum of mutually perpendicular planes. We will now show that this resolution is always possible.

If the transformation

$$r' = r \cdot M = r \cdot (X + K)$$

where X is a simple plane and r any vector in X, always gives a vector r' in X then $r \cdot K = 0$ for every r in X. That is X is completely perpendicular to K. Then the above resolution depends upon whether we can find a plane left invariant by the transformation $r' = r \cdot M$ where M is any complex 2-vector. Let

$$M = \sum_{1}^{2m} a_{ij} k_{ij} \tag{19}$$

and

$$r = \sum_{1}^{2m} b_i k_i.$$

Then if r is an invariant vector we have

$$r \cdot M = \mu r$$

which is equivalent to the set of equations

$$\begin{aligned} \mu b_1 &= \sum_{1}^{2m} a_{1j} b_j \\ \mu b_2 &= \sum_{1}^{2m} a_{2j} b_j \\ &\cdots\cdots\cdots\cdots \\ \mu b_{2m} &= \sum_{1}^{2m} a_{2mj} b_j \end{aligned} \tag{21}$$

where the b's are to be determined. The coefficients a_{ij} are seen to satisfy the relations

$$a_{ii} = 0, \quad a_{ij} = -a_{ji}, \quad i \neq j.$$

Equations (20) being homogeneous will have a solution provided the determinant of the system vanishes. This determinant is seen to be a skew determinant with each term in the principal diagonal equal to μ. From the theory of such determinants [11] it is known that it can be expanded in powers of the diagonal terms. The coefficients of the

11 Hanus, Elements of determinants. Ginn & Co., page 152.

various powers of μ are sums of principal minors of the determinant in which the μ's are replaced by zeros. That is the determinant can be expanded in the form

$$(22) \qquad \mu^{2m} + A_1\mu^{2m-1} + A_2\mu^{2m-2} + \dots + A_{2m} = 0$$

where A_1 is the sum of the first minors in which μ has been replaced by zero. These minors are then skew symmetric determinants of odd order and therefore vanish. For the same reason all the A's with odd subscripts vanish. The coefficient A_2 is the sum of all the second principal minors with μ replaced by zero. This is a skew symmetric determinant of even order and therefore can be expressed as a sum of squares, consequently it is positive. The same is true of all A's with even subscripts. Then (22) has only even powers of μ and all the coefficients are positive. Therefore the roots appear in conjugate imaginary pairs. This means for M real the invariant vectors appear in conjugate imaginary pairs. But two conjugate imaginary vectors determine a real plane. Hence we have shown that there are always m invariant real planes. If equations (21) are not all independent there will be an infinite number of values of μ and consequently an infinite number of invariant planes. This corresponds to the case $(M{\times}M)\cdot M = \lambda M$.

Now having determined that in every case there is at least one invariant simple plane, A say, we can determine λ so that $M - \lambda A$ will be a complex vector lying in a space of $2m - 2$ dimensions which must be completely perpendicular to A. To determine λ we have the relation

$$\begin{aligned}(M - \lambda A)\times(M - \lambda A)\times \dots m \text{ factors} &= 0 \\ = M\times M\times \dots m \text{ factors} - m\lambda(A\times M\times M &\dots (m-1) \text{ factors}).\end{aligned}$$

From which

$$\lambda = \frac{M^m}{m A\times M^{m-1}}$$

when the exponents indicate cross multiplication. The same reasoning as used before will show that the space in which $M - \lambda A$ lies is completely perpendicular to A. Thus we have established the theorem: *A complex 2-vector in a space of 2p dimensions can always be resolved into the sum of p mutually perpendicular planes. If the set of 2-vectors A, B,— P of (20) are not independent this resolution is not unique.*

If the 2-vectors A, B, $C \ldots P$ are all multiples of M_1 by a proper choice of axes the complex can be written in the simple form

$$M = m_1(k_{12} \pm k_{34} \pm k_{56} \pm \ldots \pm k_{2p-1,\, 2p}).$$

We will confine our attention to the single case

$$(23) \qquad M = m_1(k_{12} + k_{34} + \ldots k_{2p-1,\, 2p})$$

and the other combinations of sign can be disposed of in a similar manner. The dyadic which represents the transformation $r' = r \cdot M$ is

$$(24) \quad \Phi = m_1(k_2k_1 - k_1k_2 + k_4k_3 - k_3k_4 + \ldots + k_{2p}k_{2p-1} - k_{2p-1}k_{2p})$$

and the same transformation expressed in plane coordinates is

$$\Psi = \tfrac{1}{2}\Phi\overset{\times}{\times}\Phi,$$

which can be proved by the same method used for the case of 4-space. Similarly it can be shown that the complex

$$(25) \qquad \begin{aligned} C = {} & a_{12}k_{12} + a_{34}k_{34} + a_{56}k_{56} + \ldots a_{2p-1,2p}k_{2p-1,2p} \\ & + a_{13}(k_{13} - k_{42}) + a_{14}(k_{14} - k_{23}) + a_{15}(k_{15} - k_{62}) + \ldots \\ & + a_{35}(k_{35} - k_{46}) + a_{36}(k_{36} - k_{45}) + \ldots . \end{aligned}$$

is left invariant by the transformation $C \cdot \Psi$ where the coefficients in C are entirely arbitrary. The complex will be a simple plane if $C \times C = 0$. This gives for the invariant planes, putting $a_{12} = 1$, for convenience.

$$(26) \quad \begin{aligned} A = {} & k_{12} + (a_{13}^2 + a_{14}^2)k_{34} + (a_{15}^2 + a_{16}^2)k_{56} + \ldots \\ & \qquad + (a_{1,2p-1}^2 + a_{1,2p}^2)k_{2p-1,2p} \\ & + a_{13}(k_{13} - k_{42}) + a_{14}(k_{14} - k_{25}) + a_{15}(k_{15} - k_{26}) + \ldots \\ & + (a_{14}a_{15} - a_{13}a_{16})(k_{35} - k_{46}) + (a_{13}a_{15} - a_{14}a_{16})(k_{36} - k_{45}) + \ldots \\ & + (a_{13}a_{17} + a_{14}a_{18})(k_{38} - k_{47}) + \ldots \end{aligned}$$

Hence ∞^{2p-2} simple planes are left invariant. Then in resolving this complex into the sum of p similarly perpendicular simple planes the first plane can be chosen in ∞^{2p-2} different ways, the second in ∞^{2p-4} ways and so on. Hence the resolution can be effected in $\infty^{2(p-1)!}$ different ways.

By proper choice of axes the general complex can be put in the form

$$(27) \qquad M = m_{12}k_{12} + m_{34}k_{34} + \ldots + m_{2p-1,2p}k_{2p-1,2p}.$$

Then the dyadic which represents the transformation $r' = r \cdot M$ is

$$(28)\quad \Phi = m_{12}(k_2k_1 - k_1k_2) + m_{34}(k_4k_3 - k_3k_4) + \dots + m_{2p-1,2p}(k_{2p}k_{2p-1} - k_{2p-2}k_{2p})$$

If the transformation is applied twice to the vector $r = \pm b_i k_i$ we have

$$r'' = r \cdot \Phi = (r \cdot \Phi) \cdot \Phi^1 = r \cdot (\Phi \cdot \Phi) = -[m_{12}^2(k_1k_1 + k_2k_2) + m_{34}^2(k_3k_3 + k_4k_4) + \dots + m_{2p-1,2p}(k_{2p-1}k_{2p-1} + k_{2p}k_{2p})]$$

Then if Φ and r are real and $m_{12} = \pm m_{34} = \dots = \pm m_{2p-1,2p} = 1$ we return to r after repeating the transformation four times. Hence *if the complex consists of the sum of p mutually perpendicular unit planes, the transformation $r' = r \cdot M$ will be of order 4.*

5. **The Hamilton-Cayley equation.** From equation (12) we saw that the transformation $r' = r \cdot M$ in 4-space depends on two parameters m_1 and m_2 and to show the relation of these to the Hamilton-Cayley identical equation which Φ must satisfy we will change the reference system to that of the invariant elements. We saw that the invariant vectors were

$$k_1 \pm ik_2, \quad k_3 \pm ik_4.$$

Now put

$$r_1 = \frac{1}{\sqrt{2}}((k_1 + ik_2), \quad r_2 = \frac{1}{\sqrt{2}}(k_1 - ik_2)$$

$$r_3 = \frac{1}{\sqrt{2}}(k_3 + ik_4), \quad r_4 = \frac{1}{\sqrt{2}}(k_3 - ik_4),$$

Then

$$k_1 = \frac{i}{\sqrt{2}}(r_1 + r_2), \quad k_2 = -\frac{i}{\sqrt{2}}(r_1 - r_2),$$

$$k_3 = \frac{i}{\sqrt{2}}(r_3 + r_4), \quad k_4 = -\frac{i}{\sqrt{2}}(r_3 - r_4).$$

The dyadic Φ then becomes

$$(29)\qquad \Phi = i[m_1(r_2r_1 - r_1r_2) + m_2(r_4r_3 - r_3r_4)].$$

The multiplication table for the r's is as follows

$$r_1 \cdot r = r_2 \cdot r_2 = r_3 \cdot r_3 = r_4 \cdot r_4 = 0,$$
$$r_1 \cdot r_3 = r_1 \cdot r_4 = r_2 \cdot r_3 = r_2 \cdot r_4 = 0,$$
$$r_1 \cdot r_2 = r_3 \cdot r_4 = 1.$$

The idemfactor I_1 becomes

(30) $$I_1 = r_1 r_2 + r_2 r_1 + r_3 r_4 + r_4 r_3.$$

The Hamilton-Cayley equation then becomes

(31) $$(\Phi - i m_1 I_1)(\Phi + i m_1 I_1)(\Phi - i m_2 I_1)(\Phi + i m_2 I_1) = (\Phi^2 + m_1^2 I_1)(\Phi^2 + m_2^2 I_1) = 0.$$

If $m_1 = \pm m_2$

(29′) $$\Phi = i m_1 [(r_2 r_1 - r_1 r_2) \pm (r_4 r_3 - r_3 r_4)]$$

from which we see at once that the vectors

$$a r_1 \pm b r_3, \quad a r_2 \pm b r_4$$

are left invariant (or multiplied by constants only) for all values of a and b. The Hamilton-Cayley equation in this case becomes

$$(\Phi^2 + m_1^2 I_1) = 0$$

In terms of this new reference system the dyadic Φ expressed in plane coordinates becomes

(32) $$\Psi = \tfrac{1}{2}\Phi {}_\times^\times \Phi = - [m_1^2 r_{12} r_{12} + m_2^2 r_{34} r_{34} + m_1 m_2 (r_{13} r_{24} + r_{42} r_{13} - r_{23} r_{14} - r_{14} r_{23})]$$

The multiplication table for the coordinate planes is

$$r_{12} \cdot r_{12} = r_{34} \cdot r_{34} = -1,$$
$$r_{13} \cdot r_{24} = r_{14} \cdot r_{23} = 1,$$

and all the other products are zero. The idemfactor is

$$I_2 = \tfrac{1}{2} I_1 {}_\times^\times I_1 = - r_{12} r_{12} - r_{34} r_{34} + r_{13} r_{24} + r_{24} r_{13} + r_{14} r_{23} + r_{23} r_{14}$$

and the Hamilton-Cayley equation is

$$(\Psi - m_1^2 I_2)(\Psi - m_2^2 I_2)(\Psi^2 - m_1^2 m_2^2 I_2) = 0,$$

and if $m_1 = \pm m_2$ the equation is

$$(\Psi - m_1^2 I_2)(\Psi + m_1^2 I_2) = 0.$$

From (32) we see that the complex 2-vectors

$$ar_{13} + br_{24}, \quad ar_{14} + br_{23}$$

are left invariant for all values of a and b. The only planes belonging to this system are r_{13}, r_{24}, r_{14}, r_{23}. If $m_1 = \pm m_2$ we see at once that the complex

$$ar_{12} + br_{34} + cr_{13} + dr_{24},$$

or

$$ar_{12} + br_{34} + cr_{14} + dr_{23}$$

is left invariant and the planes belonging to this system are the invariant planes discussed before.

Choosing the invariant vectors for the coordinate system in space of $2p$ dimensions and proceed as above we at once arrive at the Hamilton-Cayley equation

$$(\Phi^2 + m_1^2 I_1)(\Phi^2 + m_2^2 I_1)\ldots(\Phi^2 + m_p^2 I_1) = 0$$

and if $m_1 = \pm m_2 = \pm m_3 \ldots = \pm m_p$ this equation becomes

$$\Phi^2 + m_1^2 I_1 = 0.$$

The equation which $\Psi = \frac{1}{2}\Phi{}^\times_\times\Phi$ satisfies follows in a similar manner.

III.

6. **Rotations in 4-space.** We saw that an infinitesimal rotation could be represented by

(5) $$r' = r + M \cdot r\, dt.$$

If M is a simple plane vector M_1 say, and if r is perpendicular to M_1, then since $M_1 \cdot r = 0$, the vector r is left absolutely fixed, and therefore the plane completely perpendicular to M_1 is left absolutely fixed. Also if r lies in M_1 it is evident that r' will likewise lie in M_1 and therefore M_1 is left invariant but not point for point. If in this rotation we take M_1 as a unit plane and write (5) in the form

$$r' = r + m_1 M_1 \cdot r\, dt$$

the constant m_1 measures the rate of rotation in the plane M_1. For if r lies in M_1

$$\frac{r' - r}{dt} = \frac{dr}{dt} = m_1 M_1 \cdot r_1$$

Since r does not change in magnitude as it rotates, the magnitude of $\frac{dr}{dt}$ divided by $\sqrt{r\cdot r}$ will be the rate at which r is turning in the plane M_1. That is

$$\sqrt{\left(\frac{dr}{dt}\right)^2} = \sqrt{m_1^2(M_1\cdot r)^2} = m_1\sqrt{r\cdot r}$$

M_1 being a unit-plane $M_1\cdot r$ has the same magnitude as r if r lies in M_1. Therefore

$$m_1 = \frac{\sqrt{\left(\frac{dr}{dt}\right)^2}}{\sqrt{r\cdot r}}.$$

which shows that m_1 measures the rate of rotation in M_1.

If in (5) M is a complex 2-vector it can be resolved into the sum of two perpendicular planes and can then be written in the form

(33) $$r' = r + (m_1M_1 + m_2M_2)\cdot r\,dt$$

where M_1 and M_2 are unit planes. In this case the motion consists of a double rotation, one parallel to the simple plane M_1 and the other parallel to the simple plane M_2. The same argument as used above will show that m_1 measures the rate of rotation in M_1 and m_2 the rate of rotation in M_2. If r lies in M_1, then

$$r' = r + M_1\cdot r\,dt$$

and the same argument used above shows that M_1 is left invariant. The same reasoning also shows that M_2 is left invariant.

In order to exhibit the whole list of invariants we will represent the transformation (33) as a dyadic, choosing the reference system so that

$$M = m_1k_{12} + m_2k_{34}.$$

The same argument as used in §2 shows that the dyadic sought is

(34) $$\Psi = I_1 + [m_1(k_2k_1 - k_1k_2) + m_2(k_4k_3 - k_3k_4)dt = I_1 + \Phi\,dt$$

and (33) then becomes

(35) $$r' = r\cdot\Psi.$$

If the vector

$$r = \sum_1^4 a_ik_i$$

is left invariant it is evident that $r \cdot \Phi$ must vanish. That is

$$a_2 m_1 k_1 - a_1 m_1 k_2 + a_4 m_2 k_3 - a_3 m_2 k_4 = 0$$

which requires that all the a's vanish. However if we require that $r' = \lambda r$ then we have $r \cdot \Phi = \lambda r$ which leads to the solutions

$$a(k_1 \pm i k_2), \quad b(k_3 \pm i k_4).$$

Using these values for r we have

$$r_1' = (k_1 + i k_2) \cdot \Psi = k_1 + i k_2 + i m_1 (i k_1 + i k_2)\, dt$$

or

$$\frac{dr_1}{dt} = i m_1 (k_1 + i k_2).$$

$$r_2' = (k_1 - i k_2) \cdot \Psi = k_1 + i k_2 + i m_1 (k_1 - i k_2)\, dt$$

$$\frac{dr_2}{dt} = - i m_1 (k_1 - i k_2).$$

Likewise for the other two we have

$$\frac{dr_3}{dt} = i m_2 (k_3 + i k_4),$$

$$\frac{dr_4}{dt} = - i m_2 (k_3 - i k_4).$$

Thus the points on $k_1 + i k_2$ and $k_3 + i k_4$ progress by the factors $i m_1$ and $i m_2$ while the point on $k_1 - i k_2$ and $k_3 - i k_4$ progress by the factors $- i m_1$ and $- i m_2$.

If $m_1 = m_2$ it is easily seen that any vector of the pencils

$$(k_1 + i k_2) + \lambda (k_3 + i k_4), \quad (k_1 - i k_2) + \lambda (k_3 - i k_4)$$

is left invariant. These vectors lie in a plane in which every vector is a minimal vector. That is they lie in a plane which contains a generator of the imaginary sphere at infinity. Any plane cutting these two planes in a 1-vector will be left invariant since it will contain two invariant vectors. If $m_1 = -m_2$, the invariant pencils are

$$(k_1 + i k_2) + \lambda (k_3 - i k_4), \quad (k_1 - i k_2) + \mu (k_3 + i k_4).$$

Each of these pencils lies in a plane cutting the imaginary sphere at infinity in a generator and any plane cutting each of these planes in a vector will be left invariant. We will however discuss these planes from a different point of view.

The dyadic Ψ can be expressed in terms of plane coordinates by means of the double product.

$$(36)\qquad \Psi_2 = \tfrac{1}{2}\Psi{}_\times^\times\Psi = \tfrac{1}{2}(I_1 + \Phi dt){}_\times^\times(I_1 + \Phi dt) = \tfrac{1}{2}I_1{}_\times^\times I_1 + I{}_\times^\times\Phi dt$$
$$= I_2 + I{}_\times^\times\Phi dt$$

and the rotation is then expressed by the formula

$$C' = C\cdot(I_2 + I_1{}_\times^\times\Phi dt).$$

If we write $M = m_1k_{12} + m_2k_{34}$

$$\Phi = m_1(k_2k_1 - k_1k_2) + m_2(k_4k_3 - k_3k_4)$$
$$I{}_\times^\times\Phi = m_1(k_{23}k_{13} - k_{13}k_{23} + k_{24}k_{14} - k_{14}k_{24}) + m_2(k_{14}k_{13} - k_{13}k_{14} + k_{24}k_{23} - k_{23}k_{24})$$

If the complex 2-vector

$$C = \Sigma c_{ij}k_{ij}$$

is left invariant, that is if $C\cdot\Psi = C$

$$C\cdot(I_1{}_\times^\times\Phi) = m_1(c_{13}k_{23} - c_{23}k_{13} + c_{14}k_{24} - c_{24}k_{14}) + m_2(c_{13}k_{14} - c_{14}k_{13} + c_{23}k_{24} - c_{24}k_{23}) = 0.$$

From which we get

$$(37)\qquad m_1c_{13} = -m_2c_{24},\quad m_1c_{23} = m_2c_{14},\quad m_1c_{14} = m_2c_{23},\quad -m_1c_{24} = m_2c_{13}.$$

If $m_1 \neq \pm m_2$ these equations are satisfied only when

$$c_{13} = c_{24} = c_{14} = c_{23} = 0.$$

Thus any complex of the linear pencil

$$c_{12}k_{12} + c_{34}k_{34}$$

is left invariant. The only simple planes belonging to this pencil are k_{12} and k_{34}. Hence these are the only planes whose magnitude and position are left invariant by the rotation.

If $m_1 = \pm m_2$ equations (37) can evidently be satisfied if $c_{13} = \pm c_{24}$, $c_{14} = \pm c_{23}$. In this case the complex

$$C = c_{12}k_{12} + c_{13}(k_{13} \pm k_{42}) + c_{14}(k_{14} + k_{23}) + c_{34}k_{34}$$

is left invariant for all values of the coefficients. The planes of this system of complexes are determined by the relation

$$C\times C = c_{12}c_{34} \pm (c_{13}^2 + c_{14}^2)$$

which, if we put $c_{12} = 1$, gives for the invariant planes

(38) $P = k_{12} + c_{13}(k_{13} \pm k_{42}) + c_{14}(k_{14} + k_{23}) \pm (c_{13}^2 + c_{14}^2)k_{34}$

Therefore, *If the rates of rotation in the planes* M_1 *and* M_2 *are different the only planes left invariant by* (33) *are* M_1 *and* M_2 *but if the rates of rotation in the two planes are the same or differ only in sign then a two parameter family of planes which belongs to a three parameter linear system of complexes is left invariant.*[12]

The planes of the system (38) all cut the planes

$$(k_{13} \pm k_{42}) + i(k_{14} \pm k_{23}),\ \ (k_{13} \pm k_{42}) - i(k_{14} \pm k_{23}).$$

These are the planes mentioned above.

We saw that in case $m_1 = \pm m_2$ the complex M can be resolved in ∞^2 different ways into the sum of two completely perpendicular planes. The pairs of planes belong to the set (38). The transformation (34) can then be represented in ∞^2 different ways as the sum of rotations parallel to pairs of completely perpendicular planes. The rates of rotation parallel to both planes of a pair are the same but different for different pairs.

The above set of invariant planes were found under the condition that their magnitude be left unchanged. We might however have

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12 In the article referred to in note 2 Cole states the theorem "Every rotation in a four dimensional space for which $\vartheta \neq 0$. (The condition here would be that neither m_1 nor m_2 is zero) can be reduced to a succession of two simple rotations whose fixed planes are absolutely perpendicular to each other. This decomposition can be effected in only one way." From the above theorem it is evident that this statement is inaccurate. He discussed finite rotations and writes the equations of the rotation

$$x' = x\cos\theta - y\sin\theta,\quad y' = x\sin\theta + y\cos\theta$$
$$z' = z\cos\varphi - \omega\sin\varphi,\quad \omega' = z'\sin\varphi + \omega'\cos\varphi.$$

He states that the invariant planes of this rotation are the xy- and zw-planes. This is true of $\theta \neq \varphi$. But if $\theta = \varphi$ any line passing through 0 and lying in the planes $x + iy = 0$, $z + i\omega = 0$ is left invariant also any line passing through 0 and lying in the plane $x - iy = 0$, $z - i\omega = 0$ is left invariant. Hence any plane containing two of these invariant lines will be kept invariant. There is a two parameter family of these planes which are real and therefore ∞^2 real planes are left invariant. If $\theta = -\varphi$ then every line passing through 0 and lying in one of the planes $x + iy = 0$, $z - i\omega = 0$ or $x - iy = 0$, $z + i\omega = 0$ is left invariant and all the planes passing through 0 and cutting each of these planes in a line is left invariant. In the first case it is easy to see that the plane $x = z$, $y = \omega$ is left invariant and in the second case $x = \omega$, $y = z$ is left invariant. The error in Cole's work arose from the fact that in determining the coordinates of the invariant planes he failed to take into account that it was possible for all the denominators of his expressions to vanish simultaneously.

planes changed by the rotation into multiples of themselves. In this case

$$C \cdot (I_1 {}_{\times}^{\times} \Phi) = \lambda C$$

which leads to the relations

$$\begin{aligned} m_1 c_{13} - m_2 c_{24} &= \lambda c_{23}, \\ -m_1 c_{23} - m_2 c_{14} &= \lambda c_{13}, \\ m_1 c_{14} - m_2 c_{23} &= \lambda c_{24}, \\ -m_1 c_{24} + m_2 c_{13} &= \lambda c_{14}. \end{aligned}$$

Four values of λ render this system consistent and the corresponding invariant planes are

$$(k_{13} + k_{42}) \pm i(k_{14} + k_{23}), \quad k_{13} - k_{42} \pm i(k_{14} - k_{23}).$$

No real plane satisfies this condition.

7. **Rotations in any even space.** Equation (5) is a rotation in a space of $2p$ dimensions if we consider M as a complex lying in that space. As before the dyadic representing the rotation, if we write M in terms of p mutually completely perpendicular unit planes which for convenience we will take as coordinate planes, is

$$\Psi = I_1 + [m_1(k_2 k_1 - k_1 k_2) + m_2(k_4 k_3 - k_3 k_4) + \ldots + m_p(k_{2p} k_{2p-1} - k_{2p-1} k_{2p})] dt.$$
$$= I_1 + \Phi dt.$$

The same transformation expressed in plane coordinates is

$$\begin{aligned} \Psi_2 &= \tfrac{1}{2} I_1 {}_{\times}^{\times} I_1 + I_1 {}_{\times}^{\times} \Phi dt. \\ &= I_2 + I_1 {}_{\times}^{\times} \Phi dt \end{aligned}$$

where

$$\begin{aligned} I_1 &= \Sigma k_i k_i \\ I_2 &= \Sigma k_{ij} k_{ij}. \end{aligned}$$

The same argument used in the preceding section will show that the p mutually perpendicular planes into which M is resolved are all left invariant. If the m's are all distinct these are all the invariant planes, but if n of them are equal there are $\infty^{2(n-1)}$ invariant planes and the rotation can be resolved in an infinite number of ways into rotations parallel to p mutually perpendicular planes.

IV.

8. **Surfaces in 4-space left invariant by all the rotations having the same two fixed planes.** All the rotations represented by the equation

$$(39) \qquad r' = r + M \cdot r\, dt = r + (m_1 M_1 + m_2 M_2) \cdot r\, dt$$

where M_1 and M_2 are unit planes and m_1 and m_2 are allowed to vary form a group since each transformation of the set leaves M_1 and M_2 invariant and consequently the product of two of them will leave these planes invariant also. The direction which a point will move by (39) with fixed values for m_1 and m_2 is

$$(40) \qquad \frac{dr}{dt} = (m_1 M_1 + m_2 M_2) \cdot r = M \cdot r.$$

If m_1 and m_2 are allowed to vary it is seen at once that all the directions which a given point can take lie in a plane since they are linear functions of the two vectors $M_1 \cdot r$ and $M_2 \cdot r$. It is seen also from this equation that the ratio $m_1 : m_2$ is all that need be considered since their actual values are necessary for determining the magnitude of $\frac{dr}{dt}$ and not its direction. If we give m_1 and m_2 definite values (40) will be the differential equation of the path curve described by the end of the vector r by this particular rotation. The unit tangent to this curve is

$$\tau = \frac{dr}{ds} = M \cdot r \frac{dt}{ds}$$

Since the magnitude of r is unity we have

$$1 = \frac{dr}{ds} \cdot \frac{dr}{ds} = (M \cdot r) \cdot (M \cdot r) \left(\frac{dt}{ds}\right)^2$$
$$= [m_1^2 (M_1 \cdot r)^2 + m_2^2 (M_2 \cdot r)^2] \left(\frac{dt}{ds}\right)^2.$$

Hence

$$(41) \qquad \left(\frac{ds}{dt}\right)^2 = m_1^2 (M_1 \cdot r)^2 + m_2^2 (M_2 \cdot r)^2.$$

As the transformation is a rotation r is a vector of constant length and also the projections on the fixed planes M_1 and M_2 are also the same for all positions which r can take by the rotation. Then $(M_1 \cdot r) \cdot (M_1 \cdot r)$ is constant and equal to the square of the projection of r on the fixed plane M_1. Likewise $(M_2 \cdot r) \cdot (M_2 \cdot r)$ is equal to the square of the projection of r on the plane M_2. It follows at once then that ds is a constant since the expression in the bracket in (41) is constant.

The curvature of the path curve is

$$
\begin{aligned}
C &= \frac{d\tau}{ds} = \frac{d^2r}{ds^2} = \left(M \cdot \frac{dr}{ds}\right)\frac{dt}{ds} = M \cdot (M \cdot r)\left(\frac{dt}{ds}\right)^2 \\
&= [m_1^2 M_1 \cdot (M_1 \cdot r) + m_2^2 M_2 \cdot (M_2 \cdot r)]\left(\frac{dt}{ds}\right)^2
\end{aligned}
\tag{42}
$$

The vectors $M_1 \cdot (M_1 \cdot r)$ and $M_2 \cdot (M_2 \cdot r)$ are the projections of r on the fixed planes M_1 and M_2 respectively and therefore constant in length. Hence: *The path curves are curves of constant scalar curvature.*

The unit vector in the direction of the curvature C is

$$c = \frac{M \cdot (M \cdot r)}{\sqrt{[M \cdot (M \cdot r)]^2}} = \frac{M \cdot (M \cdot r)}{\sqrt{C \cdot C}}$$

The vectors τ and c are unit vectors and perpendicular to each other Hence $\tau \times c$ will be the unit osculating plane to the path curve. The first torsion of the path curve is the rate of change of this plane with respect to the arc.

$$T = \frac{d}{ds}(\tau \times c) = \frac{d\tau}{ds} \times c + \tau \times \frac{dc}{ds} = \tau \times \frac{dc}{ds}$$

Since $\frac{d\tau}{ds} = c\sqrt{[M \cdot (M \cdot r)]^2}$ the product $\frac{d\tau}{ds} \times c = 0$. Substituting the values above we have

$$T = (M \cdot r) \times \{M \cdot [M \cdot (M \cdot r)]\}\left(\frac{dt}{ds}\right)^2 \frac{1}{\sqrt{C \cdot C}}$$

$$
\begin{aligned}
= (m_1 M_1 + m_2 M_2) \times \{m_1^3 M_1 \cdot [M_1 \cdot [M_1 \cdot r)] \\
+ m_2^3 M_2 \cdot [M_2 \cdot (M_2 \cdot r)]\left(\frac{dt}{ds}\right)^3 \frac{1}{\sqrt{C \cdot C}}
\end{aligned}
$$

But since $M_1 \cdot (M_1 \cdot r)$ is the projection of r on M_1, $M_1 \cdot [M_1 \cdot (M_1 \cdot r)]$ is a vector in M_1 perpendicular to this projection and consequently is equal to $M_1 \cdot r$. Similarly for the second term. Then

$$T = m_1 m_2 (m_2^2 - m_1^2)\,(M_1 \cdot r) \times (M_2 \cdot r)$$

But since $M_1 \cdot r$ and $M_2 \cdot r$ are vectors of constant length and lie in perpendicular planes their cross product has constant magnitude. Therefore *the scalar first torsion of the path curves is constant.*

From the above expression for T we see that if $m_1 = 0$ or $m_2 = 0$ or $m_1 = \pm m_2$ the torsion vanishes, that is the plane $\tau \times c$ is independent of the point on the curve. *Therefore in the group of infinitesimal transformations which leave the same pair of perpendicular planes* M_1 *and* M_2 *invariant there are four transformations whose path curves are plane curves.* If $m_1 = 0$ the motion reduces to a rotation parallel to the plane M_2 and the path curve is the circle whose plane is parallel to M_1 and whose center is on M_1. Likewise if $m_2 = 0$ the path curve is a circle in a plane parallel to M_2 and whose center lies in M_1. If $m_1 = \pm m_2$ equation (42) becomes

$$C = m_1^2[M_1 \cdot (M_1 \cdot r) + M_2 \cdot (M_2 \cdot r)] \left(\frac{dt}{ds}\right)^2.$$

But since $M_1 \cdot (M_1 \cdot r)$ and $M_2 \cdot (M_2 \cdot r)$ are the projections of the vector r on the planes M_1 and M_2 respectively and these planes are perpendicular the expression in the brackets is evidently equal to r. Hence in this case

$$C = m_1^2 r \left(\frac{dt}{ds}\right)^2.$$

From (41) we see that in this case

$$\left(\frac{ds}{dt}\right)^2 = m_1^2(r \cdot r).$$

Then

$$C = \frac{r}{r \cdot r}$$

and hence

$$C \cdot C = \frac{r}{r \cdot r}.$$

That is the scalar of the curvature of the path curve is the reciprocal of the length of r. Then in this case the path curves are circles with center at the origin. The plane of the circle is $r \times (M_1 \cdot r + M_2 \cdot r)$. This plane changes only in magnitude if we change the length of r. Hence the plane is left invariant by the transformation $dr = m_1(M_1 + M_2) \cdot r\, dt$. That is through each point in space passes one plane left invariant by this transformation. From (39) the directions of the path curves through a point, given by the transformations for which $m_1 = 0$, $m_2 = 0$, $m_1 = m_2$, $m_1 = -m_2$ form a harmonic pencil.

From (42) we see that if r is held fixed and m_1 and m_2 are allowed to vary the end of the curvature vector traces out the line joining the ends of the vectors $\frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2}$ and $\frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2}$ and it is seen that for real values of m_1 and m_2 the only points obtained are those on the segment joining the ends of these two vectors and that the ratios $\frac{m_1}{m_2}$ and $-\frac{m_1}{m_2}$ give the same point. Hence each point of the segment is counted twice. We will call this the *curvature segment.* Two directions $\frac{dr}{dt} = (m_1M_1 + m_2M_2)\cdot r$ and $\frac{dr'}{dt} = (m_1'M_1 + m_2'M_2)\cdot r$ are perpendicular if they satisfy the relation.

$$\frac{dr}{dt}\cdot\frac{dr'}{dt} = 0 = (m_1M_1\cdot r + m_2M_i\cdot r)\cdot(m_1'M_1\cdot r + m_2'M_2\cdot r)$$

$$= m_1m_1'(M_1\cdot r)^2 + m_2m_2'(M_2\cdot r)^2.$$

Hence

$$\frac{m_2'}{m_1'} = -\frac{(M_1\cdot r)^2}{(M_2\cdot r)^2}\frac{m_1}{m_2}.$$

Two perpendicular directions are then $m_1M_1\cdot r + m_2M_2\cdot r$ and $m_2(M_2\cdot r)^2(M_1\cdot r) + m_1(M_1\cdot r)^2(M_2\cdot r)$. The curvature for these two directions is

$$c_1 = [m_1^2M_i\cdot(M_1\cdot r) + m_2^2M_2\cdot(M_2\cdot r)]\left(\frac{dt}{ds}\right)_1^2$$

$$c_2 = [m_2^2[(M_2\cdot r)\cdot(M_2\cdot r)]^2M_1\cdot(M_1\cdot r) + m_1^2[(M_1\cdot r)\cdot(M_1\cdot r)]^2M_2\cdot(M_2\cdot r)]\left(\frac{dt}{ds}\right)_2$$

$$\left(\frac{dt}{ds}\right)_1 = \frac{1}{m_1^2(M_1\cdot r)^2 + m_2^2(M_2\cdot r)^2}$$

$$\left(\frac{dt}{ds}\right)_2 = \frac{1}{m_2^2[(M_2\cdot r)\cdot(M_2\cdot r)]^2(M_1\cdot r)^2 + m_1^2[(M_1\cdot r)\cdot(M_1\cdot r)]^2(M_2\cdot r)^2}$$

$$= \frac{1}{[(M_1\cdot r)^2(M_2\cdot r)^2]\,[m_1^2(M_1\cdot r)^2 + m_2^2(M_2\cdot r)^2}$$

Substituting these values of $\left(\frac{dt}{ds}\right)_1$ and $\left(\frac{dt}{ds}\right)_2$ in the expressions for c_1

and c_2 we have

$$c_1 + c_2 = \frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2} + \frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2} = 2\,h.$$

That is the sum of the curvature vectors for two perpendicular directions through the point is independent of the pair of directions taken and is equal to the sum of the curvatures of the path curves of the rotations $m_1 = 0$ and $m_2 = 0$ since $\frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2}$ and $\frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2}$ are the curvatures in these two directions. It is also to be noted that the directions for which the curvatures are the same are harmonically separated by the directions $m_1 = 0$, $m_2 = 0$. The directions which have curvature equal to h are perpendicular to each other and hence bisect the angle between $m_1 = 0$ and $m_2 = 0$.

Since the length of the radius of curvature is the reciprocal of the scalar curvature and its direction coincides with C the locus of the centers of curvature is the inverse of the curvature segment with respect to the unit circle with center at the extremity of r. Hence; *The locus of the centers of curvature of all the path curves of this group which pass through a given point is a circle of which the diameter is the line joining the origin to the point in question. For real directions through the point the centers of curvature lie on a quadrant of this circle.* From this it is evident that the curves with minimum curvature are in the directions $m_1 = m_2$ and $m_1 = -m_2$ and hence for these directions the curvature is perpendicular to the curvature segment. This can be seen also directly from (42). For the curvature of these curves being in the direction of r and the curvature segment being $\frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2} - \frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2}$ we have

$$r\cdot\left[\frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2} - \frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2}\right] = 0.$$

Since $M_1\cdot(M_1\cdot r)$ is the projection of r on M_1 and has the same length as $M_1\cdot r$ the product $r\cdot[M_1{:}(M_1\cdot r)]$ is then the length of the projection of r on M_1 multiplied by the length of r. Hence the first term of the product reduces to unity and likewise for the second term and hence the whole product vanishes.

The curvature vectors of the path curves lie in a plane determined by $M_1\cdot(M_1\cdot r)$ and $M_2\cdot(M_2\cdot r)$. But $M_1\cdot r$ is a vector in M_1 perpendicular to r and $M_1\cdot(M_1\cdot r)$ is the projection of r *on* M_1 hence these two vectors are perpendicular to each other. The vector $M_1 \cdot r$ is perpendicular to $M_2 \cdot (M_2 \cdot r)$ since they lie in completely perpendicular planes. Therefore $M_1 \cdot r$ is perpendicular to the plane of the curvature vector. Similarly $M_2 \cdot r$ is also perpendicular to this plane. Hence, *The path curves of a given point by the transformations of the group of rotations which leave the same two completely perpendicular planes fixed are all tangent to a plane* A, *and have constant curvature and torsion. The ends of the curvature vectors lie on a line cutting the two fixed planes. The plane in which these curvature vectors lie is perpendicular to the plane* A. *There are four of the path curves which are circles. The tangents to two of these are perpendicular to each other and the tangents to the four form a harmonic pencil. The centers of curvature lie on a circle whose diameter is the line joining* 0 *to the given point. The centers of curvature of the real curves lie on one quadrant of this circle.*

As the vector r is rotated by (39) the plane A will envelope a surface which will be left invariant by every transformation of the group. To obtain the equations of this surface we will integrate the vector differential equation (39). Let

$$r = x_1k_1 + x_2k_2 + x_3k_3 + x_4k_4)$$
$$M_1 = k_{12}, \qquad M_2 = k_{34}$$

Then (39) becomes

$$k_1dk_1 + k_2dk_2 + k_3dk_3 + k_4dx_4 = (m_1k_{12} + m_2k_{34}) \cdot (x_1k_1 + x_2k_2 + x_3k_3 + x_4k_4)dt$$
$$= (m_1x_2k_1 - m_1x_1k_2 + m_2x_4k_3 - m_2x_3k_4)dt$$

which is equivalent to the set of differential equations

$$\frac{dx_1}{dt} = m_1x_2, \quad \frac{dx_2}{dt} = -m_1x_1,$$
$$\frac{dx_3}{dt} = m_2x_4, \quad \frac{dx_4}{dt} = -m_2x_3.$$

Dividing and integrating we obtain for the first integrals

$$(43) \qquad x_1^2 + x_2^2 = a^2, \quad x_3^2 + x_4^2 = b^2.$$

The constants a and b are so determined that the curve will pass through the initial point. These then are the equations of the surface left invariant by each transformation of the group. The planes A are the tangent planes to the surface and the normal planes are those in which the curvature vectors lie. These normal planes all pass through the origin, that is through the point of intersection of the fixed planes. The curvature of a geodesic always lies in the normal plane to the surface from which we can conclude that the path curves are geodesics of the surface (43). We will however show this directly. The parametric equations of the surface are

$$(44) \qquad \begin{aligned} x_1 &= a \cos u, \quad x_2 = a \sin u, \\ x_3 &= b \cos v, \quad x_4 = b \sin v. \end{aligned}$$

Then

$$ds^2 = a^2du^2 + b^2dv^2$$

This shows that the surface is developable.[13] The geodesics are then the lines given by the relation

$$v = Au + B$$

which substituted in the differential equations of the path curves we find they are satisfied provided $A = \frac{m_2}{m_1}$. Hence the path curves are the geodesics. Through each point of the surface passes four geodesics which are circles. The planes of two of them are completely perpendicular being parallel respectively to the two fixed planes. The other two circular geodesics make equal angles with the two preceding, and have their centers at the origin. Their planes consequently intersect in a line, that is, lie in a 3-space. The surface can be generated by rotating any one of the path curves by any transformation of the group. Therefore it can be generated by moving a circle of fixed radius and plane parallel to the x_3x_4-plane with center in the x_1x_2-plane so that it always cuts a fixed circle lying in a plane parallel to the x_1x_2-plane. It can also be generated by a circle of radius $\sqrt{a^2 + b^2}$ with center at 0 which always cuts a fixed circle of radius $\sqrt{a^2 + b^2}$ and center at 0. The plane of the variable circle is inclined at a fixed angle to the plane of the fixed circle.

Equations (43) show that the surface is of order four. Therefore a 3-space which cuts it in a circle must cut it again in a curve of order two. Consider first a 3-space which contains one of the circles with center at 0. This will also contain a second one of these circles since they lie by twos in all the 3-spaces containing one of them. If then we pass a sphere through one of these circles for which it is a great circle, it will contain a second one of them which will also be a great circle. Hence such a sphere is tangent to the surface at two diametrically opposite points.

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13 See Levi, *loc. cit.*

The plane of one of these circles is obtained by letting $v = u + \theta$ in equations (44). The equation of this path curve then becomes

$$(45)\qquad \begin{aligned} x_1 &= a \cos u, & x_2 &= a \sin u \\ x_3 &= b \cos (u + \theta), & x_4 &= b \sin (u + \theta) \end{aligned}$$

and the plane of the curve becomes

$$(46)\qquad \begin{aligned} x_3 &= \frac{b}{a} \cos \theta\, x_1 - \frac{b}{a} \sin \theta x_2, \\ x_4 &= \frac{b}{a} \cos \theta\, x_2 + \frac{b}{a} \sin \theta x_1. \end{aligned}$$

Varying θ we obtain all circles which form one generation of the surface. These circles have no point in common. The second generation can be obtained by putting $v = -u + \theta$. The equations of these circles then is

$$(47)\qquad \begin{aligned} x_1 &= a \cos u, & x_2 &= a \sin u \\ x_3 &= b \cos(-u + \theta), & x_4 &= b \sin (-u + \theta). \end{aligned}$$

The circles of (47) do not intersect each other but each one of (47) intersects each one of (45) in two diametrically opposite points. The points of intersection are $u = \dfrac{\varphi - \theta}{2}$, $u = \dfrac{\varphi + \theta + 2\pi}{2}$. If these circles are used as parameter curves the equation of the surface becomes

$$\begin{aligned} x_1 &= a \cos (u + v), & x_2 &= a \sin (u + v), \\ x_3 &= b \cos (u - v), & x_4 &= b \sin (u - v). \end{aligned}$$

From (46) we see that the locus of the planes of these circles is

$$\frac{x_1^2 + x_2^2}{a^2} = \frac{x_3^2 + x_4^2}{b^2}.$$

In fact this quadric cone contains both sets of planes.

The planes of the other two generations of circles lie on the cylinders

$$x_1^2 + x_2^2 = a^2, \qquad x_3^2 + x_4^2 = b^2.$$

The planes on one of these cylinders are parallel to each other and consequently two of them determine a 3-space, that is, the 3-space which passes through one of these planes will contain another of the same cylinder. Then in this second double generation of circles,

circles of the same generation intersect in two points while those of opposite generations intersect in one point. Equations (47) show that the surface is also a translation surface.

Wilson and Moore [14] discussed the locus of the end of the normal curvature vector (the indicatrix) of curves passing through a given point of a surface and found that in general it is a conic. But when this indicatrix becomes a linear segment the surface has some properties of surface in 3-space. On such a surface lines of curvature can be defined as in 3-space and will be orthogonal. If we define lines of curvature as lines of maximum or minimum normal curvature we find in general there are four directions through each point but in 3-space these four directions divide into two sets of two, one the asymptotic lines and the other the lines of curvature. For surfaces whose indicatrix reduces to a linear segment not passing through the surface point in question these four directions of maximum and minimum radii of curvature again factor into two sets; one giving the curves called by Segre characteristics and the other giving lines analogous to lines of curvature in 3-dimensions. For the surface here considered all four sets of these curves are circles.

We saw that the curvature segment or indicatrix cut the planes M_1 and M_2 in the ends of the projection of r on these planes. Then as r is rotated the curvature segment will cut the circles generated by these projections. Hence the locus of the curvature segment will be the congruence of lines cutting two given circle. Also the mean curvature defined by the curvatures of two orthogonal directions.

$$2h = c_1 + c_2$$

is the vector from the surface point to the middle of the curvature segment. Then the locus of the end of the mean curvature vector will be the surface

$$x_1^2 + x_2^2 = \left(\frac{a^2 - 1}{a^2}\right)^2$$

$$x_3^2 + x_4^2 = \left(\frac{b^2 - 1}{b^2}\right)^2$$

which is a surface like (43).

We have here considered general positions of the vector r but an interesting case arises when r is so located that its projection on M_1

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14 Differential geometry of two-surfaces in hyperspace. These Proceedings, 52, 1916.

is equal in length to its projection on M_2. On the surface generated by the path curves of the group the circles for which $m_1 = m_2$ and $m_1 = -m_2$ are orthogonal. Hence the directions of the circular sections form two orthogonal pairs. The center of mean curvature bisects the curvature segment.

Rotations in 5-space give nothing new since the path curves will lie in the 4-space perpendicular to the fixed axis of the rotation and passing through the given point.

9. **Rotations in 6-space leaving the same three mutually perpendicular planes, invariant.** We will next consider the case of 6-space in detail before generalizing. Evidently these transformations form a group. The directions which a point can move by the various transformations of the group form a 3-space. These directions are defined by

$$(48) \qquad \tau = \frac{dr}{ds} = (m_1M_1 + m_2M_2 + m_3M_3)\cdot\frac{rdt}{ds}$$

τ is then a unit vector tangent to the curve given by a particular set of values of m_1, m_2, m_3. Squaring (48) we get

$$(49) \qquad \left(\frac{ds}{dt}\right)^2 = m_1^2(M_1\cdot r)^2 + m_2^2(M_2\cdot r)^2 + m_3^2(M_3\cdot r)^2$$

which is constant for given values of m_1, m_2, m_3 since $(M_1\cdot r)$, $(M_2\cdot r)$, $(M_3\cdot r)$ are of constant length. The curvature of the path curves is

$$(50) \qquad C = \frac{m_1^2M_1\cdot(M_1\cdot r) + m_2^2M_2\cdot(M_2\cdot r) + m_3^2M_3\cdot(M_3\cdot r)}{m_1^2(M_1\cdot r)^2 + m_2^2(M_2\cdot r)^2 + m_3^2(M_3\cdot r)^2}.$$

This shows that the end of the curvature vectors lie in a plane determined by the projections of r on the three planes M_1, M_2, M_3. We see that for real values of m_1, m_2, m_3 that is for real directions through the given point, the points lie inside this triangle, which we will call the *curvature triangle.* To each point in the curvature triangle corresponds four sets of values of m_1, m_2, m_3, that is, four curves through the point. Each of these curves have the same curvature.

The angle between two directions $\frac{dr}{ds}$ and $\frac{dr'}{ds}$ is given by the formula

$$(51) \qquad \frac{dr}{ds}\cdot\frac{dr'}{ds} = \frac{m_1m_1^1(M_1\cdot r)^2 + m_2m_2^1(M_2\cdot r)^2 + m_3m_3^1(M_3\cdot r)^2}{\sqrt{m_1^2(M_1\cdot r)^2 + m_2^2(M_2\cdot r)^2 + m_3^2(M_3\cdot r)^2}\,\sqrt{m_1^{12}(M_1\cdot r)^2 + m_2^{12}(M_2\cdot r)^2 + m_3^{12}(M_3\cdot r)^2}}$$

The condition that the two directions be orthogonal is

$$(52)\qquad m_1m_1^1(M_1\cdot r)^2 + m_2m_2^1(M_2\cdot r)^2 + m_3m_3^1(M_3\cdot r)^2 + 0.$$

This defines a plane of directions perpendicular to m_1^1, m_2^1, m_3^1.

From (48) we see that a linear relation among the m's gives a plane of directions through the point and from (50) we see that the end of the curvature vector will describe a conic in the curvature triangle determined by the points, $\frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2}$, $\frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2}$, $\frac{M_3\cdot(M_3\cdot r)}{(M_3\cdot r)^2}$ since the substitution of (52) in (50) gives a quadratic relation in m_1, m_2, m_3. To simplify the work let

$$\frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2} = x,\quad \frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2} = y,\quad \frac{M_3\cdot(M_3\cdot r)}{(M_3\cdot r)^2} = z$$

$$m_1^2(M_1\cdot r)^2 = \lambda^2,\quad m_2^2(M_2\cdot r)^2 = \mu^2,\quad m_3^2(M_3\cdot r)^2 = \nu^2$$

Then (50) takes the form

$$(53)\qquad C = \frac{\lambda^2 x + \mu^2 y + \nu^2 z}{\lambda^2 + \mu^2 + \nu^2}.$$

Then a linear relation

$$(54)\qquad a\cdot\lambda + b\mu + c\nu = 0$$

is equivalent to saying that the direction λ, μ, ν is perpendicular to the direction defined by

$$(55)\qquad \frac{a}{\sqrt{(M_1\cdot r)^2}},\quad \frac{b}{\sqrt{(M_2\cdot r)^2}},\quad \frac{c}{\sqrt{(M_3\cdot r)^2}}.$$

From (53) and (54) the curvature of the directions perpendicular to (55) is

$$(56)\qquad C = \frac{c^2(\lambda^2 x + \mu^2 y) + (a\lambda + b\mu)^2 z}{c^2(\lambda^2 + \mu^2) + (a\lambda + b\mu)^2}$$

This is a conic and as seen before it must lie inside the triangle determined by x, y, z and must therefore be an ellipse. The sides of the triangle are

$$(57)\qquad r_1 = \frac{\lambda^2 x + \mu^2 y}{\lambda^2 + \mu^2},\quad r_2 = \frac{\lambda^2 x + \nu^2 z}{\lambda^2 + \nu^2},\quad r_3 = \frac{\mu^2 y + \nu^2 z}{\mu^2 + \nu^2}.$$

The intersection of the conic (56) with r_1 is given by $a\lambda + b\mu = 0$ and hence the conic is tangent to r_1. The same argument shows that it is also tangent to r_2 and r_3. Hence: *The locus of the ends of the curvature vectors of curves perpendicular to a given direction is a conic tangent to the three sides of the triangle determined by the vectors x, y, z.*

The center of the conic (56) can be determined from the middle of the segment into which the conic projects on the x-, y- and z-axes. One end of each segment is at the origin. The projection on OX is

$$r = \frac{c^2\lambda^2 x}{c^2(\lambda^2 + \mu^2) + (a\lambda + b\mu)^2}.$$

The value of $\frac{\lambda}{\mu}$ which makes the denominator a minimum will make r a maximum. Similarly we can determine the projection of the ellipse on OY and OZ. Hence the center of the ellipse is the end of the vector

$$\rho_1 = \frac{(b^2 + c^2)x + (a^2 + c^2)y + (a^2 + b^2)z}{2(a^2 + b^2 + c^2)}$$

The point of the curvature triangle corresponding to the direction $a/\sqrt{(M_1 \cdot r)^2}$, $b/\sqrt{(M_2 \cdot r)^2}$, $c/\sqrt{(M_3 \cdot r)^2}$ is

$$\rho_2 = \frac{a^2 x + b^2 y + c^2 z}{a^2 + b^2 + c^2}.$$

From which we have

$$\frac{2\rho_1 + \rho_2}{3} = \frac{x + y + z}{3}.$$

The right side of this last equation is the median center of the curvature triangle. Hence the center of the curvature triangle is a point of trisection of the line joining the center of the conic to the point of the triangle corresponding to the direction $a/\sqrt{(M_1 \cdot r)^2}$, $b/\sqrt{(M_2 \cdot r)^2}$, $c/\sqrt{(M_3 \cdot r)^2}$. It can be shown that two perpendicular directions among those satisfied by (54) correspond to points at opposite ends of a diameter of the conic (56). Hence the points of the curvature triangle which correspond to three mutually perpendicular directions through the point form a triangle whose median center coincides with the median center of the curvature triangle. The points of the conic will correspond to four different planes of directions through the point. These are given by the linear relations

$$
\begin{aligned}
a\lambda + b\mu + c\nu &= 0,\\
a\lambda + b\mu - c\nu &= 0,\\
a\lambda - b\mu + c\nu &= 0,\\
a\lambda - b\mu - c\nu &= 0.
\end{aligned}
$$

By substituting these four relations in (53) it is seen that we obtain the same conic. The same point in the curvature triangle correspond to the perpendicular direction for each relation. If $m_1 = 0$ or $m_2 = 0$ or $m_3 = 0$, the corresponding points in the triangle are on the sides of it. The rotations in this case are of the four dimensional type previously discussed.

