PROCEEDINGS

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR

PROMOTING USEFUL KNOWLEDGE

VOLUME LVI

1917

PHILADELPHIA
THE AMERICAN PHILOSOPHICAL SOCIETY
1917

PRESS OF
THE NEW ERA PRINTING COMPANY
LANCASTER, PA.

CONTENTS

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ON THE ART OF ENTERING ANOTHER'S BODY: A HINDU FICTION MOTIF

By MAURICE BLOOMFIELD.

(Read April 13, 1916.)

The Yoga philosophy teaches, on the way to ultimate salvation, many ascetic practices which confer supernormal powers. Thus the third book of the prime authority on this philosophy, the "Yoga-Sūtras" of Patañjali, gives an account of these vibhūtis, or powers.[1] They cover a large part of all imaginable magic arts, or tricks, as we should call them: knowledge of the past and the future; knowledge of the cries of all living beings (animal language); knowledge of previous births (jātismara, Pāli jātissara); mind-reading; indiscernibility of the Yogin's body; knowledge of the time of one's death; knowledge of the subtle and the concealed and the obscure; knowledge of the cosmic spaces; the arrangements and movements of the stars; cessation of hunger and thirst; motionlessness; the sight of the supernatural Siddhas[2] roving in the spaces between the sky and the earth; discernment of all; knowledge of one's own mind mind-stuff and of self; supernormal sense of hearing, feeling, sight, taste, and smell; penetration of one's mind-stuff into the body of another; non-adherence of water, mud, thorns, etc.; levitation (floating in the air); subjugation of the elements; perfection of the body; subjugation of the organs; authority over all states of exist-

[1] Also named bhūti, siddhi, āiçvarya, yogeçvaratā, and the like.

[2] Perfected beings that have become quasi-divine.

ence; omniscience; and, finally, as a result of passionlessness or disregard of all these perfections, the isolation or concentration that leads up to final emancipation or salvation.

In later Yoga scriptures the supernormal powers are systematized as the 8 mahāsiddhi (great powers): (1) to render one's self infinitely small or invisible; (2, 3) assumption of levitation and gravitation; (4) power to extend one's self, so as, *e. g.*, to be able to touch the moon with one's finger tip; (5) irresistible fulfilment of wishes; (6) complete control oven the body and the organs; (7) power to alter the course of nature; (8) power of transfer at will. And, in addition to these, other, even more wonderful faculties are described, such as citing and conversing with the dead; the assumption of many bodies at one and the same time; trance and burial alive,[3] and finally even the power of creation. There are also other systematizations, such as that of the commentator to Vācaspatimiçra's "Sāṁkhya-tattva-kāumudī," mentioned by Garbe in his translation of that work, in the *Transactions of the Royal Bavarian Academy,* Vol. XIX., p. 586.

From its own point of view Yoga does not overestimate these powers; they are all considered ephemeral or unimportant or even contemptible. They are merely a progressive course towards the final goal of emancipation. Buddhist writings state repeatedly that they do not lead to perfection. The great Jain Divine, Hemacandra, once engaged in a Yoga tournament with another Jain Doctor, Devabodhi. Hemacandra made appear all the ancestors of King Kumārapāla, together with the entire Olympus of the Jainas,[4] he himself in the meanwhile floating in the air. He thus beat Devabodhi, but in the end declared that all his stunts as well as Devabodhi's were mere hallucinations.[5]

But was there ever such an enhancement of the vulgar practice of magic? Philosophy, in dealing with such matters at all, enters into partnership with fairy-tale; it sanctions, promotes, and legalizes, so to speak, every fancy, however misty and however ex-

[3] See for this matter Ernst Kuhn's statement in Garbe, "Sāṁkhya und Yoga" (Encyclopaedia of Indo-Aryan Research), p. 47.

[4] Cf. Mahābh., 15. 31. 1.

[5] See Bühler, "Über das Leben des Jaina Mönches Hemacandra," p. 83.

travagant. It is easy to foresee that both folk-lore and sophisticated narrative would simply jump at such tenets and build on their foundation fantastic structures. Nothing is impossible where the canons of time and space and number, and of every sobering empirical experience have been undermined by such a travesty on scientific thought. The fiction texts are fully aware of the support they have in Yoga, as when, *e. g.*, Kathās. 45. 79, states distinctly that magic art is founded on Sāṁkhya and Yoga, and calls it "the supernatural power, and the independence of knowledge, the dominion over matter that is characterized by lightness and other mystic properties."