The unit osculating plane is again the cross product of the unit tangent and the unit curvature. The unit curvature is

$$C = \frac{m_1^2 M_1\cdot(M_1\cdot r) + m_2^2 M_2\cdot(M_2\cdot r) + m_3^2 M_3\cdot(M_3\cdot r)}{m_1^2(M_1\cdot r)^2 + m_2^2(M_2\cdot r)^2 + m_3^2(M_3\cdot r)^2}.$$

The rate of change of the osculating plane $(\tau\times c)$ with respect to the arc is again the first torsion.

$$
\begin{aligned}
\tau = \frac{d}{ds}(\tau\times c) = \tau\times\frac{dc}{ds} &= (M\cdot r)\times\{M\cdot[M\cdot(M\cdot r)]\}\left(\frac{dt}{ds}\right)^3 \frac{1}{\sqrt{C\cdot C}}\\
&= (m_1 M_1\cdot r + m_2 M_2\cdot r + m_3 M_3\cdot r)\times\{\Sigma m_i^3 M_i\\
&\qquad \cdot[M_i\cdot(M_i\cdot r)]\}\left(\frac{dt}{ds}\right)^3 \frac{1}{\sqrt{C\cdot C}}
\end{aligned}
$$

$M_i\cdot(M_i\cdot r)$ is the projection of r on M_i and $M_i\cdot[M_i\cdot(M_i\cdot r)]$ is a vector of equal length in M_i and perpendicular to $M_i\cdot(M_i\cdot r)$ and is therefore equal to $(M_i\cdot r)$. Hence we can write for the torsion

$$
\begin{aligned}
\tau &= (\Sigma m_i M_i\cdot r)\times\{\Sigma m_i^3(M_i\cdot r)\}\left(\frac{dt}{ds}\right)^2 \frac{1}{\sqrt{C\cdot C}}\\
&= m_1 m_2(m_1^2 - m_2^2)\,(M_1\cdot r)\times(M_2\cdot r) + m_1 m_3(m_1^2 - m_3^2)\,(M_1\cdot r)\times(M_3\cdot r)\\
&\qquad + m_2 m_3(m_2^2 - m_3^2)\,(M_2\cdot r)\times(M_3\cdot r)\left(\frac{dt}{ds}\right)^3 \frac{1}{\sqrt{C\cdot C}}.
\end{aligned}
$$

For given values of m_1, m_2, m_3 the magnitude of this vector is constant. The path curves are then curves for which the rate of change of the unit osculating plane with respect to the arc is a vector of constant magnitude. The vector τ will vanish if $m_i = m_j = 0,\ i \neq j$ or $m_i = 0,\ m_j = m_k\ (i \neq j \neq k)$, or if $m_1 = \pm m_2 = \pm m_3$. The first case gives the transformations which leave two of the planes absolutely fixed and the path curves are circles whose center is the projection of the end of r on the absolutely fixed 4-space determined by the two absolutely fixed planes. The second correspond to the rotations leaving one of the planes absolutely fixed and the path curves are circles with center on the fixed plane and radius equal to the length of the perpendicular dropped from the end of r to the fixed plane. The curvature of the path curves for the last case is

$$C = \frac{M_1\cdot(M_1\cdot r) + M_2\cdot(M_2\cdot r) + M_3\cdot(M_3\cdot r)}{(M_1\cdot r)^2 + (M_2\cdot r)^2 + (M_3\cdot r)^2} =$$

$$\frac{r}{(M_1\cdot r)^2 + (M_2\cdot r)^2 + (M_3\cdot r)^2} = \frac{r}{\sqrt{r\cdot r}}$$

since $M_i\cdot(M_i\cdot r)$ is the projection of r on M_i and the sum of the projections of r on three mutually perpendicular planes is equal to r. Also from the definition of the dot product it is evident that the magnitudes of $M_i\cdot r$ and $M_i\cdot(M_i\cdot r)$ are equal. Hence these curves have curvature directed through the origin and are circles with center at the origin. The point on the curvature triangle corresponding to the direction of the tangents to these circles is the end of the vector

$$C = \frac{M_1\cdot(M_1\cdot r) + M_2\cdot(M_2\cdot r) + M_3\cdot(M_3\cdot r)}{(M_1\cdot r)^2 + (M_2\cdot r)^2 + (M_3\cdot r)^2}.$$

This vector is perpendicular to the plane of the curvature triangle. For two sides of the triangle are

$$\frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2} - \frac{M_2\cdot(M_2\cdot r)}{(M_2\cdot r)^2},\quad \frac{M_1\cdot(M_1\cdot r)}{(M_1\cdot r)^2} - \frac{M_3\cdot(M_3\cdot r)}{(M_3\cdot r)^2}$$

and it is seen at once that the dot product of C with either of these vectors vanishes and hence C is perpendicular to the plane determined by these two vectors. The four directions $m_1 = \pm m_2 = \pm m_3$ correspond to the same point in the curvature triangle viz. the foot of the perpendicular dropped from the end of r on the plane of this triangle. These circles are then the path curves of minimum curvature. The radius of curvature being the reciprocal of the curvature; *The locus of the centers of curvature of all path curves which pass through a given point is the inverse of the curvature triangle with respect to a* *unit sphere with center at the point in question and therefore is a sphere with* r *for a diameter. The centers of curvature of the real curves lie on an octant of this sphere.* In four dimensions we found that the path curves corresponding to the center of the curvature segment were orthogonal but here the path curves corresponding to the median center of the curvature triangle do not have this property.

We saw that the locus of the end of the curvature vector for directions through a given point which satisfy a linear relation, that is curves tangent to the same plane, was a conic. This conic may degenerate into the sides of the curvature triangle counted twice. The directions corresponding to the points of one of these segments are all perpendicular to the direction corresponding to the opposite vertex. To a general point in the curvature triangle correspond four directions through the point but to a general point on one of the sides correspond two directions through the point and to a vertex of the triangle corresponds just one direction. A line in the plane of the curvature triangle is defined by the linear relation $\Sigma a_i m_i^2 = 0$, and this substituted in (48) shows that the corresponding directions through the point generate a quadric cone. In particular if one of the coefficients, a_1 say, is zero and the other two have opposite signs then the quadratic relation factors into two linear relations, each of which corresponds to a plane of directions through the point. From which we see that a linear relation involving only two of the m's gives a plane of directions whose curvature segment passes through a vertex of the curvature triangle. Two perpendicular directions correspond to the ends of the segment and from the fundamental configuration for the curvature of three mutually perpendicular directions it is at once seen that the curvature of the path curve perpendicular to this plane of directions will cut a side of the curvature triangle. The configuration can be shown by a simple figure. Let ABC be the curvature triangle, AD is the curvature segment corresponding to a plane of directions through the point depending on but two of the m's. Let H be the median center of the curvature triangle and G the middle of the curvature segment. The point corresponding to the direction perpendicular to the given plane i.e. to the directions corresponding to the segment AD must be such that the center of the triangle ADF is H. It is at once evident that F must be on BC and such that $DE = EF$. This together with $a_2 = 0$ or $a_3 = 0$ are the only cases in which $\Sigma a_i m_i^2 = 0$ can be factored into two linear relations. If D coincides with E, G will coincide with H.

A line which does not pass through a vertex of ABC will contain an infinite number of point pairs corresponding to perpendicular directions. For, any point on the line can be taken as the center of a curvature ellipse which touches the three sides of ABC. The two points in which these ellipses cut the line correspond to perpendicular directions. The points corresponding to the directions perpendicular to these pairs will all lie on a line parallel to the given line.

Proceeding as in 4-space the differential equations of the path curves are found to be

$$(58)\quad \frac{dx_1}{dt} = m_1x_2, \quad \frac{dx_2}{dt} = -m_1x_1, \quad \ldots, \quad \frac{dx_5}{dt} = m_3x_6, \quad \frac{dx_6}{dt} = -m_3x_5.$$

The path curves will then all lie in the variety V_3^8 of order 8

$$(59)\qquad x_1^2 + x_2^2 = a^2,\ x_3^2 + x_4^2 = b^2,\ x_5^2 + x_6^2 = c^2,$$

where a, b, c are determined so that the curves all pass through the given point. If $m_i = \pm m_j$ the resulting path curves will lie in a 4-space but if $m_i = km_j$ ($k \neq \pm 1$) this is not the case. If $m_1 = \pm m_2 = \pm m_3$ the resulting path curves are plane curves. The argument is the same as that given in 4-space.

The parametric equations of V_3^8 are

$$x_1 = a \cos u,\ x_2 = a \sin u,$$
$$x_3 = b \cos v,\ \ x_4 = b \sin v,$$
$$x_5 = c \cos w,\ x_6 = c \sin w.$$

The element of arc is

$$(60)\qquad ds^2 = a^2du^2 + b^2dv^2 + c^2du^2$$

The variety can therefore be developed on a plane 3-space. The path curves have curvature lying in the normal 3-space (the 3-space determined by the surface point and the curvature triangle) and are therefore geodesics. That they are geodesics can be shown directly from the above equations as was done for rotations in 4-space. A linear relation among the m's will give a surface which is left invariant by a one parameter family of rotations. This is then a geodesic surface of the variety V_3^8. Furthermore the normal 4-space to this surface must contain the normal 3-space to V_3^8 and the ends of the curvature vectors of the pencil of geodesics passing through a given point will trace out a conic lying in the curvature triangle and since this lies in the normal to the surface these path curves must be geodesics on the surface K. A linear relation in the m's means a linear relation in u, v, w. This substituted in (60) shows that the surface K is also developable. This surface differs from that studied in 4-space since for this one the indicatrix is a true ellipse and not a linear segment counted twice. The plane of the indicatrix does not pass through the surface point. In particular the linear relation $m_i = 0$ will lead to a geodesic surface all of whose geodesics are curves lying in a 4-space. This will cut K in a geodesic. Hence passing through each point of K pass three geodesics which lie in a 4-space.

For each point on V_3^8 there is a curvature triangle. The locus of these triangles consists of the planes cutting three fixed circles, one lying in each of the planes M_1, M_2, M_3.

We have found plane curves (circle) and curves lying in a 4-space which are left invariant, that is, path curves. It is evident that if a space curve is left invariant the space in which it lies must be left invariant. We saw that no 3-spaces were left invariant hence there are no 3-space path curves. Also we saw that the only 4-spaces left invariant were $M_1 \times M_2$, $M_1 \times M_3$, $M_2 \times M_3$ hence the 4-space path curves mentioned above are the only ones that exist.

10. **Rotations in space of 2p dimensions which leave the same set of p mutually perpendicular planes invariant.** Having considered the case of four and six dimensions we can now easily generalize the results for space of $2p$ dimensions. Let the rotation be expressed in terms of the unit invariant planes

(61) $$r' = r + \sum_{1}^{p} m_i M_i \cdot r \, dt$$

or $$\tau = \frac{dr}{ds} = \sum_{1}^{p} m_i M_i \cdot r \frac{dt}{ds}.$$

The ∞^p transformations obtained if m_i vary, form a group and the different directions which a point can take by the various transformations of the group lie in a linear p-space. The curvature of the path curves at the point P is given by the formula

(62) $$C = \frac{\Sigma m_i^2 M_i \cdot (M_i \cdot r)}{\Sigma m_i^2 (M_i \cdot r)^2}.$$

For given values of m_i the length of this vector curvature is seen to be independent of the position which r can take by the given rotation. That is the path curves are curves of constant curvature. These curvature vectors generate a p-space which is completely perpendicular to the p-space generated by the tangents to the curves at the point in question. If any of the m's vanish the resulting rotation is equivalent to a rotation in a space of lower dimensions and therefore we shall assume that none of the m's vanish.

Equation (62) shows that, for real values of m_i, the end of the curvature vector will lie inside a p-point A, called the curvature p-point determined by the p points in which the extremity of the vector r projects on the p planes M_i. Each point of A will correspond to 2^{p-1} directions through P. The points in A which correspond to p mutually perpendicular directions through P for a p-point whose center of gravity coincides with the center of gravity of A. If a linear relation $\Sigma a_i m_i = 0$ exists among the m's (62) shows that the end of the corresponding curvature vectors will lie on a closed quadric in p–1 dimensions which touches the faces of A. The foot of the perpendicular dropped from the point P on the space in which A lies corresponds to the directions on the surface satisfying the relations

$$(63) \qquad m_1 = \pm m_2 = \pm m_3 = \ldots. = \pm m_p$$

These curves then, 2^{p-1} in number, are curves of minimum curvature.

The first torsion of the path curves is given by the formula

$$T = \Sigma m_i m_j (m_i^2 - m_j^2)(M_i \cdot r) \times (M_j \cdot r) \left(\frac{dt}{ds}\right)^3 \frac{1}{\sqrt{C \cdot C}}.$$

This formula shows that the curves of zero torsion, excluding those corresponding to rotations in a space of less than 2 p dimensions, are those which satisfy relations (63). Hence these curves are plane curves, that is, circles. It is easy to show that the center of these curves is at the origin or at the intersection of the p invariant planes M_i. Other path curves are circles but these belong to rotations which leave one or more of the invariant planes absolutely fixed, that is, are equivalent to rotations in a lower space.

The differential equations of the path curves are

$$\frac{dx_1}{dt} = m_1 x_2, \ \frac{dx_2}{dt} = - m_1 x_1, \ \frac{dx_3}{dt} = m_2 x_4, \ \frac{dx_4}{dt} = - m_2 x_3, \ldots.$$

One set of integrals of these equations is

$$x_1^2 + x_2^2 = a_1^2, \ x_3^2 + x_4^2 = a_2^2 \ldots . x_{2p-1}^2 + x_{2p}^2 = a_p^2$$

and therefore the path curves all lie in a variety V_p of order 2^p. The parameters equations of this variety are

$$x_1 = a_1\cos u_1,\ x_2 = a_1\sin u_1,$$
$$x_3 = a_2\cos u_2,\ x_4 = a_2\sin u_2,$$
$$\dots\dots\dots\dots\dots\dots\dots\dots$$
$$x_{2p-1} = a_p\cos u_p,\ x_{2p} = a_p\sin u_p.$$

The element of arc then is

$$ds^2 = a_1^2du_1^2 + a_2^2du_2^2 + \dots . a_p^2du_p^2$$

which shows that V_p can be developed on a plane space of p dimensions. A linear relation among the m's gives a variety of p–1 dimensions immersed in V_p and it is easily shown that this is also developable. The path curves are geodesics on both varieties.

For each point of V_p there is a curvature p-point and these p-points all cut p fixed circles, one lying in each of the invariant planes M_i.

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CONTRIBUTIONS FROM THE CRYPTOGAMIC LABORATORY OF HARVARD UNIVERSITY. No. LXXXI.

EXTRA-AMERICAN DIPTEROPHILOUS LABOUL-BENIALES.

By Roland Thaxter.

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In a recent Contribution (These Proceedings, **52**, No. 10) the writer included such American Laboulbeniales as were then known to be parasitic on dipterous insects. In the present paper all the extra-American forms which have accumulated in recent years have been included save only a few which, owing to their condition, or the scantiness of the available material it has seemed best to omit. In order to complete the enumeration of all the species of Stigmatomyces which have thus far come under my notice one coleopterophilous type has been added, a parasite on the coccinellid genus Chilomanes; but with this exception only dipterous hosts have been included. As in previous instances I am indebted to the kindness of Mr. Schwab and Mr. Moulton for the hosts from Kamerun and from Borneo, and several very interesting forms were found among a small number of flies which I owe to the courtesy of Dr. S. B. Wolbach, who brought them from the Gambia River. I am indebted to Dr. P. Speiser for certain interesting specimens and determinations. It has proved impossible to obtain specific and in some cases even generic determinations, especially of the peculiar African hosts. For assistance in this connection I am indebted to Prof. Aldrich and to Mr. Banks. The terminology used in the present paper is that of my previous Contribution above cited.

Index of Genera and Species.

Index of Hosts.

Dimeromyces pedalis nov. sp.

Male individual. Hyaline, the axis consisting of three cells; the basal much larger, with a well developed black foot; the two others rather narrow, subequal, of nearly uniform width, externally convex: the terminal appendage separated by a slightly blackened septum, its basal cell clearly defined, twice as long as broad; the rest of the appendage slender, slightly tapering, with an indistinct septum. Antheridium erect, the neck and venter rather clearly distinguished and of about equal length, the latter externally convex, and extending to the basal cell, its inner margin in continuous contact with those of the subbasal and terminal cells. Total length to tip of antheridium 28 × 8 μ. Antheridium 18 × 5 μ. Appendage 18 × 3 μ.

Female individual. More or less tinged with brownish yellow, especially the appendages; axis of the receptacle consisting of usually about eight cells, tapering somewhat above and below; the primary appendage erect, terminal, separated by a dark septum; its basal cell somewhat inflated, the distal portion tapering, and with an indistinct septum: secondary appendages usually four, sometimes three, relatively short, the perithecia protruding beyond their abruptly curved or recurved tips, the terminal cells inflated and often splitting in two lip-like halves which may become somewhat curled; the axis of five or usually six cells, tapering toward the base. Perithecium single in the types, usually arising from the third cell below the primary appendage, its very short stalk bent abruptly, so that it diverges somewhat irregularly sidewise; tapering slightly to a broad blunt apex which may be almost symmetrically three-papillate, the papillae large and broadly rounded, the middle one higher and broader; or more irregular according to the point of view. Spores 18 × 2.5 μ. Perithecia 42–52 × 14 μ. Receptacle 35–40 × 8 μ. Appendages, primary, 30 μ, secondary 40–50 μ.

On the legs of *Oscinosoma inaequalis* T. Beck. No. 2139, Sarawak, Borneo.

This species is intermediate between *D. Oscinosomalis* and *D. coarctatus*. Apart from other differences, it may be separated from the former by its short appendages and normal foot, and from the latter by its shorter perithecia, and less numerous appendages, which lack the peculiar right and left divergence so characteristic in the papuan type. The host has been kindly determined by Dr. Speiser.

Dimeromyces Kamerunensis nov. sp.

Male individual. Very small, hyaline or becoming faintly tinged with brown, the axis consisting of three successively smaller cells somewhat longer than broad, the terminal appendage subtended by a black septum, its basal cell faintly colored, with convex margins; the subbasal similar in size; the rest of the appendage hyaline, slender, somewhat tapering, with two indistinct septa. Antheridium single, or rarely two, the venter somewhat bulging, tapering to the slightly outcurved, blunt, pointed distal portion. To tip of antheridium 30 × 8 μ, including relatively large black foot. Appendage 20–40 × 4 μ.

Female individual. Axis of receptacle brown above, hyaline below; consisting of from six to twelve, or sometimes more, superposed cells; the basal several times as long as broad, but slightly narrower toward the base; the remaining cells broader than long, the lower more flattened, the terminal one small and rounded, bearing distally a short tapering appendage similar to that of the male; usually six to eight of the cells below it bearing single simple appendages or perithecia: the appendages erect or but slightly divergent, the cells above the basal separated by slight indentations: consisting, usually, of seven cells; the basal separated by a narrower purplish black region from the subbasal, which is about as long; the third to fifth successively smaller; the fifth somewhat broader than long; the sixth minute, distally rounded into the base of the terminal cell; which is large, greatly inflated, distally abruptly narrowing to a broadly rounded extremity, disorganized at maturity, the spreading or revolute remains of its wall persistent, and adhering around the minute subterminal cell; the appendages becoming dark brown, diverging in two more or less definite ranks, the extremities slightly incurved, one or two of the uppermost much shorter. Perithecia uniformly pale dirty brownish yellow, the apex hyaline; one or two in number, relatively small, hardly longer than the appendages, or even shorter, becoming gradually broader from the insertion upward; the lower half somewhat inflated, tapering thence to the broad termination, the compressed inner lip-edges forming a short, slightly oblique, short-conical projection, subtended by three well marked papillae. Perithecia 88–105 × 14–21 μ. Appendages, longest 105 × 12 μ; primary appendage about 25 × 3 μ.

On the head and legs of a pale yellow oscinid with slightly smoky wings. No. 2367, Kamerun, West Africa.

This striking species is most nearly related to *D. coarctatus*, but differs widely in the structure and position of its appendages and perithecia. The measurements are taken from larger specimens.

Dimeromyces Oscinosomalis nov. sp.

Male individual perfectly hyaline and very thin-walled; consisting of three superposed cells, the basal much larger and somewhat inflated below; the two others longer than broad, somewhat irregular, of nearly equal length, the terminal appendage distinguished by a slightly darkened septum and constriction, slightly inflated below and tapering distally. Antheridia one, or often two superposed in oblique contact, slightly divergent, the venter and neck not abruptly distinguished, the latter stout and blunt; a short several-celled secondary appendage rarely formed from the subbasal cell. Receptacle 25 μ. Antheridia 18 $\times$ 5 μ.

Female individual. General habit usually subsigmoid. Axis of the receptacle consisting of usually six cells; the base hardly longer than broad, much larger, stout and penetrating the host by a variably developed rhizoid which may be vesicular or taper into a short stout filament, a small, dark primary foot usually distinguishable: the two or three cells above broader than long, somewhat flattened, the two distal ones successively smaller and somewhat rounded; the inflated base of the short tapering primary appendage distinguished by a constriction and dark septum. Secondary appendages usually three, rarely four, long, slender, becoming blackish brown, the distal half curved usually inward away from the perithecium; the distal cell enlarged and abruptly curved, or even uncinulate, becoming irregularly split into an upper and lower half; the basal cell small and short, distinguished from the much larger, often somewhat inflated subbasal cell by a dark septum, the total length nearly twice that of the perithecia. Perithecia normally single, arising from the fourth cell of the receptacle, rather stout, slightly bent inward, the stalk obsolete, outer margin strongly convex, tapering slightly to the broad very irregular termination from which the lip-cells, which are all unlike and asymmetrical, project variously according to the point of view. Perithecia 50–65 $\times$ 16–20 μ. Receptacle, exclusive of rhizoid, 35–50 $\times$ 12–16 μ. Appendages, primary 18 μ; secondary, longest, 125 $\times$ 8 μ. Total length to tip of perithecium 75–95 μ.

On the inferior surface of the abdomen of *Oscinosoma inaequalis* T. Beck. No. 2139, Sarawak, Borneo.

This species is most nearly related to *D. pedalis* and *D. rhizophorus,* but is distinguished from the former by the presence of a well developed stout rhizoid, and by the conformation of its perithecial termination; while from the latter it differs in its greatly elongated appendages and simple rhizoid, as well as in other details. A minute primary foot, which forms during the early germination of the spore, usually persists beside the entering rhizoid. The male is very thin-walled and difficult to see from the fact that it is perfectly hyaline. It does not appear to enter the host, but the basal cell spreads to form a small sucker like attachment.

Laboulbenia clavulifera nov. sp.

Erect, straight or slightly bent between the basal and subbasal cells. Foot normal, well developed; basal cell somewhat longer than the subbasal, and separated as a rule by a slightly oblique septum; the subbasal slightly broader distally, pale dirty brownish; the basal nearly hyaline; cells III and VI subequal and opposite, cells IV and V nearly equal, or cell five narrower and slightly longer. Insertion-cell normal, well developed, nearly black. Base of outer appendage slightly oblique, the axis deep brown with the septa darker, erect beside the perithecium; consisting of three cells increasing in diameter distally, and bearing a terminal tuft of short irregularly developed branches. Basal cell of the inner appendage small, pale, bearing a short one-celled branch on either side, usually terminated by two large brown antheridia. Receptacle above cell II concolorous with it, the cells above cell VI not clearly distinguished. Perithecium wholly olivaceous, somewhat paler toward the base, the venter slightly inflated, its base about opposite the insertion-cell; tapering to the blunt apex, the wall-cells describing a half turn, so that the view of the apex is either anterior or posterior, and appears symmetrical, with the lateral lips forming prominent rounded projections on either side of a somewhat higher median elevation. Spores about $34 \times 2.5\ \mu$. Perithecia $70–88 \times 18\ \mu$. Appendage to tips of branchlets $70\ \mu$; the axis $42 \times 12\ \mu$, distally. Total length $150–225\ \mu$.

On the legs of a species of *Physogenia?*. No. 2748. Kamerun, W. Africa.

Although this species has the typical structure of *Laboulbenia*, it appears to be most nearly related to *L. pectinulifera*, which occurs on the same host, but has the structure of *Ceraiomyces*. The stout, clavate, deeply colored axis of the outer appendage, which is erect and bears a terminal tuft of short ill developed branchlets, gives it a characteristic appearance.

Laboulbenia Lagarocerinus nov. sp.

Basal cell bent at right angles, swollen, distinguished by a constriction, twice as long as broad, or more, lying flat on the substratum, pale brown, modified to form a concave attachment below the middle, which is somewhat darker, and serves as a foot; the axis above it straight, long and stout, erect; cell II pale dirty olivaceous, indistinctly punctate, nearly uniform, obliquely rounded distally and broader than the portion of the receptacle above it; cells III–V replaced by a single cell, two to three times as long as broad, its upper half quite free, and bearing distally a well developed unmodified insertion-cell. Appendages olivaceous, erect or bent sidewise, lying close against the lower half of the perithecium, small and poorly developed; the outer straight, simple, of two or three cells; the inner bearing two or three branchlets with short irregular terminations, and one or two stout relatively large antheridia, with rather abruptly distinguished necks; cell VI pale, somewhat broader than long; the cells above concolorous, not clearly defined, the region continuous with the base of the venter; perithecium straight, of somewhat irregular outline; the wall-cells clearly indicated by dark lines which are slightly spiral, describing somewhat less than half a turn; the venter darker, clearer olivaceous, slightly inflated below, tapering distally to the tip and apex; the latter rather narrow, the lip-cells prominently rounded; the outer larger, and lying wholly above the smaller inner ones. Perithecium $75–85 \times 20–22\ \mu$. Appendages about $35\ \mu$. Cell I $38 \times 20\ \mu$. Cell II, $62–70 \times 14\ \mu$. Total length above cell I, 140–165 μ.

On the wing of a new species of *Lagaroceras*. Gambia River, West Africa, No. 2326.

This species, which was found on one of the flies collected by Dr. Wolbach, develops on the veins of the wings, those on the intervening membrane producing only antheridia. It is most clearly distinguished by its aberrant basal cell, which lies flat on the vein, and is attached to it by a sucker-like depression just below the middle. Its structure is that of the *Ceraiomyces*-type.

Laboulbenia Muiriana nov. sp.

Foot well developed, basal cell short, hyaline, abruptly broader below the septum; subbasal cell somewhat broader, hyaline, punctate, straight, two to three times as long; cell III somewhat rounded and externally convex, but slightly larger than cell VI; cell IV externally convex, slightly broader than long; cell V as long, but narrow; cells II–VI and the small basal cell region yellow and obscurely punctate. Insertion-cell translucent reddish, thick, higher than the base of the venter; basal cell of the outer appendage narrower and about half as long as the subbasal, both hyaline; the latter bearing distally two greatly elongated, stout, nearly uniform, simple branches: an outer pale brown, the lower half of its basal cell narrow and blackened, the inner hyaline or paler, both with a tendency to enlargement at the septa. Basal cell of the inner appendage very small, hyaline, bearing several long slender olivaceous antheridia directly, and a short one-celled branch which also bears one or two. Axis of the perithecium, including the stalk- and basal cell region, diverging at an angle of about 45° from that of the receptacle; the perithecium yellow, slightly inflated at the base, especially on the inner side, tapering very slightly and then rather distinctly broader at the point where the tip is rather well distinguished, tapering to the characteristically formed apex; the inner lip-cells deeply colored, and ending in a hyaline, blunt apiculus, higher than the outer; which slope obliquely, are distally quite hyaline and distinctly prominent externally, with a similar dark colored obliquely separated suffusion of their lower half, which extends down along the margin of the tip. Perithecia $66–70 \times 18\,\mu$. Receptacle, to insertion-cell, $88\,\mu$. Subbasal cell $50 \times 16\,\mu$. Appendage $368\,\mu$. Total length $115\,\mu$.

Growing at the base of the posterior legs of a small fly belonging to the Oscinidae. No. 2181. Laloki River, British New Guinea.

I have dedicated this very beautiful species to Mr. F. Muir, who very kindly collected for me a small lot of flies in New Guinea, among which two perfect specimens were found. It is not unlike simple forms of *L. cristata*, except for its punctation, extraordinarily elongated appendage, and peculiarly modified apex.

Laboulbenia Pachylophi nov. sp.

Straight, or but slightly curved; the perithecium and basal cell of the outer appendage deep translucent olive brown. Structure normal. Basal cell hyaline, enlarged in relation to the foot to form a bulbous base; cell II slightly longer, hardly broader, becoming somewhat suffused with brown, and indistinctly transversely punctate, as are the cells above it: cells III and IV subequal, somewhat obliquely separated, hardly longer than broad; cell V long and narrow, reaching a little lower than the inner margin of cell IV. Outer appendage rather stout, the three lower cells somewhat similar, longer than broad, slightly constricted at the septa; the basal shorter, deep olive brown, concolorous with the clearly defined insertion-cell; the distal part of the appendage slightly soiled with brown, bearing a few irregular hyaline branches: basal cell of the inner appendage very small, hyaline above, and producing right and left branches, the basal cells of which are rather long, bearing one or two long slightly brownish antheridia and a few hyaline branchlets; both appendages and their branches appressed and curved against the perithecium, the branchlets reaching above its tip. Perithecium straight, its axis sometimes slightly divergent, the two lower tiers of wall-cells deeper olive brown, faintly granular-punctate; the divisions marked by rather clearly distinguished lines; the venter but slightly inflated, tapering to the blunt apex; the coarse lips nearly hyaline, the inner more prominent and subtended by a darker blackish area. Perithecium 60–65 × 22 μ. Appendages 70 μ. Total length 120–140 μ, the bulbous foot 16 μ.

On the legs of a specimen of *Pachylophus frontalis* Lev., kindly communicated by Dr. P. Speiser. From Killimandjaro, East Africa.

Laboulbenia porrigens nov. sp.

Basal cell relatively short, bent to one side, more or less swollen or distorted, bearing the foot on its under side, somewhat paler than the subbasal cell which is stained with pale dirty brownish, and punctate-roughened, almost its whole distal margin obliquely separated from cell VI. Cells III–V replaced by a single cell somewhat more deeply suffused, and more closely punctate than the subbasal, of nearly uniform diameter, and two to three times as long as broad, and projecting outward, almost at right angles, free from the receptacle; this finger-like projection bearing the appendage and insertion-cell at its extremity. Insertion-cell well developed, deep olive brown, concolorous with the basal cells of the appendages. Axis of the outer appendage consisting of two cells; the upper longer and much paler, bearing distally usually two stout branches, which branch successively about five times; the divisions above the second perfectly hyaline, slender; the ultimate branchlets tending to bend downward, and to produce rounded tooth-like projections from their lower surfaces, which are more or less irregular: basal cell of the inner appendage less than half as large as that of the outer, somewhat prominent, bearing two appressed branches, the basal cells of which bear one or two dark brown antheridia and several short dark sterile branchlets one of which may be hyaline and similar to those of the outer appendage. Basal cells of the perithecium concolorous with cell VI and indistinctly punctate; the region very broad, surrounding the base of the ascigerous cavity, and forming a very broad insertion for the base of the dark olive brown perithecium; which tapers irregularly, the two lower tiers of wall-cells distinguished by dark lines, the second rather abruptly narrower and tapering, forming a more or less distinct neck-portion; the tip and apex slightly bent outward, abruptly paler, somewhat broader, tapering to the well defined, but not very prominent, lips; the inner subtended by a darker suffusion, and not more prominent than the outer. Spores $35 \times 3\ \mu$. Perithecia $95 \times 28\ \mu$ at the base. Appendage, longest, 140–157 μ. Cell III–V, longest $40 \times 15\ \mu$, shortest 25 μ. Total length 175–210 μ.

On the superior surface of the abdomen near the tip, of a small fly of unknown family. No. 2651, Kamerun, W. Africa.

The host of the very peculiar species was unfortunately lost in the mails, but the characters of the parasite are so distinct that its identification is of less importance. The species is most nearly related to *Laboulbenia (Ceraiomyces) Dahlii*, although it does not penetrate the host by haustoria, and has a quite different appendage. The form of its perithecium, tapering from a very broad base, is very similar, as well as the elongation of cell III–V, which, however, is much more extreme. The branchlets of the appendage which projects far outward at nearly a right angle to the axis of the receptacle, recall those of *L. pectinulifera*, showing the same tendency to produce rounded, short, tooth-like projections from their under sides. This character is not so well marked, however, and more irregular.

Laboulbenia pectinulifera nov. sp.

Quite hyaline below the venter and insertion-cell or becoming faintly brownish, usually slightly curved, especially at the base. Foot normal, large, associated with a slight swelling of the basal cell above it, or, when on the wing, small, associated with a narrow black contact-induration of the abruptly curved base of cell I; cell II of about the same length and often separated by a slight indentation; cells III–V replaced by a single cell, the extremity of which is free on the inner side and externally slightly prominent below the well defined olivaceous insertion-cell; outer appendage strongly divergent, slightly curved outward, consisting of three cells; the basal somewhat narrower; the middle somewhat longer, deeply tinged with olivaceous brown, or slightly reddish; the terminal cell bearing from its broader distal surface a series of branches curved outward in a fan-like tuft, and once or even twice branched; the lower, outer, branches suffused at the base, the rest quite hyaline; all tending to produce unilateral series of from two to five short branchlets, which may be more or less regular and comb-like, or more confused and occasionally developed on both sides; inner appendage consisting of a small hyaline basal cell which may bear two or three short branches, each consisting of a single hyaline cell terminated by a pair of relatively large long brown antheridia. Perithecium slightly inflated above the base, which extends below the insertion-cell, tapering to the rather coarse-lipped apex, the inner lips more prominent and rounded; the upper and lower limits of the two lower and more deeply suffused wall-cells clearly indicated. Spores 35–40 × 3 μ. Perithecia 70–75 × 18–24 μ. Appendage to tips of branches 50–64 μ; the three basal cells 35 μ. Total length to tip of perithecium 100–150 μ.

On the thorax and wing of a sapromyzid fly, *Physogenia* ? Nos. 2662 (Type) and 2748. Kamerun, West Africa.

This species is chiefly remarkable for the spreading tuft of peculiar branches which terminate the deeply suffused, three celled axis of the outer appendage; many of the branchlets bearing on the lower side a more or less well marked series of closely set, blunt outgrowths which give them a comb-like appearance. One or more of these outgrowths may arise also from the upper side, or they may be less regularly developed. The specimens on the thorax of the host are for the most part more slender, with normally developed foot, and somewhat stouter and more uniform basal and subbasal cells, which are distinguished by a slight enlargement, rather than an indentation, at the septum. A few individuals growing at the base of the wing are also somewhat peculiar in that the axis of the appendage is distinctly reddish, and the apex of the perithecium is turned so that it is viewed at right angles to the normal position, the anterior lips projecting conspicuously and almost symmetrically on either side of the posterior, which lie between and project above them. The species is most nearly allied to *L. clavulifera*, but belongs to the *Ceraiomyces*-type, while the last mentioned species has the structure of a typical *Laboulbenia*.

Laboulbenia Psilina nov. sp.

Slightly sigmoid, the venter yellowish brown, rather coarsely punctate, the basal cell paler and punctate, the basal cell of the outer appendage dark olivaceous, the antheridia paler; otherwise nearly hyaline. Basal cell relatively short, abruptly bent above the well developed foot, subbasal cell more than twice as long, slightly broader than both the basal cell below and the receptacle above it, nearly uniform throughout; cells III–V replaced by a single cell, the distal third or less of which is free and slightly divergent, externally nearly straight, and hardly at all prominent below the thick normally blackened insertion-cell. Axis of the outer appendage consisting of three cells; the basal deeply suffused, oblique below; the second larger and faintly suffused, slightly inflated; the upper shorter and bearing distally a crest-like series of branches, from the short basal cells of which two or three somewhat irregular branchlets arise which are about as long as the rest of the appendage. Basal cell of the inner appendage small bearing an inner antheridium directly and a short one-celled branch which is terminated by a second. Cell VI oblique above and below, slightly longer than broad, the cells above it hardly distinguishable. Perithecium divergent, the translucent venter slightly inflated below, and abruptly and clearly distinguished from the hyaline tip and the basal cell region; tapering to the obliquely rounded slightly geniculate apex, which is broader, the inner lips more prominent than the broader obliquely rounded outer ones, and externally suffused; the suffusion extending down to the persistent base of the trichogyne, which remains as a slight prominence. Spores about $28 \times 3\,\mu$. Perithecia $50–55 \times 18\,\mu$. Appendage to tips of branchlets $55–70\,\mu$. Total length $120–140\,\mu$. Subbasal cell $50–62 \times 18\,\mu$.

On the superior surface of the abdomen of a small fly belonging to the Psilidae, probably belonging to the genus *Psila*. No. 2647, Kamerun, W. Africa.

This species, which is of the *Ceraiomyces*-type, is most nearly allied to *L. pectinulifera*. Its general form and coloration, and the character of the branchlets of the appendage are, however, quite different.

Laboulbenia Steleoceri nov. sp.

Pale dirty brownish, perithecium blackish olive brown, its axis and that of the basal cell bent slightly inward. Basal cell somewhat curved, or geniculate, hyaline below and broadly rounded; the small partly black foot lateral and anterior; subbasal cell distinguished by a slight constriction, slightly broader, more than twice as long, distally but slightly broadened, the suffused portions of both cells finely punctate; distinguished by a very broad oblique septum from cell VI: cells III–V replaced by a single, dark olivaceous, outwardly prominent cell. Insertion-cell free on both sides, somewhat broader than long, translucent olivaceous, bearing distally the outer appendage: which is apparently short and simple, its basal cell suffused, hardly larger than the insertion-cell; basal cell of the inner appendage slightly larger, bearing two short branches once or twice branched which bear a small number of large stout antheridia near the base. Cell VI broad, flat, subtriangular, externally prominent; cell VII small triangular, concolorous, externally prominent, both faintly punctate: basal cells broad, flattish concolorous with the cells below. Perithecium nearly opaque, subconical, convergent, externally slightly convex; its base very broad, its apex blunt, abruptly broader; the lips rounded, the outer hyaline and more prominent, the inner suffused, and subtended by a small darker area lying above a rounded paler spot; below which, externally, the tooth-like, opaque, persistent base of the trichogyne projects conspicuously. Perithecium about $50 \times 22\,\mu$ at base $\times 7.5\,\mu$ distally, the apex $\times 9\,\mu$. Cell I, $30 \times 15\,\mu$, cell II $70 \times 16\,\mu$; cell III–V, $14 \times 8\,\mu$. Total length about $150\,\mu$.

On the left wing of *Steleocerus lepidopus* Beck. No. 2328, Gambia River, West Africa.

This peculiar species was found among a small number of flies very kindly collected for me by Dr. Wolbach. Three specimens have been examined, two of which are fully matured. The appendages in all are partly broken and do not reach to the apex of the perithecium. The species belongs to the *Ceraiomyces*-type, with which it corresponds in all respects.

Rhizomyces circinalis nov. sp.

Basal cell constricted below and entering the host by a rhizoidal apparatus; subbasal cell somewhat larger, hardly longer than broad, the two tinged with brownish yellow. Axis of the appendage consisting of about thirty cells, or less, curved inward, distally circinate or helicoid; the basal cell deep reddish brown, sometimes with an abortive branch; the rest pale yellowish, with a tinge of brown; the subbasal smaller and darker than the cells above; which are somewhat longer than broad, except at the circinate extremity, thick walled, each bearing a branch distally and externally which, in the cells above the seventh or eighth, is replaced by a single cell bearing one or more antheridia; the branches, of which there are about seven, all fertile, except that from the subbasal cell which is sometimes sterile, consisting of from one to three cells forming a short divergent axis, and bearing each from one to several straight concolorous antheridia distally and inwardly; the terminal and sometimes the subterminal cells producing externally a vertical series of from two or three to five outcurved, closely set, short, rather stout, brownish, simple branchlets, which are usually slightly geniculate near the middle: the branches replaced in the cells of the main axis above the eighth by a single small cell, from which one or more antheridia arise directly. Stalk-cell of the perithecium terminal, long and stout, nearly uniform, except that the diameter is somewhat less at the base, and distally, where the basal cell region is rather abruptly distinguished; the latter rich dark red amber-brown, the basal cells surrounding the lower third of the ascigerous cavity, their external margins prominent and very thick-walled; the rest of the perithecium concolorous or somewhat darker; the two lower tiers of wall-cells marked by more or less distinct transverse lines; the whole slightly curved, somewhat inflated below, tapering distally to its more or less clearly indicated junction with the paler tip and apex, which taper to a bluntly rounded termination, with hardly distinguished lips; the tip giving rise, from almost its whole inner surface, to a slightly divergent and curved, rather slender, concolorous appendage, which subtends the apex. Spores small and numerous, perhaps about $15 \times 2\,\mu$. Perithecia, including basal cell region, $150 \times 58\,\mu$; stalk-cell $508 \times 28\,\mu$. Receptacle $35 \times 28\,\mu$. Appendage about 275–350 μ, the axis $\times\ 12\,\mu$, the branches, larger, about 40 μ. Total length to tip of perithecium 690 μ.

On the inferior surface of the abdomen of a species of *Diopsis,* near the tip. No. 2330, Gambia River, West Africa, Dr. Wolbach.

A very distinct species allied to *R. ctenophorus,* at once distinguished by its spinose perithecium and circinate or helicoid appendage.

Rhizomyces confusus nov. sp.

Rhizomyces crispatus Thaxter, pro parte. Mem. Am. Acad. Arts and Sci. Vol. XIII, No. 6, p. 323, Plate LII, figs. 19 and 21.

When this species was first described, the material of *R. crispatus* was somewhat scanty, but the examination of a large series has shown that the differences which separate the two, and are indicated in the published figures, are constant and more than sufficient to distinguish them specifically. The present species is differentiated by the characters of its receptacle, appendage and perithecium, which appear to be quite constant, and may be summarized as follows.

Subbasal cell of the receptacle prolonged to form a more or less clearly distinguished, blunt, tooth-like protrusion which projects beyond the base of the stalk-cell of the perithecium, the axis of which makes a considerable angle with that of the receptacle. Appendage more divergent and much longer than that of *R. crispatus*, the branches distinctly shorter and more numerous. Stalk-cell of the perithecium much shorter, stouter; the perithecium uniformly dirty yellowish brown, rather strongly curved outward, the apex blunt, broad, without suffusions or other modification.

This form has been obtained from species of *Diopsis;* No. 859, Berlin Museum, from northern Kamerun, and No. 739, British Museum, from Port Natal.

Abundant material of the typical *R. crispatus* has been examined as follows: Nos. 2302, 2715, 2720, from Kamerun, and also from Port Natal, Usambara and Killimadjaro, East Africa, the last kindly communicated by Dr. Speiser. The species is most readily recognized by its erect stalk-cell and very different perithecium, the tip of which is characteristically modified and colored, as is represented in the original figure; l. c. plate LII, fig. 20.

Rhizomyces cornutus nov. sp.

Receptacle yellowish; the basal cell subhemispherical, penetrating the host by a rhizoidal apparatus; the subbasal cell slightly broader than long, bearing the stalk-cell of the perithecium distally and the appendage distally and laterally. Appendage erect, or slightly divergent; its axis consisting of about twelve cells; the basal small and nearly opaque, the rest becoming yellowish with a brownish tinge, the distal one paler and smaller, all bearing single external branches superposed in a single series, that from the basal cell lacking or abortive; the rest, except at the very tip, fertile, consisting of two cells; a basal bearing above, next the axis, usually two antheridia, and externally a somewhat elongate subbasal cell in which the lumen is nearly obliterated, usually slightly curved inward and bearing externally a series of four or five slightly curved, simple, closely set, rather short and stout yellowish brown branchlets. Stalk-cell elongate, stout, nearly uniform; basal cell region abruptly distinguished, rich amber-brown, concolorous with the perithecium, its cells thick-walled, somewhat prominent, and surrounding the base of the ascigerous cavity; the two lower tiers of wall-cells distinguished by a slight indentation, the corresponding regions slightly inflated and marked by fine transverse lines; the second tier narrower below the well distinguished tip which is more or less symmetrically inflated, forming a rounded collar subtending the clearly distinguished paler apex; which is somewhat longer, very slightly bent outward, bearing a short, stout, bluntly pointed, two-celled, tooth-like outgrowth from the lower half of its inner margin. The whole perithecium, including the basal cell region, slightly curved outward. Perithecia, including basal cell region, 135–140 × 35–40 μ. Stalk-cell 280–350 × 22 μ. Appendage 185–195 μ; the branch-axis 18 μ, the branchlets 18 μ. Receptacle 28 × 20 μ. Total length to tip of perithecium 400–525 μ.

On the inferior tip of the abdomen of *Diopsis* sp. No. 2301, Kamerun, W. Africa.

Allied to *R. circinalis* and *R. gibbosus*, but differing from both in the characters of its perithecium and appendage.

Rhizomyces gracilis nov. sp.

Erect, very long and slender; foot normal. Basal cell of the receptacle broader than long, somewhat smaller and broader than the subbasal, obliquely prominent below the base of the appendage; subbasal cell longer than broad, its axis divergent, distinguished externally by a slight constriction above and below. Appendage consisting of about seventeen hyaline cells, erect, slightly exceeding the tip of the perithecium, its basal cell small and subtriangular, obliquely adjusted to the receptacle, the two cells above it hardly larger, the rest for the most part large, slightly more than twice as long as broad, except one or two of the distal ones; the branches of the appendage similar to those of *R. confusus*, consisting of five or six dark hyaline-tipped, outcurved, closely set branchlets, which arise in a vertical series from a short dark unicellular inwardly hyaline axis, in most cases subtended by a small hyaline cell bearing two or three slender antheridia; the small terminal cell of the axis bearing distally two or three similar erect branchlets. Stalk-cell of the perithecium stout, hyaline, erect, gradually broader distally; the secondary stalk-cell and the basal cells relatively large and well defined, one of the latter (?) extending from the stalk-cell to the base of the perithecium and slightly spiral; perithecium concolorous with the secondary stalk- and basal cells, yellow with a tinge of brown, the wall-cells of the venter- and neck-regions slightly spiral, and transversely punctate, the whole tapering with a slight bend to the bluntly rounded apex. Perithecium 60 × 22 μ; including basal cell region 88 μ. Stalk-cell 284 × 15 μ distally. Receptacle about 25 × 14 μ. Appendage to tip of terminal branchlets 350 μ; its lateral branches about 50 μ. Total length to tip of perithecium 355 μ.

On a species of *Diopsis*, Killimandjaro, East Africa.

This very graceful and distinct species was found in company with *R. crispatus* on a host kindly communicated by Dr. Speiser. It is most nearly allied to *R. confusus*. The branches of the appendage are shorter and less curled, and are more remote, tending to diverge in such a way as to appear grouped in threes. The perithecium of the unique type is not fully mature, and may perhaps become slightly modified with age, although asci are already formed.

Rhizomyces Kamerunus nov. sp.

Cells of the receptacle nearly equal, hardly longer than broad, the subbasal more deeply tinged with brown. Appendage suberect, or usually curved toward the perithecium, its axis indeterminate, consisting of from ten to twenty cells tinged with brown, except the terminal ones; the lower darker, especially the smaller basal and subbasal cells which may be nearly opaque; the cells above them slightly longer than broad and bearing each a branch distally and externally, the upper sterile, the rest bearing from their basal cells a hyaline triangular cell from which two or three long-necked brown antheridia arise; the rest of the branch clavate, blackened, except the inner side of its subhyaline somewhat swollen termination, bearing externally and distally two to five slightly curved branchlets, blackish with hyaline slightly enlarged tips; the successive branches diverging slightly, so that the series as a whole is more or less distinctly two-ranked. Stalk-cell of the perithecium arising terminally from the subbasal cell, usually curved near its base, so that the perithecium diverges more or less strongly, although it is sometimes erect; its base narrower, gradually enlarging to the distal end, subhyaline or becoming tinged above with yellowish brown; the basal cell region well defined, yellowish brown, concolorous with the rather stout perithecium, which is subsymmetrical, somewhat straighter on the outer side, rather evenly inflated throughout, and tapering to the hardly distinguished, blunt or almost truncate tip and apex, a small outer lip often forming a rather abrupt hyaline prominence. Spores about 22 × 2.5 μ. Perithecia 75–80 × 25 μ; stalk-cell 35–50 × 11 μ. Appendage, longest axis, 175 μ; branches 70–100 μ. Receptacle about 22 × 8 μ. Total length to tip of perithecium 140–160 μ.

On the anterior legs of a large black *Diopsis*. No. 2302, Kamerun, W. Africa.

This species is most nearly related to *R. confusus* and is of the same general type, but has little of its graceful appearance owing to the fact that its peculiar branchlets are coarse and more scanty and hardly more than curved at the tips. Owing to a slight divergence in their origin from successive cells they tend to be two-ranked. The perithecium also differs in being straight, or nearly so; and its stalk-cell is not subtended by the prominence characteristic of *R. confusus*. The axis of the appendage resembles that of an undeveloped *Rhachomyces*.

Ilytheomyces falcatus nov. sp.

More or less conspicuously curved throughout. Basal cell abruptly prominent below the insertion of the appendage, almost wholly involved by the suffusion of the foot; subbasal cell larger, lying obliquely beside and above it, hyaline. Axis of appendage divergent, consisting of four or five hardly distinguishable cells, blackened externally; the subbasal cell abruptly broader than the basal, and bearing on its inner side the relatively large partly free androphorous cell from which arises a single antheridium and a well developed branch, usually bearing several stout curved hyaline-tipped branchlets; the remaining cells of the axis bearing externally blackish brown, outcurved, hyaline-tipped branches, and on the upper side a few stout curved hyaline branches, tinged with brown and more slender below. Stalk-cell of the perithecium hyaline, rather short, distally obliquely separated from the much longer secondary stalk-cell, which lies parallel to the narrower inner basal cell: the latter of about the same length, but reaching higher, its narrow base in contact with the stalk-cell. The stalk- and basal cell regions about as long as the rest of the perithecium, the two lower tiers of wall-cells and the third (tip) distinguished by very slight elevations, purplish brown, the surface mottled-granular, the tip slightly darker; the apex slightly narrower, paler, tapering very slightly; the outer lip-cell darker purplish brown, spreading slightly distally to form an oblique snout-like termination. Spores about 25 × 2.5 μ. Perithecium 55–68 × 15–18 μ; stalk- and basal cell region 35–50 × 15 μ. Appendage about 50 μ, its longest branchlets 40 × 6.5 μ. Total length to tip of perithecium 100–120 μ.

On the superior surface of the abdomen, near the tip, of *Ilythea* sp. No. 2643, Kamerun, West Africa.

This form is not nearly allied to any of the described species. Among those which, as in this instance, lack a trigger organ, *Ilytheomyces major* perhaps approaches it most nearly; but it is very clearly distinguished by the peculiar form of its punctate perithecium and its snout like termination formed by the protrusion of the wholly suffused outer lip-cell. The specimens examined are mostly paired so that the details of the appendages, two of which are thus juxtaposed, is difficult to make out in detail. The upper branchlets are peculiar for their narrower deeply suffused bases, and curved or winding hyaline terminations. The androphorous cell is unusually large and prominent, as is the sterile branch developed from it.

Ilytheomyces Kamerunensis nov. sp.

Basal cell relatively large, wholly hyaline, four sided, bulging strongly externally; subbasal cell subtriangular, much smaller, bulging somewhat externally and becoming edged with black below and externally, the blackening continuous with the foot. Appendage much as in *I. Sarawakensis*, the branchlets slightly stouter, the basal and subbasal cells much smaller and indistinguishable, the antheridia paired, stout, straight and brown; several well developed secondary branches arising from the upper side of the successive cells of the main axis, which is somewhat more divergent. Stalk-cell of the perithecium small and narrow, wholly opaque; the basal cell region above it hyaline, abruptly much broader, monstrously developed, becoming much longer than the perithecium proper; slightly curved outward, of nearly uniform width, or slightly broader distally; the secondary stalk-cell black-edged just above the much narrower stalk-cell, occupying approximately the lower two thirds of the region, and distinguished from the outer basal cell above by a well defined indentation; the inner basal cell extending to its base, its upper half concealed by a slight general twist of the region which is continued by the body of the perithecium; the latter purplish brown deeper above, with darker longitudinal lines which indicate corresponding elevations of the wall-cells of the lower tier, the lumina of which, when they appear at the margins, are distinct; the tip darker, not distinguished; the apex abruptly narrower; the lips hyaline and somewhat irregular; the trigger-appendage relatively stout, narrow and geniculate opposite the lips, then erect and curved outward distally, reddish brown, with a blunt hyaline tip; the whole perithecium proper rather abruptly bent in the middle. Spores about $20 \times 2.5\,\mu$. Perithecia $63–70 \times 17\,\mu$; trigger-appendage $100–110 \times 8\,\mu$; basal cell region $90–100 \times 18–20\,\mu$; stalk-cell of perithecium $8 \times 8\,\mu$. Receptacle $15\,\mu$. Appendage $56–68\,\mu$. Total length to tip of perithecium $140–175\,\mu$.

On the inferior surface of the abdomen of *Ilythea* sp. No. 2643, Kamerun.

This species is remarkable for the monstrous development of the basal cell region and is quite distinct from *I. Sarawakensis*, its nearest ally, in several other respects. The wall-cells of the lower tier of the perithecium are each slightly folded outward, forming a rather narrow elevation indicated at the sides by a clearly defined lumen and between the margins by two parallel lines, the included area faintly punctate, but not conspicuously distinguished.

Ilytheomyces Sarawakensis nov. sp.

Similar to *I. elegans.* Lower portion of the basal cell combined with the foot and indistinguishable from it, opaque black-brown, except its perfectly hyaline upper anterior angle, which bulges out abruptly below the insertion of the appendage: subbasal cell wholly opaque, not prominent externally, the upper half of its inner margin in contact with the base of the appendage, its base horizontal. Axis of appendage strongly divergent and slightly curved outward; the basal and subbasal cells opaque and indistinguishable; the androphorous cell bearing two straight, paired, brown antheridia, one of which may be replaced by one or more erect sterile branches; the third cell usually producing a well developed branch on the upper side, the base of which lies close against the base of the antheridia, its axis consisting of four or five cells each of which bears from two to three branchlets which, together with those arising from both sides of the main axis above it, form a rather dense tuft; the outer branches of the main axis deeply blackened, the blackening extending to a distal point where it is obliquely separated from the subvesicular hyaline tip. Stalk-cell of the perithecium opaque like the subbasal cell below it, short, distally broader; secondary stalk-cell hyaline above and within, its basal half or third distinguished by an obliquely separated, subtriangular opaque area; basal cells quite hyaline, or the strongly convex wall of the smaller outer one slightly brownish; the inner very large and bulging toward the appendage, that on the left even intruded between the adjacent antheridia and branchlets of the appendage, that on the right less prominent. Perithecium slightly curved outward, the lower part of the ascigerous cavity surrounded by the basal cells, the outer lower wall-cell prominent, with more or less distinct lumen; the outer smaller half of the region of the two first tiers hyaline and obliquely separated, owing to a slight twist, from the larger inner half, which is increasingly suffused with slightly reddish brown from below up; the tip somewhat broader than long, distinguished by its uniformly somewhat darker color, especially its outer margin, which forms the base of the well developed trigger-organ, developed from the outer lip-cell, which is stout, its base erect, geniculate opposite the lips, thence erect, but soon curved rather abruptly outward and somewhat stouter, wholly brown, deeper below; the hyaline tip tapering slightly: the apex longer and paler than the tip, blunt with perfectly hyaline rather prominent vesicular lips. Spores about $22 \times 2.5\,\mu$. Perithecia to base of ascigerous cavity $50–75 \times 14–20\,\mu$; trigger-appendage $50–75 \times 6\,\mu$; basal and stalk-cell region $20–35 \times 18–22\,\mu$. Receptacle $10 \times 12\,\mu$. Appendage $50–60\,\mu$. Total length to tip of perithecium $100–120\,\mu$.

On the inferior surface of the abdomen of *Ilythea* sp. No. 2132, Sarawak, Borneo.

This species is very closely allied to *I. elegans* of which it may prove to be only a variety. The subbasal cell is wholly opaque from the first, and uniform with the stalk-cell, which does not show the same abrupt differentiation; the stalk and basal cell region is greatly developed and very broad, the perithecium is shorter and broader. A large branch arises from the axis of the appendage on the upper side just beside the large straight antheridium, which is usually almost as highly developed as the axis itself; the external branches being longer and less deeply blackened. The branchlets as a whole are very copious and not closely appressed. A dozen or more specimens have been examined which show no essential variations.

Ilytheomyces simplex nov. sp.

Perithecium and appendage dark brown. Basal cell of the receptacle united to the foot, minute, hardly distinguishable, except its hyaline upper edge: subbasal cell small, hyaline. Appendage stout, subclavate, with a short terminal abortive branch; its axis consisting of five cells of somewhat unequal size; a small androphorous cell obliquely separated from the second on the inner side; in the types bearing only a single short branch bent downward, a similar sterile branch, arising from the cell above, runs parallel to it. Stalk-cell of the perithecium short and stout, hyaline, the basal cell region hyaline, or tinged with brownish above; the secondary stalk-cell somewhat prominent externally. Perithecium dark brown, asymmetrical, distally bent, somewhat inflated below in the region of the two lower tiers of wall-cells; the third tier (tip) short, somewhat darker; the apex abruptly very slightly narrower, slightly paler; the termination broad and somewhat flattened, the lips appressed, not prominent. Spores $15 \times 2\,\mu$. Perithecia, including basal cell region, $60 \times 18\,\mu$. Appendage $35 \times 8\,\mu$. Total length 90–97 μ.

On the legs of a species of *Ilythea*. No. 2131, Sarawak, Borneo.

This species is smaller than *I. anomalus* to which it is very nearly allied, and differs in the character of its appendage which is more clavate, and produces no external abortive branch; while on its inner side a short relatively slender simple branch arises from the third cell, only, bending somewhat downward beside a similar branch which arises from the androphorous cell. No antheridium appears to be developed from the latter in the two mature individuals examined. The perithecium is somewhat different in shape and structure, the stalk cell and basal cells much less well developed than in *I. anomalus*. An abortive male (?) individual is united to the foot of one specimen.

On Agromyzidae.

Stigmatomyces asymmetricus nov. sp.

Receptacle stout, thick-walled, tapering continuously to the apex of the pointed foot; the basal cell half or two thirds as long as the subbasal, rather strongly curved and paler, or hyaline; the subbasal cell becoming reddish yellow with rough granulation, especially distally, both septa horizontal. Stalk-cell of the appendage reddish amber-colored, not overlapping the receptacle, about twice as long as broad, somewhat prominently rounded below the deeply colored basal cell of the appendage; which is hardly longer than broad, its axis consisting of four successively smaller cells; those above the basal paler, bearing each two antheridia, except the fourth, which bears but one, and is succeeded by a second which is terminal; the antheridia relatively short and stout, the necks turned usually sideways. Stalk-cell of the perithecium concolorous with that of the appendage, as are the cells above it, broader than long, distally in contact with the broad base of the inner basal cell; secondary stalk-cell wholly external to it, somewhat prominent, half as large, subtriangular, obliquely separated from it, as well as from the outer basal cell above; the latter more deeply colored, and prominent below the large deeply colored venter; which is asymmetrical, about twice as long as broad, distally broader, externally less convex, and distally conspicuously prominent, finely rough-granular, the wall-cells separated by slight furrows; the inner margin more or less evenly convex, the remainder of the perithecium almost exactly as long as the venter; the paler, abruptly distinguished neck tapering very slightly from its spreading base; the tip clearly distinguished, abruptly slightly narrower, tapering very slightly, the apex not distinguished, short, subhyaline, with slightly oblique inconspicuous nearly symmetrical papillate lips. Spores about $25 \times 2.5\,\mu$. Perithecia $150–180 \times 40–45\,\mu$. Receptacle $85–100 \times 25–28\,\mu$. Appendage $46 \times 10\,\mu$; its stalk-cell $25 \times 10\,\mu$. Total length $250–280\,\mu$.

On the abdomen of a small fly belonging to the Agromyzidae. Kamerun, No. 2283.

A species apparently allied to *S. Scaptomyzae*, distinguished by the peculiar modification of the subbasal cell of the receptacle, and the granular roughening of the venter of the perithecium, both of which characters become more prominent in older specimens.

Stigmatomyces divergens nov. sp.

Subsigmoid, rather stout, rather dark red amber-brown, except the hyaline receptacle; which is shorter than the perithecium, the cells of about equal length, slightly curved. Basal cell of the appendage short and stout, strongly convex externally, deeply suffused with reddish brown, separated by a deep external constriction from the narrow base of the basal cell of the appendage, the axis of which consists of four cells; the basal about as broad as long, deeply suffused, bearing no antheridia; the three others bearing each two; the series surmounted by two additional ones, the upper with a stout spine; the whole appendage relatively short and stout, diverging from the perithecium and free to its base; the antheridia turned sidewise, and distinctly tinged with brownish yellow, like the cells which bear them. Stalk-cell of the perithecium broader than long, the secondary stalk-cell much smaller, as are the basal cells; venter of the perithecium longer than the distal portion, its base hardly lower than the insertion of the appendage, evenly inflated, or more convex externally, merging distally with the neck; which is not abruptly distinguished, its outline more or less concave on both sides; the tip rather abruptly distinguished, tapering to the undifferentiated apex, which is five-lobed, the lobes rather prominent and somewhat irregular. Spores about $25 \times 3\ \mu$. Perithecia $155–170 \times 42–50\ \mu$. Appendage $42–48 \times 4\ \mu$. Receptacle $80–100 \times 28\ \mu$. Total length $250–280\ \mu$.

On the head and at the base of the wing of a small dull fly belonging to the Agromyzidae. No. 2730, Kamerun, West Africa.

Although this species is not otherwise peculiar, it seems well distinguished by its somewhat divergent, short, stout appendage, the base of which is so narrow as to appear constricted, the basal cell dark colored and narrow, the cells above it much broader. It is perhaps more nearly related to *S. Drapetis* than to any other described form.

On Anthomyidae.

Stigmatomyces macrandrus nov. sp.

Long and slender, straw-colored above the hyaline receptacle, with faint brownish shades near the base of the venter. Receptacle usually curved, of nearly uniform diameter throughout, the basal cell sometimes slightly broader, less than half as long as the subbasal, its base broad and rounded beside the small sublateral foot. Stalk-cell of the appendage slightly misplaced laterally on the right side, nearly twice as long as broad, externally rounded, distally, below the rather broad insertion. Appendage very slightly divergent, very long, reaching some distance beyond the venter, slender, tapering, slightly curved outward at the extremity; its axis consisting of seven or eight successively smaller cells; the basal cell slightly tinged with brown, somewhat longer than broad, the terminal cell minute, bearing a single antheridium, which is surmounted by a second terminating the appendage; all the remaining cells bearing two, obliquely superposed;

the necks somewhat curved, mostly free, relatively long and forming two incomplete rows. Primary and secondary stalk-cells of the perithecium subequal, so placed that they appear to overlap on the right and left sides, respectively; the basal cells relatively small, the outer slightly prominent. Venter straight, its axis coincident with that of the stalk-cell region and receptacle, slightly broader near the base; the neck concolorous, rather stout, slightly curved, nearly uniform throughout, very slightly enlarged at its junction with the abruptly slightly narrower tip; the apex somewhat shorter, hardly tapering, distinctly bent outward, the flat blunt termination with hardly prominent lips. Spores (in perithecia) about 30–35 × 3.5 μ. Perithecia 190 μ, the venter 70–75 × 30–35 μ. Appendage 100–110 × 16 μ. Receptacle 210–245 × 21 μ. Total length to tip of perithecium 385–450 μ.

On a dark fly belonging to an undetermined genus of the Anthomyidae. No. 2638, Kamerun.

This species is closely allied to *S. dubius*. None of the specimens, which include a number of very young individuals, show any signs of the conspicuous and permanent spine found in the last mentioned species. The snout-like, curved apex of the perithecium and the very slight enlargement below the tip, together with the minute, hardly indicated lips, seem further to distinguish it.

Stigmatomyces Limnophorae Thaxter.

The typical form of this species has been found on several flies from Kamerun belonging to the Anthomyidae, Nos. 2640 and 2646 as well as others, while a large form that appears also to be identical with this species and may measure nearly 800 μ in length has been received from Mr. Jacobson and was collected by him in Sumatra on *Lucilia* (?) and a similar form from the Philippines on *Lucilia dux* has been received from Mr. Banks. A closely allied form, which does not seem referable to any of the variations of *S. Limnophorae*, has been met with on an anthomyid fly from Kamerun and may be distinguished as follows.

Stigmatomyces tortilis nov. sp.

Form comparatively short and stout, slightly curved throughout, especially the neck, uniformly dirty yellowish brown above the hyaline receptacle; the subbasal cell slightly longer than the basal which is but slightly narrower at its base and distally often slightly broader than the base of the subbasal cell. Stalk-cell of the appendage overlapping the subbasal cell slightly if at all, externally convex, more so distally, but not abruptly distinguished from the basal cell of the appendage; which is hardly more than twice as long as broad, the axis curved inward, with the antheridia external, and consisting of five subhyaline cells hardly longer than broad, except the basal, and bearing each two closely associated antheridia, the fifth bearing but one, a terminal single antheridium ending the series. Stalk-cell of the perithecium broader than long, more than half enclosed by the overlapping of the secondary stalk-cell on the left side and of the basal cell which lies above it on the right side; the basal cells subequal, somewhat prominent, as is the secondary stalk-cell; venter broader and slightly inflated below, tapering slightly; the wall-cells becoming finely granular; distally slightly prominent, the curved broad neck of about the same length, the wall-cells of both distinguished by a rather broad deep spiral furrow, continuous in the two, describing a complete turn ending at the abruptly narrower tip, which is subtended by a slight enlargement; apex not distinguished from the tip, the two slightly inflated, distally subtruncate, with somewhat irregular lips, the inner more prominent. Spores about $25 \times 3.5\,\mu$. Perithecia 140×32–$35\,\mu$. Appendage $60\,\mu$, its basal cell $14 \times 6\,\mu$. Receptacle 80–90×18–$21\,\mu$. Total length 225–$250\,\mu$.

On the abdomen of a fly belonging to the Anthomyidae. Kamerun, No. 2639.

Ten individuals of this form have been examined, which were found growing on the superior surface of the abdomen, where *S. Limnophorae* usually occurs, and where it reaches its most typical development. The differences which distinguish the present species are thus evidently not due to position of growth. The deep spreading furrows which traverse the venter and neck, and the strong curvature of the latter give it a very different appearance. Unlike *S. Limnophorae*, the appendage curves inward, and the antheridia are directed outward. The appendage is also more compact than is usually the case in *S. Limnophora*, although it is of the same general type.

On Borboridae

Stigmatomyces affinis nov. sp.

Hyaline below, pale yellowish above the stalk-cells; of rigid habit, straight or but slightly curved. Receptacle tapering from apex to base, the basal cell mostly somewhat longer, a smoky brown suffusion just above the small foot. Stalk-cells of the appendage and perithecium lying side by side in a horizontal series, not differing greatly in size, the secondary stalk-cell slightly smaller and higher; that of the appendage strongly rounded outward below the insertion, otherwise nearly straight externally; the axis of the appendage externally convex, consisting of usually eight cells; which are externally convex, somewhat obliquely superposed, and similar, except the small distal and the broader flattened amber-brown basal cell: the antheridia appressed, turned inward or sidewise, one from each cell (or two from the lower?); the upper three or four usually proliferating into short, stout, septate, simple filaments. Basal cells of the perithecium similar, extending above the base of the ascigerous cavity, the inner not extending lower than the outer: venter rather short and stout, more or less abruptly inflated just below the middle, above which it is concave below four variously conspicuous protrusions corresponding to the extremities of its four wall-cells; the neck thus abruptly differentiated, stout, tapering throughout to the short, abruptly slightly narrower tip and apex; the latter externally concave below a slight externally divergent, rounded termination, formed by two lip-cells, and subtended on the inner side by two papillae. Spores about $25 \times 3.5\,\mu$ (in perithecium). Perithecia $95–105 \times 28–32\,\mu$. Appendage about $50\,\mu$. Receptacle $35–50 \times 16\,\mu$. Total length $150–175\,\mu$.

On a minute species of *Limosina*. No. 2290, Kamerun, West Africa.

This species is most nearly allied to *S. Papuanus*, but seems clearly distinguished by the character of its perithecium and the position of its stalk-cells. The apex of the perithecium is similar to that of *S. papuanus*, but its terminal projection is relatively smaller, shorter and more rounded, and the subtending inner papillae are less prominent. *Stigmatomyces Platensis* Speg. (Revision de las Laboulbeniales Argentines, p. 677, fig. 208) approaches this species very closely but the figure and description are hardly sufficiently detailed to make an exact comparison. The two may prove variations of a single species.

Stigmatomyces Borbori nov. sp.

Basal cell of the receptacle tapering below or constricted in the mid-region, the subbasal cell broad and distinctly longer, of nearly uniform diameter, the margins somewhat convex. Stalk-cell of the appendage small, broader than long, slightly convex externally, the insertion relatively broad, lying opposite the middle of the primary stalk-cell. Axis of the appendage usually consisting of six cells; the basal contrasting yellowish brown, broader than long, nearly symmetrical; the rest hyaline, successively slightly smaller, externally abruptly convex, irregularly and broadly elliptical in outline, their axes horizontal, or but slightly oblique; the basal and subbasal cell bearing each four superposed antheridia, the third and fourth each three, all borne on the inner side of the appendage, obliquely superposed, and directed to the right; the fifth cell small, and associated with two abortive antheridia, one of them terminal, the tips of which are imperforate and vesicular. Stalk-cell of the perithecium free on both sides, longer than broad, distally separated obliquely from the secondary stalk-cell, which is about as long; the outer basal cell overlapping the ascigerous cavity throughout its length, and ending in an abrupt elevation a short distance below the middle of the body of the venter; the inner large and extending somewhat above the base of the ascigerous cavity, ending in a prominence similar to that of the outer, but much lower: the whole basal and stalk-cell region forming a well developed stalk of nearly uniform diameter, or with somewhat convex margins, the axis of which diverges from that of the receptacle and appendage, and coincides with that of the perithecium: venter yellowish, straight, slightly inflated; the wall-cells with a slight twist which involves the neck, ending in distinct elevations below which the margins are slightly concave, and clearly distinguishing the slightly spreading base of the hyaline, slightly curved neck; which tapers slightly, and is distinctly bent at its junction with the tip; the latter yellowish brown; the apex rather abruptly distinguished externally, distally relatively broad, oblique, and externally prominent; the lip-cells not individually distinguished. Spores $35 \times 4.5\,\mu$. Perithecia $110–120 \times 35\,\mu$. Appendage, including antheridia $56 \times 25\,\mu$. Receptacle $65–68 \times 24\,\mu$. Total length to tip of perithecium $200–240\,\mu$.

On *Borborus* sp. No. 2732, Kamerun, West Africa.

A species most nearly related to *S. Borboridinus* from which it differs in its more highly developed appendage, differently arranged stalk-cells, and by the oblique termination of its perithecium. The basal cells of the perithecium are also peculiar, ending in a small abrupt protrusion, the inner cell lying almost wholly against the ascigerous cavity.

Stigmatomyces Borboridinus nov. sp.

Receptacle hyaline, the basal cell tapering to a narrow base, broader distally than the base of the subbasal cell; which is slightly more than half as long, short and broad, its margins somewhat convex. Stalk-cell of the appendage relatively short, its broad base somewhat oblique; externally oblique below the broad insertion, which lies opposite the upper end of the primary stalk-cell. Appendage consisting of three clearly defined yellowish brown cells, the basal somewhat darker and more reddish, slightly longer than broad, the subbasal smaller, more strongly convex externally, somewhat broader than long; both bearing three superposed relatively large antheridia on the inner side, their stout relatively long curved necks turned to the right, except the uppermost; the third cell smaller than the subbasal, somewhat oblique, followed by three antheridia which terminate the appendage; the distal, outer, one sometimes replaced by a small permanently sterile cell. Stalk-cell of the perithecium smaller than the cells above it, very obliquely separated from the secondary stalk-cell, which is about as large and long as the inner basal cell; the outer basal cell large, overlapping the ascigerous cavity, and twice prominent externally below the venter; the whole region forming a stout, well defined stalk. Venter, which comprises about half the total length of the perithecium and its stalk, pale brownish yellow, diverging at an angle of about 45° from the common axis of the receptacle and appendage; the former broader distally, hardly inflated; the wall-cells prominent and ending in conspicuous rounded projections, which abruptly distinguish the slightly spreading base of the relatively stout, nearly hyaline, short neck; the tip distinctly tinged with brownish yellow, well distinguished by a general inflation, its margins almost symmetrically convex, tapering distally to the short broad apex, the broad termination of which is almost symmetrically truncate, or slightly rounded, without projecting lips. Spores $36 \times 5.5\,\mu$. Perithecia $100–120 \times 28–32\,\mu$; the whole stalk-part, including the primary stalk-cell which is free only externally at its base, $35\,\mu$ by $20\,\mu$ above, by $14\,\mu$ below. Appendage $42 \times 22\,\mu$ including tips of antheridia. Receptacle $50–64 \times 17–20\,\mu$ distally. Total length to tip of perithecium $190–210\,\mu$.

On the legs of a fly belonging to the genus *Borborus,* or closely allied. No. 2734, Kamerun, West Africa.

This species, although related to the group of forms which occur on the borborid genus *Limosina,* differs in the characters of its appendage which closely resembles that of *S. Borbori,* although somewhat less highly developed. The nine large antheridia are closely grouped, with prominent necks. The perithecium is straight, or very slightly bent distally, its axis coincident with that of the basal and stalk-cell portion which diverges at a characteristic angle from that of the receptacle and appendage. Ten individuals have been examined.

Stigmatomyces contortus nov. sp.

Hyaline; the stalk-cells, and apparently the inner basal cell, forming a rather slender perithecial stalk, against which the receptacle is abruptly bent, so that the foot lies near the base of the venter, the appendage projecting free from the point of abrupt curvature. Basal cell of the receptacle abruptly curved and tapering somewhat below, the subbasal somewhat longer and stouter. Stalk-cell of the appendage viewed endwise, its axis tinged with brown, projecting upward and backward away from the receptacle and perithecial stalk: (appendage in young individuals borne on a stalk-cell which is rounded and nearly isodiametric, strongly convex below the insertion): consisting of four axis-cells, the basal rounded, somewhat flattened, brown, bearing a small somewhat flattened androphorous cell, which occupies most of its distal surface and bears three antheridia, the rest of the axis diverging from it at an angle of more than 45°, the three successively smaller cells very obliquely superposed, strongly convex externally, and separated by deep constrictions; the lowest (subbasal) but slightly united to the basal, bearing two antheridia, the second two, and the third one; which is surmounted by a normal antheridium, while a small terminal cell also functions as an antheridium by developing a neck from the middle of its inner side at right angles to its long axis. The stalk-cells, and apparently the inner of the basal cells of the perithecium, forming a relatively slender perithecial stalk, of nearly uniform diameter, but irregular outline, which is separated by a well marked constriction from the base of the venter: the latter broadly inflated below, owing largely to the overlapping basal cells; which extend upward beside it for some distance, tapering to the hardly distinguished, broad, irregular, slightly curved neck;

the tip distinguished by a slight indentation, and subtended on the concave side by a stout, blunt, irregular, tapering outgrowth from one of the neck wall-cells; the apex hardly distinguished, short, blunt bent slightly upward, one of the lip-cells prolonged to form a well developed stout, terminal appendage of nearly uniform diameter, slightly geniculate at its base, and distally roundish-truncate. Spores $32 \times 3.5\,\mu$. Perithecia $110 \times 35\,\mu$; its stalk-portion $38 \times 17\,\mu$; its terminal appendage $20 \times 8\,\mu$; the lateral one $18 \times 14\,\mu$ at base. Receptacle $45–50 \times 15\,\mu$. Appendage in young individuals about $40 \times 9\,\mu$.

On the wings of *Borborus* sp., or a genus closely allied. No. 2732, Kamerun, West Africa.

This species is quite unique, owing not only to the fact that it is abruptly bent upon itself, but to the presence of two outgrowths from the perithecium. Three fully mature individuals have been examined and numerous younger specimens.

Stigmatomyces divaricatus nov. sp.

Rather long and slender with irregular outline, nearly hyaline, the appendage and the perithecium, with its stalk, almost symmetrically divergent at somewhat more than a right angle from the receptacle; which is usually more or less uniform in diameter, broader at the septum, the basal cell sometimes hardly half as long as the subbasal, usually rather strongly curved below. Stalk-cell of the perithecium relatively short, the base broad, somewhat oblique, the distal half free, broader and usually symmetrically convex; the appendage consisting of about six cells; the basal pale yellowish brown, sometimes twice or even three times as long as broad, and of uniform diameter, or somewhat broader distally: the three following cells similar, but successively considerably smaller, separated by constrictions: the narrow subbasal cell twice as long as broad; usually slightly concave externally; the one or two small distal cells somewhat irregular, the uppermost sterile: the basal and subbasal cells bearing each three, the third and fourth each two, antheridia; those above the basal cell subtended by a rounded cell which occupies almost the total diameter of the axis; the fifth cell followed by two small abortive antheridia which separate it from a small sterile terminal cell; the antheridia relatively rather small, directed inward and to the right, their necks somewhat irregularly divergent. Stalk-cell of the perithecium united to the lower half of that of the appendage, but otherwise wholly free on both sides; sometimes nearly twice as long as broad, externally slightly concave, prominent below the outer basal cell, which is in contact throughout with the base of the ascigerous cavity, its apex forming a distinct prominence; the inner long and narrow, ending somewhat lower in a similar prominence and extending down to the stalk-cell. Venter irregular, slightly inflated, the wall-cells ending distally in distinct prominences, and showing a slight twist which involves the neck and tip: the neck relatively stout, slightly curved, hardly distinguished, except by the subtending prominences; the tip subtended by slight depressions on either side, its margins convex, abruptly so on the inner side, so that the short apex is subtended by a rather prominent hunch; distal margin of the apex broad, outwardly oblique, and nearly straight, the lip-edges not at all prominent. Spores $40 \times 5\,\mu$. Perithecia $120–135 \times 28–32\,\mu$; the stalk-portion about $68 \times 18\,\mu$. Appendage $75–86\,\mu$, the stalk-cell $18 \times 14\,\mu$. Receptacle $112–130 \times 18–24\,\mu$. Total length $280–315\,\mu$.

On *Borborus* sp. No. 2732, Kamerun, W. Africa.

This species is very closely allied to *S. Borbori,* although very unlike it in general appearance, and may possibly prove to be an abnormal development of the latter. Apart from its elongate form, the chief difference is found in the appendage, the principal cells of which are longer than broad, instead of the reverse, the basal separating a well marked androphorous cell bearing three superposed antheridia. About a dozen examples have been examined, none of which seem to vary toward *S. Borbori.* The hosts appear to belong to the same undetermined species of *Borborus.*

Stigmatomyces distortus nov. sp.

Strongly curved throughout, hyaline becoming tinged with pale yellowish, the venter darker brownish yellow, the appendage dull brownish below. Receptacle very slightly broader at the horizontal septum, the basal somewhat longer than the subbasal cell, slightly narrower above the foot, the subbasal broader distally, slightly concave on one or both sides. Stalk-cell of the appendage short, slightly broader distally than the broad insertion, which lies hardly higher than the distal margin of the perithecial stalk-cell. The appendage turned obliquely across the basal cell region; consisting of four persistent cells, the two lower relatively large, subequal, brownish, terminated by one or two small evanescent hyaline cells (or antheridia ?); the outer margin nearly straight, the antheridia single appressed. Stalk-cell of the perithecium squarish, about as large as the stalk-cell of the appendage which lies beside it, hardly overlapped by the externally convex and somewhat longer secondary stalk-cell, below which it is somewhat prominent, in distal contact with the base of the vertically elongate narrow inner basal cell; the three external cells of the region separated by distinct indentations, the basal cell region abruptly somewhat narrower; venter somewhat asymmetrical, broader distally where it is usually more prominent, or bears an abrupt elevation on the inner side, abruptly distinguishing the distal portion, which is irregularly bent in a subsigmoid curve; the neck, tip and apex not distinguished, tapering distally, and ending in a short, bluntly rounded, finger-like projection formed on the inner side by one of the lip-cells, the others forming slight prominences below it, irregularly placed. Spores 34 × 3.5 μ. Perithecia 85–100 × 26–28 μ, its projection 10 × 5 μ. Receptacle 40–50 × 14 μ. Appendage about 50 μ. Total length about 150 μ.

On the head of *Limosina punctipennis* Wied. No. 2653, Kamerun, West Africa.

This species does not correspond closely to any of the other forms which occur on Borboridae, and is well distinguished by its strongly arcuate habit and terminal process. The cells of the appendage are not externally convex, and in all but a few of the specimens examined only the four lower cells remain. The distal portion of the appendage appears to become rapidly disorganized, and where it still persists it is not clear which of the cells present are axis-cells and which are antheridia.

Stigmatomyces laticollis nov. sp.

Nearly hyaline, the perithecia slightly suffused. Receptacle relatively short, the cells subequal, separated by a slightly oblique septum; the basal somewhat narrower below, its anterior margin distally rather strongly convex, its axis forming a slight angle with that of the subbasal cell. Stalk-cell of the appendage somewhat larger than that of the perithecium which lies beside it; externally slightly convex throughout, more strongly so below the narrow insertion which lies slightly higher than the end of the primary stalk-cell. Axis of the appendage consisting of about seven to nine cells; the basal small, brown, flattened, distally broader; the subbasal nearly as large or even larger, externally somewhat convex, the rest successively somewhat smaller and externally abruptly convex, somewhat obliquely superposed; two or three of the terminal ones slightly proliferous, the rest bearing appressed antheridia, usually turned inward. Primary stalk-cell of the perithecium somewhat exceeded above and below by that of the appendage; secondary stalk-cell subtriangular, placed somewhat higher, and obliquely separated; the basal cells about as large, the outer often abruptly convex externally: venter asymmetrical, distally broader; the wall-cells with a distinct spiral twist, distally cushion-like, and forming broad prominences, the outer lower: the distal portion of the perithecium undifferentiated, stout, of nearly uniform diameter throughout, the broad bluntly rounded apex bent outward. Spores about $18 \times 2.5\ \mu$. Perithecia $100–105 \times 28–32\ \mu$ (venter) $\times\ 14\ \mu$ (distal portion). Appendage about $40–50\ \mu$. Receptacle $40–50\ \mu$. Total length to tip of perithecium $150–175\ \mu$.

On tip of abdomen of *Limosina* sp. No. 2739, Kamerun, W. Africa.

A species somewhat similar to *S. affinis* in the conformation of its venter, but differing in its longer basal cell region, and stout uniform distal portion, ending in a curved bluntly rounded broad apex.

Stigmatomyces Limosinoides nov. sp.

Nearly hyaline or yellowish, with a slight general sigmoid curvature, the perithecium tinged with yellowish brown. Receptacle rather long, curved below, the convexity anterior; the basal cell tapering slightly to the faintly suffused yellowish base; the subbasal cell longer stouter, distally more or less distinctly inflated below the two parallel vertically elongated stalk-cells, the combined bases of which are somewhat narrower. Stalk-cell of the appendage more than twice as long as broad, slightly longer than that of the perithecium, rather prominently rounded below the insertion, which lies slightly higher than the end of the perithecial stalk-cell: the axis of the appendage tapering, consisting of six to eight cells, the basal small, short, clear amber-brown, the rest rounded, somewhat flattened, strongly convex externally, successively smaller, all but the two or three terminal ones bearing appressed antheridia, the lower superposed in pairs; the uppermost cells small and sterile. Secondary stalk-cell about twice as long as broad, similar to the primary, but slightly shorter, lying wholly above it, its base and that of the inner basal cell coincident and slightly oblique: basal cells relatively large, surrounding the rather long narrow base of the ascigerous cavity; the inner somewhat larger than the primary stalk-cell, to the upper half of which it is somewhat obliquely united; the outer larger, lying wholly above the secondary stalk-cell; which is somewhat smaller, externally convex; the stalk- and basal cells forming an erect or slightly divergent stalk-region, narrower below and distally broader than the venter of the perithecium. Venter yellowish brown, nearly symmetrical, subelliptical, thick-walled, erect, or slightly tilted inward; the neck broad, not abruptly distinguished, longer than the venter, tapering but slightly; the short tip sometimes slightly inflated, and distinguished by an inconspicuous external depression; the apex subtruncate, abruptly compressed below the hyaline, somewhat irregularly prominent, small, papillate lips. Spores $25 \times 3.5\,\mu$. Perithecia $110–125 \times 35–42\,\mu$. Receptacle $100–130 \times 18–22\,\mu$. Appendage $50–60\,\mu$. Total length $225–300\,\mu$.

On the posterior legs of *Limosina punctipennis* Wied. No. 2133 and 2130, Sarawak, Borneo.

This species is more nearly related to *S. Papuanus,* from which it is at once distinguished by its short stout neck and broad blunt termination. What appears to be a variety of the same form was also obtained from the same locality (No. 2185) on the abdomen of a minute species of *Limosina,* several infested specimens of which have been examined. This variety is much smaller, measuring from 150–175 μ; the spores about $18 \times 2.5\,\mu$. The stalk- and basal cells of the perithecium are hardly longer than broad and the latter do not appreciably overlap the ascigerous cavity. The lips of the perithecium are not so clearly defined, but there seem to be no well defined characters by which it could be specifically separated. In almost every specimen of the type-form a spore is protruding from the pore, and, diverging slightly, might well be taken for a spinous process.

Stigmatomyces Papuanus Thaxter.

This species has been found on numerous flies from Kamerun, belonging to the Borboridae, under the following numbers: 2291, 2292, 2640, 2670, 2672, 2673, 2675, 2736, 2737, 2739, 2740 and 2741. Its variability is considerable, but is usually associated with differences in the size of the perithecia, which may be due in part to variations in the hosts and in part to differences in the position of growth. The total length of fully matured individuals may vary from 175 μ

to 600 μ, these differences being largely due to variations in the length of the perithecial neck, which may be very long and slender or short and very stout. The prolongation of the outer lips to form an obliquely pointed apex is always characteristic. The *S. Italicus* of Spegazzini, which is also said to occur on Borboridae, does not appear to differ in any respect from smaller forms of this species. It does not appear to occur in the Western Hemisphere where it is replaced by other allied forms which occur on members of the same family.

Stigmatomyces platystoma nov. sp.

More or less curved throughout, or the extremity, only, curved outward. Receptacle hyaline; the basal cell narrower below, usually somewhat longer and distally broader than the subbasal cell, the posterior walls much thicker, the margins individually somewhat convex; the subbasal somewhat prominent below the stalk-cell of the appendage; which is pale brownish yellow, small, externally somewhat concave, abruptly broader and prominent below the insertion; which is opposite the distal margin of the perithecial stalk-cells. Axis of the appendage consisting normally of seven cells; the basal and subbasal nearly equal and more deeply suffused with yellowish brown, their margins but slightly convex; those above successively slightly smaller; all strongly convex, the septa but slightly oblique; each of the four lower cells producing two superposed antheridia on the inner side; the upper seated on the under, and furnished with a longer, more conspicuous, stout, appressed neck; the fifth cell bearing a single antheridium, the terminal cell distally inflated and partly free; the subterminal bearing an abortive antheridium, which may proliferate, producing a few clavate branchlets. Stalk-cell and secondary stalk-cell of the perithecium hardly longer than broad, the latter asymmetrically and obliquely overlapping two thirds or more of the former, on its left side; the basal cells smaller, subtriangular: venter tapering to a narrow base, sometimes twice as broad distally, slightly longer than the distal portion; the neck with abruptly distinguished spreading base, its outline somewhat irregular, hardly tapering, short; the tip and apex distinguished by an abrupt constriction, somewhat inflated; the tips of the four coarse lip-cells bluntly rounded and prominent about the pore: the wall-cells developing a slight spiral twist which is usually inconspicuous. Spores 30×3.5 μ. Perithecia 85–100 μ; venter $45–55 \times 30–32$ μ distally and 16 μ at base; the apex about 20 × 12 μ. Appendage 55–65 μ. Receptacle 42–44 × 15 μ. Total length to tip of perithecium 155–160 μ.

On the legs of *Limosina punctipennis* Wied. No. 2653, Kamerun, W. Africa.

This species is most nearly allied to *S. proliferans*, the appendage being similar and occasionally showing a similar proliferation distally. In other respects, however, its appearance is very different, owing to its short receptacle, distally expanded venter, and larger, abruptly distinguished, somewhat inflated apex.

Stigmatomyces proliferans nov. sp.

Usually straight and rather slender, pale yellow, especially the venter; the receptacle hyaline; the base of the appendage tinged with amber-brown. Receptacle usually comprising nearly half the total length, the basal and subbasal cells of nearly equal diameter, the latter often slightly longer, and distally somewhat broader than the region immediately above it. Stalk-cell of the appendage relatively small, but slightly longer than broad, externally straight, or slightly concave, slightly and abruptly prominent below the rather broad insertion, which lies somewhat lower than the base of the ascigerous cavity; axis of the appendage consisting of usually seven obliquely superposed, successively smaller cells; the uppermost forming a minute erect, free, blunt projection; the basal cell hardly longer than broad, tinged with amber brown, the outer margin nearly straight, that of the three cells above it very strongly convex; all, except the uppermost, bearing single antheridia on the inner side, which are appressed and very obliquely superposed in a single row, long and slender, the neck and venter hardly distinguished; the upper two or three, including also the minute terminal cell, finally proliferous, producing partly dichotomous slender rigid branches, which form a variably developed coralloid group, their tips swollen and eventually separated (as sperm cells?) in a gelatinous mass. Stalk-cell and secondary stalk-cell of the perithecium longer than broad, overlapping laterally, nearly equal, the latter higher; the basal cells almost as large, and overlapping the ascigerous cavity above, the outer externally concave, and distally slightly prominent. Perithecium erect, rather slender, the distal portion somewhat longer than the slightly inflated venter, which tapers rather abruptly above to the not abruptly differentiated neck; the latter of nearly uniform diameter, and distinguished from the almost equally broad tip and apex by a very slight elevation; the apex, seen sidewise, abruptly truncate distally; broad, flat, more prominent externally; or, if turned one quarter, tending to appear truncate-conical: the wall-cells of the venter and neck becoming more or less clearly spirally twisted from left to right. Spore $30 \times 3.6\ \mu$. Perithecia $140 \times 30\ \mu$ (venter) $\times 14\ \mu$ (neck). Appendage 50–55 μ; to tip of proliferous branches 70–80 μ. Receptacle $120\text{–}140 \times 18\ \mu$. Total length to tip of perithecium 280–315 μ.

On the thorax of *Limosina punctipennis* Wied. Nos. 2733 and 2287, Kamerun, West Africa.

This species, which belongs to the group of *S. Limosinae,* is clearly distinguished by its straight slender form, spiral wall-cells, and proliferous appendage. The minute bodies which are separated from the tips of the ultimate branches of these proliferations, and which finally cohere in a viscous mass, appear to be abnormally developed sperm cells, but their origin is quite unlike that of other known forms having exogenous sperms.

Stigmatomyces tortimasculus nov. sp.

Short and rather stout, or more elongate and slender; nearly hyaline except the faintly brownish yellow venter of the perithecium. Receptacle variably elongate, tapering slightly to the usually curved base. Stalk-cell of the appendage evenly and slightly convex throughout, or somewhat concave below, distally abruptly broader than the narrow insertion, which lies slightly higher than the base of the ascigerous cavity. Axis of the appendage somewhat irregular, curved, and lying sidewise against the venter; consisting of five cells, the terminal one minute and forming a short blunt projection from the base of the two distal antheridia; the basal cell relatively small, distinctly yellowish brown, as broad as long; the second and third longer, nearly equal; the fourth smaller; all bearing usually two antheridia, the distal ones somewhat clustered, the long free necks variously curved and irregularly divergent in different directions. Stalk-cell of the perithecium five-sided, broader than long, the secondary stalk-cell obliquely separated from it, externally strongly convex; the basal cells small and triangular. Venter of the perithecium variable, often relatively large, short and strongly inflated, much broader than the basal cell region; the neck stout and slightly tapering, its spreading base rather clearly distinguished by a slight subtending elevation; the apex not distinguished, strongly oblique distally, or, when viewed radially, abruptly truncate, broad and bipapillate, the papillae closely associated and median. Spores $20 \times 3.5\ \mu$. Perithecia 88–100 $\times$ 32 μ, largest 120 $\times$ 35 μ. Receptacle 42–75 $\times$ 12–14 μ, largest 130 $\times$ 14 μ. Appendage about 35 μ. Total length 150–200 μ, longest 275 μ.

On a species of *Limosina*, the larger on the thorax, the smaller on the legs. Nos. 2130, 2134, and 2135, Sarawak, Borneo.

This pale and otherwise nondescript form is most clearly distinguished by the irregular curvature and divergence of the long antheridial necks, which sometimes recall the appearance of the projecting fingers of the conventional scarecrow. It is evidently related to the simpler forms which occur on other borborids.

Stimatomyces Venezuelae Thaxter.

A form corresponding in all respects to the type, has been obtained from flies belonging to the genus *Limosina*, or to one very closely allied, growing on the abdomen; No. 2674, Kamerun, West Africa, and No. 2179, Sarawak, Borneo. As in the type material, the appendage appears to be somewhat evanescent, consisting of three well defined cells, the basal brownish yellow and somewhat broader than long. The basal as well as the subbasal cell, which is strongly convex externally, appear to bear two antheridia, as well as the third, but since the antheridia are turned sidewise and none of the specimens are young, it has been impossible to determine this point with certainty. The fourth cell appears to bear a single antheridium, and to be followed by two others which are terminal and superposed. The peculiar form of the venter and receptacle is exactly that of the Venezuela specimens.

On Diopsidae.

Stigmatomyces arcuatus nov. sp.

Rather evenly arcuate, the general curvature sidewise to the right, the curvature at the extremities usually somewhat more abrupt: uniformly suffused with yellowish; the perithecium and appendage tinged with reddish. Basal cell of the receptacle usually slightly longer than the subbasal, and distally slightly broader. The stalk-cell of the appendage somewhat broader than long, with distal secondary thickening. Axis of the appendage consisting of five cells, the two lower more deeply colored; the basal broader than long, sterile; the subbasal sometimes larger and, like the third and fourth, bearing two antheridia, the fifth bearing but one, which is surmounted by two superposed; the appendage rather stout, tapering to a point distally, lying flat against the venter, which it crosses obliquely, extending beyond it, the antheridia turned to the right. Stalk-cell of the perithecium relatively large, the cells of this region indistinguishable from the fact that the mature individual, owing to its curvature, presents either an anterior or posterior view. Venter somewhat asymmetrical, more or less inflated distally, not very abruptly distinguished from the stout neck, which merges into the curved blunt tip and apex with slight differentiation; the lips hardly distinguished. Spores about $28 \times 3.5\ \mu$. Perithecia $100–112 \times 28–35\ \mu$. Appendage about $50 \times 12\ \mu$. Receptacle $45–50 \times 16\ \mu$. Total length 180–200 μ.

On the legs and wings of a species of *Diopsis*. No. 2303, Kamerun, W. Africa.

Distinguished from other known species on *Diopsis* by its appendage, the axis of which includes but five cells. The wall-cells of the venter and neck appear to have a slight continuous twist, the course of which cannot be clearly made out. The material, though not abundant, was obtained from three different individuals of the host.

Stigmatomyces longirostratus nov. sp.

Pale dirty brownish yellow throughout, greatly elongated. Basal cell slightly curved and tapering below, distally broader than the base of the somewhat paler and slightly longer subbasal cell, the margins of which are somewhat convex. Stalk-cell of the appendage about four times as long as broad and of nearly equal diameter throughout, the distal end modified by a secondary thickening, which is deeply colored and about as large as the basal cell of the appendage. Appendage slightly divergent, elongate, tapering, slender; its axis consisting of twelve cells; the basal sterile, somewhat longer than broad, more deeply colored; the subbasal concolorous, half as long as broad, bearing two antheridia, as do all the other cells of the axis except the twelfth, which bears only one and is followed by two others superposed; the antheridia directed outward, and superposed in a single row, with little if any right and left divergence. Stalk-cell of the perithecium concolorous with the subbasal cell, ending below the insertion of the appendage, somewhat prominent externally, obliquely separated from the secondary cell, which overlaps less than half its length; distally and externally prominent, and modified by a more deeply colored secondary thickening, as are the upper outer angles of the basal cells above. Basal cell region somewhat broader than the base of the venter, which is somewhat inflated below, and prolonged distally into a neck-like portion, with somewhat irregular margins, which is rather abruptly swollen below its junction with the neck proper: the latter paler, of nearly uniform diameter, slightly curved outward, its junction with the tip broader and geniculate; the tip bent outward, broad, slightly inflated, hardly distinguished from the apex; which is bent upward slightly, short and truncate, the lips hardly distinguished. Spores about $35 \times 4\,\mu$. Perithecium $320 \times 40\,\mu$. Appendage $140 \times 14\,\mu$. Receptacle $115 \times 25\,\mu$. Total length somewhat over $500\,\mu$.

On the wings of a species of *Diopsis*. No. 2715, Kamerun, W. Africa.

Allied to the other species on *Diopsis* and distinguished by its great length, twelve-celled appendage, and peculiarly shaped perithecium. Only one quite mature individual has been examined. The wall-cells of the venter appear to be slightly twisted, but this cannot be clearly made out in the type.

Stigmatomyces porrectus nov. sp.

Rather elongate, with somewhat irregular outline. Basal cell of the receptacle obconical, slightly tinged with yellowish, a secondary thickening involving the whole cell, its upper margin extending just below and parallel to the horizontal septum which it may even touch; the subbasal cell perfectly hyaline, abruptly narrower, usually distinctly shorter and subisodiametric. Stalk-cell of the appendage relatively small, somewhat irregular, about twice as long as broad, its lower half or more hyaline, the rest more or less tinged with yellow, or brownish yellow, which is associated with secondary thickening; the basal cell of the appendage as broad, or even slightly broader, more deeply suffused, slightly broader than long, sterile; the subbasal cell concolorous, very small, flattened-triangular, bearing two antheridia; the rest of the axis consisting of four, rarely three cells, all bearing two antheridia, except the last, which bears one, and is followed by two others which are superposed; the base of the appendage divergent at an angle of 45°, the rest bent or curved upward, the stout antheridial necks prominent and directed outward. Stalk-cell of the perithecium large, quite hyaline, extending considerably above the insertion of the appendage, the secondary cell subtriangular, extending half way to the base of the primary cell, hyaline below, brownish yellow above, and concolorous with the perithecium and basal cells; which are somewhat larger, irregular in form, extending upward somewhat above the base of the ascigerous cavity; the venter somewhat asymmetrically inflated near the base, often with a slight external angle, tapering distally, the wall-cells slightly spiral, describing about an eighth of a turn, the distal end hardly if at all distinguished from the base of the neck which simulates the usual venter termination, forming a slight enlargement above which the rest of the neck, which tapers slightly and is rather strongly curved outward, is rather clearly distinguished; the tip relatively large, usually slightly inflated and broader than the neck below, the apex short and blunt, the lips hardly distinguishable. Spores about $24 \times 2.5\,\mu$. Perithecia $125–155 \times 35–42\,\mu$. Appendage $52–60 \times 15\,\mu$. Receptacle $85–140 \times 20–24\,\mu$. Total length $250–350\,\mu$.

On the wings and tip of abdomen of *Diopsis* sp. No. 2301, Kamerun, W. Africa.

Specimens of this peculiar form have been examined from several individual hosts, and in all cases are somewhat irregularly developed, the asci in many cases not maturing well. It is allied to the other species on *Diopsis*, but is readily distinguished from *S. Diopsis*, the only other form having a strongly divergent appendage in the characters of the latter as well as in other respects.

Stigmatomyces Schwabianus nov. sp.

Color throughout nearly uniform dirty yellowish. Receptacle relatively small, somewhat curved, the basal cell tapering below, the subbasal cell somewhat shorter and broader. Stalk-cell of the appendage somewhat prominent distally, a secondary thickening involving its upper half or more; the appendage nearly erect, slightly incurved; the antheridia external and superposed in an almost uniform vertical series with little right and left divergence; the basal cell large, darker, sterile, hardly as long as broad, the subbasal small, subtriangular; the rest of the axis consisting of six cells all bearing, like the subbasal, two antheridia; except the uppermost which bears one, and is followed by two others which are terminal and superposed. Primary stalk-cell larger than the subequal cells above it, distally separated obliquely from the secondary cell, its extremity lying some distance below the insertion of the appendage. Venter slightly or distinctly inflated, the wall-cells describing one half to a whole turn, the curved neck being turned inward in the former case and outward in the latter; the base of the neck hardly distinguished from the venter, and separated by a more or less sharp constriction from its distal portion; which is usually narrower in the middle, swollen at either end, abruptly narrowed or constricted below the tip; which is short, inflated, tapering to the blunt, subtruncate apex; the lips closely apposed, rather broad, not prominent. Spores about $40 \times 5\,\mu$. Perithecia $175–280 \times 30–42\,\mu$. Appendage $65–80 \times 12–14\,\mu$. Receptacle $60–90 \times 21–24\,\mu$. Total length $250–400\,\mu$.

On the legs and at the base of the wings of *Diopsis* sp. Kamerun, W. Africa. Nos. 2302, 2365, 2676, 2718 and 2719.

The peculiarities of this species especially of the perithecium are more conspicuous in older individuals, the constrictions and curvature of the neck as well as the spiral character of the wall-cells varying considerably. The species is related to *S. Diopsis* and *S. porrectens*, from which it is abundantly distinct.

On Drosophilidae.

Stigmatomyces subinflatus nov. sp.

Straight, or the axis of the receptacle bent at a slight angle, pale yellow; the receptacle nearly hyaline, the basal and stalk-cells of the appendage, and the inflation below the tip tinged with reddish. Basal cell of the receptacle longer, even twice as long as the subbasal, the septum slightly oblique, the subbasal cell but slightly broader distally. Stalk-cell of the appendage twice as long as broad, faintly reddish, the outer margin straight or slightly convex, rounded abruptly inward to the basal cell of the appendage; which is relatively large, somewhat longer than broad, distally slightly oblique, sterile, more distinctly reddish, especially the septa; the rest of the axis, which is slightly and somewhat obliquely curved inward, consisting of three cells, the lowest much smaller, triangular-flattened, each bearing a single rather large antheridium, the series terminated by a fourth. Stalk- and basal cells all lying below the insertion of the appendage, relatively small and subequal. Venter rather long and narrow, and almost symmetrically inflated; the wall-cells separated by a wing-like spiral ridge which makes nearly a half turn; neck rather abruptly distinguished, the base hardly spreading, about half as long as the venter, nearly isodiametric, and swelling abruptly to form a clearly distinguished subsymmetrical enlargement at its junction with the tip; which, with the apex, forms a short blunt termination, the rounded lip-edges rather coarse, slightly prominent, and asymmetrical. Spores about $18 \times 2.5\,\mu$. Perithecia $110–120 \times 28–30\,\mu$: venter $68\,\mu$. Appendage $35 \times 9\,\mu$. Receptacle $45–55 \times 16\,\mu$. Total length $150–175\,\mu$.

On the anterior legs of a pale species of *Drosophila*. Kamerun, W. Africa, No. 2180.

This species is distinguished from other forms on Drosophilidae by its four-celled appendage, which bears but four antheridia, and the subterminal enlargement of the perithecium. The spiral ridges of the venter are similar to those of *S. Sigalossae*, which is otherwise quite different.

Stigmatomyces varians nov. sp.

Symmetrically somewhat sigmoid, the perithecium proper about twice as long as the rest of the individual. Receptacle hyaline, usually yellowish distally and above the foot; the basal cell tapering below, curved, often twice as long as, or less frequently slightly shorter than, the subbasal cell; which may be distinctly prominent above the basal, its distal end much broader, its margins usually slightly concave. Stalk-cell of the appendage slightly more than twice as long as broad, its distal third or more involved by a yellow secondary thickening, its outer margin very slightly prominent below the basal cell of the appendage, which is flattened, usually becoming reddish, broader than long, without antheridia, surmounted by a still shorter cell bearing two antheridia, which is followed by two axis-cells bearing two antheridia each, and a third which bears one; the axis ending in two terminal ones which are superposed, the upper larger and indistinctly spinose; the appendage erect or sometimes slightly divergent, the antheridia turned outward and a little sidewise. Stalk-cell four sided, but subtriangular, the three longer sides subequal, the secondary stalk-cell equal, or larger, with a yellow somewhat prominent thickening at its upper outer angle which may resemble a separated cell; the outer basal cell about as large, usually distinctly prominent externally below the venter; which is variably, sometimes considerably and evenly, inflated; or narrower and more or less prominently concave below the variably prominent endings of the wall-cells, which have a very slight spiral twist; the neck curved outward, stout, typically with broadly spreading base, which may be narrower and followed above by a slight general shallow constriction, or may enlarge gradually to its junction with the tip; which is usually more or less distinctly constricted, bent outward; the apex rather stout, short, with somewhat irregularly compressed lips. Spores $35 \times 4\,\mu$. Perithecium $120–140 \times 30–35\,\mu$. Appendage $42–45 \times 8–10\,\mu$. Receptacle $45–55 \times 20–26\,\mu$. Total length $190–225\,\mu$.

On the superior surface of the abdomen of a genus of flies belonging to the Drosophilidae. Kamerun, W. Africa, Nos. 2753 (Type), 2668 and 2667 the latter a somewhat smaller species.

This species, which belongs to the group of forms occurring on Drosophilidae and including *S. Sigalloessae*, *S. Scaptomyzae*, *S. Drosophilae*, is a variable and rather puzzling form. The portions above the receptacle are rather clear, pale, almost lemon yellow. The two lower cells of the appendage appear to represent the normal basal cell, which has divided in two, the lower remaining sterile; while the smaller, upper, bears two antheridia. The habit may be evenly, but not deeply, sigmoid, as in the type; or the axis of the receptacle and venter may be coincident and straight. The perithecium varies greatly, the termination of the wall-cells of the venter abruptly prominent in the type, or the end of the venter narrower and rounded, and subtended by a more or less evident general constriction. The neck may be stout and slightly tapering from a broad base, or more slender, basally constricted, and distally somewhat enlarged, and other variations might be mentioned. The host is a reddish brown drosophilid, with conspicuous longitudinal white lines on the thorax which contrast with a dark edging. I have been unable to obtain a determination of the genus of which more than one species is probably represented in the host material.

On Ephydridae.

Stigmatomyces excavatus nov. sp.

Straight, flexed, or slightly sigmoid; becoming pale yellowish above the hyaline, thick-walled receptacle; which is short and stout, tapering slightly from the distal end to the base, the subbasal cell usually slightly less than twice as long as the basal, which is rounded above the small foot, the septum slightly oblique. Stalk-cell of the appendage relatively broad, overlapping the subbasal cell, and forming a rounded prominence, distally and externally, extending above the small reddish brown basal cell of the appendage, which thus lies at the bottom of a socket. Appendage long, slender, attenuated; usually straight, with the antheridia external, or sometimes lateral. Axis of the appendage consisting of more often seven cells, those above the basal hyaline, flattened-triangular; the seventh bearing a single antheridium, the rest two, or the lower more than two; the rest of the appendage slightly curved, attenuated, and consisting of two to three superposed antheridia; antheridial necks short, stout and curved. Stalk-cell subtriangular, rather abruptly slightly broader than the receptacle externally, and separated by an oblique septum; the secondary stalk-cell slightly smaller, separated by a curved oblique septum, hardly larger than the basal cells above. The venter three to four times as long as broad, its base slightly narrower than the basal cell region, gradually broadening distally, usually abruptly broader below the neck; which is nearly as long, tapering from its broad base to the tip, which is hardly distinguished by a slight depression; the tip slightly inflated and tapering, twice as long as the apex, which is subtruncate and bent inward, but not otherwise distinguished. Spores about $25 \times 3\,\mu$. Perithecia $140–200 \times 20–28\,\mu$; stalk- and basal cell region $35 \times 22\,\mu$. Receptacle $80 \times 25\,\mu$. Appendage $70–95 \times 7\,\mu$; its stalk-cell $35–45 \times 10–15\,\mu$. Total length $280–335\,\mu$ or less.

On superior surface of abdomen of an ephydrid allied to *Notiphila*. No. 2637a. Kamerun, West Africa.

This species is clearly distinguished by its short stout receptacle, long slender and tapering perithecium and appendage, and especially by the protrusion of the stalk-cell of the appendage, which forms a depression overtopping the basal cell of the appendage.

Stigmatomyces ventriosus nov. sp.

Relatively short and stout. Receptacle hyaline, the basal cell usually somewhat curved below, tapering to the foot; the subbasal cell much smaller, usually broader than long. Stalk-cell of the appendage tinged with amber-brown, relatively narrow, more than twice as long as broad, its bluntly pointed base overlapping the subbasal cell slightly, if at all; its outer margin straight or slightly concave, and somewhat prominent below the broad insertion. Axis of the appendage consisting of four successively smaller cells, the fourth much smaller and bearing one antheridium, followed by two which are superposed above it, the upper spinose; all the others bearing two antheridia, which are usually turned somewhat obliquely sidewise; the basal cell somewhat longer than broad, amber-brown, the rest of the appendage slightly suffused below; the antheridia appressed with hardly divergent necks. Stalk-cell and secondary stalk-cell of the perithecium nearly equal, broader than long, flattened-triangular, concolorous with the stalk-cell of the appendage and the basal cells, which are small and subtriangular; the secondary stalk-cell slightly convex externally, its margin often reaching to the subbasal cell of the receptacle: venter somewhat darker amber-brown, short and stout, its axis diverging at a slight angle to that of the appendage and receptacle; its outer margin straight or becoming convex, its inner bulging very strongly; the wall-cell on the left side forming a slightly elevated area ending in a more or less distinct and abrupt broad ridge below the short, usually abruptly curved, neck; the tip and apex as long as the subhyaline neck, and turned abruptly inward by its curvature; the tip tinged with brownish yellow: the apex short, not distinguished, hardly tapering; the lips prominent, rather coarse, two of them lower and paired, the other two forming a blunt point which projects beyond them; the pore usually directed inward, but sometimes sidewise, owing to a slight twist of the wall-cells. Spores $30 \times 3\,\mu$. Perithecia 75–85 μ. The venter 42–48 × 30–36 μ. Appendage 45–50 × 10 μ. Receptacle $42 \times 18\,\mu$. Total length to tip of perithecium 120–140 μ.

On the inferior abdomen of a small fly resembling *Discocerina*. No. 2743a, Kamerun, West Africa.

This small species appears to be more nearly related to *S. Discocerinae*, but is very readily recognized by its "pot-bellied" venter and short incurved neck. The thirty individuals examined show no important variation.

On Ortalidae.

Stigmatomyces Ortalidanus nov. sp.