What is perhaps more important, though in a different way, no narrative of events, even historical events, is immune to this complete obliteration of the boundary line between fact and fancy. We can understand better why all professed Hindu historical texts (Caritas or Caritras) deal with alternately on the same plane, and present alternately as equally credible, things that may have happened and things that may not happen. They have been taught to believe all that by a schematic philosophy.

All narrative texts from the Mahābhārata on are full of Yoga technique,[6] and there is scarcely a single item of the Yogin's fictitious powers that has not taken service with fiction. To begin with the Yogin, or some undefined ascetic who is, to all intents and purposes, omnipotent, is met at every turn of fiction. Asceticism is practised for the avowed purpose of obtaining magic power.[7] The Yoga's most extravagant claim,[8] namely that it enables its adepts to act as the almighty Creator, is supported in epic narrative by the statement that the Yogin possesses the power of sṛṣṭi, *i. e.*, the ability to create things like Prajāpati.[9] Division of personality (kāya-vyūha) is practised not only by the gods (Sūrya in Mahābh. 3. 306. 8; or Skanda, ibid., 9. 44. 37), but even by mortals. In Kathās. 45. 342 ff., King Sūryaprabha, having accumulated at one and the same time an unusually large stock of wives, divides his body by his magic

[6] See Hopkins, JAOS. XXII. 333 ff.
[7] E. g., Kathās. 107. 81.
[8] Garbe, "Sāṁkhya," p. 187.
[9] See Hopkins, l. c., p. 355.

science, and lives with all those ladies, but with his real body he lived principally with his best beloved Mahallikā, the daughter of the Asura Prahlāda. Disappearance; making one's self small ("so small as to creep into a lotus-stalk")[10]; floating in or flying through the air[11], with or without a chariot; remembrance of former births[12]; doing as one wills are commonplaces of fiction to the point of tiresome cliché. They are used to cut the Gordian knot, or as substitutes for the deus ex machina, when convenience calls for them in the least degree.

No doubt many or most of these fairy-tales were known to folk-lore before Yoga philosophy systematized them, and many more are current in fiction which the Yoga does not take note of at all. The gods could always do as they pleased, to begin with, Yoga or no Yoga. There is an especial class of semi-divine persons, the so-called Vidyādharas, or "Holders of Magic Science," who need no instruction in Yoga and yet possess every imaginable power. They are magicians congenitally, habitually fly in the air, and are therefore also known by the name of "Air-goers" (khecara, or vihaga). In a vaguer way almost any one at all may own magic science in fiction. The fairy-tale is interested more in the individual items of magic as self-existent real properties of its technique than in their causes or their motivation. But the influence of the Yoga appears in this way: as a rule, each magic trick is dignified by the name of vidyā, "science" or "art" ("stunt," as we might say). These vidyās are in the first place the property by divine right of the above-mentioned Vidyādharas, but they may also be acquired, or called into service by mortals.

Quite frequently the vidyās are personified and cited like familiar spirits, or good fairies.[13] They appear in profusion with pedantic descriptive names. Thus there is the Vidyā called Pra-

[10] Mahābh. 12. 343. 42.

[11] Kathās. 18. 184; 20. 105, 141; 25. 262; 38. 153; 59. 106; Pārçvanātha Caritra 2. 556; Kathākoça, pp. 49, 58; Prabandhacintāmaṇi, pp. 137, 150, 195 (in Tawney's Translation).

[12] Mahābh. 13. 29. 11; 18. 4. 23–37, and on every other page of fiction.

[13] In Vikrama-Carita the eight siddhis (above, p. 2) are personified as virgins; see Weber, Indische Studien, XV. 388.

jñapti, "Prescience," or "Foreknowledge,"[14] Kathās. 51. 45; 111. 52; Pārçvanātha Caritra, 6. 879, 1141; or Prākrit Jāṇāvaṇī (Sanskrit, Jnāpanī), "Knowledge."[15] In Kathās. 111. 52, a king, suspecting that some calamity might have befallen his father, thought upon the "Science" named Prajñapti, who thereupon presented herself, and he addressed her: "Tell me how has my father fared?" The Science that had presented herself in a bodily form said to him: "Hear what has befallen your father, the king of Vatsa." Similarly, in Kathās. 30. 6 ff., Madanavega, a Vidyādhara, is worried because he is in love with the mortal maiden Kaliñgasenā. He calls to mind the Science named Prajñapti, which informs him that Kaliñgasenā is an Apsaras, or heavenly nymph, degraded in consequence of a curse. Similarly, ibid., 42. 32, Ratnaprabhā calls up a supernatural Science, called Māyāvatī, "Witching," which tells her tidings of her husband.

The "Science" called Cākṣuṣī, "Seeing," is bestowed by the Gandharvas upon Arjuna, Mahābh. i. 171. 6; the "Science" called Pratismṛti, "Memory," is taught by his brother to Arjuna, ibid., 3. 36. 30. In Bambhadatta, p. 8, l. 19, there is a "Science," called Samkari (Skt. Çaṁkarī), "Safety-bestower"; if this is merely remembered it surrounds one with friends and servants that do one's bidding (see also ibid., p. 15, l. 2). In Kathās. 46. 110, King Candradatta possesses the Science called Mohanī, "Bewildering," and for that reason is hard to conquer; similarly, in Kathākoça, p. 144, there is the Science called "Invincible" (presumably Aparājitā); and in Pārçanātha Caritra, 3. 938, the Science called Viçvavaçīkāra, "All-subjecting," presents herself in person (āvirbhavati svayam).

The last-mentioned text, in 8. 60, 158, has the Science called Khagāminī, "Flying in the air." The same Science is called Ākāçagāminī in Pārçvanātha 1. 577, and in Prabhāvaka Carita, p. 11, çloka 151; Vyomagāminī or Gaganagāminī in Prabhāvaka Carita, p. 7, çloka 109, and p. 19, çloka 148; not very different is the Science called Adhiṣṭhāyinī, "Floating in the air," Pārçvanātha 1.

[14] See also Kathākoça, pp. 22, 32. A preceptor of these sciences is called Prajñapti-Kāuçika in Kathās. 25, 284.

[15] "Story of Bambhadatta" (Jacobi, "Māhārāṣṭrī Tales," p. 8, l. 26).

599. This is, of course, the prime quality of the Vidyādharas (khecara) themselves. Frequent mention is made of the Science called "Resuscitation": Saṁjīvinī, Pārçvanātha 6. 706; or Jīvanī, Mahābh. 1. 67. 58; or Mṛtajīvinī, Skandapurāṇa, Kāçīkhaṇḍa, 16. 81. Pārçvanātha, 2. 201, has the Science called Dhuvanakṣobhinī, "Earthquake"; and Pārçvanātha 8. 158, and Pariçiṣṭaparvan 2. 173, have the Science called Tālodghāṭinī, "Opening of locks." It will be observed that texts of the Jaina religionists figure frequently in this matter, this, because of the importance which the Jainas attach to ascetic practices. These practices and the beliefs connected with them have, in their turn, stimulated the Jainas' great love of fiction. It is rather characteristic that the Pārçvanātha Caritra 1. 576 ff., mentions no less than five of these Sciences in one place, to wit: Adṛçyīkaraṇa, "Invisibility;" Ākṛṣṭi, "Compelling the presence of a person;" Rūpāntarakṛti, "Changing one's shape;" Parakāyapraveça, "Entering another's body;" and Ākāçagāminī, "Traveling in the air."

Conspicuous among these magic "Arts," as we may now call them, is the "Art of entering another's body."[16] In the Yoga-Sūtras iii. 38 it is called para-çarīra-āveça; in other Yoga writings, and in Merutuṅga's Prabandhacintāmaṇi, p. 12, para-pura-praveça;[17] in Kathās. 45. 78, 79, dehāntara-āveça, or anya-deha-praveçako yogaḥ; in the Jainist Pārçvanātha Caritra 1. 576; 3. 119; in the Metrical Version of the Vikrama Carita, story 21, lines 109–110; in the Bühler manuscript of the Pañcatantra, and in Meghavijaya's version of the same text, para-kāya-praveça (see WZKM. XIX, p. 64; ZDMG. LII, p. 649). The same designation is used in the Vikrama story in a manuscript of the Vetālapañcaviṅçati, edited by Uhle in ZDMG. XXIII, pp. 443 ff. The Vikrama Carita defines this Art (with others) as ancillary to the eight mahāsiddhis, to wit, parakāyapraveçādyā yāç ca katy api siddhayaḥ, etadaṣṭamahāsiddhipāda paṅkajasevikaḥ, "the Arts Entering an-

[16] In Hemacandra's Yogaçāstra this is preceded by the "Art of separating one's self from one's body," called vedhavidhi; see Bühler, "Ueber das Leben des Jaina Mönches Hemacandra," p. 251.