Very long and slender, straight, or but slightly curved. Basal cell of the receptacle tapering to the small foot, usually slightly bent below, with secondary thickenings of the wall which usually become blackish brown, the suffusion sometimes extending so as to stain the yellowish primary wall; subbasal cell more than twice as long, slightly narrower than the basal, just above the horizontal septum; hyaline, or yellowish, usually straight, thick-walled and nearly isodiametric. Stalk-cell of the appendage extending only to the subbasal cell, relatively narrow, its outer margin nearly straight, except for a slight elevation below the insertion, which occupies almost the whole of its distal surface. Appendage long, slender and distally attenuated, consisting of about eight to ten axis-cells; the basal amber-brown, broader than long, its upper margin somewhat oblique below a small subtriangular hyaline cell which is separated from it distally and bears two superposed antheridia; the cells above the fifth usually somewhat longer and flatter than those below; all the axis-cells hyaline, and producing two antheridia each, arranged in a double series; the necks of the lower in each turned slightly sidewise, and of the upper, outward; the appendage ending in two superposed antheridia, below which the last cell of the axis is often also transformed into two superposed antheridia. Stalk-cell region of the perithecium much elongated; the primary stalk-cell greatly enlarged, thick-walled, hyaline, extending far above the insertion of the appendage, its distal fifth to third, or even more, overlapped by the bluntly pointed base of the much smaller, long-triangular secondary stalk-cell, the upper margin of which is horizontal, with an external brownish thickening; basal cells relatively elongate, the inner sometimes extending down nearly to the middle of the secondary stalk-cell; none of the basal cells overlapping the ascigerous cavity, but this region slightly broader than the base of the venter, owing to the presence of distal brownish thickenings in each cell. Venter becoming tinged with brownish yellow, more than three times as long as broad, straight, nearly symmetrical, very slightly inflated, its extremity tapering slightly to the base of the concolorous neck; which is not otherwise distinguished, straight, slightly and evenly tapering throughout, the wall-cells slightly twisted, as are those of the venter, and becoming more or less evidently corrugated by about eight successive elevations, usually more conspicuous in the distal half; the tip distinguished by an abrupt inflation, short, slightly tapering; the apex much shorter, rather broad and blunt, straight or slightly bent, usually turned so as to appear symmetrical, with a median elevation, or oblique when seen sidewise. Spores, about $45 \times 4\ \mu$. Perithecia, stalk- and basal cell portion $100–210\ \mu \times 30–35\ \mu$; venter $90–105 \times 30–38\ \mu$; neck $122 \times 20–28\ \mu$ or less; tip and apex $25–30 \times 12\ \mu$ distally. Appendage $100–125 \times 15\ \mu$ at base; stalk-cell $50–60 \times 14–18\ \mu$. Receptacle $250–280 \times 32\ \mu$. Total length 740 or less $\times 35–40\ \mu$.

On the upper surface of the abdomen of a large black fly belonging to an undetermined genus of the Ortalidae. Kamerun, W. Africa, No. 2721.

A large species well distinguished by its elongate slender form, suffused basal cell, slender tapering appendage, corrugated neck etc. The twist in the wall-cells of the venter and neck is often conspicuous, though sometimes hardly apparent, and increases with age, as does the corrugation of the neck.

On Oscinidae.

STIGMATOMYCES CONSTRICTUS Thaxter.

Specimens of this variable species, with and without the characteristic constriction of the receptacle, have been examined from Kamerun on *Anatrichus erinaceus*, No. 2644, and on other genera of the Oscinidae, Nos. 2650, 2652, 2726, 2727, 2728 and 2729.

On Trypetidae.

Stigmatomyces Dacinus nov. sp.

Habit rigid, erect, straight or somewhat curved throughout, the walls relatively thick. Basal cell of the receptacle slightly tinged with brownish yellow, tapering to the pointed foot; the subbasal cell twice as long, or less, hyaline, of nearly uniform diameter. Stalk-cell of the appendage narrow, somewhat curved inward, about as long as the subbasal cell, which it overlaps from one quarter to one half; distally twice as broad as the insertion which lies distinctly above the primary stalk-cell of the perithecium; the antheridia mostly external; the axis of the appendage consisting of usually eight, sometimes of seven cells, the basal sterile, brownish yellow; the rest hyaline, the upper separated by slightly oblique septa, all bearing two superposed antheridia, those borne by the distal cell surmounted by an additional pair which terminate the appendage: antheridia straight, pointed, obliquely superposed. Stalk-cell of the perithecium hyaline, relatively large, more than twice as long as broad, slightly if at all broader at the base, the secondary stalk-cell yellowish brown, overlapping it about one half, hardly surpassing it distally, subtriangular, externally prominent; the basal cells relatively small, subtriangular, concolorous with the venter. Venter brownish yellow, straight, nearly symmetrical, broadly elliptical, the wall-cell making a quarter to a half turn, the spreading base of the short stout neck not abruptly distinguished; the tip subtended by a nearly symmetrical depression of the outline on both sides, abruptly and almost symmetrically inflated; the apex thus clearly distinguished, the lip-cells symmetrically paired, the inner pair turned outward, if the twist is one half, and surmounted by the outer, which form a blunt terminal free projection beyond them, half as long as the whole apex. Spores 42 × 3.2 μ. Perithecia 140–160 × 42 μ, the largest 180 × 50 μ; the terminal projection 10–15 μ. Appendage 70–85 μ. Receptacle 86–105 μ. Length from foot to insertion 100–155 μ by 42–50 μ at insertion. Total length, average, 280 μ; longest 350 μ.

On *Dacus* sp. No. 2128, Sarawak, Borneo.

This species does not seem nearly related to any described form and is quite unlike the others which are known to occur on Trypetidae. It is very clearly distinguished by the characters above enumerated, and the abundant material examined shows little variation except in size.

Stigmatomyces hexandrus nov. sp.

Similar to *S. separatus* in general appearance, larger. Receptacle hyaline, straight or slightly bent, the basal cell sometimes not more than half as long as the subbasal, and usually somewhat prominent below it on the posterior side. The subbasal cell tapering slightly and evenly from apex to base, the former slightly prominent, especially on the anterior side. Stalk-cell of the appendage hardly overlapping the subbasal cell, rather narrow, more than twice as long as broad, its margin straight or slightly concave, but slightly prominent distally below the basal cell of the appendage, which is nearly twice as long as broad; the axis of the appendage consisting of three cells, the two lower bearing each two, the third a single antheridium; a sixth terminal antheridium bent outward, its inner margin strongly convex, with a conspicuous subterminal spine; the series turned sidewise or outward. Stalk-cell of the perithecium slightly larger than the secondary cell and separated by an oblique septum; the outer basal cell smaller than the somewhat rounded inner one, and distinctly prominent externally below the venter, which broadens somewhat gradually from base to apex; its surface very finely and inconspicuously granular, its base somewhat higher than the insertion of the appendage, the margins often slightly convex; the spreading base of the neck sometimes rather abruptly distinguished; the neck for the most part somewhat longer than the venter, often slightly narrower in the middle, broader distally below the rather abruptly distinguished tip; tip and apex hardly distinguished, slightly bent and tapering, the lip-cells five-papillate, the two posterior lower, the middle of the three others highest. Spores 28–30 × 3.5 μ. Perithecium 150–180 × 32–38 μ. Appendage 55 × 10 μ. Receptacle 120–190 × 24–28 μ. Total length 280–300 μ or less; maximum 370 × 42 μ.

On the superior abdomen and legs of a fly belonging to the Trypetidae. No. 2296 and 2642, Kamerun, W. Africa.

Although less rigid and regular in outline, this species recalls *S. separatus* in general appearance and coloration. It is at once distinguished by its appendage, which is three-celled, and bears but six antheridia; the terminal one rather characteristically inflated on the inner side, and spinose. Abundant material has been examined.

Stigmatomyces separatus nov. sp.

Habit rigid and straight, or the neck and tip bent at a slight angle to the venter. Receptacle hyaline, sub-isodiametric, or tapering very slightly from apex to base; the basal cell about two thirds as long as the subbasal; the septa horizontal, both cells hyaline and contrasting with the dirty reddish brown suffusion of the part above, which includes the venter of the perithecium. Stalk-cell of the appendage overlapping the subbasal cell very slightly, about twice as broad as long, its external margin straight or more often concave, distally rather abruptly prominent below the concolorous basal cell of the appendage; which is otherwise paler yellowish, its axis consisting of five cells, the two lower producing usually three, the third and fourth two, and the fifth one antheridium; the appendage terminated by two which are superposed, the necks rather short and stout, and directed obliquely sidewise. Stalk-cell of the perithecium about as broad as long, overlapped on the left side by the secondary stalk-cell, which is slightly prominent externally; the basal cells subequal, hardly prominent; venter straight, its base nearly opposite the insertion of the appendage, slightly and symmetrically inflated below, the margins of the upper third often slightly concave, the surface faintly granular, distally somewhat prominent below the spreading base of the rather stout neck; which is almost exactly as long, slightly tapering, or more often nearly isodiametric, slightly but abruptly enlarged at its junction with the tip; the latter slightly bent inward, somewhat tapering, the apex hardly distinguished, the lips oblique, the outer being bluntly pointed and more prominent. Spores 30 × 3.5 μ. Perithecia 155–176 × 28–35 μ. Appendage 50–65 × 7 μ. Receptacle 70–80 × 18–20 μ. Total length 210–280 μ.

On the anterior surface of the head of a rather large dark fly with mottled brown wings belonging to the Trypetidae? No. 2735, Kamerun, W. Africa.

Although this large rigid form does not seem referable to any of the described species, it has no striking characters which would at once distinguish it. The appendage normally bears thirteen antheridia, but in some cases there appear to be only two on the two lower cells. The appendage is so turned that it is difficult to determine the antheridial characters without a very high magnification. A large number of individuals has been examined.

Stigmatomyces Chilomenis nov. sp.

Nearly hyaline, faintly tinged with greenish yellow. Receptacle small, the basal cell much narrower and subgeniculate above the foot, obliquely separated from the much smaller subtriangular subbasal cell; which is somewhat larger than the irregularly rounded stalk-cell of the nearly erect appendage, the basal cell of which is longer than broad, somewhat narrower below than the four subequal axis-cells above it; which are somewhat broader than long, and each bear an antheridium, the terminal cell bearing two, in the type, in addition to the terminal antheridium: antheridia with long stiff nearly straight necks directed obliquely upward and outward. Stalk-cell of the perithecium small and narrow, constricted in the middle, with a slight twist; the secondary stalk-cell half as large, obliquely separated; the basal cells surrounding the base of the ascigerous cavity, and forming about one fifth of the stout body of the perithecium, which comprises the venter-, neck- and tip-regions, the neck-region somewhat broader and separated from the tip-region by a slight indentation; the relatively broad apex abruptly somewhat narrower, the lip-cells developing four erect appendages; two lateral and opposite, more slender, longer, tapering slightly to a blunt point, each subtended by a small rounded outgrowth hardly longer than wide; one posterior, straight, tooth-like, tapering evenly from a broad base to a small rounded apex, and somewhat shorter: one anterior opposite the last and somewhat shorter, similar, rather abruptly broader distally, the extremity broadly rounded. Spores $28 \times 3\,\mu$. Perithecium to tips of appendages, including basal cell region, $135\,\mu$; the appendages, longer, $30\,\mu$. Appendage $60 \times 7\,\mu$ at base. Receptacle $60 \times 18\,\mu$, including sharply pointed foot. Total length about $200\,\mu$.

On the elytra of *Chilomenes lunata* Fabr. No. 2158, Nairobi, British East Africa, Mearns.

This species is intermediate between *S. virescens* and *S. coccinelloides;* resembling the former in the character of its appendage, and to some extent, in the form of the perithecial outgrowths, more closely than the latter. Its very narrow, short stalk-cell and the form of the body of the perithecium recalls *S. coccinelloides.* The erect, symmetrically placed perithecial appendages are different from any of the varieties of the two related forms.

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RECORDS OF MEETINGS.

One thousand and sixty-sixth Meeting.

OCTOBER 10, 1917.— STATED MEETING.

The Academy met at its House.

The PRESIDENT in the Chair.

There were seventy-three Fellows present.

The following letters were presented by the Corresponding Secretary: — from R. C. Archibald, B. A. Behrend, C. F. Brush, E. W. Burlingame, R. A. Cram, E. W. Emerson, H. H. Furness, C. N. Greenough, H. E. Gregory, F. B. Gummere, J. C. Hoppin, W. G. Howard, G. F. Hull, F. J. Foakes Jackson, C. W. Johnson, F. B. Loomis, Arthur Lord, R. S. Lull, Allan Marquand, Alexander McAdie, W. J. Miller, Frank Morley, C. E. Park, L. V. Pirsson, P. E. Raymond, W. N. Rice, Frederick Slocum, R. C. Sturgis, J. B. Watson, John Zeleny, accepting Fellowship; from F. D. Adams, Tullio Levi-Civita, R. M. Pidal, accepting Foreign Honorary Membership; from E. D. White, declining Fellowship.

The Chair announced the deaths of the following Fellows: John Williams White, Class III., Section 2; Joseph Hodges Choate, Class III., Section 1; Bela Lyon Pratt, Class III., Section 3; James Mason Crafts, Class I., Section 3; Herbert Langford Warren, Class III., Section 4; William DeWitt Hyde, Class III., Section 1; William Bullock Clark, Class II., Section 3.

A biographical notice of E. H. Strobel, by Samuel Williston was presented by the Corresponding Secretary.

On recommendation of the Council, it was

Voted, To appropriate two hundred ($200) dollars to be expended at the discretion of the President.

The following Communication was presented: Dr. James J. Putnam, "A General View of the Psychoanalytic Movement."

The following paper was presented by title: "The Post-glacial History of Boston," by H. W. Shimer.

The meeting then adjourned.

One thousand and sixty-seventh Meeting.

NOVEMBER 14, 1917.— STATED MEETING.

The Academy met at its House.

The PRESIDENT in the Chair.

There were eighty-two Fellows and many guests present:

The Chair announced the death of George Vasmer Leverett, Fellow in Class III., Section 1.

The following Communication was presented: Senator Henry Cabot Lodge, "War Legislation."

The meeting then adjourned.

One thousand and sixty-eighth Meeting.

DECEMBER 12, 1917.— STATED MEETING.

The Academy met at its House.

The PRESIDENT in the Chair.

There were forty-five Fellows present.

A letter was presented from the University of California inviting the Academy to send a delegate to its fiftieth anniversary, March, 1918.

The chair announced the death of Gaston Camille Charles Maspero, Foreign Honorary Member in Class III., Section 2.

The following votes of the Council were presented: 1. To refer the invitation of the University of California to the President with power. 2. That in the opinion of the Council it is inexpedient that ladies should be invited to meetings of the Academy unless by vote of the Academy or the Council for particular meetings. 3. That at his discretion the Treasurer be authorized, on request, to remit the dues of any Fellow called from the Commonwealth for service in the present war, for the term of his absence.

The following Communications were presented:

Professor G. F. Moore, "The Properties of Numbers and the Doctrine of Ideas."

Professor H. W. Shimer, "The Post-Glacial History of Boston."

Professor A. E. Kennelly, "The Speeds, Powers, and Fatigue of Racing Animals," illustrated by lantern.

The following papers were presented by title:

"On Dyadics Occurring in Point Space of Three Dimensions," by C. L. E. Moore and H. B. Phillips.

"A Table of the Legendre Functions of the Second Kind $Q_1(x)$ and $Q'_1(x)$ by Willard J. Fisher, presented by A. G. Webster.

The meeting then adjourned.

One thousand and sixty-ninth Meeting.

JANUARY 9, 1918.— STATED MEETING.

The Academy met at its House.

The PRESIDENT in the Chair.

There were forty-seven Fellows present.

In the absence of the Recording Secretary, the Corresponding Secretary was appointed Recording Secretary *pro tem.*

A biographical notice of De Amicis by W. R. Thayer was presented by the Corresponding Secretary.

Suggestions from E. B. Wilson regarding amendments of the Statutes were referred to a committee consisting of E. B. Wilson, H. W. Tyler and E. V. Huntington.

The following gentlemen were elected Fellows of the Academy:

Grinnell Jones, of Cambridge, to be a Fellow in Class I., Section 3 (Chemistry).

Irving Langmuir, of Schenectady, to be a Fellow in Class I., Section 3 (Chemistry).

William Ebenezer Ford, of New Haven, to be a Fellow in Class II., Section 1 (Geology, Mineralogy and Physics of the Globe).

William Crawford Gorgas, of Washington, to be a Fellow in Class II., Section 4 (Medicine and Surgery).

Robert Battey Greenough, of Boston, to be a Fellow in Class II., Section 4 (Medicine and Surgery).

Henry Jackson, of Boston, to be a Fellow in Class II., Section 4 (Medicine and Surgery).

Thomas Willing Balch, of Philadelphia, to be a Fellow in Class III., Section 1 (Theology, Philosophy and Jurisprudence).

Willard Bartlett, of Brooklyn, to be a Fellow in Class III., Section 1 (Theology, Philosophy and Jurisprudence).

Charles Warren Clifford, of New Bedford, to be a Fellow in Class III., Section 1 (Theology, Philosophy and Jurisprudence).

Charles Evans Hughes, of New York, to be a Fellow in Class III., Section 1 (Theology, Philosophy and Jurisprudence).

James Madison Morton, of Fall River, to be a Fellow in Class III., Section 1 (Theology, Philosophy and Jurisprudence).

George Burton Adams, of New Haven, to be a Fellow in Class III., Section 3 (Political Economy and History).

Charles McLean Andrews of New Haven, to be a Fellow in Class III., Section 3 (Political Economy and History).

Evarts Boutell Greene, of Champaign, Ill., to be a Fellow in Class III., Section 3 (Political Economy and History).

William MacDonald, of Berkeley, Cal., to be a Fellow in Class III., Section 3 (Political Economy and History).

Harold Murdock, of Brookline, to be a Fellow in Class III., Section 4 (Literature and the Fine Arts).

The following gentlemen were elected Foreign Honorary Members:

William Napier Shaw, of London, Eng., to be a Foreign Honorary Member in Class II., Section 1 (Geology, Mineralogy and Physics of the Globe).

Thomas Barlow, of London, Eng., to be a Foreign Honorary Member in Class II., Section 4 (Medicine and Surgery).

Francis John Shepherd, of Montreal, Canada, to be a Foreign Honorary Member in Class II., Section 4 (Medicine and Surgery).

Charles Scott Sherrington, of Oxford, Eng., to be a Foreign Honorary Member in Class II., Section 4 (Medicine and Surgery).

The following Communications were presented:

Judge Robert Grant, "Ancestors and Posterity."

Professor L. C. Graton, "A Geological Study of Copper Ores supported by American Mining Companies."

Professor M. L. Fernald, "Some Living Remnants of Ancient Floras on the Coast of New England."

The following paper was presented by title:

"Ballistic Experiments by means of the Electrometer," by A. G. Webster and Mildred Allen.

The meeting then adjourned.

One thousand and seventieth Meeting.

FEBRUARY 13, 1918.—STATED MEETING.

The Academy met at its House.

The PRESIDENT in the Chair.

There were forty-one Fellows, one Foreign Honorary Member, and two guests present.

The following letters were presented by the Corresponding Secretary: from G. B. Adams, C. McL. Andrews, T. W. Balch, Willard Bartlett, C. W. Clifford, W. E. Ford, E. B. Greene, R. B. Greenough, C. E. Hughes, Henry Jackson, Grinnell Jones, Irving Langmuir, J. M. Morton, Harold Murdock, accepting Fellowship; from F. J. Shepherd, accepting Foreign Honorary Membership; from J. H. Wright, resigning Fellowship; from the Historical Society of Florence, announcing the death of Pasquale Villari.

The Chair announced the following deaths: Paul S. Yendell, Fellow in Class I., Section 1; Charles E. Faxon, Fellow in Class II., Section 2; Pasquale Villari, of Florence, Foreign Honorary Members in Class III., Section 3.

The appointment of Professor Arthur A. Noyes as delegate to represent the Academy at the semi-centennial of the University of California, March 18–23 was announced.

The Council announced the receipt of biographical notices as follows: Cyrus Ballou Comstock, and Benjamin Baker, by G. F. Swain; Charles Francis Adams, by W. C. Ford; Thomas Raynesford Lounsbury, by Barrett Wendell.

The following Communications were presented:

Dr. S. B. Wolbach, "Studies on the Etiology of Rocky Mountain Spotted Fever."

Dr. H. A. Christian, "The String Galvanometer in the Study of Heart Disease."

Dr. H. C. Ernst. "An Old and New Microscope."

The meeting then adjourned.

One thousand and seventy-first Meeting.

March 13, 1918.— Stated Meeting.

The Academy met at its House.

The President in the Chair.

There were thirty-five Fellows and one guest present.

The following letters were presented by the Corresponding Secretary: — from Sir Thomas Barlow, W. N. Shaw, and C. S. Sherrington, accepting Foreign Honorary Membership; from O. K. O. Folin, resigning Fellowship; from the Kansas Academy of Science, inviting a delegate from the Academy to attend its semi-centennial anniversary at Lawrence, March 15 and 16, 1918.

A biographical notice of William Sellers by F. R. Hutton was presented.

The Chair announced the appointment of W. W. Campbell, to represent the Academy at the semi-centennial of the University of California, in place of A. A. Noyes, who was unable to attend.

It was also announced that an invitation to attend the meeting of the Academy had been extended to the Archbishop of York, who replied that owing to his departure from the city, he was unable to accept.

On motion of A. C. Lane, it was

Voted, That the following request be sent to the United States Fuel Administration.

"We the undersigned respectfully request the United States Fuel Administration, that if it fixes prices for coal at the mine and to the consumer, it give a heating value, to be determined, if required, by analysis or calorimeter test, which within reasonable limits of variation, such coal shall have; that deductions from, or additions to these prices be permitted for coal that proves by test to be of substantially different heating value; and since extra heating value is worth nearly as much at the mine as at the point of consumption (costing no more for freight, storage, and handling) buyers should be allowed to pay the mines for the extra heating value they may wish in proportion to the amount the coal is worth at the point at which it is to be consumed. This would have the public advantage that it would lead the mines to ship the most concentrated fuel to the farthest points, and thus relieve the transportation system of the burden of carrying useless slate."

The Librarian read a letter of thanks from the Committee on the Union List of Periodicals, for further assistance from the Academy.

The Chair appointed the following Councillors to act as Nominating Committee:

Frederick S. Woods, of Class I.

Alfred C. Lane, of Class II.

Samuel Williston, of Class III.

On recommendation of the Council, the following appropriations were made for the ensuing year: —

From the income of the General Fund, $5800, to be used as follows: —

for General and Meeting expenses	$ 300.
for Library expenses	2500.
for House expenses	2000.
for Treasurer's office	800.
for President's expenses	200.

From the income of the Publication Fund, $3500, to be used for publication.

From the income of the Rumford Fund, $2945.76 to be used as follows: —

for Research	$1000.
for Books, periodicals and binding	200.
for Publication	600.
for use at the discretion of the Committee	1145.76

$250 was transferred from the unexpended balance of the current appropriation for "Publications" to "Research" for the coming year.

From the income of the C. M. Warren Fund, $800, to be used at the discretion of the Committee.

The following communications were presented:

Prof. E. C. Jeffrey, "On the Origin of Rubber."

Prof. Waldemar Lindgren, "Some Geological Observations along the West Coast of South America."

The meeting then adjourned.

One thousand and seventy-second Meeting.

April 10, 1918.— Stated Meeting.

The Academy met at its House.

The President in the Chair.

There were thirty-one Fellows and one guest present.

A letter was presented by the Corresponding Secretary from William MacDonald, accepting Fellowship.

The Committee to which the proposed Amendments to the Statutes were referred recommended the following changes: —

Chapter II., Article 4, to read as follows: —

"If any person, after being notified of his election as Fellow or Resident Associate shall neglect for six months to accept in writing, or, if a Fellow or resident within fifty miles of Boston shall neglect to pay his Admission Fee, his election shall be void; and if any Fellow resident within fifty miles of Boston or any Resident Associate shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this Article of the Statutes in the meantime, he shall cease to be a Fellow or Resident Associate respectively; but the Council may suspend the provisions of this Article for a reasonable time."

Paragraph 2, line 8. After the word "Fellows" insert "or Resident Associates".

Article 5, line 1. After the word "Fellow" insert "resident within fifty miles of Boston".

Line 6, Omit "except in the case of Fellows elected at the January meetings, who shall be obliged to pay but one half of such Annual Dues in the year in which they are elected."

Line 8. After the word "Fellow" insert "or Resident Associate".

Article 7, line 3. Omit "all the Fellows and".

Line 4. Add "and to Fellows on request".

Article 8, line 2. Insert after the word "Member," "or Resident Associate".

Chapter III., Articles 1 and 2, to read as follows: —

"CHAPTER 3, ARTICLE 1. Elections of Fellows and Foreign Honorary Members shall be made by the Council in April of each year, and announced at the Annual Meeting in May.

ARTICLE 2. Nominations to Fellowship or Foreign Honorary Membership in any Section must be signed by two Fellows of that Section or by three voting Fellows of any Sections; but in any one year no Fellow may nominate more than four persons. These nominations, with statements of qualifications and brief biographical data, shall be sent to the Corresponding Secretary. All nominations thus received prior to February 15 shall be forthwith sent in printed form to every Fellow having the right to vote, with the names of the proposers in each case and a brief account of each nominee, and with the request that the list be returned before March 15, marked to indicate preferences of the voter in such manner as the Council may direct. All the nominations, with any comments thereon and with the results of the preferential indications of the Fellows, received by March 15, shall be referred at once to the appropriate Class Committees, which shall report their decisions to the Council, which shall thereupon have power to elect. Persons nominated in any year, but not elected, may be placed on the preferential ballot of the next year at the discretion of the Council, but shall not further be continued on the list of nominees unless renominated.

Notice shall be sent to every Fellow having the right to vote, not later than the fifteenth of January, of each year, calling attention to the fact that the limit of time for sending nominations to the Corresponding Secretary will expire on the fifteenth of February."

Article 3. To be omitted.

Chapter IV., Article 2, to read as follows:

"If any officer be unable, through death, absence, or disability, to fulfil the duties of his office, or if he shall resign, his place may be filled by the Council in its discretion for any part or the whole of the unexpired term."

Chapter VI., Article 1, paragraph 2, line 2. After the word "Members" insert "or Resident Associates".

Paragraph 3, line 2. After the word "Fellows" omit "and"; after the word "Members" insert "and Resident Associates".

Article 2, paragraph 2. After the word "Fellows" insert "or Resident Associates".

Paragraph 3, line 3. After the word "Fellows" insert "and Resident Associates".

Paragraph 4, line 1. After the word "Fellow" insert "and Resident Associate".

Chapter VII., Article 2, line 4. After the word "Fellows" insert "and Resident Associates".

Chapter VIII., Article 5, line 3. After the word "Fellow" insert "or Resident Associate".

Line 6. After the word "Fellow" insert "or Resident Associate".

Chapter IX., Article 4. After the word "Fellowship" insert "or Resident Associateship".

Article 7. In place of the word "Memoir" insert the words "biographical notice".

Chapter XI., Article 4, line 2. After the word "Fellow" insert "or Resident Associate".

Line 3, After the word "Fellow" insert "or Resident Associate".

Article 5. After the word "Fellow" insert "or Resident Associate".

Standing Vote 2. After the word "Fellows" insert "or Resident Associates".

Standing Vote 4, paragraph 1. To read as follows: —

"There may be chosen by the Academy, under such rules as the Council may determine, one hundred Resident Associates. Not more than forty Resident Associates shall be chosen in any one Class."

Paragraph 2. To be omitted.

Paragraph 3. In place of the words "one half that" insert "the same as those".

Add Standing Vote 5, as follows: —

"Communications offered for publication in the Proceedings or Memoirs of the Academy shall not be accepted for publication before the author shall have informed the Committee on Meetings of his readiness, either himself or through some agent, to use such time as the Committee may assign him at such meeting as may be convenient both to him and to the Committee, for the purpose of presenting to the Academy a general statement of the nature and significance of the results contained in his communication."

On motion, it was

Voted, To amend the Statutes in accordance with the report, the amendment to Chapter 3, to take effect May 9, 1918.

On motion of J. J. Putnam, it was

Voted, That the President be authorized to sign the following letter:

"Dear Sir:

Some of the personal friends and colleagues of Josiah Royce, who believe that his work and his character made a deep impression upon a wide circle of men and women, and that he became, in fact, the centre of a large spiritual community, many of whose members were unknown to him, as he was unknown personally to them, feel that the reverence and affection which went out to him as a thinker and as a man should be embodied in some appropriate memorial of him at Harvard University, where he expressed himself in characteristic speech and writing for thirty years.

It is proposed, with this end in view, to create a fund of $20,000 to be known as the Josiah Royce Memorial Fund, the income of which shall go to Mrs. Royce during her lifetime, and thereafter to the Department of Philosophy of Harvard College, to be used in such ways as the Department shall decide from year to year.

There are evident reasons why this appeal should not be delayed until the return of normal conditions, natural as such postponement might on some accounts appear to be. And further, the due honoring of our moral heroes though a privilege under all circumstances is especially a privilege and a duty in heroic times.

If you desire to subscribe, please send your check to Charles Francis Adams, Esq., Treasurer of Harvard College, 50 State Street.

(signed) The American Academy of Arts and Sciences,

by CHARLES P. BOWDITCH,

President."

The following Communications were presented:

Professor Clifford H. Moore. "The Decay of Nationalism under the Roman Empire."

Professor W. M. Davis. "New Coast Survey Charts of the Philippine Islands, and their bearing on the Coral-reef Problem."

The following papers were presented by title:

"Rotations in hyperspace," by C. L. E. Moore.

"Extra-American Dipterophilous Laboulbeniales" and

"New Laboulbeniales from Chile and New Zealand," by Roland Thaxter.

The meeting then adjourned.

One thousand and seventy-third Meeting.

May 8, 1918.— Annual Meeting.

The Academy met at its House.

The President in the Chair.

There were forty-five Fellows and one guest present.

The Corresponding Secretary presented the following letters: from W. C. Gorgas, accepting Fellowship; from E. B. Drew, resigning Fellowship. The following biographical notices were also presented: J. M. Crafts, by T. W. Richards, L. P. Kinnicutt, by W. L. Jennings, S. P. Langley, by John Trowbridge, B. O. Peirce, by E. H. Hall, F. W. Taylor, by I. N. Hollis, O. C. Wendell, by S. I. Bailey, Robert Koch, by H. C. Ernst, A. S. Packard, by A. D. Mead, Ferdinand Bruntière, by Barrett Wendell and Louis Allard, Edward H. Hall, by W. W. Fenn, W. G. Sumner, by T. N. Carver, W. W. Howe, by W. H. Dunbar.

The Chair announced the deaths of Henry Adams, Fellow in Class III., Section 3, and Marcus Perrin Knowlton, Fellow in Class III., Section 1.

The following report of the Council was presented: —

Since the last report of the Council, there have been reported the deaths of twelve Fellows: J. W. White, J. H. Choate, B. L. Pratt, J. M. Crafts, H. L. Warren, W. DeW. Hyde, W. B. Clark, G. V. Leverett, P. S. Yendell, C. E. Faxon, Henry Adams, M. P. Knowlton; and of two Foreign Honorary Members: G. C. Maspero, Pasquale Villari.

Forty-eight Fellows have been elected, of which number, one has declined Fellowship. The elections of Alexis Carrel and Edward Weston have lapsed. The limit of time of acceptance has been extended for J. D. Irving. One Fellow has been dropped from the list for non-payment of dues. Two Fellows have resigned Fellowship.

Seven Foreign Honorary Members have been elected. The elections of four, (Barrois, Bonnat, Marconi and Nernst) have lapsed.

The roll now includes 515 Fellows and 67 Foreign Honorary Members.

The annual report of the Treasurer was read, of which the following is an abstract: —

General Fund.

Receipts.

Balance, April 1, 1917	$4,030.62	
Investments	3,826.30	
Assessments	3,285.00	
Admissions	400.00	
Sundries	264.05	$11,805.97

Expenditures.

Expense of Library	$2,426.64	
Expense of House	1,729.32	
Treasurer	741.03	
Assistant Treasurer	250.00	
General Expense of Society	640.70	
Income transferred to principal	282.92	$6,070.61
Balance, April 1, 1918		5,735.36
		$11,805.97

Rumford Fund.

Receipts.

Balance, April 1, 1917	$2,270.62	
Investments	3,295.05	
Sale of instrument returned	40.00	$5,605.67

Expenditures.

Research	$1,800.00	
Periodicals and binding	55.41	
Publication	680.97	
Sundries	12.44	
Income transferred to principal	154.64	$2,703.46
Balance, April 1, 1918		2,902.21
		$5,605.67

C. M. Warren Fund.

Receipts.

Balance, April 1, 1917	$2,592.27	
Investments	1,428.39	$4,020.66

Expenditures.

Research	$300.00	
Sundries	3.17	
Income transferred to principal	43.91	$347.08
Balance, April 1, 1918		3,673.58
		$4,020.66

Publication Fund.

Receipts.

Balance, April 1, 1917	$1,921.83	
Appleton Fund investments	932.78	
Centennial Fund investments	2,404.35	
Authors' Reprints	118.70	
Sale of Publications	181.26	$5,558.92

Expenditures.

Publications	$2,570.37	
Sundries	10.00	
Income transferred to principal	163.06	$2,743.43
Balance, April 1, 1918		$2,815.49
		$5,558.92

Francis Amory Fund.

Receipts.

Investments	$1,222.50	$1,222.50

Expenditures.

Publishing statement	29.50	
Income transferred to principal	1,193.00	$1,222.50

The following reports were also presented: —

Report of the Library Committee.

The Librarian begs to submit the following report: —

During the year 73 books have been borrowed by 23 persons, including 15 Fellows and 5 libraries. Many books have been consulted, although not taken from the library. All books taken out have been satisfactorily accounted for.

The number of volumes on the shelves at the time of the last report was 35,228. 472 volumes have been added during the past year, making the number now on the shelves, 35,700. This includes 22 purchased from the income of the General Fund, 11 from that of the Rumford Fund, and 435 received by gift or exchange. The pamphlets added during the year number 203.

The expenses charged to the Library during the financial year are: —

Salaries	$1,824.00
Binding: —	
General Fund	584.10
Rumford Fund	20.60
Purchase of periodicals and books: —	
General Fund	114.85
Rumford Fund	34.81
Miscellaneous	54.54
Total	$2,596.90

A. G. Webster, *Librarian.*

May 8, 1918.

Report of the Rumford Committee.

The Committee organized November 14, 1917. Charles R. Cross was chosen to be chairman for the ensuing year and Arthur G. Webster, secretary.

During the past year grants for research have been made as follows:

November 14, 1917. To Professor Raymond T. Birge in aid of his research on the structure of Series Spectra $150

To Professor Ancel St. John for the purchase of a refrigerating machine and accessories to be the property of the Academy and

sent to Professor St. John for use in connection with his researches on Crystal Structure by means of X-Rays	$500
To Professor Theodore W. Richards in aid of the publication of Marie's Physical and Chemical data	250
March 13, 1918. To Professor F. A. Richtmyer in aid of his researches on the Optical Properties of Thin Films (additional)	500
To Professor Arthur L. Foley, for his research on the photography of the electric spark at different periods of its history .	150
To Dr. Olin Tugman in aid of his research on the Conductivity of thin metal films when exposed to ultra violet light . .	100

Reports of progress in their several researches have been received from the following persons: —

Messrs. C. G. Abbot, W. M. Baldwin, R. T. Birge, W. W. Campbell, A. L. Clark, D. F. Comstock, H. Crew, F. Daniels, E. B. Frost, R. C. Gibbs, H. C. Hayes, H. P. Hollnagel, L. R. Ingersoll, N. A. Kent, L. V. King (research finished), C. A. Kraus, E. Kremers, A. B. Lamb (research finished), C. E. Mendenhall, R. A. Millikan, H. W. Morse (research finished), C. L. Norton, F. Palmer, Jr., J. A. Parkhurst, H. M. Randall (research finished), T. W. Richards, F. A. Richtmyer, A. St. John, W. O. Sawtelle, A. W. Smith, F. A. Saunders, B. J. Spence, F. W. Very, D. L. Webster.

Most of these researches have been temporarily suspended because of the engagement of the various grantees in work for the Government.

The following paper has been published with aid from the Rumford Fund in the Proceedings of the Academy since the last annual meeting: P. W. Bridgman, "Thermo-electromotive Force, Peltier Heat and Thomson Heat under Pressure." Volume 53, No. 4, March, 1918.

At its meeting of January 9, 1918, it was unanimously voted by the Rumford Committee for the first time and on February 13, 1918, for the second time to recommend to the Academy the award of the Rumford Premium to Theodore Lyman for his researches on Light of very short wave length.

Professor Lyman, though a member of the Rumford Committee, has been abroad in the service of his country since autumn.

Charles R. Cross, *Chairman.*

May 8, 1918.

Report of the C. M. Warren Committee.

The C. M. Warren Committee begs to submit the following report:

The unexpended balance of appropriations held by the Committee at the date of the last report was $2271.50. In March, 1918, a further appropriation of $800 was made by the Academy.

Only one application for a grant from this Fund has been received during the year, namely, that of Dr. James H. Ellis, for the sum of $300 for the study of equilibrium conditions of the reaction employed in the Bucher process for the fixation of atmospheric nitrogen. This application was approved by the Committee on November 7, 1917. The results of this investigation should be of direct value to the National Government.

It appears to be the general experience of Trustees of research funds that the past year has been one of little or no activity with respect to applications for grants. These conditions will doubtless continue during the war, but it seems to the majority of your Committee that, at the close of the war, there is likely to be an increased field of usefulness for these funds, and that the income should be allowed to accumulate, or, if invested, it should still be regarded as available for appropriation for the present. One member (Professor Baxter) dissents from this view. The balance at the disposal of the Committee at the present time is $2771.50 and the Treasurer reports that there is an unappropriated income amounting to about $1300.

During the year Professor S. L. Bigelow has published the results of his investigations upon Metallic Osmotic Membranes.

The results of Professor J. F. Norris's investigations are being prepared for publication.

Respectfully submitted,

H. P. Talbot, *Chairman.*

May 8, 1918.

Report of the Publication Committee.

The Committee of Publication submits the following report for the period from April 1, 1917, to April 1, 1918.

During this period, 710 pages of the Proceedings have been issued, namely, Nos. 10–13 of Vol. 52, and Nos. 1–5 of Vol. 53.

Two of these numbers, namely 52: 12 and 53: 4, were paid for out of the funds of the Rumford Committee, the total charge against the Rumford Fund being $680.97.

The accounts of the Committee of Publication stand as follows:

Balance on hand April 1, 1917	$1,756.29
Appropriation for 1917–1918	3,000.00
Proceeds from sale of publications	181.26
Total available funds	$4,937.55
Expenses	2,451.67
Balance on hand April 1, 1918	$2,485.88

During the present year, authors have ordered "extra" reprints through the Committee, to the amount of $118.70.

Respectfully submitted,

Edward V. Huntington, *Chairman.*

May 8, 1918.

Report of the House Committee.

The House Committee submits the following report for 1917–18.

With the balance left from last year, an appropriation of $1600 and money received from other societies for the use of the rooms, the Committee has had at its disposal the sum of $1789.62. The total expenditure has been $1769.32, leaving an unexpended balance on April 1, 1918, of $20.30. The expenditure has been as follows:

Janitor		$869.00
Electricity	A. Light	92.40
	B. Power	46.80
Gas		12.73
Water		8.00
Telephone		57.91
Coal	Furnace	582.30
	Water Heater	20.30
Care of elevator		23.19
Ice		15.00
Janitor's materials		21.31
Upkeep		20.38
Total expenditure		$1,769.32

The amount of $40. contributed by other societies for the use of the building leaves the net expense of the House $1729.32.

A private subscription enabled the Committee to equip the library stack building with double windows fitted with rubber gaskets. These have proved effective in greatly diminishing the amount of dirt that collects on the books. It is thought that in an ordinary winter the result will be a material saving in coal.

Meetings have been held as follows: —

The Academy	8
Harvard Biblical Club	5
Colonial Society	4
American Antiquarian Society	1
Archaeological Institute of America	1

The rooms on the first floor have been used many times for Committee meetings.

In the death of William J. Reardon, on February 9, at the Cambridge Tubercular Hospital, the Academy has lost a faithful and efficient employee, who since January, 1912, has given the care of the building undivided attention.

Respectfully submitted,

G. R. Agassiz, *Chairman.*

May 8, 1918.

On recommendation of the Rumford Committee, it was

Voted, To award the Rumford Premium to Theodore Lyman, of Cambridge, Mass., for his Researches on Light of very short Wave-length.

On motion of the Treasurer, it was

Voted, That the Annual Assessment be ten ($10) dollars.

The annual election resulted in the choice of the following officers and committees: —

Charles P. Bowditch, *President.*
Elihu Thomson, *Vice-President for Class I.*
William M. Davis, *Vice-President for Class II.*
George F. Moore, *Vice-President for Class III.*
Harry W. Tyler, *Corresponding Secretary.*
Wm. Sturgis Bigelow, *Recording Secretary.*
Henry H. Edes, *Treasurer.*
Arthur G. Webster, *Librarian.*

Councillors for Four Years.

George D. Birkhoff, *of Class I.*
Charles H. Warren, *of Class II.*
Frederic Dodge, *of Class III.*

Finance Committee.

Henry P. Walcott,
John Trowbridge,
Harold Murdock.

Rumford Committee.

Charles R. Cross,
Arthur G. Webster,
Edward C. Pickering,
Arthur A. Noyes,
Louis Bell,
Elihu Thomson,
Theodore Lyman.

C. M. Warren Committee.

Henry P. Talbot,
Charles L. Jackson,
Walter L. Jennings,
Arthur D. Little,
Arthur A. Noyes,
Gregory P. Baxter,
William H. Walker.

Publication Committee.

Edward V. Huntington, *of Class I.*
Jay B. Woodworth, *of Class II.*
Albert A. Howard, *of Class III.*

Library Committee.

Harry M. Goodwin, *of Class I.*
Thomas Barbour, *of Class II.*
William C. Lane, *of Class III.*

House Committee.

George R. Agassiz,
Louis Derr,
Wm. Sturgis Bigelow.

Committee on Meetings.

THE PRESIDENT,
THE RECORDING SECRETARY,
WILLIAM M. DAVIS,
EDWIN B. WILSON,
GEORGE F. MOORE.

Auditing Committee.

GEORGE R. AGASSIZ,
JOHN E. THAYER.

The following gentlemen were elected Fellows of the Academy:—

Henry Bayard Phillips, of Boston, to be a Fellow in Class I., Section 1. (Mathematics and Astronomy.)

David Locke Webster, of Ann Arbor, to be a Fellow in Class I., Section 2. (Physics.)

Edmund Burke Delabarre, of Providence, to be a Fellow in Class III., Section 1. (Theology, Philosophy and Jurisprudence.)

William Herbert Perry Faunce, of Providence, to be a Fellow in Class III., Section 1. (Theology, Philosophy and Jurisprudence.)

Leighton Parks, of New York, to be a Fellow in Class III., Section 1. (Theology, Philosophy and Jurisprudence.)

Endicott Peabody, of Groton, to be a Fellow in Class III., Section 1. (Theology, Philosophy and Jurisprudence.)

Francis Greenwood Peabody, of Cambridge, to be a Fellow in Class III., Section 1. (Theology, Philosophy and Jurisprudence.)

Edward Capps, of Princeton, to be a Fellow in Class III., Section 2. (Philology and Archaeology.)

George Lincoln Hendrickson, of New Haven, to be a Fellow in Class III., Section 2. (Philology and Archaeology.)

Elijah Clarence Hills, of New York, to be a Fellow in Class III., Section 2. (Philology and Archaeology.)

Rudolph Schevill, of Berkeley, to be a Fellow in Class III., Section 2. (Philology and Archaeology.)

Brooks Adams, of Quincy, to be a Fellow in Class III., Section 3. (Political Economy and History.)

Isaac Minis Hays, of Philadelphia, to be a Fellow in Class III., Section 3. (Political Economy and History.)

Gamaliel Bradford, of Wellesley Hills, to be a Fellow in Class III., Section 4. (Literature and the Fine Arts.)

Charles Allerton Coolidge, of Boston, to be a Fellow in Class III., Section 4. (Literature and the Fine Arts.)

Edward Waldo Forbes, of Cambridge, to be a Fellow in Class III., Section 4. (Literature and the Fine Arts.)

Morris Gray, of Chestnut Hill, to be a Fellow in Class III., Section 4. (Literature and the Fine Arts.)

Archer Milton Huntington, of New York, to be a Fellow in Class III., Section 4. (Literature and the Fine Arts.)

Thomas Nelson Page, of Washington, to be a Fellow in Class III., Section 4. (Literature and the Fine Arts.)

Walter Hines Page, of Garden City, to be a Fellow in Class III., Section 4. (Literature and the Fine Arts.)

The following communications were presented: —

Professor Henry P. Talbot, "The Nitrogen Question and the War."

Professor Forris J. Moore, "Graphic Formulas of Organic Chemistry: To what extent may they be considered true pictures of Molecular Structure?"

The following papers were presented by title: —

"On Stability in Dynamics." By G. D. Birkhoff.

"I. Diagnoses and Notes relating to tropical American Eupatorieae. II. A descriptive Revision of the Colombian Eupatoriums. III. Keyed Recensions of the Eupatoriums of Venezuela and Ecuador." By B. L. Robinson.

The meeting then adjourned.

BIOGRAPHICAL NOTICES.

CHARLES FRANCIS ADAMS (1835–1915)

Fellow in Class III, Section 3, 1871.

Charles Francis Adams, of famous ancestry, was born in Boston, May 27, 1835, the second son of Charles Francis and Abigail Brown (Brooks) Adams. Of his early education and associations he has said much in his "Autobiography," but heredity counted for much in his characteristics. He had a clear recollection of his grandfather, John Quincy Adams, then engrossed by his contest for freedom, and he had inherited a questioning spirit which placed him in opposition to the social and political conventions of the day. Passing through a private school at Hingham and the Boston Latin School he entered Harvard College and pursued the usual course of studies without indication of possessing unusual aptitude or a special bent in any one direction. On graduating in 1856 he entered the law office of Dana and Parker. The personal relations with two such men exerted a strong influence upon the young Adams, to whom law could never be a serious profession any more than it was to his grandfather; but the writings of the English scientists and the speculations of Spencer were an even stronger influence, encouraging his tendency to question existing conditions and to test the strength of the economic and political structure on which the democratic community rested.

The war of secession interrupted this training in the law, though Mr. Adams did not at first consider military service as necessary. His father had been appointed United States Minister to the Court of St. James and his son was in charge of his business at home. A younger brother, Henry, accompanied his father to London to be his private secretary, and on Charles rested the management of the family affairs. The call, however, became too strong to be resisted, and in December, 1861, he received a commission as First Lieutenant in the First Massachusetts Cavalry. His service exercised a lasting influence upon his career, for it later engaged him in a series of studies upon the war which placed him high among critics of military strategy, and which yielded rich return in the connected field of the diplomacy of the period. Serving in South Carolina and Virginia, he became Captain in October, 1862, was chief of squadron through the campaign of Gettysburg and in the advance upon Richmond, and in the autumn of 1864 was transferred as Lieutenant-Colonel to the Fifth Massachusetts Cavalry (colored). Seriously affected in health he was ordered home in 1865, and while there he received an invitation to join the military family of Major-General Humphreys, as Assistant Inspector General. Such was his idea of his duty to his colored regiment that he declined this flattering offer. He entered Richmond at the head of his regiment in April, 1865, but was obliged to resign on account of broken health. He subsequently received the brevet of Brigadier General. His later opposition to the scandalous waste in pensions and the manifestly dishonest methods of agents in securing them called out no little hostile criticism on his military service; but the charges were easily disproved or explained by him, and the record shown to be highly honorable to himself. In the face of great difficulties he won for himself a reputation for attention to duty, a desire to master the needs of the service and a care for detail and discipline which won for him the notice of his superior officers and the devotion of his followers.

Returning from the army he proposed to resume the study and practice of the law, but the social conditions which followed the war called upon his interest and directed his energy into a field of investigation which he made his own. Conscious of a certain faculty for clear expression and an unusual quality of style he wrote much on currency, politics and tax questions. The situation in which the railroads were left by the war attracted his study, and he soon gained prominence in a field where reforms were much needed and where New England, thanks to him, was to lead the war to better conditions. His fearless denunciation of dishonest practices and his clean cut policy for a better conduct of railroad management led to his appointment on the first really effective State Board of Railroad Commissioners, that of Massachusetts. For ten years his best service was rendered in this capacity, and for seven years, as chairman of the commission, he wrote its reports and established it on such a plane that it became the model of similar commissions, state and national. These reports may still be read with profit for their remarkable grasp of an intricate subject and for their definite propositions for bettering the condition of the railroads and their relations to the state. So thorough was the plan worked out that it was readily applied to the electric roads when they came into existence. He was called upon to serve as a government director on the Union Pacific Railroad, becoming the President of that road in 1884. This naturally led to his resignation from the State commission. He did much to lift the Union Pacific out of the slough of ill repute into which it had fallen, and did much more than a less honest and fearless reformer could have accomplished; but he never looked with satisfaction upon the experience, for he was contending against influences of a sinister character which in the end proved stronger than his own efforts. His confidence in the future of the road was fully justified in later years, and to its subsequent success Mr. Adams contributed more than was at the time recognized.

After leaving the army Mr. Adams had been occupied in public business and the affairs of a great railroad; there came to him now a period of comparative rest. So active a mind could not remain unoccupied. He took up the subject of education, and when on the State Board of Education, where he sat for only one year, he formulated a plan of studies to be followed in the common schools. As an Overseer of Harvard University from 1882 to 1907 he criticised freely, but also did much constructive work, one of the important items being his report on the English department which led to changes in that department greatly to its improvement. His challenge to the classics — A College Fetish — awakened wide interest, and to him was due the requirement in entrance examination of only one of the classical languages, instead of two. He reformed the school system of the town of Quincy, and the "Quincy School System" has been followed in many localities, for it applied business methods to the common schools, resulting in a higher efficiency.

Of Mr. Adams' historical work little need be said, for it speaks so well for itself. How he came to engage in it he has told in his "Autobiography," and for forty years it constituted his principal enjoyment, the best realization of his powers for investigation and exposition. Whether it was the story of the beginnings of the plantation of the Massachusetts-Bay, or the diplomatic career of his father, or a biography of a man of law and letters, the result proved his unusual qualification and high equipment. In each department he sought to be complete — to approach as near to finality as the records permitted. His "Three Episodes of Massachusetts History," which was really a history of the town of Quincy, is a model of local history, when treated in its relations to national history. It was in preparing this work that his thorough methods tempted him to edit Thomas Morton's "New-English Canaan" and the Winthrop-Weld tract on "Antinomianism in New England," two side-studies to the larger undertaking on which he left little still to be interpreted. The "Life of Richard Henry Dana" is also a model of its kind, wherein the subject of the biography is made to tell his own story, the compiler adding only what was needed for a full comprehension of the text. But how much the "compiler" added, and how he made clear the path to the reader can be grasped only by a careful reading of the volume. As to the life of his father, he wrote an admirable and well-proportioned sketch of it for the "American Statesmen," but the larger adventure, planned on a very much larger scale, occupied much of his time and thought for years, and had been carried to 1861, when the end came. Certain it is that it can never be completed as he intended it, for his later studies in English and American records led him to modify many of his earlier conclusions. Invited in 1913 to give at Oxford the lectures on American history, he utilized the opportunity to gather a rich harvest of private and official correspondence which was to be used in the extended life of his father.

His connection with the Massachusetts Historical Society encouraged his historical leanings and offered him a vent for his many studies in American history. His value to the Society was early recognized, and he rapidly rose in the official line, becoming a member in 1875, the Vice-President in 1890, and the President in 1895, holding that position until his death. What he accomplished for the Society, changing it from a small social "club" to an active historical society, may be seen in the printed "Proceedings." He brought to it the same energy, the same questioning attitude, and the same fearlessness as had given him reputation as a writer on social problems. Possessing a true historical instinct he contributed freely from his own ability and called out from others the best that was in them in historical investigation. In time, in money, and in papers he did more for the Society than the records will show.

In 1871 he was elected a Fellow of the American Academy of Arts and Sciences. He was not a regular attendant on its meetings.

Mr. Adams married, November 8, 1865, Mary Howe Ogden of Newport, R. I., who survived him. He died in Washington, D. C., March 20, 1915.

Of Mr. Adams' many activities and positions, public and corporate, it would be impossible to speak here. The list would be a long one, and only a full presentation of each item could give a fitting conception of his aims and accomplishment. He was a man of letters, possessed of a style at once clear, trenchant and individual, and capable of deep investigation and an orderly presentation of conclusions. He had wide sympathies, was a generous supporter of social movements and agencies, and encouraged the younger generation by aid as well as by example. A liberal in religion, in politics and in social questions, he retained an open mind and an independent position, recognizing no party ties or dead conservatism. Eminently social, he yet retained a certain shyness which invited open intercourse and suggested the strong nature beneath this genial surface. It was a privilege to win his regard and to be associated with him closely in his work and ambitions.

He left an "Autobiography" which is a frank and penetrating measure of himself. Naturally it is not complete, and his desire to explain his own conduct has made him unjust to himself. No other person could have said as much, or said it as well; it is therefore characteristic, and must be held in high estimation as an open and honest attempt at self-appreciation, a form of expression which has become all too infrequent. In every sense he was a lovable character, vivid, stimulating, loyal and independent.

WORTHINGTON CHAUNCEY FORD.

SIR BENJAMIN BAKER (1840–1907)

Foreign Honorary Member, Class I, Section 4, 1899.

Sir Benjamin Baker, K. C. B., K. C. M. G., D.Sc., LL.D., M. A. I., F. R. S., was born at Keyford, Frome, Somerset, March 31, 1840, and died suddenly from heart failure May 19, 1907. At the age of 16 he was apprenticed to Messrs. Price and Fox of Neath Abbey Iron works, and remained with them four years. During the next two years he was engaged on railway work, and in 1862 joined the staff of the late Sir John Fowler, with whom he remained associated until the death of the latter in 1898; — rising from the position of Junior Assistant to that of partner.

During this long period Mr. Baker was actively engaged upon various kinds of engineering work, including some works of the greatest importance. Although without collegiate training, Mr. Baker early established a reputation as an authority on the theory and practice of engineering, displaying a remarkable combination of practical and scientific knowledge. He was interested in education, and did much to bridge the gulf which had long separated theory from practice.

Much of Mr. Baker's work was connected with railways. He was consulting engineer for the earliest "tube" railway in London, and also for the first projected Hudson River Tunnel in this country. He was for many years connected with great engineering works in Egypt. He was also consulted in the design and construction of railways and other engineering works in West Africa and other colonies, and in the construction of docks and bridges in England.

The two greatest works, with which his name will forever be associated, are the Forth Bridge in Scotland, and the Assuan Dam in Egypt.

The Forth Bridge, in its present form, owes its conception and design to him, who worked it out upon scientific principles with the greatest care. This bridge possessed for many years the longest span in the world, which is now only surpassed (and by only 90 feet) by the recently constructed bridge across the St. Lawrence at Quebec.

Mr. Baker was undoubtedly one of the greatest engineers that England or the world has ever produced. The great variety of his work, the care with which he studied and worked out the various problems upon which he was called to advise, the combination of experience, judgment, and scientific knowledge which he possessed, made him a tower of strength, upon which those who consulted him could rely with confidence. He was an honorary member of the American and Canadian Society of Civil Engineers, and of the American Society of Mechanical Engineers; and in 1895 was President of the British Institution of Civil Engineers. He became a Foreign Honorary Member of the American Academy of Arts and Sciences in 1899. His name and works will not be forgotten. He did much for humanity, education, and the engineering profession, and to prove to the world that the development of civilization depends largely upon the work of the engineer.

G. F. Swain.

FERDINAND BRUNETIÈRE.

(1849–1900.)

Foreign Honorary Member in Class III, Section 4, 1890.

I.

Ferdinand Brunetière was born at Toulon, on the 19th of July, 1849. His father, a naval officer, came from the region still best remembered as La Vendée, about whose name lingers a romantic savor of loyalty to tradition. As a boy Brunetière seems to have had no fixed home, but an unusual experience of France, ranging from Provence to Britanny. He studied at the Lycée of Marseilles, and finally at the Lycée Louis Le Grand in Paris, where among his fellow-students was Paul Bourget. In 1869 he was examined for admission to the École Normale, and was rejected — an ironic incident in the life of a man destined to be the most eminent French critic of literature during the next thirty years.

In 1870 he served as a soldier in the defense of Paris. The subsequent excesses of the Commune probably intensified his temperamental distrust of revolution as distinguished from evolution. The next four or five years he passed obscurely, reading and studying with characteristic intensity and precision, but supporting himself by teaching at secondary schools. Among his fellow-teachers he again met Paul Bourget, to whose thenceforth close friendship he owed the chance which fixed the outlines of his career.

In 1875, the director of the Revue des Deux Mondes asked Bourget to write an article which required more conservative affection for literary tradition than Bourget then cherished. He therefore called the attention of the director to his friend Brunetière, whose opinions happened to coincide with those desired. This almost accidental introduction to the Revue des Deux Mondes not only brought to public notice the remarkable individuality of Brunetière, but began the relation between the man and the review destined to last and strengthen steadily. For years before he died, people thought of them together — almost as one. Though Brunetière in time found many other vehicles of expression, his numberless writings for the Revue des Deux Mondes were the basis of all the rest. Yet his other fields of work were various and noteworthy. In 1887, for example, his rejection at the École Normale was more than nullified by his appointment there as a lecturer on literature. He was soon recognized as, on the whole, the most distinguished lecturer of his generation, even by those who dissented from his principles and disliked the massive power of his written style. No teacher has ever had much more influence on his pupils. Public lectures presently fell to him, at the Sorbonne, in various regions of France, and finally in foreign countries — in Italy, in Spain, in Holland, in Switzerland, in the United States. Meanwhile he had other recognitions,— the Legion of Honor, for example, in 1887. Six years later, in 1893, he received the crown of French literary distinction, admission to the Académie Française. In this year, he became head of the Revue des Deux Mondes. He remained so for the rest of his life.

In 1895 came the beginning of the last phase of his career. During a visit to Rome, he had a private audience with Leo XIII, of which the result was an article in the Revue des Deux Mondes implicitly setting forth the opinions uttered by the Pope, and also implying Brunetière's increasing disposition to accept Catholic orthodoxy. Up to this time he had been technically a free thinker, whose freedom of thought had led him to increasing respect for tradition. Before long, he joined the church, and presently became, so far as a layman could be, the most conspicuous exponent in France of intelligent Catholic thought. The politics and the passions of that time and of his ensuing years made this course at once bold and self-sacrificing. The tendency of the French government was by no means favorable to established religion; the Dreyfus affair gave rise to discussions and misunderstandings — profoundly honest on both sides — which intensified beyond precedent the warmth of feeling always smouldering beneath differences of religious and political principle; and finally the abolition of the Concordat disestablished the church in France. Meanwhile Brunetière was deprived of his chair at the École Normale, and was refused all opportunity of teaching in any institution under government control, such as the established universities and the Collège de France.

Though by this time stricken with the tuberculosis which proved fatal, he never relaxed his energy, nor his prodigious fecundity of expression. So long as his voice lasted, he lectured still, his private lecture-rooms always full to overflowing. When his voice was no longer at his command, he wrote if possible more copiously and vigorously than ever. During the last year of his life he exhibited his highest powers, as a critic, a thinker and a man of letters, in what he wrote concerning matters literary, political and religious alike. He died at Paris, the mere shadow of a body enshrining the full power and brilliancy of his mind, on December 9th, 1906.

II.

Among the numerous notices of Brunetière, and of his strong and copious literary work during a full thirty-five years, three stand out, as deeply sympathetic. Immediately after his death, Monsieur Paul Bourget sent Le Temps a letter of tenderly personal reminiscence; this is published in Bourget's "Pages de Critique et de Doctrine," (1912) I, 282–293. Less than a month later, the Revue des Deux Mondes, for January, 1907, published an analogous paper by the Vicomte Eugène-Melchior de Vogüé, like Bourget a fellow academician and a personal friend, though in this case the friendship began after Brunetière's reputation had become established; the article is reprinted in Monsieur de Vogüé's "Les Routes" (1910), 202–225. And in the Revue des Deux Mondes (1 March, 1908, and 1 April, 1908) Brunetière's pupil, Monsieur Victor Giraud, published a more careful study of the master's life and work, which was later included in Monsieur Giraud's "Maîtres de l'Heure" (1912), 59–137. All three of these articles are critical in that excellent sense of the word which implies earnest effort sincerely to set forth what is best in thought and in life, with no sentimental suppression of what is not quite so. All three are affectionately sympathetic. Together they give an extraordinary impression of a character which all must respect, even though now and again disposed hardly to agree with the conclusions honestly and combatively set forth in its profuse and scattered utterances.

The power of summary possessed by Monsieur Victor Giraud is held by those whose works he has had occasion to summarize remarkable for intelligence, for sympathy and for justice. In the case of Brunetière, his summary is based not only on love for a teacher who stimulated him when he was a student, and thereafter was a personal friend and guide, but also on thoughtful study of everything that Brunetière had published. "Thirty-two volumes," he tells us — mostly collections of articles for the Revue des Deux Mondes, etc.,— "two pamphlets, five editions of (French) classics, a hundred articles or so scattered far and wide and never collected, represent the visible and tangible work of a man who was not only a writer but a professor, a lecturer, and the editor of the *Revue*, and who died at the age of fifty-seven. He touched on criticism, history, aesthetics, sociology, ethics, pedagogics, philosophy, apologetics, and theology; and if he did not remake them all, he seldom left things exactly as he had found them. By signs like that you can recognize the true masters. Brunetière was probably among the two or three greatest influences upon the French thought of his time."

To attempt here any detailed summary of this great though fragmentary work would be presumptuous. It is not, perhaps, presumptuous to say that Monsieur Giraud's memorable tribute to his master and friend revives and confirms an impression which Brunetière made on American readers and hearers during his life time. Nobody was ever more French than he, in uncompromising intellectual honesty, in untiring assiduity of work, in a vigor and a precision of thought inexhaustible and ultimate, in fervent effort to attain and to set forth the truth. Nobody was ever more French, either, in what may perhaps be called the limitations inevitable to precision. To see things clearly, you must fix your point of view. This fixed, you may look either backward, bemoaning the faded virtues of the past; or forward, anticipating the gleaming virtues of the future; or you may strive to define that inexorable process of change which the optimism of America calls progress and complacently assumes to tend heavenward.

Brunetière, intensely French, chose the third of these alternatives, always conscious that the present is the creature of the past and the creator of the future. In their passage from past to future, those who love the past are apt to lament and those who love the future are apt enthusiastically to hope; meanwhile, the general run of mankind are content to live in the present, thoughtlessly accepting commonplace. Now commonplace is the instinctive expression of humanity:— in literature, for example, it asserts the enduring merit of works which survive to be classics; in religion, it comfortably accepts the doctrine of the church. Which is all very sensible; but, when asked to account for its conclusions, its reasons are apt to be stupid and flimsy. A rather shallow kind of conventional thought, nowadays called radical, assumes that the task of intelligence is to dissipate the fog of canting reasons in which commonplace assumptions are enshrouded, and ingenuously believes that folly can thus be swept nowhere. A more distinguished type of mind, admitting the old reasons often wrong, is not willing to conclude that the old assumptions are equally so. It believes that the highest task of the intellect is not to reject what has been unreasonably accepted, but rather to give true reasons for sound conclusions hitherto accepted chiefly as a matter of instinct. This seems on the whole to have been the purpose of Brunetière from beginning to end. There has hardly ever been work more faithfully true than his to an ideal once stated in this country as the aim and end of all education — the illumination of the commonplace.

III.

We are fortunate in having among us now a French scholar and man of letters who was a pupil of Brunetière at the École Normale. Without his friendly aid, this memoir must have stayed secondary. He has kindly consented to make it more memorable. So instead of proceeding with my own fragmentary memories of Brunetière when he was hereabouts in 1897, and when I saw him at Paris in 1905, I have been so bold as to ask Professor Louis Allard, of Harvard University, to send the Academy some account of his personal memories of the master, and of the master's teaching. And, remembering that "translation is at best like the back of an embroidery" I have asked him to send it in his own French words. Whoever reads them will surely share my gratitude for his kindness.

BARRETT WENDELL.

IV.

M^r^. le Professeur Barrett Wendell m'a fait l'honneur de me demander d'ajouter quelques notes personnelles à l'article substantiel qu'il a écrit sur Ferdinand Brunetière.

Je le remercie de l'occasion qui me permet de rendre hommage à la mémoire d'un maître que j'ai beaucoup admiré et aimé. Ce n'est donc pas que je me propose ici de donner de son oeuvre une analyse critique. Ou peut la trouver dans les livres que M^r^. Wendell a signalés, et surtout dans "Les Maîtres de l'heure" de M^r^. Victor Giraud, qui me paraît avoir dit sur le sujet le mot définitif. Brunetière, d'ailleurs, avait désiré un jour qu'il fût son biographe; et je ne doute pas qu'il n'eût été content d'un portrait dessiné par le disciple avec amour et fidélité. Mon but est plus modeste. Sur l'invitation de M^r^. Wendell, je retracerai de mémoire quelques traits de l'homme et du professeur, qui pourront peut-être rendre un peu de relief et de couleur à une figure jadis si vivante, et qui n'auront d'autre mérite que d'être l'oeuvre d'un témoin oculaire.

J'ai eu Ferdinand Brunetière pour professeur de littérature française, pendant ma seconde année d'École Normale. Il était alors à l'apogée de sa carrière. Directeur de la Revue des Deux Mondes, membre de l'Académie française, il avait été récemment, dans l'amphithéâtre de l'ancienne Sorbonne, le conférencier acclamé d'un public de dix-huit cent personnes qui avaient suivi avec enthousiasme ses leçons sur l'évolution de la poésie lyrique. Ce public avait consacré sa réputation d'orateur; et c'était de son éloquence qu'il était le plus fier. Son éclatant succès lui avait été d'autant plus sensible qu'il rencontrait de l'opposition, peut-être devrai-je dire, de l'antipathie chez certains professeurs de la Faculté des Lettres, depuis surtout sa visite au Vatican et le fameux article qui en avait été le résultat. A coup sûr, les applaudissements qui l'interrompaient ou saluaient la fin de chaque leçon, en prenaient pour son amour-propre plus de saveur. Quelque temps avant l'ouverture de son cours, il avait confié à l'un de mes amis: "Je leur montrerai ce que je peux faire chez eux." Et certes, il n'avait jamais été plus inspiré: grand critique, il s'était révélé maître de la parole.

J'ai fait allusion à cet article qui souleva tant de polémiques, et qui lui attira tant de reproches, bien qu'il protestât n'avoir jamais voulu proclamer la faillite de la science. Comme le remarque Mr. Wendell, son entrevue avec le pape Léon XIII était le point de départ d'une nouvelle orientation de sa pensée: il allait au catholicisme. Bientôt même, il devait délaisser les travaux de pure critique littéraire pour prendre une part de plus en plus active aux luttes religieuses de son temps.

C'est alors que normalien de la section des lettres de seconde année, j'assistai, avec mes vingt-six camarades, à ses deux cours sur Molière et sur l'Encyclopédie du XVIIIe siècle.

Les bruyantes discussions qui venaient de s'agiter autour de son nom stimulaient notre curiosité d'approcher d'un homme qui avait pris déjà une si grande autorité dans le monde intellectuel. Tous, nous ne l'avions vu que de loin, dans la salle de la Sorbonne, ou même nous ne le connaissions que par la Revue des Deux-Mondes. Quelques-uns, et parmi ceux là le Charles Péguy à vingt ans, à cause de leurs opinions politiques radicales ou socialistes, se tenaient sur leurs gardes, et adoptaient par avance une attitude défiante: ils reconnaissaient volontiers en lui le lettré et l'orateur, mais ils lui déniaient le droit ou la capacité de penser en philosophe.

Brunetière avait quarante-sept ans. Petit, maîgre, et légèrement voûté, le front plissé, le visage fatigué et mélancolique, parfois éclairé d'un sourire ironique, il gardait l'empreinte de l'homme qui avait connu les labeurs d'une dure jeunesse, avait prodigieusement lutté pour parvenir, et s'était habitué à regarder sans illusions le monde et la vie.

Il venait à l'École avec un cahier à converture de serge noire, qu'il ouvrait sur sa table, pour s'aider des grandes lignes du plan de sa leçon. Il ne le regardait que très rarement. Pendant une heure et demie, il nous parlait avec le même soin, la même verve, la même éloquence que si nous eussions été le public de ses grandes conferences de Sorbonne. Les yeux perçants et fureteurs sous le lourd lorgnon d'écailles circulaient autour de la petite salle comme pour nous saisir sous le joug de ses idées. Mais surtout ce qui s'imposait à nous dès le début, ce qui nous prenait, ce qui séduisait les plus rebelles à sa pensée, c'était cette voix si nette, si sonore, si métallique qui le servait à merveille, lorsqu'il lisait des textes pour illustrer le cours. Et au moyen de cet organe incomparable, il développait, dans un ordre aussi inflexible qu'un sermon de Bossuet et dans des phrases souvent périodiques qui coulaient de ses lèvres comme une improvisation naturelle, ces sèries d'arguments qui se pressaient vers leur conclusion avec une vivante logique. C'est qu'il ne lui suffisait pas de jeter sur le solide charpente de ses leçons les chaines des faits et des idées; quand le sujet le portait, il y mettait un mouvement qui venait de l'ardeur de sa conviction et de son énergie de lutteur. C était de la dialectique vibrante. Un geste lui était familier. Entrainé par la force de ses idées, et pour donner à l'une d'elles plus d'accent, il jetait la main droite en avant, tout en tirant sa manchette.

Parfois ce geste s'adressait à un adversaire qu'il lui fallait réfuter, ou raillait une sottise, ou détruisait une erreur: mouvement de polémiste qui adorait le combat aussi bien contre les morts que contre les vivants, Voltaire et Jean-Jacques Rousseau, comme Ernest Renan ou Berthelot. Il lui arrivait de donner à son humeur un tour amusant. Dans une de ses premières leçons sur Molière, il avait pris à partie le notaire qui, dressant l'inventaire de la succession du poète, avait oublié sa bibliothèque. Je l'entends encore, de sa voix mordante et scandant les mots, la manchette en avant, dire son fait au tabellion comme s'il eût été encore de ce monde: "Eh! qu'est ce que cela nous importe, Messieurs, que cet imbécile de notaire ait pensé à nous donner le compte des chemises du grand homme si tout justement il a oublié l'essentiel qui était de nous apprendre quels livres il lisait sans doute le plus volontiers?" — Le reproche était mérité. Brunetière regrettait une source précieuse de renseignements sur la formation intellectuelle de Molière. Il donnait aussi par là un exemple de la conscience de cette érudition inépuisable qu'il possédait en littérature, en histoire, et en philosophie. Il paraissait avoir tout lu et tout retenu. Oui, sans doute, il était l'homme ou l'orateur des idées générales; il y ramenait toute sa science et toute sa réflexion. Mais il n'a jamais prononcé ou écrit une phrase à vide; sa logique et son éloquence reposaient sur des faits accumulés par une lecture inlassable, étudiés avec une conscience rigoureuse, classés avec une réflexion tenace. J'en ai une preuve sous les yeux, dans des notes que j'ai conservées de ses conférences. Seulement, les faits n'étaient pour lui que la base indispensable. " Faites-les vivre " nous disait-il. Ne prenez l'érudition que comme un moyen et non un but. Des faits, doivent jaillir les idées. Et c'est ainsi que son enseignement était à la fois si nourri et si vivant. Voici comment il pratiqua sa méthode en collaboration avec ceux d'entre nous qui devaient, en troisième année, subir le concours d'agrégation des lettres. Il s'était chargé des six premières leçons sur Molière, chefs-d'oeuvre par la sûreté de l'information et la pénétration de la critique. Puis, à tour de rôle, chacun de nous devait analyser et discuter une comédie; pendant la dernière demi-heure, il corrigeait la conférence de l'élève et quelquefois la refondait. Ce travail achevé, il fit six leçons de conclusion qui étaient six leçons d'idées générales, interprétation des faits ou des remarques que les analyses avaient fournis ou suggérées sur l'art, le naturalisme et la morale de Molière.

On a parlé souvent de son dogmatisme, et on lui a fait la réputation d'une sorte de préfet de police de la littérature, qui ne pouvait souffrir la contradiction. Certes, il tenait fortement à ses idées, et il combattait pour elles de toute son âme, avec une puissance oratoire que Jaurès seul, de son temps, a égalée. Mais ce serait le voir sous le jour le plus faux que de croire qu'il cherchait à imposer ses opinions comme la vérité intangible. Au contraire, il n'appréciait rien tant chez les autres que l'indépendance de l'esprit, et il aimait à solliciter la discussion.

Dans la seconde de ses conférences hebdomadaires, il traitait, comme je l'ai dit, des Encyclopédistes. Sujet brûlant alors, car la France, à la suite de l'affaire Dreyfus, était déchirée par les dissensions religieuses. En un temps où il passait par les premières étapes de sa conversion et commençait à s'affirmer comme le champion de l'Église, il avait vu l'occasion de rechercher au XVIII^{e} siècle les origines de nos luttes et de manifester un jugement à la lumière de ses nouvelles convictions. Quelques-uns de mes camarades, qui se groupaient autour de Jaurès, étaient prêts à lui opposer une vigoureuse résistance. Il le savait. Aussi, chaque fois, avant de parler, nous demandait il de faire nos objections ou de poser des questions à propos de la leçon précédente. Si la discussion était offerte en termes courtois, il était heureux d'y entrer. Ce mérite fut éminent chez lui: ayant horreur pour lui-même, de l'opinion toute faite, du cliché, du convenu, il excitait ses élèves à en avoir le même dégoût; avant tout, il leur imposait le devoir intellectuel de penser par eux-mêmes. Aussi a-t-il été un incomparable éveilleur d'esprits, et quinze générations de normaliens lui ont rendu cet hommage. J'emprunterai là dessus un témoignage significatif à un de mes contemporains de l'École, connu pour son socialisme anticlérical, et qui, lancé dans le journalisme, écrivait au lendemain de la mort de Brunetière: "Ce n'était pas seulement un professeur, c'était un *maître*....Ceux qui secouaient son joug en gardaient quand même l'empreinte....Frais émoulus du collège, ses élèves prenaient plaisir à brûler dans son feu tout ce qu'ils avaient adoré avec leurs maîtres de rhétorique. Brunetière n'enseignait pas l'admiration convenue, mais le doute méthodique et l'irrespect: il animait ses disciples de ses haines vigoureuses; juste ou non, sa critique excitait l'intelligence, et en l'affranchissant des manuels, des clichés et des formules, lui apprenait à penser librement.,,

Comme je l'ai marqué au début, je n'ai pas l'intention de refaire ce qui a été si bien fait, l'analyse de son esprit et de son oeuvre. Je voudrais cependant dire un mot de sa conversion. J'étais son élève, au moment où il s'acheminait vers le catholicisme. Sa croyance était alors d'ordre tout intellectuel; il ne devait arriver à la pratique que plus tard, à la pratique intégrale que vers la fin de sa vie. J'ai cru en ce temps-là, et comme beaucoup d'autres, que c'était pour des raisons d'ordre social qu'il acceptait la religion catholique, et je l'ai cru longtemps. En relisant plus attentivement ses Discours de Combat, j'ai changé d'avis, et j'ai admis une explication plus simple. Brunetière, à l'époque où il niait Dieu, la Divinité de Jésus et la liberté morale, admirait passionnément Bossuet. Tourmenté par les problèmes de notre origine et de notre fin, n'en trouvant pas la solution dans la philosophie, il fut amené à la demander à la révélation et à l'Église, et cela conduit par la main de notre grand orateur chrétien. Ecoutons-le à Besançon, en 1900: "Moi aussi, quand je me suis mis à l'école de Bossuet, nourri que jétais des ideés de mon temps et des leçons de mes maîtres, moi aussi j'ai résisté, et j'ai résisté longtemps.

Puis, quoi qu'on dise qu'un homme ne peut pas beaucoup sur un autre, j'ai trouvé dans ce commerce avec Bossuet tant de bon sens, tant de génie, tant de probité intellectuelle, que je me suis laissé faire...." Oui, j'en suis convaincu aujourd'hui, c'est la lecture de Bossuet qui l'a amené au seuil du Vatican. A partir de 1895, il mit toute son ardeur de logique et toute la force de sa parole au service de l'idée religieuse. L'enseignement n'occupait plus dans ses préoccupations qu'une place secondaire. Cet apostolat lui apportait un immense surcroît de travail. Mais il avait travaillé toute sa vie et il affrontait ses multiples responsabilités avec une énergie surhumaine. C'est en ces années-là qu'il montra "ce que peut, selon le mot de Bossuet, une âme indomptable dans le corps qu'elle anime." Ce corps portait les marques des labeurs acharnés de sa première jeunesse. M^r^ Paul Bourget nous a raconté comment, après s'être livré tout entier pendant le jour à ses devoirs ingrats de professeur libre, en y montrant la conscience intransigeante qu'il eut toujours, il passait ses nuits à lire et à étudier. Dès l'âge de vingt-quatre ans, sa santé était compromise. Pourtant, il avait continué de travailler inlassablement. Alors qu'il était mon maître, la phthisie commençait à s'emparer de lui, ou, du moins, à le menacer. Il semblait défier la maladie, "en menant de front des travaux suffisants pour user quatre activités d'homme." "Mon ami," lui disait le Comte d'Haussonville, "la vie que vous menez est une gageure, vous la perdrez."— "Qu'est-ce que cela fait?" répondait-il.— Pour lui la vie ne valait la peine d'être vécue que s'il pouvait s'en servir.— Pendant les dix dernières années, il fut un miracle perpétuel de volonté invincible: en voici un émouvant témoignage.

Un matin qu'il devait comme d'habitude venir à neuf heures et demie donner son cours sur l'Encyclopédie, nous avions lu dans les journaux que, trés souffrant, la veille, il avait appelé en consultation deux illustres médecins spécialistes. A notre grande surprise, nous le vîmes apparaître à l'heure fixée. Ayant su que la presse avait répandu le bruit qu'il était gravement malade, il s'était habillé à la hâte, jeté dans un fiacre, et il était accouru nous apporter par le fait de sa présence son démenti. Il parlait de Montesquieu. Toutes ses énergies étaient ramassées dans ses yeux un peu fiévreux et dans sa voix plus vibrante et plus dominatrice peut être que de coutume. Soudain, il fut interrompu par une terrible quinte de toux qui le secouait tout entier et qui nous parut interminable. Nous attendîmes, douloureusement oppressés. Il acheva enfin de tousser, sourit de ce léger sourire ironique qui plissait parfois ses lèvres pincées et dit comme pour s'excuser: "Messieurs, la nature est la plus forte." Puis il continua sa conférence jusqu'à onze heures, et retourna prendre le lit pour quelques jours. Tel était l'homme.

Sa vigueur morale se reflétait dans la gravité un peu janséniste de son allure. Il n'invitait pas la familiarité. Aussi ses ennemis, et ils étaient nombreux dans la littérature, dans la politique et dans le journalisme, le représentaient-ils comme d'abord revêche et hargneux. La vérité est que je n'ai pas connu d'homme plus poli, mais sa politesse était digne et mesurée comme d'un homme de Port-Royal; sa parfaite courtoisie dans sa conversation comme dans sa correspondance avait le ton des "Messieurs." Ce qui ne veut pas dire qu'il n'aimât pas à se détendre, jusqu'à la plaisanterie, et parfois au calembour. Dans ses cours, il avait des éclairs de raillerie mordante ou d'amusante mauvaise humeur qui nous faisaient rire. Chez lui, rue Bara, près du Luxembourg, ou dans son cabinet de la Revue des Deux-Mondes, quand il se sentait en confiance, il s'épanchait volontiers à propos des idées qui l'occupaient alors. Je dois dire que sa conversation tournait vite au monologue; mais elle apprenait ou suggérait tant de choses qu'on n'eût pas pensé à s'en plaindre. Ici et là, il décochait un trait à l'adresse de quelqu'un de ses contemporains. La dernière fois que je le vis, en 1904, pour lui rendre compte d'une mission littéraire dont je lui devais l'honneur, il me parla de différentes personnes que nous connaissions. D'un prélat dont il était vaguement question à Rome pour le cardinalat, il caractérisait la vertueuse mais un peu terne personnalité en ces mots; "c'est une sainte nullité"; d'un journaliste qu'il n'aimait pas, "c'est un écrivain qui est toujours à la veille d'avoir du talent"; ou encore d'un évêque canadien de passage à Paris, "aimable homme," disait-il, "mais qui a l'air de prendre la France pour un petit Canada". Et la malice, chaque fois, touchait juste. On m'a dit qu'à table, hôte ou invité, dans l'intimité de personnes qui lui plaisaient particulièrement, il pouvait être le plus étincelant des causeurs.

Sous le masque sévère, qui lui était le plus habituel, et qui effarouchait les timides, il cachait une bonté tendre que n'ont connu que ceux qui en ont été l'objet ou qui ont vécu près de lui. En vrai fidèle de l'esprit du grand siècle, il mettait une pudeur jalouse à dissimuler ses sentiments ou à en atténuer l'expression. Il les prouvait surtout, sans les montrer. Ce qui le caractèrise de ce point de vue, c'est la manière dont il protégea les débuts de Paul Hervieu qu'il ne connaissait pas encore. Après l'avoir reçu froidement à propos d'un roman de jeunesse qu'il avait promis d'accepter pour la Revue des Deux

Mondes, en sa qualité de lecteur, et qui n'avait pas encore paru, il menaça Buloz, alors directeur, de donner sa démission, si le roman n'était pas inséré. Hervieu en sut que douze ans plus tard que Brunetière, devenu un de ses chers amis, avait joué son avenir pour rester fidèle à sa parole. Il poussait si loin la discrétion et la retenue dans la manifestation de sa confiance et de son estime que certains de ses anciens élèves n'en eurent la révélation qu'après sa mort. M^{r}. Bédier, aujourd'hui le brillant successeur de Gaston Paris, au Collège de France, avait eu avec lui depuis l'École Normale des relations affectueuses qui n'avaient jamais été jusqu'à l'intimité. Grande fut sa surprise, lorsque M^{me}. Brunetière lui apprit que par son testament, son mari l'avait chargé de l'examen et du classement de ses papiers. S'il était permis de parler de soi, j'ajouterais que j'ai eu l'expérience de cette bonté qui s'exerçait avec délicatesse et gravité. Mais il apportait dans le discernement de ses protégés et dans la maniére d'accorder ses bienfaits la scrupuleuse conscience qu'il mettait à remplir ses devoirs de critique, de professeur et d'homme privé.

C'est sur ce mot de conscience que je voudrais terminer cette rapide esquisse. Puissant écrivain, orateur hors de pair, il a été dans sa vie comme dans son enseignement et dans son oeuvre littéraire un grand honnête homme.

Louis Allard.

ARTHUR TRACY CABOT, M.D. (1852–1912)

Fellow in Class II, Section 4, 1889.

It is not easy, at once adequately and briefly, to set forth even the salient facts and evolution of the life of a man of such varied activities and interests as was the late Arthur Tracy Cabot.

He was of complex ancestry, Scotch, Irish, English and Norman French (Chabot, Island of Jersey) blood mingling in his veins. One of his great grandfathers, Thomas H. Perkins, was perhaps the most conspicuous merchant of his day in Boston, public spirited, enterprising, a large man in every sense of the word. The Perkins Institution for the Blind is one of his monuments. Samuel Cabot married one of his daughters and became a partner in the firm of Perkins & Company. Samuel Cabot, jr., was the second son of this marriage, the first of the family to embrace medicine as a profession. After the completion of his medical studies in Paris he went to Yucatan on the Stevens Expedition. His independence of thought and action, his sterling character, his services to this community as one of its leading practitioners and for many years surgeon to the Massachusetts General Hospital are still fresh in the memory of many.

Dr. Samuel Cabot married his distant cousin, Hannah Jackson, daughter of Patrick T. Jackson, whose brothers James and Charles were as eminent in medicine and law as was he in business.

Arthur, third son of this marriage, was born in 1852. From the Perkins-Cabot side he inherited largely his marked taste for nature, out-of-door manly sports and love of art, traits so prominent in some of the race as to be almost over-mastering. From the Jackson side he derived his physique, a slight but wiry frame, dominated by a will and sense of duty which go far to promote sustained effort. Promptly after his graduation at Harvard in 1872, he began the study of medicine, taking his M.D. in 1876, and serving as Surgical Interne at the Massachusetts General Hospital. He then went abroad, giving special attention to surgical pathology, but neglecting no opportunity of laying a firm foundation in all pertaining to the Healing Art. In Vienna and Berlin he got nothing helpful in the line of antiseptic surgery; but later passed a month in London, heard Lister's Inaugural Address at King's College, and ever after kept on the crest of the advancing wave of clean surgery. In 1877 he began general practice in Boston, and steadily won recognition, alike from the profession and the public. To surgery he had strong leanings from the first; but, conservative, cautious, ruled by reason more than impulse, always thinking things out to their ultimate results, it was not until ten or more years later that he gave up all strictly medical practice. From 1878 to 1880 he was Instructor at the Medical School in Oral Pathology and Surgery; from 1885 to 1896, Instructor in Genito-Urinary Surgery. He would, doubtless, have become full Professor but for his election to the higher position on the Corporation in the latter year. He was for several years Surgeon to the Carney Hospital, Assistant Surgeon at the Children's Hospital from 1879 to 1881, Visiting Surgeon 1881 to 1889; Surgeon to Out-Patients at the Massachusetts General Hospital, 1881 to 1886; Visiting Surgeon, 1886 to 1907.

As a general surgeon he was eminent; as a genito-urinary surgeon, pre-eminent. True surgeon that he was, his head always ruled his hand. He could not be persuaded into operating. He must be convinced in his own mind of its necessity or desirability; nor would he undertake any operation which he thought could be better performed by another. This absolute integrity of character, combined with rare soundness of judgment and with manual skill, won him the implicit confidence of all who came into contact with him, and naturally led to a wide consulting practice. He was as painstaking and conscientious in the after-treatment as in deciding whether or not to operate. He never in the least shirked responsibility; but it wore upon him more than it does upon some men of different temperament, and prevented him from doing as much work as he might otherwise have done.

Among his contributions to general surgery may be mentioned his use of the valve acting dressing and chlorinated soda irrigation for empyema operations, and a wire splint for fractures of the lower leg, devised while Surgeon to the Children's Hospital, in large use throughout the world, and, curiously enough, save in Boston, known by his name. It displaced the old fracture box. He early advocated and practised incision *without drainage* for tubercular peritonitis. In 1874 to 1875 he assisted his father in the first two successful abdominal operations connected with the Massachusetts General Hospital. They were on hospital patients, but the operations were done in a neighboring house in Allen Street. It appears that Dr. Arthur Cabot did the first successful abdominal operation within the hospital walls in 1884, on a case of large strangulated umbilical hernia. The patient had been admitted to Dr. Hodges' service. He, however, being ill, Dr. Bigelow was taking his place, and Dr. Cabot, then Surgeon to Out-Patients, was assisting the latter. Dr. Cabot was called in the evening. Dr. Hodges had recently published a paper on cases of this nature, concluding that operation was always fatal, recovery occasional without operation. Dr. Cabot therefore sought Dr. Bigelow, whom he found at Dr. Hodges' house. He stated the case. Dr. Bigelow: "What do you want to do?" Dr. Cabot: "Operate." Dr. Bigelow: "Whether you operate or not the patient will die, therefore do as you like. Is not that so, Dr. Hodges?" Dr. Hodges: "No, if you operate he will die; if you don't he may get well." After some discussion, Dr. Bigelow agreed that Dr. Cabot should do as he liked, so he returned to the hospital, operated, and in a few weeks the patient was well. We tell the story thus in full for the light it throws on the state of surgery less than thirty years ago. In 1886, Dr. Cabot had three successful cases of laparotomy in rapid succession, one for ovarian cyst, two for fibroids.

Dr. Cabot's qualities did not escape the keen eye of the late Dr.

Henry J. Bigelow, who made him his heir, as it were, in litholapaxy, and thus led to Dr. Cabot's becoming the leader in genito-urinary surgery that he was, admitted to be such far and wide.

As evidence of his thoroughness and of the soundness of his judgment it may be mentioned that in his paper on "Rupture of the Bladder," 1891, and in another on "Rupture of the Urethra," 1896, he laid down rules of procedure which stand unchanged today.

Here, as well as elsewhere, may be mentioned that about 1886, realizing the importance of immediate pathological examination of many surgical cases while under operation in order to determine the scope and nature of the necessary operation, he and his brother Samuel established a fund of $10,000, known as the "Samuel Cabot Fund for Pathological Research," in memory of their father. The interest on this fund is used for paying a pathologist to be on hand operating days and making such examinations as the surgeons require. If not the first, it was surely an early effort to make thorough pathological study go hand in hand with the surgical operation. Dr. Cabot was also the prime mover in starting the Clinico-Pathological Laboratory, was a leader in raising the necessary funds and planning the building. He became Librarian to the Hospital, and evolved order from chaos in the book and case records, both now thoroughly available.

He was President of the Massachusetts Medical Society in 1905 and 1906. In his visitations to the District Societies he did yeoman service in stirring up our profession to more actively interesting itself in the campaign against tuberculosis. It was probably this leadership which induced Governor Guild in 1907 to appoint him a Trustee of the Massachusetts State Hospitals for Consumptives, and at the first meeting of the Trustees, in September of that year, he was elected Chairman. The amount and quality of his work in this capacity deserves fullness of treatment, which, it is to be hoped, it will receive, but which it is impossible to give here. In his automobile he traversed the State to select suitable sites for the three hospitals for one hundred and fifty patients each. The North Reading Hospital was opened in the fall of 1908, those of Lakeville and Westfield early in 1909. The appropriation of $300,000 was not exceeded, and the requirements were fully met at a cost of $700 a bed as against nearly $2000 a bed for the Boston Consumptives Hospital at Mattapan. The Rutland Hospital was then placed under the Trustees. Only those on the inside fully know how much of the conspicuous success of this new departure was due to the compelling wisdom and unremitting labor of Dr. Cabot. In this, as in all his other work, its quality was only matched by his modesty. He was influential in procuring the passage of the bill requiring instruction in hygiene and preventive disease in the public schools. His counsel was sought by the General Electric Company with regard to the safeguarding and promoting the health of its employees at Lynn and Pittsfield. So deeply did he become interested in this line of work that in the spring of 1910 he retired from all practice and its emoluments that he might husband his strength for public work alone.

During about thirty years he published over one hundred and twenty papers. The last is a plea for the prevention and treatment of tuberculosis in childhood, to be found in the *Atlantic Monthly* for November, 1912. He was a member of many medical societies and of the American Academy of Arts and Sciences.

This is a meagre account of his strictly professional activities. In 1896, as has been stated before, he was chosen a member of the Corporation of Harvard College, that small body of seven which fills its own vacancies, has exclusive charge of the funds, the initiative in most appointments, and may, in a way, be compared, as regards the government of the University, to the Senate of the United States; though it has more power, relatively, to that of the lower House — the Overseers. Membership in the Corporation is no sinecure. It involves a deal of work. Questions large in variety and great in moment constantly arise and demand careful, deliberate, ripe judgment. Nobody in active professional or business life can accept the honor and the service without large sacrifice of time and strength; no physician without also loss of income. After careful consideration he accepted the election, and we saw the unprecedented occupation of two seats on the Board by physicians. The part which he and Dr. Walcott have taken in the marvelous development of the Medical School can be, in a measure, appreciated by the most matter-of-fact. They were the Building Committee on the part of the Corporation.

Dr. Cabot's feeling and love for art, always keen and discriminating, led to the Trusteeship in the Museum of Fine Arts in 1899. Here, too, he was a worker. Everywhere and always the "good enough" for him was nothing short of the best of which he was capable. In social life he was more and more sought after. He had at times a certain grimness of manner which could be raised to the nth power by anything mean, petty or under-handed. This grimness concealed more or less to the casual acquaintance the steady glow of one of the warmest of hearts and the most lovable of natures; but abated, in a measure, as he grew older. He was sympathetically receptive, and gave close attention to those who asked his opinion or advice. He was fond of horses and a good judge of them, played polo and rode to hounds. No form of boating was foreign to him. Tennis, golf and the like he enjoyed and played when he could get time and opportunity. His vacations were mostly spent in hunting and fishing trips from Florida to Canada, and as far as the Rockies. Shortly before his death he sold his interest in the Long Point Ducking Club, probably the best in the country, and devoted the proceeds to the purchase and maintenance of land in Canton, his legal residence, as a playground for the town.

Combining harmoniously and in a high degree intelligence, sound judgment, courage both moral and physical, sense of duty, manual dexterity and mechanical skill, he devoted his powers to the service of others, with small thought of pecuniary return. For him to give was, indeed, more blessed than to receive. He was, in truth, a noble gentleman, a conspicuous example of a man born in high social position, with means sufficient to tempt a less ardent nature to idleness, but serving only to carry him to fields of great usefulness and public service. He taught us how to live, and, again, how to face disease and death with cheerful fortitude.

He is survived by his widow, Susan, daughter and only child of the late George O. Shattuck, a leader of the Suffolk Bar.

F. C. Shattuck.

CYRUS BALLOU COMSTOCK (1831–1910)

Fellow in Class I, Section 4, 1892.

General Cyrus Ballou Comstock was born in West Wrentham, Massachusetts, February 3, 1831, and represented the ninth generation of an old New England family, which came from Devonshire, England. His ancestors lived in New London, and the earliest of them in this country fought in the Pequot war, taking part in the expedition which captured the fort at Mystic in 1637. Later generations of the family lived in Rhode Island and in Massachusetts. The General's great-grandfather was a Quaker, and took no active part in the Revolution, but was a member of the Massachusetts convention which ratified the Constitution of the United States, February 7, 1788, and was also a member of the General Court of Massachusetts in 1789.

General Comstock was educated in the local public schools and at a private academy. His interest in engineering arose from his happening to see the operations and instruments of a party making a railroad survey, and also of a coast survey party. The General began his professional work as a rodman and leveler on the Providence & Worcester Railroad, but in 1851 was nominated as a candidate to West Point, and was graduated with first honors in 1855. He served through all grades in the Corps of Engineers to that of Colonel, and was retired from active service by operation of law in 1895. He was promoted to the grade of Brigadier General on the retired list in 1904.

General Comstock, after serving on the construction of fortifications before the Civil War, and as Professor of Natural Philosophy at West Point from 1859 to 1861, was, during the Civil War, engaged in the construction of the defences of Washington, and in service on the engineering staff of the Army of the Potomac, of which he was Chief Engineer. He was present, under General Grant, at the siege of Vicksburg, and in 1864 was appointed Aide-de-camp to General Grant, being engaged in a number of the most sanguinary battles of the war. During the war he received rapid promotion, and attained the rank of Major in the Corps of Engineers, and Brevet Brigadier General.

General Comstock's principal work after the war was in the conduct of the geodetic survey of the Great Lakes, which had been inaugurated in 1841. This work was conducted with all the precision necessary to determine not only the topography and hydrography of the region, but also to be of geodetic value. The measurements were made with extreme accuracy, involving eight primary base lines, a primary triangulation about 1650 miles in length, and a hydrographic survey covering nearly 10,000 square miles, and also the investigation of the earth's magnetism. His report on this great work, published as Professional Paper No. 24 of the Corps of Engineers, in 1882, is a document of great value and permanent interest to geodesists, and is a monument to his professional ability and that of his associates.

General Comstock was also engaged in studies relating to the improvement of rivers and deltas, and was sent to Europe to investigate these subjects. He served on several boards, and was Superintending Engineer to examine the progress of jetties built by Captain Eads at the mouth of the Mississippi. He was a member of the Mississippi River commission for 16 years, and its President for five years, during which time he had to deal with many difficult hydraulic problems. He was also a member of the permanent Board of Engineers for fortifications and river and harbor improvements, and commanded the Engineer School of Application at Willets Point, New York, for about a year.

General Comstock was a member of the National Academy of Sciences, to which he donated a trust fund to be devoted to researches in electricity, magnetism and radiant energy, the value of which subjects his own experience had led him to appreciate. He became a member of the American Academy of Arts and Sciences in 1892.

In addition to his classic report on the Lake survey, General Comstock's name appears as a signer of the reports of sixty local engineering boards, of twenty-one of which he was President. His life furnished a good illustration of the value of science to the professional engineer, and of the value of the engineer to science.[1] He died at New York City, May 29, 1910.

G. F. Swain.

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1 This memoir is abstracted from a longer memoir of General Comstock by General Henry L. Abbot, in the annual of the association of graduates of the United States Military Academy, in 1912.

JAMES MASON CRAFTS (1839–1917)

Fellow in Class I, Section 3, 1867.

The passing of another from among the few survivors of the older generation of leading chemists arouses sorrow for our great loss and gratitude for his devoted labor. Among the honored names of American scientific men of the 19th century that of Professor Crafts will always be remembered. Both in the direction of organic chemistry and in that of physical chemistry he rendered contributions of great permanent value.

James Mason Crafts was born at Boston on March 8, 1839. He was the son of Royal Altamont Crafts and Marianne (Mason) Crafts. He is remembered by his schoolmates at the Sullivan School in Boston as a serious boy, but one glowing with vigor and at times full of fun and jollity. The most vivid impression was of his mechanical ingenuity and dexterity: he was able at the age of nine or ten to pull to pieces and successfully reassemble his watch — a rare possession in those days among school children. All his childhood was spent in Boston, where he completed at the Boston Latin School and under the private tuition of Dr. Samuel Eliot the excellent training in mathematics with which he entered the then recently founded Lawrence Scientific School of Harvard University in 1856. At Harvard he pursued the study of chemistry under Professor Horsford, and graduated with the degree of S. B. in 1858.

The winter of 1858–59 he spent as a graduate student of engineering at Cambridge, whence he went to the Bergakademie at Freiberg in Saxony to continue once more the study of the science to which he was to devote his lifework. In 1860 he migrated to the University of Heidelberg, where he studied under Robert W. Bunsen, at that time and for many years afterwards director of the chemical laboratory there. In the following year the young chemist left Germany for Paris, where he came under the influence of Wurtz, and for four years continued his studies at the École de Médicine. Ever afterwards his interest centered in France rather than in Germany.

Returning to America in 1865 he became mine examiner in Mexico during 1866–1867 — a task which involved courage and resourcefulness as well as expert knowledge, since the country was alive with bandits and filled with difficulties. His adventures were thrilling, but he told of them very modestly. In the following autumn (1867) he became professor of chemistry and dean of the chemical faculty at Cornell University, a position which he retained for three years. From Ithaca he was called to the professorship at the Massachusetts Institute of Technology as successor to Professor F. H. Storer. He devoted himself to the work, and his health suffered. The call of France was insistent, and changing in 1874 his title to that of non-resident professor at the Massachusetts Institute, he turned again to Paris, where, in collaboration with Professor Charles Friedel, he discovered the important organic reaction which will always bear his name. After 1880, when he resigned even the non-resident professorship at the Massachusetts Institute, he spent most of the succeeding decade in France, and it was not until 1891 that he returned to America as a permanent abiding place. Then he once more became connected with the Institute in Boston, conducting research there, and for five years (1892–97) filling the chairmanship of the chemical department and the professorship of organic chemistry. His work as a teacher was inspiring and effective. From October, 1897 to 1900 he was first acting president and then president of this great technical school. After his resignation of the presidency, which offered a sort of work never entirely to his taste, he returned to the labors which really claimed his interest, namely, research in the direction of organic and physical chemistry, still doing part of his work in the old Walker building of the Institute near Copley Square. He worked for the love of science, not for fame or money, and his ample means never led him away from high aims and solid attainments.

His noteworthy contributions to the sum of human knowledge gained for him recognition on all sides. In 1885 he received the Jecker prize of the Paris Academy of Sciences, and was made Chevalier of the Legion of Honor of France. In 1898 he was awarded the honorary degree of LL.D. by Harvard University, and in 1911 the Rumford Medal by this Academy "for his researches in high temperature thermometry and the exact determination of fixed points on the thermometric scale." He was first elected a fellow of the Academy in 1867 and was reelected to resident membership in 1891 after an interval of non-membership due to his prolonged absence in France. As long ago as 1872 he became a member of the National Academy of Sciences, and was later corresponding member of the British Association for the Advancement of Science, foreign member of the Royal Institution of Great Britain (1904) as well as fellow of many other learned academies and chemical societies. He was a member also of the Saturday Club of Boston, famous in the annals of American literature.

On June 13, 1868, he married Miss Clemence Haggerty of New York, who died in 1912. He is survived by four daughters: Mrs. Russell S. Codman, Mrs. Gordon K. Bell, Miss Elizabeth Crafts and Miss Clemence Crafts.

Although much of a traveler during the early part of his life, toward the end he divided his time between his Boston residence on Commonwealth Avenue and his beautiful country place at Ridgefield, Connecticut, where he had a small laboratory well fitted for his work, and where he enjoyed quiet and seclusion, always more to his taste than publicity or the whirl of city life. He retained his vigorous mental powers to the end, although somewhat restricted in physical activity by illness during his last few years. His well-rounded and useful life of over seventy-eight years came to an end at Ridgefield on June 20, 1917, when he succumbed to a sudden, painful illness of the heart.

As already stated, his scientific work divides itself naturally into two groups of researches, namely, those in organic and those in physical chemistry. His earliest published contributions to knowledge concerned the organic compounds of silicon, upon which he published an interesting and important paper in 1865. This was followed by work upon the arsenic and arsenious esters, which appeared in 1871. Six years afterwards, with Professor Charles Friedel, he published in volume 84 of the Comptes Rendus the first notice of the method of organic synthesis by means of the chloride of aluminum, which has had such a remarkable effect upon the growth of organic chemistry. In the succeeding years paper after paper from these two eminent collaborators appeared, amplifying their great discovery. In 1880 Professor Crafts's work upon accurate thermometry showing the peculiar hysteresis effects in glass, which must be considered in any accurate determination of temperature by the mercury thermometer, began to appear. At about this time also he published valuable papers in collaboration with Professor Friedel and others concerning vapor densities of the halogens at high temperatures.

His work on thermometry led to the determination of new fixed points to which the thermometric scale might be referred; and his study of the boiling points of naphthalene and of mercury attained a degree of accuracy little short of amazing, considering the state of these matters before they had come under the scrutiny of his insight and patient experimentation. Later in Boston, from 1900 almost to the time of his death, he devoted himself to chemical research, especially to the study of organic catalytic reactions in concentrated solutions, feeling that such reactions had not received the attention which was their due. At the same time he spent much time and thought on the construction of an exceedingly accurate barometer, by means of which he could measure atmospheric pressure with great precision and thus obtain yet more accurate values for the boiling points of various substances which should serve as standards.

In viewing collectively the outcome of Professor Crafts's varied work, one may note that much of it, both physical and organic, had as its object the providing of means and methods for further advance, of use to others in many fields. Those whose labor is lightened, broadened, and simplified by the important contributions of his scientific imagination and of his persistent, effective research in the laboratory are deeply grateful for the indispensable aid which he rendered, and will be, far into the future. His intimates mourn a generous, loyal, high-minded friend, whose vigorous intellect always turned toward worthy ends.

THEODORE W. RICHARDS.

EDMONDO DE AMICIS (1846–1908)

Foreign Honorary Member in Class III, Section 4, 1901.

Edmondo De Amicis was born at Oneglia, a little town on the sea-coast southeast of Genoa, October 21, 1846. Having attended school at Cuneo and Turin, he went to the Military Academy at Modena, from which in 1865, he was appointed Second Lieutenant of the Third Regiment of the Line. The following year he took part in the Battle of Custozza. In 1867 he became managing editor of *Italia Militare*, an important military journal published at Florence. To this he contributed many sketches of the life actually lived by Italian soldiers and officers, and when these were reprinted in a volume with the title "La Vita Militare" in 1868, they gave him an immediate popularity which went on widening until his death. They had also real influence in improving the conditions of the soldiers, by moderating the harshness of their discipline, a harshness then common in European armies. De Amicis continued to edit the Journal for some time and he remained in the Italian army until 1871. He was present when Cadorna's troops entered by the Porta Pia and freed Rome from Papal rule September 20, 1870. After resigning from the service he devoted himself to literature, making Turin his headquarters and he was, with two or three exceptions, probably the only Italian writer of that time whose works had so wide a circulation as to bring him a livelihood. They were of three kinds: first, fiction, including under this head several novels and his very realistic sketches; second, descriptions of his travels; and third, poems. His books of travel made him known outside of Italy and were translated into several languages. The earliest, on Spain, appeared in 1873; Holland in 1874; Constantinople, 1877; Morocco, 1879; Argentina, to which he gave the title "Sull' Oceano" in 1877; besides recollections of London and of Paris. In his later years he became like Lombroso and other intellectuals at Turin and Milan, a socialist, and he issued several volumes in support of this cult. He interested himself in writing for the young and his "Cuore," of which more than 400,000 copies had already been sold several years ago, aims at teaching the young, (through a story which has enchanted them by multitudes), the elements of a strong and noble character. No other book in modern Italian, except Manzoni's "I Promessi Sposi" has been so popular. He wrote also, "L'Idioma Gentile" which glorifies the Italian language; and, besides several polemical tracts and later recollections, he produced more fiction, of which "Il Romanzo d'un Maestro" was the most important. He died at Turin, March 12, 1908. De Amicis was a remarkably clear writer, a master of vivid description, and he possessed an indefinable charm which endeared him to most of his readers and diffused a magnetic quality over whatever he wrote.

William Roscoe Thayer.

WILLIAM WATSON GOODWIN (1831–1912)

Fellow in Class III, Section 2, 1859 (President 1903–1908).

William Watson Goodwin died in Cambridge, June 15, 1912. He was elected Fellow of the Academy, January 26, 1859, was a member of the Publication Committee from 1871 to 1880, and President from 1903 to 1908, in which year his failing health compelled him to decline re-election. His interest in the Academy was shown by frequent addresses and by letters when he was in Europe. His last communication was an interesting description of the character of the meetings in his early years (*Proceedings*, vol. XLVI, 1910).

The son of Hersey Bradford Goodwin (Harvard College 1826, Harvard Divinity School 1829) and Lucretia Ann Watson, he was born May 9, 1831, at Concord, Mass., where his father was the colleague of the Senior Minister, Dr. Ezra Ripley. Both his parents having died during his infancy, he lived at Plymouth with his grandmother, Lucretia Burr (Sturges) Watson until he entered Harvard College in 1847. After receiving his Bachelor's degree in 1851 he lived in Cambridge for two years as resident graduate taking a few private pupils, (among others John C. Ropes), but devoting the major part of his time to the pursuit of his own studies in company with Ephraim Whitman Gurney and Henry Williamson Haynes. Finding, however, that there was no opportunity for advanced study at Harvard (the Graduate Department was unknown until 1872), he determined to seek instruction in Göttingen, which had been the resort of many Harvard men, such as Everett, Bancroft, Longfellow, Motley, and, nearer his own day, Gould, '44, and Child and Lane (both '46), with whom he was to be so long associated in Cambridge. He used to recall with interest the fact that of the five holders of the Eliot Professorship of Greek Literature, since its foundation, three had studied at the Georgia-Augusta. The great classical scholars there in his day were Schneidewin and K. F. Hermann, the latter the last of the encyclopaedists in classical philology. After studying in Göttingen, Bonn, and Berlin for two years, he received the degree of Ph.D. from Göttingen in 1855. His doctor's dissertation dealt with the Sea Power of the Ancients ("De potentiae veterum gentium maritimae epochis apud Eusebium"). During his stay abroad he visited Italy and Greece.

Returning in 1856, Goodwin found that he had been made Tutor in Greek and Latin at Harvard, a post he exchanged, in the following year, for that of Tutor in Greek. In 1860, he succeeded Felton, who, in that year, resigned the Eliot Professorship of Greek Literature to become President of the College. For forty-one years Goodwin was in active service; even after his resignation in 1901, when he became *Emeritus*, his zeal did not permit him to sever himself from the work of actual instruction, and for seven years he continued to lecture on Plato and Aristotle. From 1903 to 1909 he was Overseer of the University, a distinction attained by relatively few of its teachers.

In the history of education in America few men have exceeded Goodwin's period of service; and few have conferred greater distinction on American scholarship. His life is no exception to the rule that the annals of a scholar's career are short and simple. His many years were spent in unremitting and unobtrusive labor for the welfare of Harvard in a period fruitful in far-reaching changes, a period that witnessed the decline of the old type of American college and the rise of the American university. He was clear-sighted in his judgment and temperate in his reasoning alike when he advocated, or when he opposed, the policies that shaped the conduct of Harvard University to its present estate.

The controlling motive that directed him during the revolutionary changes that transformed the Harvard of his youth was the welfare of scholarship, not merely in the Classics, but in every other discipline as well. He opposed the reduction of the college course from four years to three years because he believed that any reduction should be made at the beginning, not at the end; and he never changed his opinion as to the importance of classical study as a basis of literary culture. He was ingenuously dismayed at the failure of some of his contemporaries to see the value of Greek for modern education; and he witnessed with regret a generation of youth invited, as it were, to aim at literary culture without a knowledge of the language of Homer, Sophocles, and Plato. But if he could not view untroubled the dissolution of all the old ideas as to the value of a "liberal" education, he never wished for the return of the system of required studies prevalent in his undergraduate days and still in force until 1867–68; he advocated the abandoning of obligatory Greek in the Sophomore year; he welcomed the advent of the more fully developed elective system, though he foresaw some of the defects it has disclosed. He was not a blind worshipper of the classical literature of the ancients; he saw in it, not an agent for the discipline of the intellect of all youth, but an instrument, imperative for the understanding of the development of European letters, and salutary for those who would win a true appreciation of English literature. In him the intellectual spirit of scientific research in the field of grammar did not blunt the literary and artistic sense, which, as has well been said, is partly also moral. The old-time humanities translated themselves in him into the spirit of just and refined living. He did not confine his sympathies to the ancient world that was his by the association of daily work; but he realized, in the words of Renan, that "progress will eternally consist in developing what Greece conceived"; and from Greece he gathered, what many of the noblest and best have gathered thence, a large part of that wisdom of life which is more precious and more enduring than mere learning.

As a teacher, as I recall him in the late seventies, Goodwin insisted on rigid accuracy in the understanding of the words of the text as the approach to the larger understanding of the thought — the only true method, if a vapid sentimental enthusiasm is not to be the goal of the appreciation of Greek, or of any other, literature. He laid no special emphasis on formal grammar, but he had taken to heart, perhaps unconsciously, the saying of Godfried Hermann, that without grammar there can be no appreciation of literature. Looseness of method Goodwin detested, and as he held us to strict accuracy, so in his range of exposition he confined himself to essentials in comment and illustration. His instruction was sound and informing, laying stress on fact rather than on subjective impressions. He managed his large store of knowledge with an ease and a security that awakened at once our admiration and our confidence. In textual criticism, as elsewhere, he abhored supersubtle ingenuity; he permitted no difficulty or obscurity, especially in phraseology or historical allusion, to pass unexplained, but he had the sincerity to confess his inability to understand passages corrupt beyond all cure.

No one who knew Goodwin, no one who has ever listened to the sustained flow of his facile translation of the "Agamemnon," could ever doubt that he had a deep love for Greek literature. But he was temperamentally alien to panegyric; he would not allow the language of emotional appreciation to trouble the beauty, the calm, the harmony of imagination and reason that give to Greek literature its sempiternal charm. Like the very reticences of that literature, the reticence of its expositor marked his power. He appealed therefore less to the many than to those, who, like himself, needed no spur in their "chase after beauty"— if I may use Plato's phrase in another application. His formative influence may be traced in the temperate and rational style, in the absence of extravagance, exaggeration, and perverse ingenuity, in the work of many of his pupils.

It is the common fate of men who have devoted themselves with success to the welfare of a beloved college, that later generations should allow the memory of their many labors to pass into forgetfulness. As an Hellenist, however, Goodwin's name will live, for directly and indirectly, as an interpreter of the literature and language of ancient Greece, he had a large influence on the temper and conscience of classical scholarship in the United States.

In the middle of the last century our native classical scholarship had scarcely awakened to the possibility of the independence born of original research. A leisurely interest in the classics as the humanities, a somewhat torpid belief in their efficiency as a discipline for all mental dispositions, which was tempered but rarely by incursions into the larger meanings of Hellenic literature, sufficed with but rare exceptions for the generation under which Goodwin grew to manhood. In the year when, at the age of twenty-nine, he succeeded Felton in the Eliot Professorship, Goodwin gave evidence with a certain brilliant audacity that he had severed himself from the past. The year 1860 may well be taken as the mark of the appearance of a new spirit in our classical scholarship. In that year Hadley at Yale published his "Greek Grammar" based on the work of Georg Curtius; at Harvard, Goodwin brought out the book with which his name will be longest associated — the "Syntax of the Moods and Tenses of the Greek Verb."

I cannot discover that Goodwin had occupied himself especially with the problems of systematic Greek grammar in any of its aspects during his residence at the universities of Göttingen, Bonn, and Berlin; but the "Moods and Tenses" is itself a witness to the quickening spirit exercised by European masters upon the American philologists who, about the middle of the last century, began to cross the ocean in search of the inspiration they could not find at home. Yet the work, alike in its first form and when rewritten and greatly enlarged thirty years afterwards, owes relatively little to European research for its essential distinction. Not that Goodwin was not indebted, as he himself gladly acknowledged, to the labors of the great Danish scholar Madvig, or that some of his positions had not already been occupied by German syntacticians. But at the very outset of his career he had learned to think for himself — "Librum aperi, ut discas quid alii cogitaverint; librum claude, ut ipse cogites." It was due to his native and trained sense and knowledge of language as the instrument of the most delicate and refined expression that he was enabled to safeguard the subject of the modal and temporal relations of the Greek verb from the twofold danger that menaced it at the time. On the one hand, metaphysical subtlety exercised a malign influence in disturbing a clear understanding of the facts and their interpretation; on the other hand, comparative grammar, a science at that time in its infancy, by the very width of its horizon and the insecurity of its basis, threatened to carry back to the primitive home of the Aryans many of the problems that pertained in the first instance to the history of the Greek language on Greek soil.

It was Goodwin's clarity of judgment — with characteristic modesty he called it "common sense"— that saw the truth when the Germans had generally failed to release themselves from the intricacies of philosophical abstractions; and with equal sagacity and discernment he refused to trust himself upon the shifting sands of comparative syntax. The metaphysical syntax that held sway when Goodwin began his career is largely a thing of the past; but historical syntax, both in the wider area of the Indo-European languages and on Greek territory, has immeasurably increased its influence as it has steadily built upon securer foundations.

The wonder is that after thirty years the large increments of scientific research should have found themselves easily at home and should have worked no disturbance to the principles laid down in a book, of which its author, in his revision of 1890, said that it had appeared "in the enthusiasm of youth as an ephemeral production." The truth is that the "Moods and Tenses" of 1890 is at bottom the "Moods and Tenses" of 1860; for, though there was much to add in a work designed to fill a larger compass, there was astonishingly little to curtail, to modify in important particulars, or to reject out-right. I know of no book of like character that possesses the quality of prescience in equal degree. The "Moods and Tenses," like every other piece of work done by its author, is marked by perfect sanity, displays the working of an independent and resourceful thinker, who with steadied purpose aimed at presenting the vital principles and the essential facts, freed from the entanglements of specious and shifting theories. It is the expression of a cautious scholar who possessed a varied and exact knowledge of English speech, which he wielded with precision in setting forth the fine distinctions of the delicate Greek idiom. To its judicious presentation of the facts, to its lucidity and exactness of statement, perhaps even to its very refusal to enter at all points and at all hazards upon the treacherous ground of absolute definition, the book owes its fame as a standard work, still indispensable, despite the subsequent mass of treatises, both large and small, that traverse the whole or some part of the same field. And it has had a wider and more salutary influence than any American or English book in its province for more than half a century.

Apart from its virtues of lucidity and orderliness, there are certain special features of the "Moods and Tenses" that have commanded most attention: the distinction between the time of an action and the character of an action, the distinction between absolute and relative time, the division of conditional sentences (and in particular the treatment of *shall* and *will* and *should* and *would* conditions, which Goodwin discussed at some length in the *Transactions of the American Philological Association*, Vol. 7 (1876), and in the *Journal of Philology*, Vol. 8

(1879)), the relation of the optative to the subjunctive and other moods, and the origin of the construction of *οὐ μή* with the subjunctive and the future indicative.

The author of the "Mood and Tenses," the *doctor irrefragabilis* of Greek syntax, as he has been called, would have been the last to claim that he had, with Browning's grammarian, settled all of "*ὅτι's* business." He had not been, like Tom Steady in "The Idler," "a vehement assertor of uncontroverted truths; and by keeping himself out of the reach of contradiction, had acquired all the confidence which the consciousness of irresistible abilities could have given." There is much in Greek syntax that is debatable territory; but whenever Goodwin entered that territory — though he was not a statistician, as the earlier great scholars were not — his prevailing soundness of judgment and his range of illustration afford the controversialist only rarely the luxury of holding a different opinion.

Goodwin's "Greek Grammar" appeared ten years after the "Moods and Tenses," and inherited as by right the distinction and the distinctive features of the earlier work. The "Moods and Tenses" appealed to the advanced student and the teacher; the "Grammar" brought before the neophyte the facts of the language in exact and clear form; and showed that its author possessed the rare (and often underestimated) faculty of making a good elementary book. Only he who has himself followed in the tracks of Goodwin can adequately realize the clarity and compactness of his statements that never err through undue emphasis either on logical or on aesthetic relations.

The very excellence and success of Goodwin's work in the department of grammar made the wider public, and to a certain degree even the Hellenists of this country, ignorant of the scope and the distinction of his work in other fields. It is an altogether erroneous notion that Goodwin was purely a grammarian, honorable as that title has been made by many illustrious scholars. The range of his sympathies with Greek literature was indicated early in his career. The "Greek Grammar" appeared in 1870; in the same year was published Goodwin's revision, in five volumes, of the translation of Plutarch's "Morals" made by various hands in the seventeenth century. Innumerable errors and infelicities of the old translation were cleared away by Goodwin, whose work was termed a "vindication" of Plutarch by Emerson, who contributed an Introduction to the revision. English readers who would acquaint themselves with the deep and broad humanity of the sage of Chaeronea, in whom the intellect was illuminated by the force of morals, will long continue to use the translation of the Cambridge scholar.

In common with many men of his position Goodwin turned at times to editorial work of a humbler character. He re-edited Felton's edition of Isocrates' "Panegyricus" (1863), of the "Birds" (1868) and the "Clouds" (1870) of Aristophanes. One of the most excellent books of its kind is the "Greek Reader" (1877, and in many later editions), while his edition of the "Anabasis" (1885, and in many later editions), prepared in conjunction with his colleague, Professor J. W. White, and augmented by an Illustrated Vocabulary, the work of Professors White and Morgan, is a model for its exact attention to grammatical details.

With Greek philosophy Goodwin never claimed the intimate acquaintance of one whose special interests and sympathies mark him as a philosopher by profession. The temper of his mind was not metaphysical. Yet he had a large knowledge of the great ethical books of Greek literature, and years of close study made him a wise and judicious interpreter of the "Republic" of Plato and of Aristotle's "Ethics." To the investigation of the history, antiquities, and law of ancient Greece he brought a mind keenly observant of the similarities and differences between ancient and modern times. It is in the interpretation of the masterpiece of Greek oratory that the scholar must be able to draw, in well-nigh equal measure, upon a sound knowledge of ancient history and ancient law. Goodwin's mastery of this double field appears in his editions of Demosthenes' "On the Crown" (1901) and "Against Midias" (1906). He wrote also on "The Relation of the *πρόεδροι* to the *πρυτάνεις* in the Athenian Senate," and on "The Value of the Attic Talent in Modern Money" (*Traasactions of theAmerican Philological Association*, Vol. 16, 1885). To Thucydides he devoted a large share of his attention, and for many years lectured also on certain masterpieces of the Greek drama.

It is to be regretted that Goodwin would not allow himself to be persuaded to prepare an edition of Aeschylus, to the interpretation of whose text he devoted years of profound study. He edited the text and prepared a translation of the "Agamemnon," to be used in connection with the public presentation of that play by the Department of Classics at Harvard in 1906. Of his critical method we have a luminous example in the paper entitled "On the Text and Interpretation of certain passages in the Agamemnon of Aeschylus." (*Transactions Amer. Philol. Assoc.*, Vol. 8, 1877). In confronting the great difficulties of the text of Aeschylus, Goodwin was invariably hostile to the sciolist who complacently substitutes his emendations for the words of the poet. "Est quaedam etiam nesciendi ars et scientia"—an admonition applied far more rigorously by the American scholar than by its German author.

It was Goodwin's good fortune to visit Greece as a young man when fresh from his studies in Germany; and it was he who was the first Director of the American School of Classical Studies at Athens (1882–83), an appropriate honor for the foremost Greek scholar of his time who was also one of the founders of the American Institute of Archaeology. To his acquaintance with the land of Greece, reinforcing his knowledge of Greek literature and history, we owe the admirable paper on "The Battle of Salamis," first published in 1885 (*Papers of the American School of Classical Studies in Athens*, vol. I); and in another form in 1906 (*Harvard Studies in Classical Philology*, vol. XVII). Goodwin's careful sifting of the evidence determined the several localities in question and convincingly described the dispositions and movements of the Greek and barbarian forces in connection with that memorable contest. During his sojourn in Greece he became intimate with Prime Minister Tricoupis and long continued in association with the family of that statesman. His interest in the land of Greece was fittingly signalized by his being named a Knight of the Greek Order of the Redeemer.

Apart from the books and separate articles already mentioned, Goodwin wrote relatively little. He contributed to "The Christian Register" an appreciation of Jowett which deals sympathetically with the "Essays and Reviews"; he prepared memoirs of Professors Torrey and Lane, and communicated to the Massachusetts Historical Society the Records of the Old Colony Club (1769–1773). In 1896, when the Venezuelan dispute was in the air, he sent to the *Crimson* a vigorous reply to Roosevelt's letter in the same journal branding as unpatriotic a Harvard protest against the war-policy of the national executive and national legislature. But of all his writings not dealing with things Greek, the most admirable in its tone and farthest-reaching in its influence is the address "On the Present and Future of Harvard College," delivered before Phi Beta Kappa in 1891. It commands attention for its description of the standards of the College in his undergraduate days and for its temperate discussion of the elective system, which in his view had immeasurably raised the scholarship of the studious though it had possibly dulled the high personal enthusiasm that marked the ambitious three generations ago. But, above all, the address is invaluable for its analysis of the relation between liberal and professional studies and for its expression of Goodwin's profound loyalty and affection for his College, which, "like a queen, can do no wrong," though her ministers may err, and which, "has more than an imperial treasury in the love and respect of her sons and in the confidence of the community."

His life was bound up with the interests of Harvard, with which he was connected, as student or as officer, for fifty-six years. Long before he reached an advanced age he delighted in reminiscence, in tales of the simplicity of college life in the fifties, and not the least part of his charm for those of the younger generation who had a lively interest in Harvard's past, consisted in the inexhaustible (and now irrecoverable) fund of anecdotes about early academic worthies — and unworthies — that lay in the memory of one who had been a student under Everett and Sparks and an officer of the college during the administrations of Walker, Felton, Hill and Eliot. Harvard has had few sons who have displayed greater devotion than he; a devotion that he was able to signalize by the foundation of a Scholarship in memory of his son Charles Haven, whose career of promise was cut short by his death one year after his graduation in 1888; and, at the end, by a bequest sufficient to establish one of the best endowed Scholarships in the bestowal of the University.

To the cause of the higher education of women Goodwin gave his influential support. He was one of the first of the few teachers of Harvard who were early encouraged to try the experiment of giving instruction to advanced women students; and for many years he continued to make certain of his courses accessible to members of Radcliffe. He was one of the incorporators of the Society for the Collegiate Instruction of Women and afterward of Radcliffe College, served on the Academic Board of the Annex from 1882 to 1893, was Chairman of that Board in 1885–86, a member of the Council of Radcliffe College from 1888 to 1911, and a member of the Associates of Radcliffe College from its incorporation until his death.

Such are the landmarks in the career of a scholar whose life was spent in quiet devotion to high things, a life that made no parade and sought none of the noisy ways of fame. Yet to few Americans of our time has been given an ampler measure of the tribute of recognition that great powers have been used effectively and serviceably. Goodwin's mastery of Greek syntax enfranchised in Great Britain the Hellenic scholarship of the United States. The "Moods and Tenses" became there, as at home, a standard treatise; the *Journal of Philology* and Liddell and Scott's *Greek Lexicon* contain further evidences of his exact learning. He received the degree of LL.D. from Cambridge in 1883, from Edinburgh in 1890, and the degree of D. C. L. from

Oxford also in 1890. In 1905 Göttingen renewed *honoris causa* the degree of Ph.D. which he had received at that University in 1855. At home he received honorary degrees from Amherst, Chicago, Columbia, Yale, and Harvard. He enjoyed the rare distinction of being twice president of the American Philological Association (1871 and 1884); he was vice-president of the Egypt Exploration Fund; for many years he was closely identified with the work of the Archaeological Institute of America. He was a member of the American Philosophical Society, an honorary member of the Hellenic Society of London, of the Philological Society of Cambridge, England, of the Hellenic Society of Constantinople, of the Archaeological Society and Academy of Science at Athens, and a foreign member of the Imperial German Archaeological Institute.

Like the "high-minded man" of Aristotle, praise or blame neither elated nor dejected him. He was unfeignedly modest, and always took for himself far less than he deserved. He knew much about things of which he professed to know nothing. Laudation of his work did not cause him to think unduly of his powers, and he could rejoice in siding with a critic against himself, the mark (according to Emerson) of the cultured man. He kept unimpaired the serenity of the scholar whose only aim is the truth and who sinks his personality in his work. He was no lover of controversy and indirect challenge did not provoke him to break silence. He never strove to be eloquent or subtle. Disingenuousness was utterly foreign to him. His every spoken and written word was as clear and simple and straightforward as his life.

Not that he made his deeper self familiar even to his friends. Reserve warded off the aggression of emotion in others as it was his defence against its promptings in himself; but, like some undemonstrative natures, he had a large capacity for tenderness. He had none of the latent unsociability of the typical scholar, but was averse to "talking shop," when many would gladly have had him yield to that academic temptation. He delighted in the offices of an unostentatious and refined hospitality; he seasoned life with humor and keen wit. At the public dinner in 1901 in commemoration of his retirement he proposed to amend Solon's maxim "call no man happy till he is dead" to "call no man happy till he resigns." He relished the dry humor of the descendants of the Pilgrims at Plymouth, and matched their aphorisms with those of the ancients. His sayings about people often had a quaint and humorous acidity, but they were never prompted by ungenerous feeling. No one could pass the barrier of his aloofness and come really to know him without loving him for the warmth of his heart, his sympathy and his never-failing kindliness.

The large influence enjoyed by Goodwin was not due merely to his profound scholarship and solid achievements, nor to the fact that he was the embodiment of Greek culture, nor yet because to the younger generation he was the representative of an older time and had clothed himself with the wisdom of long experience. His influence was due above all to his high personal distinction. To his intellectual vigor and broad culture he united a noble temper, energy in repose, and a character that commanded respect and veneration. He measured the efficiency of his college by an exalted standard of scholarship; he was just and fair and broad-minded; never disabling his judgment by surrendering it to the caprices of momentary feeling; his character retained the sterling qualities of his Pilgrim ancestry while it had been softened to a gracious gentleness by the temper of his culture and a cosmopolitanism that had made him conversant with many lands and many men of distinction. But, more than all this, his whole life bore witness to purity and loftiness of soul. And his beautiful face and noble bearing affirmed the inner man — in very truth *καλὸς καὶ ἀγαθὸς ἀνήρ*.

HERBERT WEIR SMYTH.

EDWARD HENRY HALL (1831–1912)

Fellow in Class III, Section 4, 1907.

Edward Henry Hall was born in Cincinnati, Ohio, April 16, 1831, and died in Cambridge, Massachusetts, February 22, 1912. He was son of Edward Brooks Hall (Harv. A. B. 1820, S. T. D. '48) and Harriet Ware Hall, daughter of Henry Ware, Sr., Hollis Professor of Divinity 1805–1845 (emeritus after 1840). After graduating from Harvard College in 1851, and from the Divinity School in 1855, he was ordained minister of the First Church in Plymouth on January 5, 1859, where he remained until July 1867, with an interruption from September 12, 1862 to June 18, 1863, during which he served as chaplain of the 44th Inf. M. V. M. From February 10, 1869 to February 26, 1882, he was minister of the Second Congregational Church of Worcester, and from March 30, 1882 to March 31, 1893 of the First Parish and Church in Cambridge. He was also Lecturer on the History of Christian Doctrine in the Harvard Divinity School, 1899–1900. In 1902 Harvard conferred upon him the honorary degree of S. T. D. as, in the apt phrases of President Eliot, "army chaplain in the Civil War, pastor, preacher, candid student of early Christian history, independent outspoken citizen."

Dr. Hall was a conspicuous example of the clerical type once prevalent here in New England but now rapidly disappearing. Abhorring sensationalism and sentimentalism, he maintained the most exigent ideals of personal and civic righteousness, intellectual integrity and personal honor. Utterly fearless, and with the sincerity and simplicity which accompany courage at its best, he spoke out his full mind on theological and social topics. Severely aristocratic in his tastes and pleasures, with a native dignity superior to all baseness and a fine contempt for sham and pretence, which he was keen to detect, he was also thoroughly democratic in social principles and mental attitude. There was a significant difference between his appearance on foot and on horseback. Walking the streets of Cambridge, often accompanied by his dog, he would have attracted little attention from a casual passer-by unless, indeed, the raising of his head to acknowledge the greetings of a friend had given a glimpse of his keen, strong, intellectual face, but when he rode, erect and martial, he was a distinguished figure of whom no one could have failed to take notice. As a scholar, he was interested in Christian History, particularly in the earlier period. In this field his work was conscientiously thorough and accurate, but the "enthusiasm" of the early church, and particularly of Paul, was so alien to his own habits of mind and life, as to make sympathetic appreciation difficult and hence he never quite succeeded in making its scenes and characters live. The title of his last book "Paul the Apostle, as viewed by a Layman" was significant of his devotion to the ideals of Congregationalism according to which a clergyman, as such, has no existence apart from his relation to the particular church of which he is minister. From this point of view, Dr. Hall, having resigned his Cambridge pastorate, properly and consistently described himself as a layman.

His published works are:—

Orthodoxy and Heresy in the Christian Church—Worcester (privately printed) 1874; Boston, American Unitarian Association, 1883.

First Lessons on the Bible — Boston, Unitarian Sunday School Society, 1882.

Lessons on the Life of Paul — Boston, Unitarian Sunday School Society, 1885.

Discourses — Boston, George H. Ellis, 1893.

Papias and his Contemporaries — Boston and New York, Houghton, Mifflin & Co., 1899.

Paul the Apostle, as viewed by a Layman — Boston, Little, Brown & Co., 1906.

W. W. Fenn.

WILLIAM WIRT HOWE (1833–1909)

Fellow in Class III, Section 1, 1900.

William Wirt Howe was born at Canandaigua, New York, on November 24, 1833. He was of English descent, an ancestor having come to America from Warwickshire about 1630. After graduating from Hamilton College in 1853 he studied law in St. Louis and began to practise there, but attracted by the greater opportunities in the East soon moved to New York City. At the outbreak of the civil war he gave up his profession for service in defense of the Union and became a Lieutenant in the 7th Kansas Volunteers. Throughout the war he was continuously engaged in military duty and rose to the rank of Major. In 1862 he was married at Utica, New York, to Frances A. Gridley.

At the end of the war Mr. Howe established himself in New Orleans and resumed the practise of the law. He was appointed by General Sheridan during the latter's military administration under the Reconstruction Act as judge of the principal Criminal Court in New Orleans, and in 1868 was appointed by Governor Warmoth to the Supreme Court of Louisiana, a position which he held until 1873. In 1900 he was appointed by President McKinley, United States District Attorney for the Eastern District of Louisiana; he was reappointed by President Roosevelt and served until in 1907 failing health compelled his resignation. In 1909 Judge Howe died at the age of seventy-six. He left a widow and one son, Wirt Howe, a graduate of Harvard University and of the Harvard Law School.

In his profession Judge Howe achieved success and a reputation for character as well as for capacity that was rewarded by his election in 1907 to the presidency of the American Bar Association of which he had become a member in 1881, three years after its organization. In his profession too he was recognized as a lecturer of exceptional ability and delivered courses of lectures at the St. Louis Law School, the Law Schools of the University of the South, Boston University, the University of Pennsylvania and Columbia University. At Yale University he delivered the Storr's series of lectures and these were published in 1896 and a second edition in 1905 under the title of "Studies in the Civil Law."

Judge Howe's interests and activities were not, however, confined to the law. For four years he was president of the New Orleans civil service board, receiving his appointment from the mayor of the city. He served as president of the Louisiana Historical Association and published a Municipal History of New Orleans, a Monograph of Johns Hopkins and a life of Francois Xavier Martin, for more than thirty years a judge of the Supreme Court of Louisiana and known as the "Father of Louisiana Jurisprudence." Always prominent in philanthropic and public enterprises Judge Howe was one of the incorporators and at his death a trustee of the Eye, Ear and Nose Hospital; one of the original members of the Louisiana Association for the Prevention of Cruelty to Animals; administrator of the Charitable Hospital of New Orleans; treasurer of Tulane University; an incorporator and first president of the New Orleans Art Association; an active member of the New Orleans Chamber of Commerce and Board of Trade; for thirty-four years senior warden of Christ Church Cathedral, and a trustee of the Carnegie Institution in Washington.

Settling in New Orleans immediately after the civil war in which he himself had taken an active part on the Northern side, Judge Howe began his career in a hostile community. The stormy years of reconstruction followed. A Northerner and a republican, he could not look with favor on the reestablishment of the old slaveholding aristocracy, and he received his judicial appointments from the republican party. But whatever sympathy he may have felt with the original aspirations of the radical republicans who for five or six years were supported by the federal government and maintained a precarious rule only through the use of federal troops, he revolted from the carnival of extravagance, dishonesty and corruption that marked the period of republican control. He was not one of the infamous horde of carpet baggers who after the war invaded the South intent only on loot, and, seeking to enrich themselves at the expense of an impoverished and distracted people, greatly aggravated the difficulties, sufficiently great under the best circumstances, of the race problem. When Judge Howe settled in New Orleans it was with no desire to exploit the South but with the purpose of becoming a permanent resident and of doing his part as he would have done it elsewhere for the public good. Long before his service as a judge of the Supreme Court ended it had been demonstrated that continuance of the negro republican rule meant the ruin of Louisiana. Judge Howe, like other good citizens, rallied to the support of Francis T. Nicholls and the men who with him were struggling to save the state from further spoliation and degradation, and without renouncing his political faith worked patriotically for redemption of the city and the state.

It is seldom that any man starting life afresh at over thirty years of age in a new environment, almost an alien in race, under the handicap of most violent political and social prejudices, achieves success. Judge Howe faced all these conditions. Probably no community in the South felt a greater bitterness towards the North than did New Orleans at the end of the war. This bitterness was increased ten fold by the experiences of the reconstruction period. Yet Judge Howe succeeded in overcoming the obstacles. First appointed to public office by a hated military commander and later to a higher judicial office by an equally hated republican governor, he so won the esteem of political opponents and enemies as to be selected by a staunch democrat and ex-confederate soldier for a position of honor and responsibility as administrator of the Charity Hospital, and long before his death had become, as the roll of offices of trust and honor which he held shows, one of the leading citizens of his adopted state.

The secret of Judge Howe's success was character. Those thrown into association with him could not fail to recognize the cultured gentleman, the public spirited citizen, and the loyal friend and associate. Political advancement, if he desired it, he could not expect in Louisiana, without apostasy to his republican convictions. But once the political atmosphere was cleared so that men judged their fellows by other than political tests his integrity, ability and high standards earned for him the respect and the confidence of his neighbors in New Orleans, as they earned for him national recognition. His election to the presidency of the American Bar Association stamped him as a fit representative of the South in his chosen profession; his appointment as a trustee of the Carnegie Institution showed that his reputation as a wise and responsible administrator had become more than local.

An interesting and amusing conversationalist, of ready wit, with a store of dry humor and a mind well stocked with reading, study and travel, he was much in demand for both public and private entertainments and filled with distinction a social position seldom attained in a city like New Orleans by one coming from without.

Judge Howe's work upon the Supreme bench of Louisiana showed courage, learning and conscientious discharge of his duties. He dared in a strong dissenting opinion to declare against the constitutionality of a state law which denied to one who in good faith had purchased for value a note originally given for the price of a slave the right to recover on the note. But the times were not favorable for any great judicial career in Louisiana, and the practice of the court which did not favor long opinions makes the reports of his decisions for the most part little more than a record of the conclusions reached. On the bench and in his subsequent career Judge Howe acquired a deserved distinction as a capable judge, an able counsellor and an effective lecturer. He lacked perhaps the attainments that would warrant calling him a great jurist, a great advocate or a great teacher. But if he fell short of the highest professional rank, his diversified interests, his large public spirit, the traits which won him the respect and esteem of the community and the affection of numerous friends, fully entitle him to be written down as "one who loved his fellow men" — and served them well.

William H. Dunbar.

LEONARD PARKER KINNICUTT (1854–1911)

Fellow in Class I, Section 3, 1883.

Leonard Parker Kinnicutt [1] was born in Worcester, May 22, 1854, the son of Francis H. and Elizabeth Waldo (Parker) Kinnicutt. He received his early education in the schools of Worcester, graduating from the high school in 1871. He went at once to the Massachusetts Institute of Technology, where he devoted himself chiefly to the study of chemistry. Following his graduation in 1875 he spent four years in professional studies in Germany. At Heidelberg he came under

1 This sketch was published by the writer in Science April 28, 1911.

the inspiring influence of Bunsen from whom he acquired an appreciation of the value of careful and accurate analysis. Here also under Bunsen's guidance he was initiated into the refinements of gas analysis. This was the period when organic chemistry was developing with tremendous rapidity especially in Germany. Bunsen had passed the zenith of his career and was not in sympathy with the new tendency which was manifesting itself in chemistry. It is not surprising then to find the young Kinnicutt leaving Heidelberg and matriculating at Bonn. Only ten years before, Kekulé had been called to the University of Bonn to take charge of the newly built laboratory which at that time was the finest in all Germany and after which later laboratories were patterned. Kekulé's was a charming personality. His lectures were a model for simplicity of arrangement and clearness of presentation, and the experimental demonstrations were carried out with such fascinating ease and dexterity that the young Kinnicutt was captivated by the spirit and beauty of organic chemistry and devoted himself diligently to its study.

He was fortunate in being accepted into the private laboratory of the master, where he became associated with Richard Anschütz, the present director of the Chemical Institute at Bonn. In collaboration with Anschütz he published a number of papers, chiefly on phenylglyceric acid. This association ripened into a lasting friendship. Returning to the United States in 1879, he spent a year in study with Ira Remsen at the Johns Hopkins University, and then three years at Harvard, where he served as instructor in quantitative analysis and as private assistant to Wolcott Gibbs, at that time Rumford Professor of Chemistry. In 1882 he received from Harvard the degree of doctor of science and in September of the same year accepted an appointment as instructor of organic chemistry at the Worcester Polytechnic Institute. In the following January he became assistant professor of chemistry; three years later he was made full professor, and from 1892 was director of the department.

As early as 1885 Professor Kinnicutt began to give attention to the question of sewage disposal and sanitary problems. He became an authority on the sanitation of air, water and gas; on the methods of analysis and on the disposal of wastes. He paid particular attention to the examination of water and watersheds and the contamination of rivers and ponds by trade wastes and sewage. He made numerous reports, both as regards private and public water supplies.

He visited England on an average every other year since 1894, familiarizing himself with the work done in that country and the results were embodied in various articles which he published on the subject. He paid special attention to the subject of the pollution of streams by wool-washings, and made a careful study of this problem at Bradford, England, where a greater amount of wool is washed annually than in any other city in England or in this country.

He was employed as an expert in numerous cases regarding the pollution of streams and ponds, and was one of the experts in the case of the pollution of the Mississippi River at St. Louis by the sewage of Chicago. In 1903 he was appointed consulting chemist of the Connecticut Sewage Commission, a position which he retained up to the time of his death. He was a frequent contributor to scientific periodicals and the proceedings of learned societies upon topics relating to his specialty.

In 1910 in collaboration with Professor C. E. A. Winslow, of the Massachusetts Institute of Technology, and Mr. R. Winthrop Pratt, of the Ohio State Board of Health, he published a book entitled "Sewage Disposal" which is considered to be one of the best treatises on the subject of sewage disposal in the English language.

Professor Kinnicutt's reputation was not confined to this country. He enjoyed a wide acquaintance, both in England and on the continent, and possessed the rare faculty of keeping ever fresh and active a friendship once established. One of his highest honors was the appointment as president of the Section of Hygiene of the International Congress of Applied Chemistry, which was held in Washington and New York in September, 1912. Even to within a few days of his death he continued to work with characteristic zeal in perfecting plans for the success of the section over which he was to have presided. Professor Kinnicutt was deeply interested in the sanitary problems of his native city, Worcester. He kept a careful watch upon the city's water supply. During the "water famine" of the winter of 1910 to 1911 he directed from his sick bed the tests to be made, had daily reports brought to him and outlined the policy by which, in his opinion, the city's health might be best safeguarded.

He devoted a great deal of time and money to secure a pure milk supply in summer for the babies in needy families, and at the time of his death he was a member of the Worcester Medical Milk Commission. Professor Kinnicutt was widely connected with scientific associations; he was a fellow of the American Academy of Arts and Sciences, an active member of the C. M. Warren Committee from its foundation in 1893 and its chairman from 1903 to his death; a fellow of the American Association for the Advancement of Science, of which he was vice-president in 1904; a member of the American Chemical Society, and councillor for a succession of years; a member of the

Society of Bacteriology; a fellow of the New England Water Works Association; of the Boston Society of Civil Engineers; of the American Antiquarian Society, and of various foreign associations, including the Association of Managers of Sewage Disposal Works of England, the London Chemical Society, and the German Chemical Society. He was a member of several social clubs in Worcester and Boston and retained to a remarkable degree his interest in the alumni reunions of the Massachusetts Institute of Technology, of the John Hopkins University and of Harvard University, and he rarely failed to be present and add his geniality to the general good cheer.

Esteemed and honored by the scientific world, and beloved by a wide circle of acquaintances, yet it was as a teacher that the true worth of his character manifested itself. Possessed of a broad training and knowledge of his subject, and a fund of personal experiences, with which he punctuated his lectures, he was enabled to drive home the truths which he desired to impress on the minds of his students. Interest in his students, however, did not cease with the lecture or the laboratory. He was ever ready to listen sympathizingly and indulgently to those students who were in distress, and to all such he gave liberally of his time and purse. This conscientious devotion to duty and unselfish human interest endeared him to the students and alumni. It came as a great shock to all when, after a delightful summer of European travel and the resumption of his academic duties, apparently in his usual good health, he was attacked by a slow fever which confined him to the house after but a few days of activity. The trouble was diagnosed finally as tuberculosis. He received his first warning that he had this insidious disease in his system when he was a student in Germany, but had apparently fully recovered from this earlier attack. It was hoped that a year's leave of absence and careful nursing would restore him to health and the resumption of a part at least of his former activities. Toward the end of January, 1911, however, his heart became seriously affected, and he failed rapidly until the end came peacefully on the morning of the sixth of February.

Professor William T. Sedgwick, a lifelong friend paid a fitting tribute to his memory when he said, "His was a unique, lovable and altogether charming personality. Kindness and friendship such as his life exemplified could no further go. He was critical, yet just; fearless, yet considerate of others; honest to a fault; a hard worker; and to a degree nowadays unusual, an accomplished and cultivated gentleman."

W. L. Jennings.

ROBERT KOCH (1843–1910)

Foreign Honorary Member in Class II, Section 4, 1901.

Robert Koch died May 27, 1910, in his sixty-seventh year. He was born in Klaustal; was one of thirteen children; eleven sons and two daughters.

He was at first intended to be a tradesman, but later was allowed to carry out his own desire, which was to study medicine.

In April, 1862, at the age of eighteen, he entered the University of Göttingen, and devoted himself to the study of mathematics, physics and botany. The physiologist, Meissner, and the pathologist, Henle had a special influence upon him during his stay here. In his second semester, he was made an assistant in the Pathological Museum, and shortly after took an academic prize.

In January, 1866, he took his Doctor's examination in Göttingen, and in March of the same year, after a short stay in Berlin, passed his state examination with great distinction at Hanover. He then spent a month as an assistant in the General Hospital of Hamburg, and from October, 1866 to July, 1868, combined general practice with that of physician to the Idiot's Hospital of Langenhagen near Hanover. He then practised a short time in Neimegk in Brandenburg, and from 1869 in Rakwitz in the province of Posen. From Rakwitz he went as a volunteer surgeon to the war against France; returning home — at the suggestion of one of his friends, he passed the examination for, and until 1872 served as, District Physician in Wollstein near Rakwitz.

In spite of all the interruptions that come to a busy practitioner, Koch had found time for microscopic studies during the preceding years, but it was first in Wollstein that, thanks to his improved financial condition, he secured better apparatus and instruments and could control his time better. He cut off half his consulting room for a laboratory, in which was installed a photomicrographic apparatus and a dark room. It was in this room that the young District Physician and busy practitioner made the discoveries that stamped him as a master of knowledge. The aims of his life stood now clear before his eyes. He threw a search-light on the darkness surrounding the infectious diseases: he placed the old, much disputed doctrine of contagium vivum upon a solid foundation, and showed the methods of attack and control of pestilences.

The opportunity offered itself, at this time, to study anthrax, which formed the subject of his first recorded and published paper: ("Die Ätiologie der Milzbrandkrankheit, begründet auf die Entwickelungsgeschichte des Bacillus anthracis," Cohn's *Beiträge z. Biologie der Pflanzen*, II, 1876, 1 Pl.) This was the first of the series of papers upon this disease: studies which involved him in the bitter controversy with Pasteur. Before this was finished, came his special contributions on methods ("Verfahrung zur Untersuchung, zum Konservieren und Photographieren der Bakterien," Cohn's *Beiträge*, II, 1877, and "Zur Untersuchung von pathogenen organismen," *Mitt. a. d. Kais. Gesundheitsamte*, I, Berlin, 1881). Then came his work on suppurations and septicemias ("Untersuchung über die Ätiologie der Wundinfektionskrankheiten," Leipzig, 1878) on disinfection ("Über Desinfektion," *Mitt. a. d. Kais. Gesund.*, I, Berlin, 1881), and his results on tuberculosis, first indicated in 1882 ("Die Ätiologie der Tuberkulose. Nach einen in der Physiologische Geselleschaft zu Berlin am 24 Marz, 1882, gehalten Vortrage, *Berlin, Klin. Woch.* 1882," and "Die Ätiologie der Tuberkulose," *Mitt. a. d. Kais. Gesund.*, II, Berlin, 1884.) This subject took much of his attention for many years, and as his demonstration of the etiological factor served to give his reputation the solid world-wide acceptance that it received, so the forced circumstances surrounding the announcement of the remedial substance "tuberculin," and the disappointment of the extreme hopes aroused, served to embitter much of his later life. The circumstances of this occurrence are tragic, as those familiar with the facts well know. In 1882, however, his work on tuberculosis was interrupted by the expedition to Egypt and India for the study of cholera. The results appeared in 1887 in a separate volume (*Arb. a. d. Kais. Gesundheitsamt*, 1887, III), and like all his previous communications bear the marks of painstaking research and great accuracy.

His work on "infectious-wound-diseases" especially aroused Cohn's interest, so that through his influence, Koch became District Physician in Breslau in 1879. But his reputation was so rapidly growing that on June 28, 1880, he was brought to the Kaiserlichen Gesundsheitsamt in Berlin, and was at last free to work and carry out his great aims uninterrupted. It was here that he perfected his methods of staining, of photomicrography, and of solid culture media — all of them used before, but not widely known and accepted — methods that form the base of much of our knowledge of microscopic organisms, and the perfecting of which is in itself a claim to great distinction.

In 1885 a new promotion came — to the Chair of Professor of Hygiene in the Medical Faculty of the University of Berlin, and Director of the newly established Hygienic Institute.

In June, 1891, he was again transferred — to become the head of the new Institute for Infectious Diseases, with a hospital attached. In this place he became the leader and director of campaigns against epidemics in all parts of the Empire. He was made Surgeon-General of the Health Service, and Professor and Fellow of the Science Senate of the Kaiser Wilhelm's Academy.

As early as 1881, he had suggested that other micro-organisms than bacteria might be the cause of some infectious processes, and that blood-sucking insects might easily be the intermediate hosts. This he later demonstrated in his work in India, New Guinea and Africa upon many of the infections there prevalent.

Koch's characteristics were those necessary for the successful investigator — patience, a strong will and great persistence. The earlier part of his career was marked by such definite and clear-cut results in all his published papers that the scientific world was ready to accept the claims attributed to him as to the effects to be expected from the use of tuberculin. His personality was modest and unassuming, his diction, in conversation, simple, clear and convincing. These qualities seem to have been lessened in later life, for there then appears a tendency to general and dogmatic statement, and a greater inclination to controversial methods than had been seen before. Nevertheless, second only to Pasteur, his career stands as one of the first importance in the advance of our knowledge of the infectious diseases and the relief of human suffering.

H. C. Ernst.

SAMUEL PIERPONT LANGLEY (1834–1906)

Fellow in Class I, Section 2, 1883.

What can a writer of a notice of Samuel Pierpont Langley, twelve years after his death, add to the notices already published in the leading scientific societies of the world: especially the full notices at the memorial meeting in the Smithsonian Institution, Dec. 3, 1906? The American Academy of Arts and Sciences, however, would feel that it would be lacking in respect to the memory of one of its most distinguished members if it did not commemorate, even in a brief note, his achievements. The American Academy early recognized his ability by the bestowal of the Rumford medals; and it can now point with pride to the justification of their confidence in the value of his work.

Samuel Pierpont Langley was born in Roxbury, Mass., Aug. 22, 1834. He was educated in the Boston Latin School and in the Boston High School. Having adopted the profession of an architect and a civil engineer, he went to the West and engaged for a time in practical life; but his scientific tastes prevailed and he came back to the east to take up the study of astronomy. He became an assistant in the Harvard College Observatory, and at the age of thirty-two was appointed Director of the Allegheny Observatory, where he remained for twenty years.

He became a pioneer in the new subject of astrophysics and soon began a series of investigations on radiant energy, especially manifested in the solar spectrum. In his early experiments he used the apparatus made classical by previous investigators — the combination of junctions of bismuth and antimony, called the Melloni pile. These junctions are very sensitive to radiant heat, and the thermo-electric currents developed at the junctions can be measured by a suitable instrument — a galvanometer — placed in an electric circuit — namely the circuit of the junctions and the galvanometer. Langley found, as so many did, that thermo-electricity cannot be depended upon for accuracy of indications of small amounts of heat. He therefore adopted the electric balance, in which the increase of electrical resistance in a coil submitted to heat, is balanced by other coils. The electrical balance is what is known as the Wheatstone's Bridge. Langley's contribution to the electrical balance was the use of an excessively fine metallic filament for the resistance submitted to radiant energy. This filament responded to extraordinarily small increments of heat. I well remember his enthusiasm, when on a visit to Cambridge, he showed me the modification of the balance which he called a bolometer and said "I have found a means of overcoming all my difficulties." A new instrument often marks the beginning of a new epoch in science, Langley opened a great field of investigation in that portion of the solar spectrum which extends into darkness beyond the visible red — the portion called the infra red; and mapped lines and absorption bands in a region eight to ten times the extent of the visible spectrum.

With his bolometer he undertook an investigation of the heat of the moon; but could not distinguish between the heat given off by the body of the moon and that due to reflection of the sun's rays. He made journeys to Mt. Whitney where the height and steadiness of the atmosphere promised to enable him to determine the constancy of the radiation of the sun. He laid the foundation of the subsequent refined measurements of Dr. Abbot. When Langley was called to the Smithsonian, as Director he founded an astrophysical observatory in connection with the Institution which has become renowned as a centre of investigation of radiant energy.

Langley obtained by his investigations with the bolometer an enduring place in the history of science which, however, was to be greatly increased by his later work on the aeroplane. My acquaintance with him began on a camping out expedition in Maine. He impressed me as a man wrapped in heavy thought. One evening Professor Alfred M. Mayer, who was of the party, expressed the conviction that a scientific man could acquire in half an hour the practical experience which had taken our guide twenty years to obtain; and he and Langley took lessons in paddling a canoe. There was no wind and the lake, on the shores of which we were encamped was placid. Langley, taking with him a copy of Maxwell's Matter and Motion, paddled across the lake. A thunder cloud presently arose and Langley endeavored to return; but there was no stone in the bow of the canoe; and it did not occur to him to shift his position to the middle of the canoe. He had to summon the guide. Later we were together in London, and on one occasion while riding in the suburbs, he broke a moody silence by remarking, "How absurd it is to be carried by this horse — a mass of flesh and bones, nine hundred pounds in weight, I have an engine, which weighs only four pounds and develops two horse power."

When the idea of flying possessed him he went ahead without regard to the universal ridicule which greeted those who believed that flying was possible — a ridicule fully expressed by the poem, "Darius Green and his flying machine," and was constantly showing his friends little devices, modifications of boomerangs, arrangements of wings and screws which showed marvellous capabilities of flight. Finally in 1896 he constructed a machine which was driven by a small steam engine and which flew down the Potomac a distance of over a mile. The machine was set off on a car which ran forward on ways, and which fell down at the extremity of the car's motion, releasing the aeroplane for its flight.

In 1898 a board consisting of army and navy officers was appointed to investigate Langley's experiments. Their report was favorable and the board allotted $50,000 for the development and construction of a large aeroplane. A difficulty was met in obtaining a suitable light engine and suitable materials for the guys and wings. In 1901 a gasoline engine was secured and work proceeded. The first machine weighed 830 pounds and had a surface of 1,040 square feet. The entire power plant weighed less than 5 pounds to the horse power. The successful small mechanical model which made the flight of a mile, weighed 58 pounds, had a surface of 66 square feet and an engine which developed $2\frac{1}{2}$ to 3 horse power. The same launching apparatus which had worked successfully in the case of the small model was prepared for the large machine. The weather conditions on the Potomac were most baffling. It seemed as if the winds followed the course of the river and Langley, with hope deferred must have suffered great perturbation of spirit in studying the weather conditions. There seemed to be a malevolence in nature; which we feel in war times. A small house had been erected on the banks of the Potomac and the launching ways carefully tested. On October 7, 1903, in the presence of a curious throng of spectators the conditions of the atmosphere seemed propitious. The engineer took his seat and the car with the aeroplane sped down the ways. Just as it left the track, with the 50 horse power engine whirling the propellor, one of the guys was caught by the falling ways, a front guy post was also caught. The front of the machine was dragged downwards and the machine plunged into the water about 50 yards in front of the boathouse.

After some repairs a second attempt was made on December 8, 1903, with a resulting disaster. The rear guy post seemed to drag, bringing the rudder down on the launching ways with a crashing rending sound and a collapse of the rear wings. The machine was wrecked and the funds, exhausted. Langley said, "Failure in the aerodrome itself, in its engines there had been none: and it is believed that it is at the moment of success, and when the engineering problems have been solved, a lack of means has prevented a continuance of the work." If he had only thought of mounting his aeroplane on bicycle wheels! what a small thing prevented his success. One recalls the canoe episode on the Maine lake. I know of no more touching episode in the history of invention. He had success in his grasp. A critic has said that he ought to have stopped with his mechanical model; for he had not the engineering skill to perfect his invention. It seems to me that this is not true. Langley combined with his theoretical knowledge of mechanics a remarkable practical skill. His aeroplane afterwards flew. Perhaps he underated the necessity of practical experience in balancing even after a successful launching. With what exultation of spirit he would survey today the progress of aviation. It is one of the unintelligible things in this life that this exultation was denied him; for he was a man especially fond of distinction. He failed for the want of a few thousand dollars; and the United States Government is now appropriating millions for aeroplanes. In the Smithsonian Miscellaneous Collections for 1907, will be found a complete bibliography of Langley's papers. It contains 284 references.

John Trowbridge.

THOMAS RAYNESFORD LOUNSBURY (1838–1915)

Fellow in Class III, Section 2. 1896.

I

Thomas Raynesford Lounsbury, son of Thomas and Mary Janette (Woodward) Lounsbury, was born on January 1st, 1838, at Ovid, New York, where his father was pastor of the Presbyterian Church. At the age of seventeen he entered Yale College; he took his degree in 1859. His undergraduate career was distinguished by sundry prizes and other such recognitions of literary propensities. After graduation he was for some time employed on the not too mature staff engaged in preparing Appleton's New American Cyclopaedia. From 1862 to 1865 he served as an infantry officer in the Civil War, during the latter part of this time as Adjutant of the Draft Rendezvous at Elmira, New York, which was also a depot for Confederate prisoners. The next five years he passed in school teaching, private tutoring, and eager study, particularly of the English language and literature. In 1870 he returned to Yale, as instructor in English at the Sheffield Scientific School; the next year he was made professor of English there. As such he continued his work, scholar and teacher alike, for thirty-five years, retiring in 1906. He died at New Haven, on April 9th, 1915.

For a long time he had then been recognized not only as one who will hardly be forgotten among the worthies of Yale but as a scholar of national and international importance — after the death of Professor Child, of Harvard, in 1896, undisputedly the most eminent master of his subject in the United States. This eminence was attested by many degrees and similar honors. He was Doctor of Laws of Yale, of Harvard, and of Aberdeen; he was Doctor of Letters of Princeton; and, to go no further, he was from the first a member of the American Academy of Arts and Letters. He had been made a Fellow of the American Academy of Arts and Sciences April 8, 1896.

Apart from occasional writing, his publications were not precocious. The first which he chose to record in Who's Who was a compact handbook concerning the History of the English Language, published so late as 1879. In 1882 — though it bears the date of the following year — appeared his Life of James Fenimore Cooper, in the American Men of Letters Series. In 1891 came what is generally thought his most important work, the three-volume Studies in Chaucer, affectionately dedicated to Professor Child. Between 1901 and 1906 came the three volumes which he grouped together under the title of Shakespearan Wars: Shakespeare as a Dramatic Artist, Shakespeare and Voltaire, and The Text of Shakespeare. Meanwhile, in 1904, he had extended into a small volume papers originally written for occasional purposes, concerning The Standard of Pronunciation in English. This was followed in 1908 by a similar but rather more extensive book on The Standard of Usage in English. In 1909, he completed this third of his trilogies by his book on English Spelling and Spelling Reform. In 1911 appeared his four lectures, originally given at the University of Virginia, on the Early Literary Career of Robert Browning; in 1912 followed that most compact and satisfactory of anthologies, The Yale Book of American Verse. His last considerable publication was posthumous: The Life and Times of Tennyson (From 1809 to 1850) he had left unfinished; in December, 1915, only eight months after his death, it was printed under the supervision of his junior colleague and devoted friend, Professor Wilbur Cross.

In 1871, Professor Lounsbury married Jane, daughter of General Thomas J. Folwell, of New York. With one son, she survived him.

II

It is happily characteristic of Professor Lounsbury that when he retired from the drudgery of teaching, in 1906, a neighbor more than twenty years younger than he sent the Yale Alumni Weekly a column touching on the humanity of him just as a neighbor. There have rarely been men more stoutly themselves; but you could hardly meet him, even occasionally and casually, without a contagious sense of human fellowship. As one thinks of him now, the first thought is that he was of the few who can unwittingly help fellow beings to be better fellows. His appearance was by no means academic; rather his burly vigor bespoke the old soldier. So late as 1915, when he was more than seventy-five years old, he allowed to stand in Who's Who the statement that his favorite recreations were cycling and tennis. A tall man and a large, sandy-haired and bearded, with heavy-lidded eyes which troubled him in his later years, he might have looked ponderous, if he had been less alert. He was voluble yet affable; whether you talked back to him or not, you felt as if you did. His boundless range of information was always at his command. He had the buoyant potency of a great scholar; he could master books and they could not master him. No man was ever more free from the insidious bonds of pedantry. Life is real, books are the record of past realities; to understand books we must take them for what they truly are — the data from which imagination can revive aspects of life no longer visible to living men. Your pedant stops at the letter, imprisoned in the walls of his library; your scholar finds his library an open gate to worlds he can never explore too eagerly. He loves his path, no doubt, but mostly because it is the way to boundless journeys of discovery; and discovery is discovery, be it of a new flower or of a new continent or planet. We may seem to be straying from a life which passed half its allotted span in the teaching of boys at an American Scientific School; yet those who remember Professor Lounsbury can hardly help, from the very force of his memory, starting away from daily commonplace.

How tremendously commonplace the circumstances of his professional work must have been, anyone who has taught undergraduates must sadly know. The independence of Professor Lounsbury's nature kept him apart from the rigid curriculum which persisted at Yale College during the greater part of his teaching years. In the Scientific School he was more free to deal with his still new and somewhat suspected subject of English than he could have been in the college itself; but this very freedom brought its penalties. Students of science, at least in his time, have been so largely because they would not take the trouble to make themselves students of the humanities; and students of English, as a class, have been so largely for the reason that they could thus dispense with the vexatious need of learning any other language than their own. Until very late in Professor Lounsbury's career as a teacher, there was little graduate study of English at Yale: even now, your graduate student of English anywhere is seldom inspiring. So perhaps only men who have had to teach English at a Yankee college can fully enjoy two of his remembered comments on this task. The first is in his life of Cooper (p. 7), who was for a while an undergraduate at Yale. "We need not feel any distrust," writes Lounsbury, "of his declaration that little learning of any kind forced its way into his head. Least of all will he be inclined to doubt it whom extended experience in the class-room has taught to view with profoundest respect the infinite capability of the human mind to resist the introduction of knowledge." The second of his comments on pupils, though perhaps legendary, is at once equally characteristic and more familiar. Towards the close of an unusually restless hour, he is said to have admonished his class in some such words as these: "You must stay with me a little longer. I have a few more pearls to cast before you."

And pearls they were, those words of his, whether they concerned learning or sport, reminiscence or what a less robust nature would have found the benumbing chill of college conservatism. He was a Yale man to the core, and lived to be in his later years among the most secure of Yale worthies in the hearts of men that loved Yale. The way in which he instinctively combined simplicity with distinction breathed the best spirit of the college which was his from boyhood to the last. He was a born and a trained lover of literature. Above all, though, he was a pitiless enemy of literary cant; he never forgot the supreme truth of fact; and no one ever sought or asserted fact with more sturdy common-sense. Before his time, the teaching of English at Yale had been mostly concerned with formal rhetoric and oratory. His own first teaching directed the attention of his pupils straight to the texts of Shakespeare, of Milton, of Dryden, and of

Pope — poets who have survived so surely that, whether you care for them or not, their works are touchstones by which those who will may test the worth of works lesser or newer. And what he thought of the trivial conventions of petty literary grace may be gathered from the saying attributed to him by Professor Cross, that "a man who hasn't brains enough to write a grammar writes a rhetoric."

Those who knew Professor Lounsbury, even though slightly, can never forget him. No one can remember him without interest, few without affection.

III

Whoever, with such memory, turns now to the books where he has left his record for future times must feel, more than usual, how little books, even though deeply characteristic, can preserve the atmosphere of a memorable personality. Something similar is true of two Harvard worthies — Lowell and Norton. Lowell's poems and essays are securely placed among the standards of literature in America, Norton's books and letters are lasting records of the most gracious American culture. But Harvard men who studied under Lowell or Norton, or who know them as they lived and moved in the Cambridge they had seen transformed from a unique college town to populous suburban commonplace, grow impatient of their printed utterance. This is doubtless good; but the men themselves were so much better that the sense of their loss grows heavier with each page. Lounsbury's books are as characteristic as either of theirs — not least for his disdainful disregard of conventional literary pretension. He wrote, as he talked, volubly and idiomatically. He did not attempt to make literature; he was content to know it, to love it, to assert the standards of it and to maintain them with all the power of his insatiable study and of his unswerving common-sense. No man ever had a sounder appreciation of literary and poetic values; none could insist on them more sanely or more valiantly. When he came to discussing them, however, he was a little too apt to take them for granted. This, as one reflects, was evident in his talk. There one felt nothing to seek; if he strayed a bit from things themselves worth while to things about them, a word or two would recall him to the heart of the matter; oftener, gladly yielding to the sweep of his utterance, one was content for the moment to take for granted with him that there was no need to dwell on what we all knew anyway. The pitiless impersonality of print, however, reveals too clearly this error, if indeed it be not a foible, of his strength.

A shrewd contemporary of his, at another college, was apt to say that books are alive, that books about books are anaemic, and that books about books about books are still-born. In his writing as in his talk Lounsbury was red-blooded and always animated. As one turns the pages of his volumes, though, one sometimes suspects that the greatest wonder of all about him is that he could manage to make a constant impression of vigor in works which may so nearly be generalized as books about books about books.

This is not the case throughout, to be sure. His little handbook on the English Language, compact from the conditions of its limits, states the facts as they were ascertained in 1879 so firmly and with such animation that after forty years it still seems an authority. His Life of Cooper is an excellent piece of literary biography, where you may find not only faithful portraiture set in veracious historic background, and supplemented by compact critical comment, but now and again pearls of such water as that which we took from its setting a little while ago. His Studies in Chaucer, generally deemed his principal work, may justly be called diffuse and disorderly; but, for all their voluble vagrancies, they unquestionably accomplish the essential task of books about books. They make you eager to read the poet they concern, impatient again to open his pages which they irradiate with countless gleams of new light, and above all aware of what manner of human being that poet was, the greatest gentleman who ever made English poetry. When we come to Lounsbury's second trilogy, however, which has to do with Shakespeare, the case is different. Shakespeare lurks in the background; the foreground is full of faintly reanimated folks who between his time and ours have had opinions about him. The tireless erudition displayed throughout is beyond compare; Lounsbury read more extinct criticism, you grow to feel, than would have seemed within the range of human power. What is more, his own vigor gives his statements about this forgotten stuff a semblance of animation. But, after all, discussions of such things as the Unities and as Eighteenth Century Views do not lead you into the heart of Hamlet or of The Tempest; and if Voltaire had done nothing but first praise and then jealously blame the greatest of English poets we should trouble ourselves no more about Voltaire; and when it comes to The Text of Shakespeare, the matter leads us rather to the murky depths of the Dunciad than either to anything Pope lives by or a bit to the poetry with which Theobold dealt so faithfully as to rouse Pope's hateful spite. Lounsbury's Virginia lectures on the early career of Browning, too, tell you not so much about Browning as about what critics thought of him. And Lounsbury's unfinished study of Tennyson leaves on your mind more distinct notions of English reviewing before 1850 than of either the poetry or the poets with whom the reviewers concerned themselves. Your notions of Tennyson himself meanwhile grow rather hazier than clearer, and in the end you are not eager to clear them up.

On the whole, The Yale Book of American Verse gives one the best notion of how admirable the critical sense of Lounsbury really was. There are some thirty-five pages of discursive introduction, nowhere more sturdily his own than where he touches on our national hymns, the Star-Spangled Banner and America (pp. xlii–xliv). There are some five hundred and fifty pages of selections from American verse, beginning with a hymn by Timothy Dwight (1752–1817) and ending with two longish poems by William Vaughn Moody (1869–1910). The pages are admirably printed and widely spaced. As should always be the case with poetry, they tempt the eye to linger and the mind to read at leisure; and, as there are extracts, sometimes rather long, from the work of fifty-two nineteenth century poets, there is not too much of anybody. The very mention of our national hymns, and of the names which open and close the selections, is enough to remind us that these range widely in point both of quality and of renown. The two sure things about the book are first that whoever knows our national characteristics cannot help feeling it admirably and comprehensively American, and secondly that it demonstrates as hardly ever before the merit of poetry in nineteenth century America. Thus dealing directly with literature, Lounsbury could surely make others know afresh what literature is.

His disdain of conventional rhetoric somewhat obscures this power. Professor Cross, in his pious introduction to the posthumous volume on Tennyson, draws a touching picture of Lounsbury, in his later years and with sadly weakened eyes, writing in the dark, and carefully considering the turn of his phrase. Except for incessant clearness, one would hardly suspect from his published work that he could ever have been haunted by any such artistic conscience as is here implied. In general his style seems carelessly diffuse; and his passion for the neuter pronoun was almost unholy. To take a casual example of this, he was capable of writing and of leaving unchanged in his proof such a sentence as "It is equally evident that it is Shakespeare's practice which is the one followed upon the modern stage" (Shakespeare as a Dramatic Artist, p. 13). Amid the very pages blurred with these rhetorical inadvertences, however, you will constantly find passages to prove that if he had chosen he might have been a master of style. Here are two or three, taken at random as one reads. Writing of Chaucer's character of the Knight, he closed a paragraph thus: "He must be a man of honor, he must be a man of courage, above all, he must be a gentleman in his feelings, his instincts, his aspirations. He might be stupid; it was incumbent upon him to be chivalrous. If his virtues were heroic, his vices accordingly had to be of the same stamp. They must be of a bold and open sort. The knight could be licentious and arrogant and even cruel; the thing forbidden him was to be petty and mean and false." (Studies in Chaucer, II, 481–2). Again, he could summarize Warton's opinion of Chaucer in words like these: "In his eyes Chaucer was a Goth — a Goth of genius, to be sure — but still a Goth. Being a Goth, he had not the severe self-restraint of the moderns, their chastity of diction, their propriety of manner; in fine, their Art." (Studies in Chaucer, III, 250). Better still, when touching on an edition of Chaucer once projected by Samuel Johnson, he thus concludes, "Scholarship suffered no loss by the failure to carry out a scheme which was probably never more than vaguely thought about. Literary criticism certainly has. An edition of Chaucer by Johnson could never have been an authority, but it would always have proved an entertainment." (Studies in Chaucer, I, 299). You must search far and long to find criticism or parody better than that.

Another feature of his learned books bespeaks if not literary conscience at least literary instinct. One may fairly doubt whether any other American scholar of the nineteenth century was capable of disfiguring so few pages with footnotes. On general principles, everybody would probably agree that what belongs in a book ought to be there and that what does not belong there ought to be left out; in general practice, the Germanic passion of American scholars for annotating their own texts rivals Lounsbury's passion for the neuter pronoun. Lounsbury's repugnance for this kind of troublous cant was part of his pervasive common-sense. He carried it, indeed, almost to excess. More than once, as you read his torrents of authoritative statements, you would be glad if he had given you more references to supplement or to verify what he says. All the while, you rejoice that when he chose to say anything he said it out loud and not in the whisper of small print.

Lounsbury's third trilogy comprises his most nearly popular work. Originally written for Harper's Magazine, or other similar periodicals, his papers on Pronunciation in English, on Usage in English, and on English Spelling at once delighted the cock-sure and enraged the meticulous. He expanded them into three small volumes which appeared between 1904 and 1909. In the matters of pronunciation and usage, he stood firm on the ground that the true question concerning any language still unmummied is not what ought to be the case but what has been the case and what is. In the matter of spelling, his extensive reading, his knowledge of language and his impatience of pedantic pretence combined to transform his common-sense into that semblance of folly which, throughout the whole range of human activities nowadays, claims authority under the magic name of reform. So far as English spelling goes, most will agree that there has never been any long settled practice, and the practice imposed by nineteenth century proof readers is little better than nonsense. Wherefore, you may feel for once, here is a region where common-sense and general principles may unite. Perhaps so. What the reformers forget is the essential amenity of acknowledged manners — the civilizing effect of not doing a thing for the simple reason that it is not done. Good men have been known to raise a casuistical question as to whether your word of honour can fairly be held binding when honor is spelt without the *u*. The spelling-books of the nineteenth century are often condemned as training only that unimportant phase of the mind, the memory. So they do, if you are thinking only of the reasoning powers in contrast. There is another aspect of the whole question, though. To master the luxuriant unreason of modern English spelling, any child must develop to considerable degree the power of accurate observation. More than a few old-fashioned teachers are apt to believe, unreasoningly if not unreasonably, that the training thus given children has had a value beyond reason.

Not to dispute, now and then, would be not to admit the mood which Lounsbury excited and loved to excite. Throughout his books you may often find yourself reluctant to agree; and the very sturdiness of his voluble assertions may arouse a temper of denial. As he loved sport, he loved contest, for its own invigorating sake; but he was a true sportsman, he played fair. His writings, as we have said, do not express anything like the fulness of his contagious humanity, yet, as one thinks of them altogether, one cannot avoid the glad knowledge that, like his human self, these writings are strong, honest, manly, simple and masterly in their union of erudition with common-sense.

IV

One dare hardly hope, no doubt, that his books will long survive, except as old mile-stones in the interminable journey of scholarship.

His memory, more living now than any of his living words, must fade as those who knew him pass. Yet his life has done work which must endure. Whether he attracted or repelled, he never left indifferent those whom he influenced, and he influenced almost all who came within his range. Among the scholars and teachers who have made the study of the English language and of English Literature important in American universities, he was second only to Professor Child, his elder by half a generation. Child, like Lounsbury, may soon be little more than a name, or the shadow of a name. But the spirit of them lives and shall live so long as the language and the literature they loved and taught are studied and taught and loved.

Barrett Wendell.

CHARLES SEDGWICK MINOT (1852–1914.)

Fellow in Class II, Section 3, 1882.

Charles Sedgwick Minot was born in Boston, December 23, 1852. His parental home, five miles from Boston, and comprising about thirty acres, stood on the edge of the forest area which then stretched from Forest Hills on the north to the Blue Hills and the Great Ponds in Canton and Braintree on the south. The region even now, as seen from the summit of Blue Hill, is largely a low forest, most of it of second and third growth, with areas of cleared land in which are small towns and villages, with farm lands about them. There are interspersed fine villas inhabitated by wealthy Bostonians, and most of the Forest is now included in the Metropolitan Park system and will be preserved. There are extensive low marshy flats, subject to overflow, along the Neponset River, and included in the forest there are large areas of swamp. Fine trees, elms, oaks, ash, beeches and pines abound in the region, but the trees in the forest areas are generally small. The flora and fauna are abundant and diversified. It is a stimulating region even now to a boy who has the capacity to see things and joy in seeing the wonder and beauty in nature. In Minot's boyhood the region must have been much wilder and hence more interesting than now. In such surroundings the boy grew up and early acquired the love of nature, the capacity of seeing, and the scientific curiosity to find out the meaning of the things he saw, which distinguished the life of the man.

He was a member of a large and well known family, with inherited wealth and distinguished in useful service. The usual course for a boy in his social class would have been to go through Harvard College and it is uncertain why he went to the Institute of Technology instead. The Institute had but recently been founded, it was just entering upon the great career which it has attained, and had the glamour of a new enterprise. At that time Minot could not have obtained in the Institute much stimulation in the study of natural science which from boyhood he had enthusiastically followed. He had already, at the age of sixteen, made his appearance in scientific literature by the description of the male of Hesperia Metea, a small butterfly captured in Dorchester and of especial interest because only the female of the species had been previously found. He derived probably a great stimulus from the meetings of the Boston Society of Natural History, which he regularly attended and took part in the discussions. He graduated from the Institute in 1872, at the age of twenty. The influence of the training he acquired at the Institute can be seen in his later life by the interest he had in mechanics and which led him to devise a number of laboratory instruments, among them the well known Minot microtome, which were characterized by simplicity of structure and admirable adaptation to the end in view. The microtome made it possible to cut thin serial sections of organs and is now, with slight and unimportant modifications, the instrument almost universally used for this purpose.

After graduating from the Institute he studied for a time with Agassiz, but he found the most congenial atmosphere in the laboratory of his friend, Henry Bowditch, who had returned from Europe in 1871 and established the first physiological laboratory in this country. Minot was his first research student and found in the older man both a congenial friend and an enthusiastic teacher. The period was one in which teaching in medical science with the laboratory as a basis was just beginning in this country. Previous to this the only laboratories, if they could be called such, in connection with medical schools were the dissecting rooms, and in Bowditch's laboratory the torch of science which was kindled in the ardent flame of the physiological laboratory in Leipzig burned brightly. His work with Bowditch turned his mind into channels which he afterwards followed, his early interest in form and structure being never lost, although modified by his study in physiology of the phenomena of life. In 1874 he published, in collaboration with Bowditch, a paper on the influence of anaesthetics on the vasomotor system, and in 1876 a short paper on transfusion and autotransfusion.

He went to Europe in 1873, working first at Leipzig with Ludwig in physiology, then at Paris with Ranvier in histology, and at Würzburg with Semper in zoölogy. His was not the common fleeting visit to these laboratories, but in each his stay was sufficiently long for him to become acquainted not only with the laboratory work and methods, but with the ideals which directed it. While at Leipzig under Ludwig's direction, he studied the production of CO_2 in the active and resting muscle. He returned to America in 1876 and conducted an extensive series of experiments on tetanus, which was published in 1878, and in the same year received from Harvard University the degree of Doctor of Science.

In 1880 he received his first academic appointment, that of Lecturer on Embryology in the Harvard Medical School, and Instructor in Oral Pathology and Surgery in the Dental School. At that time it was unusual anywhere that instruction in a medical subject should be given by a person who had never taken the degree of Doctor of Medicine, and the appointment of Minot was a distinct break in the academic tradition. The appointment was due to the far-sighted intelligence of Mr. Eliot, who recognized the ability of Minot and desired for the Medical School the influence which a man trained in the traditions of pure science would exert on both the faculty and the students. The appointment was not welcomed in the faculty, and for a long time Minot undoubtedly suffered from his supposed deficiencies. The idea that a man teaching in a medical school should have some knowledge of disease and be able to give an added interest to the subject he teaches by pointing out the practical application of what is taught is not altogether a faulty one, for medicine, certainly for the majority of those entering into it is an art, but like all other arts founded on science. In 1883 he was advanced to the position of Instructor in Histology and Embryology, and this subject was given a satisfactory place in the curriculum, though it was a number of years before laboratory instruction in this subject was made obligatory and a definite part of the course. In the year 1887 he was advanced to the position of Assistant Professor. After the usual term of five years he was made Professor of Histology and Embryology, and when the James Stillman Professorship of Comparative Anatomy was founded he was transferred to that position. Upon the death of Doctor Dwight, in 1911, the subjects of Anatomy and Histology were placed together, and in 1912 he was made Director of the combined laboratories.

As a member of the faculty Minot was always outspoken, clear and logical. He never sought to obtain any end by suavity or the claims of friendship. His arguments were always keen, definitely to the point in view which was strongly presented, sometimes even too much so. There is apt to be some suspicion in the minds of men when a policy advocated is too clearly presented; it is not flattering to those holding the opposite view. The general discussions in medical faculties do not suffer from clear and logical statement, and Minot's presentation of a subject was in marked contrast to that usually heard. While it often took a long time for men to agree with him, and he usually obtained what was desired, there was never a suspicion that the ends in view were personal and selfish. His active support could always be obtained for any measure looking to the betterment of instruction and the advance of scientific interest.

He was in all respects an admirable teacher; as a lecturer simple and clear, interesting, often enlivening the subject by shafts of keen humor, and in the laboratory stimulating, always insisting that the students should cultivate the faculties of independent observation and judgment. Minot was the first to introduce into the medical schools of the country the laboratory method of student instruction, and the way is never easy for the pioneer. It was a method new to the students, for the men entering the medical schools seem to acquire neither in the home, nor in the schools, nor in the colleges sufficient training in the methods of science. Minot lived to see the modest beginning of this method of teaching, which he made under most unsatisfactory conditions in the old Medical School on Grove Street, become the dominant method used alike in the pre-clinical and clinical branches.

Minot was an excellent director of a laboratory. His laboratory was always orderly, giving one entering it the impression given by a well ordered household. He devised a method of giving each student the use of a microscope by having him pay the school a small sum, which sufficed for their upkeep and renewal. He early began the collection of embryological material, the embryos being cut in serial sections and arranged in suitable and permanent steel cabinets which he devised. In the course of time this grew into an unrivalled collection, serving an admirable purpose, not only in teaching, but in research also, as is shown by the number of researches based upon the material of the collection. The collection was freely used by the other departments of the school, so that any question arising which was wholly or partly based upon the course of embryological development could be here studied on admirably preserved material. Minot gave much time and thought to the plans for his new laboratory at the school and here first put into effect what he described as the laboratory unit. The unit of the teaching laboratory is a room for twenty-five students, provided with the essential instruments for laboratory work and under the direction of one instructor. The entire class comes together for lectures and demonstrations. The method renders it possible to extend a laboratory indefinitely without confusion, provided the necessary space and instructors are at hand. Minot had moreover an excellent business sense and made the small budget at his disposal cover a wide field.

He was a prolific writer, his most striking contributions being not in small single researches, but in more extensive publications in which he brought together and made more serviceable the accumulated knowledge of a subject. Sometimes, as in the case of his well-known Human Embryology, the work covered a large field. This large and comprehensive work, the result of ten years labor, was in no sense a compilation, but was based on his personal knowledge of facts, expanded by the knowledge contributed by others. The American edition was published in 1892 and a German edition in 1894. Of this work His, at that time the leading anatomist of Germany, says, "Minot's work is at present the fullest embryology of man which we possess, and it will retain its value as a bibliographical treasure-house even after its contents in many parts have been superseded." He early became interested in the subject of growth, the stimulus probably coming from Bowditch, who was carrying on his well known studies on the growth of school children while Minot was working in his laboratory. His first paper on the subject, 1878, was "Growth as a Function of Cells" which was quickly followed by another "On Certain Laws of Histological Differentiation" and in the same year he presented in an address "On Conditions to be Filled by a Theory of Life" an outline of his future work. There were many papers on the subject of growth and senescence, the whole being brought together in a book "The Problem of Age, Growth and Death" based on lectures at the Lowell Institute, March 1907. This work has been so well analyzed by Lewis in his Memoir that I quote from it. "Senescence and rejuvenation were studied by tabulating the weights of guinea-pigs from birth to old age, and of rabbit embryos up to the time of birth, using weight as a measure of growth. The conclusion was drawn that the fertilized ovum is endowed with an enormous power for growth, over ninety-eight per cent of which has been lost at the time of birth. The remaining two per cent is largely exhausted in infancy. Therefore he concludes that "senescence is at its maximum in the very young stages and the rate of senescence diminishes with age." He protests against "the medical conception that age is a kind of disease," chronic and incurable, of any such nature as intestinal intoxication or arteriosclerosis. On the contrary he finds that it has a cytological cause, equally operative in the lower animals which have neither intestines or arteries and in man; and he ascribes senescence to the increase and differentiation of cytoplasm as compared with nucleoplasm.

In 1901 he proposed "the new term cytomorphosis to designate comprehensively all the structural alterations which cells, or successive generations of cells may undergo, from the earliest undifferentiated stage to their final destruction." His latest works on this subject, aptly characterized as "thoughtful and suggestive," refer to cytomorphosis as a most promising field for further study, and at the time of his death, plans had been made for careful investigations to test the validity of his cytomorphic hypothesis concerning age."

Of Minot's shorter contributions perhaps the best known is a paper, 1900, "On a hitherto unrecognized form of blood circulation in the organs of Vertebrata." Everyone was familiar with the differences in the thin walled capillaries running in the connective tissue of most organs, easily compressible, their calibre varying with the activity of the circulation, and the vessels in the liver which were wide, closely applied to the parenchyma and whose calibre cannot easily vary. He regarded such vessels not as capillaries but as sinusoids, showed their manner of development and the organs in which they were found.

Minot was greatly in demand as a giver of addresses and these cover a wide range of subjects. His style was vigorous, graceful, the subject enlivened by humor, sometimes with a little satire, and always interesting. They were collected and issued in a German translation under the title "Die Methode der Wissenschaft und andere Reden" — Jena, 1913. Altogether he has published more than one hundred and eighty notes and papers, including his addresses.

In 1912–1913 he was Harvard Exchange Professor at Berlin and Jena, and used the position largely in bringing to the attention of his German colleagues the amount and character of the contributions of American investigators. The position was very enjoyable to him, for he renewed and extended his wide acquaintanceship with the German men of Science.

Minot possessed a wide acquaintance with scientific men here and abroad; he was constant in his attendance on scientific meetings, taking part in the discussions, and occupying a prominent place in the conduct of societies. He was at different times chosen President of the Naturalists, the Anatomists, the American Association for the Advancement of Science, and the American Academy of Arts and Sciences, and was frequently a member of the councils and of important committees. He was an active or corresponding member of many of the learned societies of Europe, and was honored with the L. L. D. of Yale, 1899, Toronto, 1904, St. Andrews University, Scotland, 1911, and Sc. D. of Oxford, 1902.

No account of Minot would be complete without some mention of his beautiful country home at Hyde Park, the region over which he must have rambled as a boy. The house was a plain one, roomy, furnished simply and in exquisite taste, and stood near the road, the land sloping away from it toward the south and west to a low lying wood, through which a small brook ran. The whole place was in keeping with Minot's character. It was well ordered in its plan and keeping. The trees he planted were properly placed, selected with care, and were fine specimens of the species. He bought a large number of seedlings of many varieties and as these grew he selected from them the finest specimens for planting. Every tree and shrub was well cared for and showed the effects of this in their health and vigorous growth. The garden, formal in design, with well kept grass paths, was at the foot of the slope, some distance from the house, and entered through a small arbor covered with climbing roses. Though formal, it was not severe and contained good specimens of the usual annuals and perennials and many rare plants. The two plants to which he gave most attention were irises and peonies, of each of which, but particularly of the latter, he had a large and rare collection. There were several hundred varieties of peonies, every plant showed intelligent care, and his system of cataloging and labelling was as simple and complete as the system in his laboratory. It was a great joy to go with him among the blooming peonies and see their beauty through his observant and well trained eyes. It is not an easy thing for an amateur gardener to obtain the prizes of the Massachusetts Horticultural Society, but Minot obtained prizes both for peonies and for the general excellence and beauty of the garden as a whole. The grounds and garden showed that highest art by which art is concealed and every plant grew and bloomed as though for the mere joy of living under conditions in all respects the best. There was a profusion of bloom from the earliest spring bulbs to the late chrysanthemums. Many of his plants had a personal history which he would delightfully relate, as having been procured under unusual conditions, or being transferred to a more suitable situation, or having developed some uncommon and interesting characteristic. He was most generous with his plants, delighting to assist young beginners in horticulture. Through the wood along the brook there wandered a simple path, along the sides of which were many flowering plants collected from the swamps and fields, each in the situation best adapted for its growth and display; as a mass of dog toothed violets at the base of a decayed stump overgrown with moss, or a yellow mass of marsh marigolds intermingled with the beautiful though maloderous swamp cabbage.

I first became acquainted with Minot through the series of excellent articles on anatomy of the uterus and the changes associated with pregnancy, which were published in 1886 in the Handbook of the Medical Sciences, to which I also contributed. He was at all times a delightful companion, always loyal as a friend, sympathetic and helpful. He never hesitated to testify to his friendship. He was in all things generous, in helping younger men both materially and otherwise, a hospitable host, one who knew how to make a guest feel that he contributed to the pleasure of the host. He spoke well on most subjects, as an impromptu speaker thought came clearly and quickly and was expressed in simple language and without hesitation.

In June, 1889, he married Lucy Fosdick of Groton, Mass., in whom he found a sympathetic, helpful companion, and those who knew Minot will always associate her in their thoughts of him.

Science has been enriched by his life; in devising instruments which facilitated work, in teaching and inculcating good methods, in the research he personally conducted, and in his masterful method of presenting the work of others he added to the sum of knowledge and made its pursuit more profitable. He was a good patriotic citizen with high ideals of civic duty. He increased the joy of living by bringing to many people a richer and fuller sense of the beauty of living things; the world is a better place by his having lived.

In the preparation of this Memoir I have made use of the Memoirs by Frederick T. Lewis, by H. H. Donaldson, and by Charles W. Eliot.

W. T. Councilman.

ALPHEUS SPRING PACKARD (1839–1905)

Fellow in Class II, Section 3, 1868.

Alpheus Spring Packard was born in Brunswick, Maine, on February 19, 1839, and died at his home in Providence, R. I., on February 14, 1905.

In view of the present interest in the backgrounds of American scholars it may be recorded that his grandfather Hezekiah Packard, a revolutionary soldier, received from Harvard College the degrees of A.B., A.M. and D.D. and was an able preacher, teacher and writer. The Rev. Dr. Jesse Appleton, one of the early Presidents of Bowdoin was his maternal grandfather. His father was the Professor Alpheus Spring Packard who for sixty-five years taught various classical subjects at Bowdoin, the venerable scholar to whom Longfellow addressed his "Morituri Salutamus."

Packard graduated from Bowdoin in 1861; received the degrees of A.M., Bowdoin, 1862; M.D., Bowdoin, 1864; S.B., Harvard, 1864; Ph.D., Bowdoin, 1879; LL.D., Bowdoin, 1891.

After graduation he studied under Louis Agassiz at Cambridge for three years and subsequently taught with him at the Anderson School of Natural History at Penikese. The comprehensiveness of his interests which included geology, paleontology, systematic, structural and economic zoölogy, embryology and anthropology may be said perhaps to have been an academic heritage through Agassiz from the generation of Humbolt, Cuvier, Lamarck and St. Hilaire. His geological researches are recorded in books and papers on glacial phenomena of Labrador, Maine and the White Mountains. He published (1867) a "Revision of the Fossorial Hymenoptera of N. A." In the U. S. Geological Survey (1875–1877) under Hayden he served as a zoölogist. As a member of the Kentucky Geological Survey in 1874 he investigated with Putnam the great caves and their fauna of which he later wrote, "The Cave Fauna of N. A.," 1888. He studied also the Florida reefs and the fossil fauna of Charleston, S. C. In 1882 he published a text book "First Lessons in Geology." He published works so diversified as "The Development and Anatomy of Limulus Polyphemus," 1871, the "Monograph of North American Phyllopod Crustacea," 1883, the "Life History of Animals, including Man, or Outlines of Comparative Embryology," 1876, the "Zoology for Students and General Readers," 1879, miscellaneous notes and papers on anthropology and ethnology and the notable book "Lamarch, the Founder of Evolution, his Life and Work," 1901. Entomology, however, was his chief interest. Professor Samuel Henshaw in "The Entomological Writings of Alpheus Spring Packard," enumerates three hundred and thirty-nine papers, books and notes, published up to 1887. He continued to produce papers upon this subject literally up to the last week of his life when he corrected the proof of his "Monograph of the Bombycine Moths of America" etc., Memoir of the National Academy of Sciences.

In his long and active career as Naturalist, Packard was associated with many American institutions and had a prominent part in founding some of them. In 1865 he became, on returning from service as assistant surgeon in the Army of the Potomac, librarian and acting custodian of the Boston Society of Natural History. With Hyatt, Morse and Putnam, his former associates in Agassiz's laboratory, he accepted a position in the Essex Institute in Salem, and subsequently when the Peabody Academy of Science absorbed the Essex Institute, he became Curator of Invertebrates and later, 1876, Director of the Academy. The American Naturalist was founded by this group of men in the Peabody Academy in 1868 and Packard remained its editor-in-chief for twenty years. He was also prominently connected with that novel undertaking of Agassiz's which has proved to have been of inestimable value to biology in America, the Anderson School at Penikese. He taught there both years and when the school was given up on account of Agassiz's death, he perpetuated the idea by establishing a summer school of natural history at Salem under the auspices of the Peabody Academy. This he directed until 1878 when he left Salem to accept the Professorship of Zoölogy and Geology at Brown University, the position which he held until his death. As is evident from the title this professorship permitted a latitude in subject matter that suited the range of his scientific interest.

As a teacher, judged from the view point of students who have since achieved maturity, Professor Packard represents a well recognized type. He was not a disciplinarian, a pedagogue or an "educator." With impregnable faith in youth, he tried unremittingly to awaken his students to the vision of nature which to him was totally absorbing.

"It was from the judgment of his confreres, from the men who had traversed the same intellectual territory and knew it, that he reaped his supreme honors. From these alone could the reward have come;

for below the judgment of his peers there was no other guide but conscience." "Precisely to such bodies of inexorable critics did the intrinsic strength of the work of Professor Packard ultimately appeal."[2] The American Academy of Arts and Sciences elected him to membership in 1868; the Société Royale des Sciences de Liège, 1875; the Society of Friends of Natural Science in Moscow, in 1891. In 1891 he was elected foreign member of the Linnean Society of London. He was elected also to membership in the entomological societies of London, Paris, St. Petersburg, Stockholm and Brussels; was made one of the honorary presidents of the International Zoölogical Congress in Paris, 1899; honorary president of the Zoölogical Section of the French Association for the Advancement of Sciences; vice-president (1899) of the corresponding Section of the American Association.

A. D. MEAD.

BENJAMIN OSGOOD PEIRCE (1854–1914)

Fellow in Class I, Section 2, 1884.

The following biographical notice of Professor Benjamin Osgood Peirce is taken for the most part from the Minute on his life and services which was placed on the records of the Harvard Faculty of Arts and Sciences at the meeting of February 17, 1914. A much more extended biography will be published by the National Academy of Sciences.

Our colleague, Benjamin Osgood Peirce, who died in Cambridge on the fourteenth of January, 1914, was born in Beverly, Massachusetts, February 11, 1854, of a family belonging for several generations to the city of Salem. Of his ancestors, Richard Norman came to Gloucester in 1623, John Peirce to Watertown in 1637, John and Christopher Osgood to other parts of eastern Massachusetts before 1640. John Peirce had a son Robert, but after the Cromwellian era names taken from the Old Testament prevail in the family, and it is hard to refrain from using the robust terms of the Old Testament genealogies in recit-

2 Carl Barus, Memorial Address.

ing the generations that follow. The son of Robert was Benjamin, and the son of Benjamin was Jerathmiel, and the son of Jerathmiel was Benjamin, 2d, who fell at Lexington, and his son was Benjamin, 3d, whose son was Benjamin Osgood, 1st, the father of our friend.

From Jerathmiel, potent name, were descended also Jerathmiel, 2d, and his son Benjamin, Librarian of Harvard College from 1826 to 1831, and his son Benjamin, Tutor or Professor of Mathematics at Harvard from 1831 to 1880, among whose sons were James Mills, also Professor of Mathematics at Harvard; and Charles Sanders, projector of the philosophic cult of Pragmatism. In the annals of intellectual achievement in America there is no greater name than Peirce.

The father of our colleague was a graduate of Waterville College in Maine. He married, in 1841, Miss Mehetable Osgood Seccomb, a native of Salem, whom he had met for the first time in Georgia, where both were engaged in teaching. After his marriage Mr. Peirce remained for several years in the South as Professor of Chemistry and Natural Philosophy at Mercer. Returning to Massachusetts in 1849, he engaged in the South African trade, and in 1864 he visited the Cape of Good Hope, taking his son with him.

When the son was sixteen years of age and a graduate of the Beverly High School, he developed an indisposition to study, a phenomenon which must have seemed a portent in his household. He was accordingly apprenticed to learn carpentry, and he worked for two years at this trade, an experience which was doubtless to his advantage in various ways.

The boy having proved a faithful apprentice received in 1872 permission to go to Harvard. He devoted himself to his studies with great zeal for the next two or three months in preparation for the College examinations, which he took all at one time in September, 1872, and he was then admitted to Harvard, with a condition, it is said, in some particular of elementary mathematics. He did not have a college room, but lived with his family in a rather distant part of Cambridge, whence he ran a telegraph line to the room of two classmates and intimate friends, Lefavour and Pine, in one of the College Halls. It is said that his health was somewhat impaired for a time by his too severe labor in preparation for the admission examinations, and it is not improbable that he established the telegraphic communication with his friends by way of diversion during this indisposition. Illness was usually for him an opportunity to do something which he might not have found time for in health.

His first scientific paper, *On the Induction Spark Produced in Breaking a Galvanic Circuit between the Poles of a Magnet,* was printed in the Proceedings of this Academy, having been presented February 9, 1875, about the middle of his Junior year in college.

He graduated at Harvard in 1876, ranking second in his class for the whole course, his friend Lefavour being first. He remained at Harvard for a year more, as an assistant to Professor Trowbridge in the Physical Laboratory, and then went to Leipsic, where he received the degree of Ph.D. in 1879. After a year in the University of Berlin, and a year of teaching Mathematics in the Boston Latin School, he returned to Harvard as Instructor in Mathematics. In 1884 he was made Assistant Professor of Mathematics and Physics, and in 1888, on the retirement of Professor Lovering, he became Hollis Professor of Mathematics and Natural Philosophy. At the time of his death he was a Fellow of the American Academy of Arts and Sciences, a member of the American Physical Society (its President during the last year of his life), of the American Philosophical Society, of the American Mathematical Society (Vice-president in 1913), of the Astronomical and Astrophysical Society of America, of the National Academy of Sciences, of the Société Française de Physique, and of the Circolo Matematico di Palermo.

He married in 1882 Miss Isabella Turnbull Landreth of Edinburgh, whom he had met when she was a student at the Leipsic Conservatory. Intimacy with her brothers, all ministers of the Scotch Church, has been one of the happy relations of this marriage. His wife and his two daughters survive him.

Our colleague was a great scholar and a remarkable man. Big and powerful of body, and ambidextrous, he was in mind also capable and proficient far beyond the ordinary measure of his fellows. He seemed to grasp with equal ease and to retain with equal tenacity the profoundest generalizations of mathematics or physics and the smallest bits of information likely to be of service in his work. He always knew the best materials and the best tools to use and the best way to use them. Fertile in ideas, strong of purpose, ceaseless, literally so, in industry, businesslike by instinct and tradition from his merchant ancestors, sympathetic and generous beyond the wishes of his friends, he was a mighty, beneficent, and genial power, wherever he took his stand; and he was successful, as few men are successful, in winning the confidence, the admiration, and the affection of those with whom he was associated.

His work, always masterly, thorough, and important, was never of a kind, in subject or in treatment, to flare upon the attention of the public; but whenever he made the acquaintance of a mathematician or a physicist of the first rank, like the late Sir George Darwin, he was recognized as a fellow and a peer. Professor Andrew Gray of Glasgow says, "All mathematicians and physical workers in this country looked up to him as a leader of thought and investigation in America." Sir Joseph Larmor speaks of "the increasing company over here who knew and appreciated him personally" and of "the still larger number who knew only his scientific work." Karl Pearson, who was a fellow student with Peirce in Germany, writes, "Benjamin Osgood Peirce was representative of all that was best in science; he was never a self-seeker nor a self-advertiser, and I learnt more from him than from many of our professed teachers in Berlin."..."If I had to give the name of the man who represented America best to me, I should still say, after thirty-four years, Benjamin Osgood Peirce." It is plain from these quotations that the reputation of our friend was increasing at the time of his death.

Eminent in his profession, beyond its wide limits he was an outstanding personality to all who knew him well. He was a prodigious reader, and once told the present writer that he had read the Encyclopedia Britannica through several times. He was fond of meeting classical scholars on their own ground; not long before his death he quoted Ovid fluently and evinced a lively interest in the psychology of the Greek Optative. His service for many years as a member of the Harvard Committee on Honors and Higher Degrees in Music was justified by his extraordinary musical sensibility and his appreciation, intuitive as well as learned, of musical compositions. He made music in various ways, some of them rather surprising.

In a place and a time of the least restraint in religious matters he quietly declined to enter upon discussions of personal religious belief, and, though perhaps shaken at times by the same tremendous questions which beset Carlyle, he remained steadfastly in the Baptist communion to which his father had belonged. With characteristic force of grotesque phrase he described the varieties of belief which were exhibited in Appleton Chapel after the breaking up of the World's Congress held at Chicago, in 1893, as "a job lot of religions." These words indicated no bitterness or bigotry, but merely his conviction of the needlessness and uselessness of seeking abroad for religious doctrine or spiritual inspiration. At the last his own faith and trust were serene.

Peirce was proverbial among his friends for a certain habit of extravagant self-depreciation and for a frolicsome humor of speech and action. His self-depreciation was partly caution, partly genuine modesty, of which he had great store, partly an endeavor, not always successful, to make others content with themselves, and partly it was a humorous pose. A man of his intelligence could not be altogether unaware of the scope of his own powers, and a man of his keen sympathy could not be indifferent to the appreciation of his fellows. If he found that his habitual professions of ignorance concerning matters of which he was a master were being taken seriously, he speedily took effectual measures to remove the false impression.

His habit of humorously grotesque speech was the natural outcome of abounding energy, lively invention, and an amiable desire to entertain; but it was sometimes also a measure of precaution, intended to prevent the discovery and invasion of his real thought. For, with all his genuine and hearty good-fellowship, Peirce was a man of profound reserve; he was wont to go into his closet and shut the door, and his privacy was respected. Behind his superficial timidity and his abounding kindliness there was always the suggestion of something formidable, and he was not a man to be trifled with.

Peirce's last scientific paper, *The Maximum Value of the Magnetization in Iron*, June, 1913, was, like his first paper, printed in the Proceedings of this Academy. This was, indeed, his customary channel of publication, and all the members of the Academy may well be proud of this fact.

EDWIN H. HALL.

ISRAEL COOK RUSSELL (1852–1906)

Fellow in Class II, Section 1, 1904.

The bones of a living memorial of I. C. Russell are found in the successive volumes of Who's Who down to 1906–7. Among the notices shortly after his death two are pre-eminent,— the one by Bailey Willis, his colleague on the U. S. Geological Survey,[3] which contains a full bibliography. This notice was prepared for the Geological Society of America, of which Russell was President when he died, and for which he had prepared his Presidential Address just before he was stricken with pneumonia, his last sickness. The other was by one of his colleagues at Ann Arbor, Dr. Chas. A. Davis,[4] who himself has just been called from this life.

Professor Russell's life may be divided into three parts: —

1. *Before his connection with the Geological Survey.* He was born at Garrattsville, N. Y., Dec. 10, 1852, son of Barnabas Russell and Louisa Sherman Cook Russell. He was of New England descent, and Willis tells good stories of the New England reserve characteristic of his ancestors and somewhat of Russell himself. When he was twelve years old he moved to Plainfield, N. J. He was then on the Newark formation, a monographic study of which was one of his principal scientific works. From his birth until the time of his connection with the United States Geological Survey we might consider him in training,— first in the High School near his home, then in the Hasbrook Institute in Jersey City, next in New York University (A. B. and C. E. 1872) then in the Columbia School of Mines. In 1874 he was photographer and naturalist to the U. S. Transit of Venus Expedition to New Zealand and Kerguelen Island. When he came back he was made assistant Professor of Geology at the Columbia School of Mines and was there from 1875 to 1877. This time included a season in New Mexico and a journey to Europe and finished the first quarter century of his life. Probably the happiest and most fruitful part of his career was the period from 1875 to 1892.

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3 (Bulletin of the Geological Society of America, Vol. 18, p. 582).

4 (Published in the 9th report of the Michigan Academy of Sciences for 1907, p. 28). See also Science, Oct. 5, 1906, vol. 24, p. 427, and Journal of Geology, vol. 14 (1906), p. 663.

2. *Work as Government Geologist, 1877–1892.* For a quarter of a century he was a servant of the United States in the Geological Survey. And that was practically his sole occupation until 1892. He ranked with Gilbert and Powell as one of the great geologists of the early years of the Survey. Like them he was an explorer, like them he had an admirable literary style. I remember he once said that it was his custom never to write anything until the end of the day's work. In this he was doubtless aided by his retentive memory. In the relatively arid regions of the great West where geology was on a large scale such a method was no doubt quite serviceable and gave to his work a literary quality which constant jottings cannot pretend to have. But I remember well the shock it gave to one who, accustomed to working in the mines and Michigan woods, would have been utterly lost unless he had kept some sort of continuous notes. Artistic temperament was manifest in Russell not only in his literary style but in his keen appreciation of the beauties of nature, which he saw not only with the eye of the savant but with that of the artist. His description of his ascent of Mt. St. Elias is interesting to any one; his report of the Mono Lake region of California was so vivid that a demand was made for a reprint of the report, to be paid for by the residents as a tourist advertisement of the region, for which purpose its beauties of style well fitted it. His artistic temperament was also shown in his skill and success as a photographer. Many of the illustrations of the U. S. Geological Survey which are reprinted in the text books of geology will be found to have been taken by him. He had the knack of knowing whether a photograph would really show and bring out the scientific point which one can often see with the naked eye so much better than in a photograph. He also took pains to get something which would make his records not only of scientific but also of artistic value.

His artistic temperament also showed in a certain fastidiousness and reserve which perhaps made him less successful as a teacher. To be a popular teacher one must not be too fastidious or too critical of the half-baked endeavors of the partly educated. And he had not much of that superficial bonhommie which goes far toward making one generally popular.

3. *At Ann Arbor.* In 1892 he became Professor of Geology at the University of Michigan and remained so the rest of his life. He continued his connection with the U. S. Geological Survey after he became Professor of Geology at Ann Arbor; being, however, employed upon various special problems, often connected with water

resources. Even such problems, however, he could not handle solely from an economic point of view. His studies of Snake River Valley and other similar problems made a decided contribution to the general scientific theory of igneous action.

In Michigan University he made no such impression as in the work of the Geological Survey. President Angell himself told me that he did not consider that it was necessary for every State University to build up a great geological department; and as Wisconsin had had two great geologists as presidents he did not feel called upon to rival her. Nor was Russell, with his artistic temperament, the type of man who rejoices in running a large department.

He was, however, keenly interested in the Michigan Academy of Science, was among its early presidents, and served it in many ways. As his connection with the U. S. Geological Survey became less he found time to take up some of the local problems of Michigan. He was never a specialist in Paleontology and therefore did not pretend to continue the researches of Alexander Winchell, his predecessor; but he reverted naturally to those studies of the lakes and of surface geology which had interested him from the very first paper he printed. He really inspired the study of the almost unique delta of the St. Clair River made by Leon J. Cole, one of his students. He also prepared a study of the surface geology of a good part of the upper peninsula and its molding under the ice, and threw light on the origin of drumlins and hills of the same canoe-shaped type due to the remodelling of preexisting till sheets, and also on the curious Indian ridges known as eskers. Having been used to topographic maps in his western work he naturally felt the lack of them on coming to Michigan and began to agitate for the co-operation of the State with the U. S. Geological Survey in their preparation. If it had not been for him I do not think this co-operation would have begun as soon as it did.

His scientific works, a complete bibliography of which is given by Willis, may be grouped as follows:—1st, a series of papers on lakes, their origin and phenomena, in which he treats the modern Great Lakes and those of New Zealand and those shrunken remnants of lakes like the Great Lakes, out West, especially Lake Lahontan, the monograph on which he prepared; 2nd, a series of papers culminating in a correlation essay on Triassic and allied beds of the Atlantic Coast, which he called the "Newark Formation"; 3rd, a series of descriptions, in which he appears both as artist and savant, of those great contrasted phenomena of nature, the volcanic eruption and the wondrous obelisk of Mt. Pêlée on the one hand, and on the other

Mount St. Elias and its piedmont glaciers. Thus his studies in the igneous rocks of the Newark formation, into the activities of Mount Pêlée, the Snake River and other volcanic regions of the great West, gave him opportunities to add materially to our knowledge of igneous geology, while his explorations in Alaska, the northwestern United States and Michigan, made him one of the authorities in glacial geology.

He was, as C. A. Davis says, a delightful story teller if drawn out, brilliant and witty, so that his speeches at the early dinners of the Geological Society of America, and the passages at arms between him and Emerson shine in the writer's memory, yet he was not a man of many words. Physically he seemed small and slender for one who had proved himself an intrepid explorer, and is another illustration of the fact that much may be done by one of small size. His civic public spirit was shown by his careful report on the water supply of Ann Arbor. He held the academic distinctions which one might expect; he was President of the Michigan Academy of Science, Chairman of Section E of the American Association for the Advancement of Science, was President of the Geological Society of America at the time of his death, May 1, 1906, and was honorary Doctor of Laws of New York and Wisconsin Universities. He was married Nov. 27, 1886, to J. Augusta Olmsted and by her had four children, three daughters, Ruth, Helen, Edith, and a son, Ralph. Ruth was graduated with the degree of A.B. from the University of Michigan in 1910, and subsequently married and now resides in Salt Lake City. Helen also married and lives in Chicago.

ALFRED C. LANE.

AUGUSTUS SAINT GAUDENS (1848–1907).

Fellow of Class III, Section 4, 1896.

Born in Dublin, Ireland, on the first day of March 1848, the son of an Irish mother and a French father, Augustus Saint Gaudens, brought to this country at the age of six months, lived to see himself acclaimed as the foremost of American sculptors. His bent for artistic expression first took the form of cameo-cutting by which he practically supported himself from the time he was thirteen till he was twenty and to which he occasionally turned for revenue during his course of art study abroad,— in Paris at the *Academie des Beaux Arts* from 1867 to 1869 and in Rome from 1869 to 1872. His first important work of a public character was the statue of Admiral Farragut erected in Union Square, New York, in 1881. This work was instantly hailed as a masterpiece and the test of thirty-five years upholds the judgment of the moment.

Saint Gaudens' fame dates from this time and was augmented by his later productions,— the Lincoln in Chicago, the Shaw in Boston, the Adams Memorial in Washington and the Peter Cooper and the equestrian statue of Sherman in New York,— all on the same high plane of excellence and all with an appeal so general as to win the applause and interest of the man in the street as well as of the artist and the connoisseur.

The success of Saint Gaudens as a sculptor of heroic works was equaled by his skill in portrait relief. One has but to recall the Stevenson Memorial, and the children of Mr. Jacob H. Schiff to acknowledge his supremacy in this domain. His treatment of the medallion, as exemplified in the portraits of Sargent and LaFarge, of Howells and Gilder, of Millet and Bunce established a precedent for an attractive form of the art that bids fair to be followed (probably at a respectful distance) for all time.

The art of Saint Gaudens is unique. Although it possesses the qualities of technique and composition, of truth to nature and respect for traditions that are common to all good art, his style is so personal, the technique is so entirely his own, and his conceptions are so original that we are hardly reminded of any preceding master in looking at them. To everything that he did, he gave the best that was in him with a thoroughness born of conscientiousness and of devotion to the art that he loved and revered. Critical and suspicious of his own work, proving and trying every experiment by which any improvement might be gained, entirely regardless of the time expended, his successes were achieved by infinite patience and travail. This thoroughness and conscientiousness had a marked effect upon his contemporaries, and the example that he set by them and by his absolute fidelity to his ideals of perfection, by his sincerity and his impatience with sham and affectation, and, finally, by the superlative excellence of the works themselves, was felt not only by his associates, but wherever art was practiced in the land.

Besides the general influence of his finished productions, he had a more direct, if less extensive, influence through the sacrifice of time and strength that he made in teaching modeling both in his own studio and in the art schools in New York. His connection with the World's Fair in Chicago in 1893 afforded another opportunity through which his influence upon the art and artists of the country was widely extended. He was one of the committee which conceived the splendid plan of the Exposition and was the principal advisor for the sculptural decoration of the grounds, aiding incalculably the impetus that was given to art in general and to sculpture in particular by this great object lesson. It was in Chicago that the movement was inaugurated by McKim and seconded by Saint Gaudens that led to the founding of The American Academy in Rome. Even more important was the service that he rendered to the Nation as a member of the Commission, appointed by Congress, which made the comprehensive plan for the development of the City of Washington, now being carried out.

Of "Honors" Saint Gaudens naturally had many. The Degree of LL.D. from Harvard, Yale and Princeton, his election as an Officer of the Legion of Honor of France and as Corresponding Member of the *Société des Beaux Arts* in 1899, and his election as a member of the Royal Academy of London in 1906 were among the most important. Many medals came to him, also.

An urbanite from infancy, it was not till he was nearly forty years old that he discovered the country. In 1885 he began spending his summers in Cornish, N. H. where he later acquired a home and lands among the hills, and practiced, with the delight of a novice, the pastimes of skating and swimming, of tennis and golf, of which he had been defrauded in his childhood. His position as a sculptor, and the fascinating qualities of mind and heart that endeared him to all who came near him, attracted to him many distinguished artists and literary people who, with their disciples and families, made up the community which has become famous. His later years were spent entirely here, and here on the third of August, 1907 he died after a long and painful illness.

This notice of a master-sculptor cannot close better than with the characterization of him by President Eliot upon giving to Saint Gaudens the Degree of LL.D. at Harvard in 1905: — "Augustus Saint Gaudens,— a sculptor whose art follows but enobles nature, confers fame and lasting remembrance and does not count the mortal years it takes to mold immortal forms."

Daniel Chester French.

WILLIAM SELLERS (1824–1905)

Fellow in Class I, Section 4, 1875.

Mr. William Sellers was a representative of the school of Engineers, Manufacturers, Producers and Works Managers, which the modern trend of industry has caused very largely to disappear. He grew up with his establishment from small beginnings previous to the Civil War and was able to carry the burdens of personal supervision of its increasing work through the years until his death.

He was born in Upper Darby, Pa., on September 19, 1824. His early education was in a private school maintained by his father and his relatives for the education of their children. He served the usual apprenticeship to the machinists' trade with his uncle, John Morton Poole, of Wilmington, Del., and in 1845 he took charge of a large machine shop in Providence, R. I. After moving to Philadelphia the firm of Bancroft and Sellers was formed in 1848, and in 1853 what was then called the "new shop" at 16th Street and Pennsylvania Avenue was occupied. The firm became William Sellers and Company on the death of Mr. Bancroft about 1856, and in 1886 the company was incorporated with Mr. Sellers as President. Their specialty was the manufacture of heavy machine tools and they followed largely the practice set by the British designers as contrasted with the types which had their origin in the shops for lighter machine work in New England. For example, they adhered to the lathe bed of flat-top shears and had no use for the V-top shears of the smaller builders.

Probably the best known of his achievements in this field is the spiral gear planer drive, in which the table is moved back and forth by a multi-thread screw engaging with a rack on the under surface of the table.

In 1868 Mr. Sellers formed the Edgemoor Iron Company which furnished the structural material for the Centennial Exhibition buildings of 1876, in Philadelphia and the structural material for the first bridge between New York and Brooklyn.

In 1873 he reorganized the Midvale Steel Company at Nicetown near Philadelphia which, under his management entered the field of producing material for steel cannon for the Government.

In 1860 Mr. Sellers had his attention directed to the Gifford injector for feeding hot water to steam boilers. He commenced the manufacture of injectors under this design, but in 1865 invented and patented the self-adjusting combining tube, which automatically adjusted the supply of water to the apparatus to meet the varying requirements as the steam pressure in the boiler might vary. These injectors were made in the Sellers shop by metric sizes and with the special gages which the use of this unusual standard compelled. Further developments led to more advanced and larger sizes of injectors, particularly for locomotive service.

The Navy Department at Washington sent out specifications for a turning and boring lathe in 1890 for its 16″ steel cannon. The bed was to be 73 feet long with an extension of 53 feet for the boring arrangement. Mr. Sellers made a complete new design which he considered superior to that offered by the Governmental Departments and with the co-operation of a special commission created in the American Society of Mechanical Engineers, at the request of the Navy Department and of which the late Professor John F. Sweet was an active member, the Sellers design was accepted and the Navy design was discarded. This lathe weighed more than 250 tons.

The Sellers firm is also identified with the formulation, through the Franklin Institute, of a system of standard screw threads which became known as the United States standard and was presented to the Institute at a meeting on September 16, 1864.

Mr. Sellers received about 90 U. S. patents, the earliest one in 1857 and some were pending at the time of his death — January 24, 1905, in the 81st year of his age.

Mr. Sellers received many honors in the field of applied sciences. He became a member of the Philosophical Society in 1864, and of the American Academy of Arts and Sciences in 1875. He was a member of the Institute of Mechanical Engineers of Great Britain, the Iron and Steel Institute of Great Britain, of the American Society of Mechanical Engineers of which he was a founder in 1880 and of the American Society of Civil Engineers. He was a corresponding member of the Societé d'Encouragement pour L'Industrie Nationale and also a Chevalier de la Legion d'Honneur. This decoration was conferred upon him at the close of the Paris Exposition in 1899.

F. R. Hutton.

EDWARD HENRY STROBEL (1855–1908)

Fellow in Class III, Section 1, 1902.

It does not often fall to the lot of an American to fill positions so varied in character as those which Edward Henry Strobel held during his life of fifty-two years — Third Assistant Secretary of State, Secretary of Legation, Minister Plenipotentiary, head of a special mission, sole arbitrator between two powers, Professor of Law in the Harvard Law School, the trusted adviser of a progressive oriental government.

He was born in Charleston, South Carolina, on December 7, 1855, of a family on whose fortunes the civil war bore heavily. After due preliminary education, he entered Harvard College, was graduated with his class, that of 1877, and thereafter entered the Harvard Law School in the autumn of 1877, but did not take the degree of LL.B. until 1882. After having been admitted to the bar, he practised in New York for a short time, but soon turned to public life.

He participated in the presidential campaign of 1884, contributing an interesting pamphlet on Mr. Blaine and his foreign policy. This document seems to have attracted the attention of Mr. Cleveland, for when the latter became President, he offered Strobel the post of Secretary of Legation at Madrid. Strobel spent about five years in Spain, and acted as Chargé d'Affaires during a third of the time. In 1888 he was sent on a special mission to Morocco. On the change of administration, he tendered his resignation, but was retained in office until 1890. In 1893, President Cleveland appointed him Third Assistant Secretary of State. In 1894 he became Minister to Ecuador, and shortly thereafter was made Minister to Chile. He remained at the latter post until 1897, accomplishing excellent work under somewhat trying conditions. At the close of his stay, he received a signal mark of distinction in being chosen by both France and Chile to arbitrate a claim of a French citizen against the government of Chile.

In 1898, Strobel was called to the Bemis Professorship of International Law in the Harvard Law School. The founder of the chair had expressed the desire that the occupant should be not merely a professor of the science, but a practical co-operator in the work of advancing knowledge and good will among nations and governments. Strobel's intellect and temperament peculiarly fitted him to improve the relations between States, and the years spent in the diplomatic service had added the qualification of experience which the late George Bemis had also mentioned when making his bequest.

As Bemis Professor, Strobel gave courses in the Law School in International Law and Admiralty. He also taught International Law in the College. He was an interesting and able instructor, and gathered large classes about him. Perhaps he felt a little impatience with "theorizing," but it is to be remembered that he had successfully handled large affairs and had carried considerable responsibilities. After four years of service as a teacher, he was called to a very different field.

In a distant corner of the Far East there lies a land which has succeeded in maintaining its independence while many other empires, kingdoms, and principalities of Asia have fallen under alien rule. How Siam has been able to accomplish this — often only with great difficulty — forms an interesting study, but it is a study which cannot be undertaken here. Suffice it to say that when in 1902 Strobel entered into relations with Siam, its political situation was one of considerable danger. He was offered, and he accepted, the post of General Adviser to the Siamese Government. While he did not reach Bangkok until March, 1904, he was occupied during a great part of the intervening time in negotiations in Europe. These resulted in a treaty with France, signed in 1902, which failed of ratification by the French Government, and of another treaty signed on February 13, 1904, and afterwards duly ratified. On the evening of the day on which the latter treaty was signed in Paris, he started for Bangkok, with the new treaty sewed in his coat pocket.

The post to which he was called was one which exactly suited his abilities and experience. Siamese foreign affairs occupied most of his attention, and here of course he was at home. The foreign affairs of the kingdom were in a condition where "theorizing" upon legal rights and wrongs would do more harm than good. What was needed was a practical solution of problems, some of which had been pending for years. The amount of work that came into the office of the General Adviser was overwhelming. But Strobel's mind quickly grasped the questions at issue, and — what was at least as important — he understood the men with whom he had to deal. These men were of many nations and races, they came from all the countries of Western Europe and of Eastern Asia. In addition to foreign relations, he was confronted with many questions of internal administration, and to them he brought the same intelligence and skill.

In December, 1905, Strobel went home on leave. He stopped in Egypt on the way, and there was stricken with blood-poisoning, from which he never fully recovered. After fifteen months' absence, during most of which he suffered greatly, he was able to return to Siam, and immediately resumed his many activities; but he was not to be long spared, for on January 15, 1908, he died in the midst of his labors.

While the time he actually spent in Siam amounted to only about two and a half years, he left behind him a memory which is seldom, if ever, the crown of even a lifetime of work in the Far East. From the beginning, he inspired the confidence both of the Government which he served and of all with whom he came in touch. Before his arrival, perhaps not all persons in Siam looked forward with pleasure to the coming of an American to fill the highest post there open to a European. But Strobel speedily made it clear that he felt he could best serve the Siamese Government by dealing fairly and justly with every matter laid before him. Once that reputation was established, the rest was easy.

SAMUEL WILLISTON.

WILLIAM GRAHAM SUMNER (1840–1910)

Fellow in Class III, Section 3, 1881.

William Graham Sumner, for thirty-eight years professor of Political and Social Science in Yale University, passed away on April 12, 1910, at Englewood, New Jersey. He was born at Paterson, New Jersey, October 30, 1840, of English parents, his father, Thomas Sumner, having come to America in 1836 and his mother, Sarah Graham, in 1825. He states in an autobiographical sketch that his ancestors on both sides had been artizans, and that, so far as he knew he was the first member of the family who ever studied Latin and Algebra.

His early years were spent at Hartford, Connecticut, he was graduated from Yale College in 1863, studied French and Hebrew in Geneva in 1863–64, Divinity and History at Göttingen in 1864–66, and during a part of the year 1866 he studied Anglican Theology at Oxford. Having been elected tutor at Yale he entered upon his duties in September, 1866, in which position he remained until March, 1869. He was ordained deacon in the Protestant Episcopal Church in 1867, and became assistant to the rector of Calvary Church in New York City in 1869. From September, 1870 to September, 1872, he was rector of the Church of the Redeemer at Morristown, New Jersey. In September, 1872, he began his long career as Professor of Political and Social Science at Yale, having been elected in June of that year.

His death marked the close, as his appointment at Yale had marked the beginning, of an epoch in university teaching and in the development of economic thought in this country. When he began the teaching of Political and Social Science at Yale in 1872, his subject had received very little attention in our institutions of learning, and the scientific attitude was non-existent in our public discussions. Francis A. Walker began his work in the Sheffield Scientific School the same year, and Charles F. Dunbar had begun at Harvard the year before. For many years Professor Perry at Williams and Amasa Walker at Amherst had been lecturing on Political Economy. But the rapid development of interest in these subjects may be said to date from the early seventies. Probably no one contributed more to that awakening than Professor Sumner. His teaching was so clear, so strong, and so free from sentimentality or humbug as to compel respectful attention even on the part of those who resisted his relentless logic.

During the long controversy over soft money and free silver he stood uncompromisingly for sound money based upon the gold standard. During the equally long controversy over protectionism, he stood with equal firmness for free trade. During the greater part of this period of controversy he was on the unpopular side of both questions, but he lived to see the unpopular become the popular side of the currency question and he only lacked two years of seeing it become the popular side of the question of protectionism. His death, therefore, marks the close of the epoch in which questions of currency and protectionism were the dominant questions in American politics.

Though he began as a teacher of Political and Social Science, he soon found it necessary to restrict his field and to specialize. His final years were devoted to sociology in some of its historical and anthropological phases. Some of the results of this final specialized study were published in his book entitled "Folkways," which is a monument of exact knowledge and vast learning.

It is unfortunate that no complete list of his publications has yet been compiled. Articles from his pen are still being discovered, but the list which closes this notice, while far from complete, will indicate something of the breadth of his interests and the scope of his tireless energy.

If one were looking for the best example of the austere and productive life, the life of Professor Sumner might well be selected. His austerity and self-discipline were proverbial among his colleagues and students, but it was not a useless austerity imposed for its own sake. It was the austerity which harnesses every ounce of energy to productive work.

The following is as complete a list of Professor Sumner's works as the writer has been able to compile.

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T. N. CARVER.

FREDERICK WINSLOW TAYLOR (1856–1915)

Fellow in Class I, Section 4, 1915.

It is not difficult to estimate the place of Frederick W. Taylor in the industries even though only a short time has elapsed since his death. He is the legitimate successor of James Watt. Many engineers and manufacturers have made valuable additions to the efficiency of the steam engine and to labor-saving machinery but the improvement of James Watt opened the gateway to all the inventions of the nineteenth century. Out of them have sprung the development of power and the labor-saving machinery as we have them today, and also an entirely new problem in the relation of great masses of labor to society.—It is exactly to this problem that Mr. Taylor has turned our attention. His solution of it is of precisely the same significance as James Watt's contribution to the steam engine and Mr. Taylor's work will equally transform society.

He was born in Germantown, Pa., in the year 1856. His early education was in America and two years in France and Germany. He was prepared at Phillips Exeter to enter Harvard in 1874 but his eyesight failed and he became an apprentice in the Enterprise Hydraulic Works from 1875 to 1878. Then owing to business depression he took a job as laborer in the Midvale Steel Works, where his ideas on the subject of greater system in the management of industry began to form themselves. Six years from the time of entering the Midvale Company he was Chief Engineer. In 1880 he began at night the engineering course as required at Stevens Institute, where he obtained the degree of Mechanical Engineer in 1883.

He left Midvale in 1890, having inaugurated a system of shop management and having increased the output from two hundred to three hundred per cent. From 1890 to '93 he was manager of the Manufacturing Investment Company, operating paper mills in Maine. From then on he was consulting engineer on machine-shop efficiency. He was employed by the Bethlehem Steel Company and there made the investigation on tool steel and with Mr. Maunsel White discovered the process of heat treatment which has revolutionized shop practice. He presented his system of shop management to the American Society of Mechanical Engineers in a paper called "The Piece Rate System" and in 1906, when he was president of the Society, he presented the result of twenty-six years' investigation in an exhaustive paper on "The Art of Cutting Metal." This was a splendid example of scientific research by an engineer in active practice of his profession. He died on March 21, 1915.

The term "scientific management," under which his work will probably be known, was devised by Mr. Taylor and gained currency chiefly through the testimony of Louis D. Brandeis before a committee of Congress on the Railroad Petition for a Raise in Rates. If the writer of the above may be permitted to comment through his personal acquaintance with Mr. Taylor, he would say that the system never was intended or planned to fetter in any way the enterprise of workmen but was thought by the inventor to be a method of promoting ambition and the highest good of every workman as well as of society. His system, scientific management, is simply a plan under which the work of the industries can be done effectively and with a minimum expenditure of energy. It has come to stay because it has called attention to absolutely necessary organization if mankind is to have a real and lasting benefit from the inventions that followed the use of the steam engine and of stored energy.

I. N. Hollis.

FRIEDRICH DANIEL VON RECKLINGHAUSEN (1833–1910)

Honorary Foreign Member in Class II, Section 4, 1898.

Friedrich Daniel von Recklinghausen, one of the foremost among the German pathologists, distinguished both as a teacher and investigator, was born in Westphalia in 1833. After passing through the gymnasium he studied medicine in the Universities of Bonn, Würzburg, and Berlin, and obtained the doctor degree in 1855. His dissertation and his first medical publication in 1855 was "De pyaemiae theoriis" in which he reviewed and discussed the different theories concerning pyaemia, giving the reasons in favor of its separation from wound infection. His entry into medicine was at the age when men here are graduating from college. He then devoted himself to pathology in the laboratory of Rudolf Virchow and after three semesters in Berlin, and studies in Vienna, Rome, and Paris, he was named an assistant in the pathological institute in Berlin in 1858, holding this position until 1864. In the summer of this year, without passing through the usual stages of Docent and Professor Extraordinary, he was chosen as Professor of Pathological Anatomy in Königsberg, and, after one-half year here, to the higher post in Würzburg. In 1872 he was one of the first professors chosen to the new University founded in Strassburg, where he remained as Professor of General Pathology and Pathological Anatomy until 1906, at which time he became Emeritus. After this he continued to work with his usual diligence in the institute with which his name will always be associated, complaining of the short space of time remaining to him for the completion of his numerous investigations. He was instrumental in having called to the new university such men as Golz, Leyden and Waldyer. In 1877 he constructed the new laboratory of the University, and which at that time was regarded as in all respects a model. In 1883 he functioned as Rector of the University, and in 1884 he refused the call to Leipzig as the successor to Cohnheim. He died suddenly in 1910 in his seventy-seventh year.

Up to 1862 he had published as assistant to Virchow a large number of minor papers on a variety of subjects, some of them involving chemical research. In 1862 appeared the first of the great monographs for which he was distinguished on "Die Lymphgefässe und ihre Beziehungen zum Bindegewebe." In this he first described the method of the use of silver to demonstrate the lines of junction of cells, and showed that the connective tissue was filled with spaces communicating with lymphatics, and in which the cells lie. This work led him to the study of the character of the cells in the tissue, and in a further publication "Über Eiter und Bindegewebs-körperchen" he showed the amoeboid motion of certain of the cells, and their identity with leucocytes and pus cells. This work undoubtedly paved the way to the studies of Cohnheim on leucocyte migration and inflammation, Cohnheim being a young assistant in the laboratory. During his professorship in Würzburg a great number of important publications on pathological anatomical conditions appeared, in one of which "Über Pilzmetastasen" he showed for the first time the relation between metastatic inflammatory foci and masses of bacteria in the blood vessels.

It was during the period in Strassburg that his wonderful activity in scientific research reached its acme. There are few subjects, either in general pathology or in pathological anatomy, which were not advanced through his work. His various researches on the blood, the heart and circulation were followed in 1883 by a large and comprehensive work "Handbuch der Ernährung." This work, which treats of the different forms of disturbances of the circulation and nutrition, is based on his rich experience and his wide knowledge of the literature of the subject, and remains a veritable mine of information for one working on the subject. In 1881 the monograph "Über die multiplen Fibrome der Haut und ihre Beziehung zu den multiplen Neuromen" appeared as a contribution in honor of Rudolf Virchow's twenty-five year jubilee. The article is a classic, showing the relation of the multiple fibromas to the nerves of the skin, and the condition since then has been known as von Recklinghausen's Disease. In 1886 appeared in Virchow's Archives a series of articles "Untersuchungen über Spinabifida" which must be reckoned among the most important contributions of this painstaking and prolific author. The work is based on thorough macro and microscopic investigation of a large amount of material, and the subject, formerly obscure, was completely cleared up.

The peculiar tumors of the uterus and Fallopian tubes, the adenomyomata, are treated in a series of articles between 1893–99. He was especially attracted to the diseases of bones which form, from the complexity of the tissue and the nature of the material, one of the most difficult subjects in pathology. In 1891 he published a large monograph on "Die fibröse oder deformierender Ostitis," a condition which is also known as von Recklinghausen's Disease, and this was followed by a great number of articles on various forms of bone disease and resulting deformities. The last great work, on the subject "Untersuchungen uber Rachitis und Osteomalacie" with 127 illustrations and 41 plates, appeared in 1910, the year of his death.

In addition to the great number of medical publications he found time for several important addresses, he attended medical societies and associations and took part in discussions. He was never controversial, although critical of all that seemed to lack in scientific accuracy. He was equally great as a teacher; many of the men who hold important positions in pathology received their first inspiration and training from him, as Friedländer, Zahn, Schmidt, Köster, Foa, Stilling, Perteck, Aschoff, Murpiergo, Griffini and Sacordotti. His laboratory was sought by both German and foreigners, and there was a constant flow of publications from his students. As a lecturer he was simple and direct, using specimens freely in illustration; his style in writing however was the reverse of simple, and he was difficult to follow. The laboratory was constructed on the cell system, the students were given a small room, a subject for work, and material, and he inculcated independence of observation with simplicity of method. In all of his work he used the simple methods with which he had begun to work, and it is amazing what he was able to do with scalpel, scissors and microscope. When I worked in his laboratory in 1883 there was not a microtome in it, and this instrument had long been regarded as indispensable for microscopic work. Sections were stained with picrocarmine and mounted in glycerine, and he was suspicious of all the newer methods which were coming into use and which have led to enormous advance in knowledge of structure. I found his demonstrations in pathological anatomy, which were held three times in the week, of great interest and value. The students, each with a microscope and a few reagents, were seated at long tables along which the specimens were passed after the professor had explained them, and each student took pieces for study as they went along. The disadvantage of the method was that the progress of the material was so slow that in the two hours of the exercise the specimens rarely reached the last fourth of the class.

Although in his great work on the diseases of the circulation he treated the pathology of function as well as structure, his conclusions are based more on his rich anatomical knowledge than on experimental evidence. He was by nature conservative, and though he welcomed each advance in knowledge, he did not seem to realize the great change in the point of view which came into pathology with the discovery of the methods of bacteriological investigation, although his observations on bacterial emboli are among the fundamental studies in bacteriology. He was essentially a pathological anatomist, his work was based on embryology and the study of stages of processes, as revealed in the abundant material which was at his disposal and of which he made skilful use, rather than on the experimental method. There is a disposition at present to decry all knowledge not based on experiment, but we must remember that there is not a radical difference between the methods of observation and experiment in disease. The anatomical lesions studied are the results of experiments made by nature in which it is true all the conditions are not known and judgment as to their nature mode of production and relations are based on embryology and stages in the process revealed in the differing single examples which arise. Of this method von Recklinghausen was a master, and most of his work has borne the test of time.

He was a tireless worker, arriving at the laboratory at seven in the morning, and often remaining late into the night. His life was quiet, without distraction, and eminently serviceable. Our ideas of German culture have been derived from the work and lives of such men as this.

W. T. Councilman.

OLIVER CLINTON WENDELL (1845–1912)

Fellow in Class I, Section 1, 1884.

Oliver Clinton Wendell was born at Dover, N. H., on May 7, 1845. After a life largely devoted to astronomical research, he died in Cambridge, Mass., on November 5, 1912.

Mr. Wendell was fitted for college in the old academy of his native town, and graduated from Bates College in 1868. From this college, also, he received the degree of Master of Arts, in 1871, and of Doctor of Science, in 1907. He was one of the comparatively few men who seemed "predestined" to a specific career, for on his graduation it was announced by the President of the college that one of the small class of five was to be an astronomer. This was Wendell, who apparently had come to this decision in his sophomore year. Two months after leaving college he began work at the Harvard College Observatory, but a year later he was compelled to resign his position on account of illness.

For about ten years he found it necessary to engage in outdoor pursuits. During a part of this time he was an assistant to the eminent engineer, James B. Francis, a man to whom he often referred in terms of the highest admiration. During this period, also, he was offered a professorship of astronomy at Bates College, a position he was obliged to decline on account of ill health. This was, perhaps, unfortunate, for such a position would have given him, as a teacher, an excellent opportunity for the full expression of his personality.

He returned to the Harvard Observatory in 1879, and was made Assistant Professor of Astronomy in 1898, a position he held during the remainder of his life. His work at the Observatory was chiefly with the 15-inch equatorial, which in early days was often referred to as "The Great Telescope." During the latter part of his life he was almost the sole observer with this telescope, and his relation with it was of the nature of an intimate friendship. Even on cloudy nights, when no work could be done, he appeared to enjoy being near the instrument, which he really loved.

Mr. Wendell observed the eclipses of the satellites of Jupiter from 1891 to 1912. This work required his presence at all hours of the night, a hardship which did not lessen his enthusiasm. He often came to the Observatory on cold winter nights, even when the chance of securing observations was small. He took part in the observation and reduction of the work of the 4-inch meridian photometer, but his principal work was with the photometer having achromatic prisms, attached to the 15-inch telescope. With this instrument he observed variable stars and asteroids. The results are probably the most accurate which had been obtained up to that time. He discovered several new variable stars and two variable asteroids. Although he was able to devote less time to the subject, he had a deep interest in comets, and, in his earlier years at the Observatory, took part in their observation and the computation of their orbits. The results of his astronomical work will be found in Volumes 13, 23, 24, 33, 37, 52, and 69 of the Annals of the Astronomical Observatory of Harvard College.

Mr. Wendell took his vocation with great seriousness. To him, nothing compared in interest with astronomy. It absorbed him, not, however, to the exclusion of a poetic element, which expressed itself at different times in verse. Regarding this phase of his character, however, he was very reticent. Also, he had a sincere faith in the truth of the Christian religion, and an intense belief in the immortality of the soul. He was married, in 1870, to Sarah Butler, of Hanover, Mass., who was a most devoted and loyal helper. Her death, in 1910, was a shock from which he never fully recovered. It left him lonely and inconsolable till his own death two years later. Two sons survive them.

S. I. Bailey.

American Academy of Arts and Sciences

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(Corrected to July 1, 1918.)

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(Number limited to six hundred.)

Class I.— *Mathematical and Physical Sciences.*— 183.

Section I.— *Mathematics and Astronomy.*— 39.

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Henry Taber	Worcester
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Richard Cockburn Maclaurin	Boston
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Grinnell Jones	Cambridge
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Charles August Kraus	Worcester
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Harmon Northrop Morse	Baltimore, Md.
Samuel Parsons Mulliken	Boston
Charles Edward Munroe	Washington, D. C.
James Flack Norris	Brookline
Arthur Amos Noyes	Boston
William Albert Noyes	Urbana, Ill.
Thomas Burr Osborne	New Haven, Conn.
Samuel Cate Prescott	Brookline
Ira Remsen	Baltimore, Md.
Robert Hallowell Richards	Jamaica Plain
Theodore William Richards	Cambridge
Martin André Rosanoff	Pittsburgh, Pa.
Stephen Paschall Sharples	Cambridge

Miles Standish Sherrill . . . . Brookline
Alexander Smith . . . . New York, N. Y.
Julius Oscar Stieglitz . . . . Chicago, Ill.
Henry Paul Talbot . . . . Newton
William Hultz Walker . . . . Boston
Willis Rodney Whitney . . . . Schenectady, N. Y.

Class I., Section IV.— *Technology and Engineering.*— 41.

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Comfort Avery Adams . . . . Cambridge
Bernard Arthur Behrend . . . . Boston
William Herbert Bixby . . . . Washington, D. C.
Francis Tiffany Bowles . . . . Boston
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Desmond FitzGerald . . . . Brookline
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Class II.— *Natural and Physiological Sciences.*— 170.

Section I.— *Geology, Mineralogy, and Physics of the Globe.*— 53.

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Joseph Barrell	New Haven, Conn.
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Herdman Fitzgerald Cleland	Williamstown
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William Morris Davis	Cambridge
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William Ebenezer Ford	New Haven, Conn.
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Herbert Ernest Gregory	New Haven, Conn.
Ellsworth Huntington	Milton
Oliver Whipple Huntington	Newport, R. I.
Robert Tracy Jackson	Peterborough, N. H.
Thomas Augustus Jaggar	Honolulu, H. I.
Douglas Wilson Johnson	New York, N. Y.
Alfred Church Lane	Cambridge
Andrew Cowper Lawson	Berkeley, Cal.

Charles Kenneth Leith	Madison, Wis.
Waldemar Lindgren	Brookline
Frederic Brewster Loomis	Amherst
Alexander George McAdie	Readville
William John Miller	Northampton
Charles Palache	Cambridge
John Elliott Pillsbury	Washington, D. C.
Louis Valentine Pirsson	New Haven, Conn.
Raphael Pumpelly	Newport, R. I.
Percy Edward Raymond	Cambridge
William North Rice	Middletown, Conn.
Robert Wilcox Sayles	Cambridge
Charles Schuchert	New Haven, Conn.
William Berryman Scott	Princeton, N. J.
Hervey Woodburn Shimer	Watertown
Charles Richard Van Hise	Madison, Wis.
Thomas Wayland Vaughan	Washington, D. C.
Charles Doolittle Walcott	Washington, D. C.
Robert DeCourcy Ward	Cambridge
Charles Hyde Warren	Auburndale
Herbert Percy Whitlock	Albany, N. Y.
Bailey Willis	Palo Alto, Cal.
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Jay Backus Woodworth	Cambridge
Frederick Eugene Wright	Washington, D. C.

Class II., Section II.— *Botany*.— 30.

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George Perkins Clinton	New Haven, Conn.
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Bradley Moore Davis	Philadelphia, Pa.
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Alexander William Evans	New Haven, Conn.
William Gilson Farlow	Cambridge
Merritt Lyndon Fernald	Cambridge
George Lincoln Goodale	Cambridge

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Edward Charles Jeffrey	Cambridge
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Burton Edward Livingston	Baltimore, Md.
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Winthrop John Vanleuven Osterhout	Cambridge
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Willaim Codman Sturgis	New York, N. Y.
Roland Thaxter	Cambridge
William Trelease	Urbana, Ill.

CLASS II., SECTION III.— *Zoölogy and Physiology.*— 54.

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Joel Asaph Allen	New York, N. Y.
John Wallace Baird	Worcester
Thomas Barbour	Boston
Francis Gano Benedict	Boston
Henry Bryant Bigelow	Concord
Robert Payne Bigelow	Brookline
John Lewis Bremer	Boston
William Brewster	Cambridge
Charles Thomas Brues	Boston
Hermon Carey Bumpus	Tufts College
Walter Bradford Cannon	Cambridge
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Charles Value Chapin	Providence, R. I.
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Richard Swann Lull	New Haven, Conn.
Franklin Paine Mall	Baltimore, Md.
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George Howard Parker	Cambridge
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Arthur Wisswald Weysse	Boston
William Morton Wheeler	Boston
Harris Hawthorne Wilder	Northampton
Edmund Beecher Wilson	New York, N. Y.
Frederick Adams Woods	Brookline
Robert Mearns Yerkes	Washington, D. C.

Class II., Section IV.— *Medicine and Surgery.*— 33.

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Harvey Cushing	Boston
David Linn Edsall	Boston

Harold Clarence Ernst	Jamaica Plain
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Robert Battey Greenough	Boston
William Stewart Halsted	Baltimore, Md.
Reid Hunt	Brookline
Henry Jackson	Boston
Abraham Jacobi	New York, N. Y.
Elliott Proctor Joslin	Boston
William Williams Keen	Philadelphia, Pa.
Frank Burr Mallory	Brookline
Samuel Jason Mixter	Boston
Edward Hall Nichols	Boston
Sir William Osler, Bart.	Oxford, Eng.
Theophil Mitchell Prudden	New York, N. Y.
William Lambert Richardson	Boston
Milton Joseph Rosenau	Boston
Frederick Cheever Shattuck	Boston
Theobald Smith	Princeton, N. J.
Elmer Ernest Southard	Boston
Richard Pearson Strong	Boston
Ernest Edward Tyzzer	Boston
Frederick Herman Verhoeff	Boston
Henry Pickering Walcott	Cambridge
John Collins Warren	Boston
William Henry Welch	Baltimore, Md.
Francis Henry Williams	Boston
Simeon Burt Wolbach	Boston
Horatio Curtis Wood	Philadelphia, Pa.

Class III.— *Moral and Political Sciences,*— 172.

Section I.— *Theology, Philosophy and Jurisprudence.*— 47.

Thomas Willing Balch	Philadelphia, Pa.
Simeon Eben Baldwin	New Haven, Conn.
Willard Bartlett	Brooklyn, N. Y.
Joseph Henry Beale	Cambridge
Melville Madison Bigelow	Cambridge
Charles Warren Clifford	New Bedford
Edmund Burke Delabarre	Providence, R. I.

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Frederic Dodge	Belmont
Edward Staples Drown	Cambridge
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Timothy Dwight	New Haven, Conn.
William Herbert Perry Faunce	Providence, R. I.
William Wallace Fenn	Cambridge
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Eugene Wambaugh	Cambridge
Edward Henry Warren	Boston
Samuel Williston	Belmont
Woodrow Wilson	Washington, D. C.

CLASS III., SECTION II.— *Philology and Archæology.*— 50.

Francis Greenleaf Allinson	Providence, R. I.
William Rosenzweig Arnold	Cambridge
Maurice Bloomfield	Baltimore, Md.
Franz Boas	New York, N. Y.
Charles Pickering Bowditch	Jamaica Plain
Eugene Watson Burlingame	Albany, N. Y.
Edward Capps	Princeton, N. J.
Franklin Carter	Williamstown
George Henry Chase	Cambridge
Roland Burrage Dixon	Cambridge
William Curtis Farabee	Philadelphia, Pa.
Jesse Walter Fewkes	Washington, D. C.
Jeremiah Denis Mathias Ford	Cambridge
Basil Lanneau Gildersleeve	Baltimore, Md.
Charles Hall Grandgent	Cambridge
Louis Herbert Gray	Boston
Charles Burton Gulick	Cambridge
William Arthur Heidel	Middletown, Conn.
George Lincoln Hendrickson	New Haven, Conn.
Bert Hodge Hill	Athens, Greece
Elijah Clarence Hills	New York, N. Y.
Edward Washburn Hopkins	New Haven, Conn.
Joseph Clark Hoppin	Boston
Albert Andrew Howard	Cambridge
William Guild Howard	Cambridge
Aleš Hrdlička	Washington, D. C.
Carl Newell Jackson	Cambridge
Hans Carl Gunther von Jagemann	Cambridge
James Richard Jewett	Cambridge
Alfred Louis Kroeber	Berkeley, Cal.
Kirsopp Lake	Cambridge
Henry Roseman Lang	New Haven, Conn.
Charles Rockwell Lanman	Cambridge
David Gordon Lyon	Cambridge
Clifford Herschel Moore	Cambridge
George Foot Moore	Cambridge
Hanns Oertel	New Haven, Conn.
Bernadotte Perrin	New Haven, Conn.
Edward Kennard Rand	Cambridge

George Andrew Reisner . . . . Cambridge
Edward Robinson . . . . New York, N. Y.
Fred Norris Robinson . . . . Cambridge
Rudolph Schevill . . . . Berkeley, Cal.
Edward Stevens Sheldon . . . . Cambridge
Herbert Weir Smyth . . . . Cambridge
Franklin Bache Stephenson . . . . Claremont, Cal.
Charles Cutler Torrey . . . . New Haven, Conn.
Alfred Marston Tozzer . . . . Cambridge
Andrew Dickson White . . . . Ithaca, N. Y.
James Haughton Woods . . . . Cambridge

CLASS III., SECTION III.— *Political Economy and History.*— 37.

Brooks Adams . . . . Quincy
George Burton Adams . . . . New Haven, Conn.
Charles McLean Andrews . . . . New Haven, Conn.
Charles Jesse Bullock . . . . Cambridge
Thomas Nixon Carver . . . . Cambridge
John Bates Clark . . . . New York, N. Y.
Archibald Cary Coolidge . . . . Boston
Richard Henry Dana . . . . Cambridge
Andrew McFarland Davis . . . . Cambridge
Davis Rich Dewey . . . . Cambridge
Ephraim Emerton . . . . Cambridge
Henry Walcott Farnam . . . . New Haven, Conn.
Irving Fisher . . . . New Haven, Conn.
Worthington Chauncey Ford . . . . Cambridge
Edwin Francis Gay . . . . Cambridge
Frank Johnson Goodnow . . . . Baltimore, Md.
Evarts Boutell Green . . . . Champaign, Ill.
Arthur Twining Hadley . . . . New Haven, Conn.
Albert Bushnell Hart . . . . Cambridge
Charles Homer Haskins . . . . Cambridge
Isaac Minis Hays . . . . Philadelphia, Pa.
Henry Cabot Lodge . . . . Nahant
Abbott Lawrence Lowell . . . . Cambridge
William MacDonald . . . . Berkeley, Cal.
Roger Bigelow Merriman . . . . Cambridge
Samuel Eliot Morison . . . . Boston
William Bennett Munro . . . . Cambridge

James Ford Rhodes	Boston
William Milligan Sloane	New York, N. Y.
Henry Morse Stephens	Berkeley, Cal.
John Osborne Sumner	Boston
Frank William Taussig	Cambridge
William Roscoe Thayer	Cambridge
Frederick Jackson Turner	Cambridge
Thomas Franklin Waters	Ipswich
George Grafton Wilson	Cambridge
George Parker Winship	Cambridge

Class III., Section IV.—*Literature and the Fine Arts.*—38.

George Pierce Baker	Cambridge
Arlo Bates	Boston
James Phinney Baxter	Portland, Me.
William Sturgis Bigelow	Boston
Le Baron Russell Briggs	Cambridge
Charles Allerton Coolidge	Boston
Ralph Adams Cram	Boston
Samuel McChord Crothers	Cambridge
Wilberforce Eames	New York, N. Y.
Henry Herbert Edes	Cambridge
Edward Waldo Emerson	Concord
Arthur Fairbanks	Cambridge
Arthur Foote	Brookline
Edward Waldo Forbes	Cambridge
Kuno Francke	Gilbertsville, N. Y.
Daniel Chester French	New York, N. Y.
Horace Howard Furness	Philadelphia, Pa.
Robert Grant	Boston
Morris Gray	Boston
Chester Noyes Greenough	Cambridge
Francis Barton Gummere	Haverford, Pa.
Henry Lee Higginson	Boston
James Kendall Hosmer	Minneapolis, Minn.
Mark Antony DeWolfe Howe	Boston
George Lyman Kittredge	Cambridge
William Coolidge Lane	Cambridge
Allan Marquand	Princeton, N. J.
Albert Matthews	Boston

Harold Murdock	Brookline
William Allan Neilson	Northampton
Herbert Putnam	Washington, D. C.
Denman Waldo Ross	Cambridge
John Singer Sargent	London, Eng.
Ellery Sedgwick	Boston
Richard Clipston Sturgis	Boston
Barrett Wendell	Boston
Owen Wister	Philadelphia, Pa.
George Edward Woodberry	Beverly

FOREIGN HONORARY MEMBERS.—66.

(Number limited to seventy-five).

Class I.— *Mathematical and Physical Sciences.*— 22.

Section I.— *Mathematics and Astronomy.*— 6.

Johann Oskar Backlund	Petrograd
Felix Klein	Göttingen
Tullio Levi-Civita	Padua
Sir Joseph Norman Lockyer	London
Charles Emile Picard	Paris
Charles Jean de la Vallée Poussin	Louvain

Class I., Section II.— *Physics.*— 9.

Svante August Arrhenius	Stockholm
Oliver Heaviside	Torquay
Sir Joseph Larmor	Cambridge
Hendrik Antoon Lorentz	Leyden
Max Planck	Berlin
Augusto Righi	Bologna
Sir Ernest Rutherford	Manchester
Rt. Hon. John William Strutt, Baron Rayleigh	Witham
Sir Joseph John Thomson	Cambridge

Class I., Section III.— *Chemistry.*— 4.

Johann Friedrich Wilhelm, Adolf, Ritter von Baeyer	Munich
Emil Fischer	Berlin
Fritz Haber	Berlin
Wilhelm Ostwald	Leipsic

Class I.— Section IV.— *Technology and Engineering.*— 3.

Heinrich Müller Breslau . . . . Berlin
Vsevolod Jevgenjevic Timonoff . . . . Petrograd
William Cawthorne Unwin . . . . London

Class II.— *Natural and Physiological Sciences.*— 22.

Section I.— *Geology, Mineralogy, and Physics of the Globe.*— 8.

Frank Dawson Adams . . . . Montreal
Waldemar Christofer Brögger . . . . Christiania
Sir Archibald Geikie . . . . Haslemere, Surrey
Viktor Goldschmidt . . . . Heidelberg
Julius Hann . . . . Vienna
Albert Heim . . . . Zürich
Sir William Napier Shaw . . . . London
Johan Herman Lie Vogt . . . . Trondhjem

Class II., Section II.— *Botany.*— 6.

John Briquet . . . . Geneva
Adolf Engler . . . . Berlin
Wilhelm Friedrich Philipp Pfeffer . . . . Leipsic
Hermann, Graf zu Solms-Laubach . . . . Strassburg
Ignatz Urban . . . . Berlin
Eugene Warming . . . . Copenhagen

Class II.— Section III.— *Zoölogy and Physiology.*— 2.

Sir Edwin Ray Lankester . . . . London
Magnus Gustav Retzius . . . . Stockholm

Class II., Section IV.— *Medicine and Surgery.*— 6.

Sir Thomas Barlow, Bart. . . . . London
Emil von Behring . . . . Marburg
Angelo Celli . . . . Rome
Adam Politzer . . . . Vienna
Francis John Shepherd . . . . Montreal
Charles Scott Sherrington . . . . Oxford

CLASS III.— *Moral and Political Sciences.*— 22.

SECTION I.— *Theology, Philosophy and Jurisprudence.*— 4.

Arthur James Balfour	Prestonkirk
Heinrich Brunner	Berlin
Albert Venn Dicey	Oxford
Sir Frederick Pollock, Bart	London

SECTION II.— *Philology and Archæology.*— 8.

Friedrich Delitzsch	Berlin
Hermann Diels	Berlin
Wilhelm Dörpfeld	Athens
Henry Jackson	Cambridge
Hermann Georg Jacobi	Bonn
Alfred Percival Maudslay	Hereford
Ramon Menendez Pidal	Madrid
Eduard Seler	Berlin

SECTION III.— *Political Economy and History.*— 5.

James Bryce, Viscount Bryce	London
Adolf Harnack	Berlin
Alfred Marshall	Cambridge
John Morley, Viscount Morley of Blackburn	London
Rt. Hon. Sir George Otto Trevelyan, Bart.	London

SECTION IV.— *Literature and the Fine Arts.*— 5.

Georg Brandes	Copenhagen
Thomas Hardy	Dorchester
Jean Adrien Antoine Jules Jusserand	Paris
Rudyard Kipling	Burwash
Sir Sidney Lee	London

STATUTES AND STANDING VOTES

STATUTES

Adopted November 8, 1911: amended May 8, 1912, January 8, and May 14, 1913, April 14, 1915, April 12, 1916, April 10, 1918.

CHAPTER I

The Corporate Seal

Article 1. The Corporate Seal of the Academy shall be as here depicted:

Article 2. The Recording Secretary shall have the custody of the Corporate Seal.

See Chap. v. art. 3; chap. vi. art. 2.

CHAPTER II

Fellows and Foreign Honorary Members and Dues

Article 1. The Academy consists of Fellows, who are either citizens or residents of the United States of America, and Foreign Honorary Members. They are arranged in three Classes, according to the Arts and Sciences in which they are severally proficient, and each Class is divided into four Sections, namely:

Class I. *The Mathematical and Physical Sciences*
- Section 1. Mathematics and Astronomy
- Section 2. Physics
- Section 3. Chemistry
- Section 4. Technology and Engineering

Class II. *The Natural and Physiological Sciences*
- Section 1. Geology, Mineralogy, and Physics of the Globe
- Section 2. Botany
- Section 3. Zoölogy and Physiology
- Section 4. Medicine and Surgery

Class III. *The Moral and Political Sciences*
- Section 1. Theology, Philosophy, and Jurisprudence
- Section 2. Philology and Archaeology
- Section 3. Political Economy and History
- Section 4. Literature and the Fine Arts

Article 2. The number of Fellows shall not exceed Six hundred, of whom not more than Four hundred shall be residents of Massachusetts, nor shall there be more than Two hundred in any one Class.

Article 3. The number of Foreign Honorary Members shall not exceed Seventy-five. They shall be chosen from among citizens of foreign countries most eminent for their discoveries and attainments in any of the Classes above enumerated. There shall not be more than Twenty-five in any one Class.

Article 4. If any person, after being notified of his election as Fellow or Resident Associate, shall neglect for six months to accept in writing, or, if a Fellow or resident within fifty miles of Boston shall neglect to pay his Admission Fee, his election shall be void; and if any Fellow resident within fifty miles of Boston or any Resident Associate shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this

Article of the Statutes in the meantime, he shall cease to be a Fellow or Resident Associate respectively; but the Council may suspend the provisions of this Article for a reasonable time.

With the previous consent of the Council, the Treasurer may dispense (*sub silentio*) with the payment of the Admission Fee or of the Annual Dues or both whenever he shall deem it advisable. In the case of officers of the Army or Navy who are out of the Commonwealth on duty, payment of the Annual Dues may be waived during such absence if continued during the whole financial year and if notification of such expected absence be sent to the Treasurer. Upon similar notification to the Treasurer, similar exemption may be accorded to Fellows or Resident Associates subject to Annual Dues, who may temporarily remove their residence for at least two years to a place more than fifty miles from Boston.

If any person elected a Foreign Honorary Member shall neglect for six months after being notified of his election to accept in writing, his election shall be void.

See Chap. vii. art. 2.

ARTICLE 5. Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of Ten dollars.

Every Fellow resident within fifty miles of Boston shall, and others may, pay such Annual Dues, not exceeding Fifteen dollars, as shall be voted by the Academy at each Annual Meeting, when they shall become due; but any Fellow or Resident Associate shall be exempt from the annual payment if, at any time after his admission, he shall pay into the treasury Two hundred dollars in addition to his previous payments.

All Commutations of the Annual Dues shall be and remain permanently funded, the interest only to be used for current expenses.

Any Fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the Treasurer within three months thereafter Annual Dues for the current year, failing which his Fellowship shall cease; but the Council may suspend the provisions of this Article for a reasonable time.

Only Fellows who pay Annual Dues or have commuted them may hold office in the Academy or serve on the Standing Committees or vote at meetings.

ARTICLE 6. Fellows who pay or have commuted the Annual Dues and Foreign Honorary Members shall be entitled to receive gratis one copy of all Publications of the Academy issued after their election.

See Chap. x, art. 2.

Article 7. Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the Secretaries, shall be given to Foreign Honorary Members and to Fellows on request.

Article 8. If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member or Resident Associate shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership; and if three fourths of the Fellows present, out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll.

See Chap. iii.; chap. vi. art. 1; chap. ix. art. 1, 7; chap. x. art. 2.

CHAPTER III

Election of Fellows and Foreign Honorary Members

Article 1. Elections of Fellows and Foreign Honorary Members shall be made by the Council in April of each year, and announced at the Annual Meeting in May.

Article 2. Nominations to Fellowship or Foreign Honorary Membership in any Section must be signed by two Fellows of that Section or by three voting Fellows of any Sections; but in any one year no Fellow may nominate more than four persons. These nominations, with statements of qualifications and brief biographical data, shall be sent to the Corresponding Secretary.

All nominations thus received prior to February 15 shall be forthwith sent in printed form to every Fellow having the right to vote, with the names of the proposers in each case and a brief account of each nominee, and with the request that the list be returned before March 15, marked to indicate preferences of the voter in such manner as the Council may direct.

All the nominations, with any comments thereon and with the results of the preferential indications of the Fellows, received by March 15, shall be referred at once to the appropriate Class Committees, which shall report their decisions to the Council, which shall thereupon have power to elect.

Persons nominated in any year, but not elected, may be placed on the preferential ballot of the next year at the discretion of the Council, but shall not further be continued on the list of nominees unless renominated.

Notice shall be sent to every Fellow having the right to vote, not later than the fifteenth of January, of each year, calling attention to the fact that the limit of time for sending nominations to the Corresponding Secretary will expire on the fifteenth of February.

See Chap. ii.; chap. vi. art. 1; chap. ix. art. 1.

CHAPTER IV

Officers

Article 1. The Officers of the Academy shall be a President (who shall be Chairman of the Council), three Vice-Presidents (one from each Class), a Corresponding Secretary (who shall be Secretary of the Council), a Recording Secretary, a Treasurer, and a Librarian, all of whom shall be elected by ballot at the Annual Meeting, and shall hold their respective offices for one year, and until others are duly chosen and installed.

There shall be also twelve Councillors, one from each Section of each Class. At each Annual Meeting three Councillors, one from each Class, shall be elected by ballot to serve for the full term of four years and until others are duly chosen and installed. The same Fellow shall not be eligible for two successive terms.

The Councillors, with the other officers previously named, and the Chairman of the House Committee, *ex officio*, shall constitute the Council.

See Chap. x. art. 1.

Article 2. If any officer be unable, through death, absence, or disability, to fulfill the duties of his office, or if he shall resign, his place may be filled by the Council in its discretion for any part or the whole of the unexpired term.

Article 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of three Fellows having the right to vote, one from each Class. This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Recording Secretary not later than four weeks before the Annual Meeting.

See Chap. vi. art. 2.

Article 4. Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call therefor, and shall be mailed to all the Fellows having the right to vote.

See Chap. vi. art. 2.

Article 5. The Recording Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office.

CHAPTER V

The President

Article 1. The President, or in his absence the senior Vice-President present (seniority to be determined by length of continuous fellowship in the Academy), shall preside at all meetings of the Academy. In the absence of all these officers, a Chairman of the meeting shall be chosen by ballot.

Article 2. Unless otherwise ordered, all Committees which are not elected by ballot shall be appointed by the presiding officer.

Article 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or, in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized.

See Chap. ii. art. 7; chap. iv. art. 1, 3; chap. vi. art. 2; chap. vii. art. 1; chap. ix. art. 6; chap. x. art. 1; 2; chap. xi. art. 1.

CHAPTER VI

The Secretaries

Article 1. The Corresponding Secretary shall conduct the correspondence of the Academy and of the Council, recording or making an entry of all letters written in its name, and preserving for the files all official papers which may be received. At each meeting of the Council he shall present the communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such as the Council may determine.

He shall notify all persons who may be elected Fellows or Foreign

Honorary Members, or Resident Associates, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma. He shall also notify all meetings of the Council; and in case of the death, absence, or inability of the Recording Secretary he shall notify all meetings of the Academy.

Under the direction of the Council, he shall keep a List of the Fellows, Foreign Honorary Members, and Resident Associates, arranged in their several Classes and Sections. It shall be printed annually and issued as of the first day of July.

See Chap. ii. art. 7; chap. iii. art. 2, 3; chap. iv. art. 1; chap. ix. art. 6; chap. x. art. 1; chap. xi. art. 1.

Article 2. The Recording Secretary shall have the custody of the Charter, Corporate Seal, Archives, Statute-Book, Journals, and all literary papers belonging to the Academy.

Fellows or Resident Associates borrowing such papers or documents shall receipt for them to their custodian.

The Recording Secretary shall attend the meetings of the Academy and keep a faithful record of the proceedings with the names of the Fellows and Resident Associates present; and after each meeting is duly opened, he shall read the record of the preceding meeting.

He shall notify the meetings of the Academy to each Fellow and Resident Associate by mail at least seven days beforehand, and in his discretion may also cause the meetings to be advertised; he shall apprise Officers and Committees of their election or appointment, and inform the Treasurer of appropriations of money voted by the Academy.

After all elections, he shall insert in the Records the names of the Fellows by whom the successful nominees were proposed.

He shall send the Report of the Nominating Committee in print to every Fellow having the right to vote at least three weeks before the Annual Meeting.

See Chap. iv. art. 3.

In the absence of the President and of the Vice-Presidents he shall, if present, call the meeting to order, and preside until a Chairman is chosen.

See Chap. i.; chap. ii. art. 7; chap. iv. art. 3, 4, 5; chap. ix. art. 6; chap. x. art. 1, 2; chap. xi. art. 1, 3.

Article 3. The Secretaries, with the Chairman of the Committee of Publication, shall have authority to publish such of the records of the meetings of the Academy as may seem to them likely to promote its interests.

CHAPTER VII

The Treasurer and the Treasury

Article 1. The Treasurer shall collect all money due or payable to the Academy, and all gifts and bequests made to it. He shall pay all bills due by the Academy, when approved by the proper officers, except those of the Treasurer's office, which may be paid without such approval; in the name of the Academy he shall sign all leases of real estate; and, with the written consent of a member of the Committee on Finance, he shall make all transfers of stocks, bonds, and other securities belonging to the Academy, all of which shall be in his official custody.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council.

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the appropriation thereof, and render them annually.

His accounts shall always be open to the inspection of the Council.

Article 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources during the ensuing financial year. He shall also report the names of all Fellows and Resident Associates who may be then delinquent in the payment of their Annual Dues.

Article 3. He shall give such security for the trust reposed in him as the Academy may require.

Article 4. With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible; or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the funds of the Academy.

Article 5. At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments.

Article 6. The Financial Year of the Academy shall begin with the first day of April.

Article 7. No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy, except cash or invested funds, without the previous consent and approval of the Council.

See Chap. ii. art. 4, 5; chap. vi. art. 2; chap. ix. art. 6; chap. x. art. 1, 2, 3; chap. xi. art. 1.

CHAPTER VIII

The Librarian and the Library

Article 1. The Librarian shall have charge of the printed books, keep a correct catalogue thereof, and provide for their delivery from the Library.

At the Annual Meeting, as Chairman of the Committee on the Library, he shall make a Report on its condition.

Article 2. In conjunction with the Committee on the Library he shall have authority to expend such sums as may be appropriated by the Academy for the purchase of books, periodicals, etc., and for defraying other necessary expenses connected with the Library.

Article 3. All books procured from the income of the Rumford Fund or of other special Funds shall contain a book-plate expressing the fact.

Article 4. Books taken from the Library shall be receipted for to the Librarian or his assistant.

Article 5. Books shall be returned in good order, regard being had to necessary wear with good usage. If any book shall be lost or injured, the Fellow or Resident Associate to whom it stands charged shall replace it by a new volume or by a new set, if it belongs to a set, or pay the current price thereof to the Librarian, whereupon the remainder of the set, if any, shall be delivered to the Fellow or Resident Associate so paying, unless such remainder be valuable by reason of association.

Article 6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

Article 7. The Librarian shall have the custody of the Publications of the Academy. With the advice and consent of the President, he may effect exchanges with other associations.

See Chap. ii. art. 6; chap. x. art. 1, 2.

CHAPTER IX

The Council

Article 1. The Council shall exercise a discreet supervision over all nominations and elections to membership, and in general supervise all the affairs of the Academy not explicitly reserved to the Academy as a whole or entrusted by it or by the Statutes to standing or special committees.

It shall consider all nominations duly sent to it by any Class Committee, and present to the Academy for action such of these nominations as it may approve by a majority vote of the members present at a meeting, of whom not less than seven shall have voted in the affirmative.

With the consent of the Fellow interested, it shall have power to make transfers between the several Sections of the same Class, reporting its action to the Academy.

See Chap. iii. art. 2, 3; chap. x, art. 1.

Article 2. Seven members shall constitute a quorum.

Article 3. It shall establish rules and regulations for the transaction of its business, and provide all printed and engraved blanks and books of record.

Article 4. It shall act upon all resignations of officers, and all resignations and forfeitures of Fellowship or Resident Associateship; and cause the Statutes to be faithfully executed.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation.

They shall hold their respective positions during the pleasure of the Council.

ARTICLE 5. It may appoint, for terms not exceeding one year, and prescribe the functions of, such committees of its number, or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests.

ARTICLE 6. At its March meeting it shall receive reports from the President, the Secretaries, the Treasurer, and the Standing Committees, on the appropriations severally needed for the ensuing financial year. At the same meeting the Treasurer shall report on the expected income of the various Funds and from all other sources during the same year.

A report from the Council shall be submitted to the Academy, for action, at the March meeting, recommending the appropriation which in the opinion of the Council should be made.

On the recommendation of the Council, special appropriations may be made at any Stated Meeting of the Academy, or at a Special Meeting called for the purpose.

See Chap. x. art. 3.

ARTICLE 7. After the death of a Fellow or Foreign Honorary Member, it shall appoint a member of the Academy to prepare a biographical notice for publication in the Proceedings.

ARTICLE 8. It shall report at every meeting of the Academy such business as it may deem advisable to present.

See Chap. ii. art. 4, 5, 8; chap. iv, art. 1, 2; chap. vi. art. 1; chap. vii, art. 1; chap. xi. art. 1, 4.

CHAPTER X

STANDING COMMITTEES

ARTICLE 1. The Class Committee of each Class shall consist of the Vice-President, who shall be chairman, and the four Councillors of the Class, together with such other officer or officers annually elected as may belong to the Class. It shall consider nominations to Fellowship in its own Class, and report in writing to the Council such as may receive at a Class Committee Meeting a majority of the votes cast, provided at least three shall have been in the affirmative.

See Chap. iii. art. 2.

Article 2. At the Annual Meeting the following Standing Committees shall be elected by ballot to serve for the ensuing year:

(i) *The Committee on Finance,* to consist of three Fellows, who, through the Treasurer, shall have full control and management of the funds and trusts of the Academy, with the power of investing the funds and of changing the investments thereof in their discretion.

See Chap. iv. art. 3; chap. vii. art. 1, 4; chap. ix. art. 6.

(ii) *The Rumford Committee,* to consist of seven Fellows, who shall report to the Academy on all applications and claims for the Rumford Premium. It alone shall authorize the purchase of books publications and apparatus at the charge of the income from the Rumford Fund, and generally shall see to the proper execution of the trust.

See Chap. iv. art. 3; chap. ix. art. 6.

(iii) *The Cyrus Moors Warren Committee,* to consist of seven Fellows, who shall consider all applications for appropriations from the income of the Cyrus Moors Warren Fund, and generally shall see to the proper execution of the trust.

See Chap. iv. art. 3; chap. ix. art. 6.

(iv) *The Committee of Publication,* to consist of three Fellows, one from each Class, to whom all communications submitted to the Academy for publication shall be referred, and to whom the printing of the Proceedings and the Memoirs shall be entrusted.

It shall fix the price at which the Publications shall be sold; but Fellows may be supplied at half price with volumes which may be needed to complete their sets, but which they are not entitled to receive gratis.

Two hundred extra copies of each paper accepted for publication in the Proceedings or the Memoirs shall be placed at the disposal of the author without charge.

See Chap. iv. art. 3; chap. vi. art. 1, 3; chap. ix. art. 6.

(v) *The Committee on the Library,* to consist of the Librarian, *ex officio,* as Chairman, and three other Fellows, one from each Class, who shall examine the Library and make an annual report on its condition and management.

See Chap. iv. art. 3; chap. viii. art. 1, 2; chap. ix. art. 6.

(vi) *The House Committee*, to consist of three Fellows, who shall have charge of all expenses connected with the House, including the general expenses of the Academy not specifically assigned to the care of other Committees or Officers.

See Chap. iv. art. 1, 3; chap. ix. art. 6.

(vii) *The Committee on Meetings*, to consist of the President, the Recording Secretary, and three other Fellows, who shall have charge of plans for meetings of the Academy.

See Chap. iv. art. 3; chap. ix. art. 6.

(viii) *The Auditing Committee*, to consist of two Fellows, who shall audit the accounts of the Treasurer, with power to employ an expert and to approve his bill.

See Chap. iv. art. 3; chap. vii. art. 1; chap. ix. art. 6.

Article 3. The Standing Committees shall report annually to the Council in March on the appropriations severally needed for the ensuing financial year; and all bills incurred on account of these Committees, within the limits of the several appropriations made by the Academy, shall be approved by their respective Chairmen.

In the absence of the Chairman of any Committee, bills may be approved by any member of the Committee whom he shall designate for the purpose.

See Chap. vii. art. 1, 7; chap. ix. art. 6.

CHAPTER XI

Meetings, Communications, and Amendments

Article 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April and May. Only at these meetings, or at adjournments thereof regularly notified, or at Special Meetings called for the purpose, shall appropriations of money be made or amendments of the Statutes or Standing Votes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation.

Special Meetings shall be called by either of the Secretaries at the request of the President, of a Vice-President, of the Council, or of ten

Fellows having the right to vote; and notifications thereof shall state the purpose for which the meeting is called.

A meeting for receiving and discussing literary or scientific communications may be held on the fourth Wednesday of each month, excepting July, August, and September; but no business shall be transacted at said meetings.

Article 2. Twenty Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special Meetings. Fifteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

Article 3. Upon the request of the presiding officer or the Recording Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

Article 4. No report of any paper presented at a meeting of the Academy shall be published by any Fellow or Resident Associate without the consent of the author; and no report shall in any case be published by any Fellow or Resident Associate in a newspaper as an account of the proceedings of the Academy without the previous consent and approval of the Council. The Council, in its discretion, by a duly recorded vote, may delegate its authority in this regard to one or more of its members.

Article 5. No Fellow or Resident Associate shall introduce a guest at any meeting of the Academy until after the business has been transacted, and especially until after the result of the balloting upon nominations has been declared.

Article 6. The Academy shall not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its Publications.

Article 7. All proposed Amendments of the Statutes shall be referred to a committee, and on its report, at a subsequent Stated Meeting or at a Special Meeting called for the purpose, two thirds of the ballot cast, and not less than twenty, must be affirmative to effect enactment.

Article 8. Standing Votes may be passed, amended, or rescinded at a Stated Meeting, or at a Special Meeting called for the purpose, by a vote of two thirds of the members present. They may be suspended by a unanimous vote.

See Chap. ii. art. 5, 8; chap. iii.; chap. iv. art. 3, 4, 5; chap. v. art. 1; chap. vi. art. 1, 2; chap. ix. art. 8.

STANDING VOTES

1. Communications of which notice has been given to either of the Secretaries shall take precedence of those not so notified.

2. Fellows or Resident Associates may take from the Library six volumes at any one time, and may retain them for three months, and no longer. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

3. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy without the leave of the Librarian.

4. There may be chosen by the Academy, under such rules as the Council may determine, one hundred Resident Associates. Not more than forty Resident Associates shall be chosen in any one Class.

Resident Associates shall be entitled to the same privileges as Fellows, in the use of the Academy building, may attend meetings and present papers, but they shall not have the right to vote. They shall pay no Admission Fee, and their Annual Dues shall be the same as those of Fellows residing within fifty miles of Boston.

The Council and Committees of the Academy may ask one or more Resident Associates to act with them in an advisory or assistant capacity.

5. Communications offered for publication in the Proceedings or Memoirs of the Academy shall not be accepted for publication before the author shall have informed the Committee on Meetings of his readiness, either himself or through some agent, to use such time as the Committee may assign him at such meeting as may be convenient both to him and to the Committee, for the purpose of presenting to the Academy a general statement of the nature and significance of the results contained in his communication.

RUMFORD PREMIUM

In conformity with the terms of the gift of Sir Benjamin Thompson, Count Rumford, of a certain Fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court of Massachusetts for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of the Rumford Fund, as it now exists, at any Annual Meeting, an award of a gold and a silver medal, being together of the intrinsic value of three hundred dollars, as a Premium to the author of any important discovery or useful improvement in light or heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American Islands; preference always being given to such discoveries as, in the opinion of the Academy, shall tend most to promote the good of mankind; and, if the Academy sees fit, to add to such medals, as a further Premium for such discovery and improvement, a sum of money not exceeding three hundred dollars.

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