[17] *E. g.*, Aniruddha to Sāṁkhyas. p. 129. The Sanskrit Lexicons either omit or misunderstood this word; see Böhtlingk, VII, p. 356, col. 1.

other's body and some others are subservient to the foot-lotuses of the these mahāsiddhis (the great Arts)." For all that the parakāya-praveça is an art destined to make a brilliant career in fiction. It is applied in two rather distinctive ways, one more philosophical, the other plainly folk-lore. In its philosophical aspect "the mind-stuff penetrates into the body of another." Patañjali's Commentator (Yoga-Bhāṣya of Veda-Vyāsa) remarks that the Yogin, as the result of concentration reduces his karma, becomes conscious of the procedure of his mind-stuff, and then is able to withdraw the mind-stuff from his own body and to deposit it in another body. The organs also fly after the mind-stuff thus deposited.[18] In its folk-lore aspect the art consists of abandoning one's body and entering another body, dead or in some other way bereft of its soul. The second form is naturally more popular in fiction.

There is but one elaborate instance of the art of pervading another's body with one's mind-stuff, Mahābhārata, 13. 40 ff. A noble sage, named Devaçarman, had a wife, Ruci by name, the like of whom there was not upon the earth. Gods, Gandharvas, and Demons were intoxicated by her charms, but none so much so as the God Indra, the slayer of Vṛtra, the punisher of Pāka. Indra is of old a good deal of a *viveur* and man about town. In remote antiquity he established for himself his dubious reputation by violating Ahalyā, the beautiful wife of the great Sage Gāutama; therefore he is known ever after as the "Paramour of Ahalyā" (ahalyāyāi jāraḥ).[19] Now Devaçarman, the great Sage, understood the nature of women, therefore guarded that wife with every device and endeavor. Also, he was aware that Indra, seeker of intrigues with the wives of others, was the most likely source of danger: hence he yet more strenuously guarded his wife. Being minded to perform a sacrifice he pondered the means of protecting his spouse during his absence. He called to him his disciple Vipula, and said: "I am going to perform a sacrifice; since Indra constantly

[18] Wood, The Yoga-System of Patañjali, HOS. Vol. XVII. p. 266. Cf. the kāmāvasāyitva of the commentator to Vācaspatimiçra's "Sāṁkhya-tattva-kāumudī," l. c.

[19] From Çatapatha Brāhmaṇa, 3. 3. 4. 18, on to Kathāsaritsāgara 17. 137 ff.; see my Vedic Concordance under ahalyāyāi.

lusts after Ruci, do thou guard her with all thy might. Unceasingly must thou be on thy guard against him, for he puts on many disguises!" Then Vipula, ascetic and chaste, clean like the sheen of fire's flame, knowing the moral law and truthful, consented to take charge.

As the Master was about to start Vipula asked him: "What are the shapes that Indra contrives, when he comes? What sort of beauty and majesty does he assume, pray tell me that, O Sage?" Then the Master recounted to him Indra's wiles in detail: "He appears with a diadem, carrying his war-bolt, with jewels in his ears; the next moment like a Paria in appearance; as an ascetic with a tuft on his head, clothed in rags; of body great, or of body small. He changes his complexion from red to pale, and again to black; his form from stalwart youth to decrepit old age. He appears in the guise of Brahman, Kṣatriya, Vāiçya, Çūdra, indifferently of high or low caste; may show himself beautiful in white robe; disguised as swan or koïl-bird; as lion, tiger, or elephant; in the guise of god, or demon, or king; fat or lean; as a bird, or stupid animal of many a form, even as a gnat or fly. He may vanish, so as to be visible only to the eye of knowledge; turn to thin air."

The Sage in due time starts on his journey, leaving his fiduciary pupil in charge of the wife. Indra, as forecast, appears upon the scene, and Vipula finds that Ruci is wayward. Then, by his Yoga, he invades her mind (cittasya paraçarīrāveçaḥ) and restrains her. He abides in her "limb by limb," like a shadow, like a person stopping in an empty house which he finds on his way, soiling her as little as a drop of water soils a lotus-leaf, standing in her like a reflection in a mirror.

Ruci is unconscious of the influence, but the operator's eye is fixed, for his spirit is far away. When Indra enters she wishes to say politely to the guest, "Who are thou?" but, stiffened and restrained by the magic presence in her soul, she is unable to move. Indra says: "Compelled by the bodiless God of Love I come for thy sake, O sweetly smiling woman," but she is still unable to rise and speak, because the virtuous pupil restrains her by the bonds of Yoga. Vipula finally returns to his own body, and Indra, shamed by his reproaches, slinks off.

Twice more in the Mahābhārata the motif takes the form of pervading another with one's self. In 12. 290. 12 the Sage Uçanas, perfect in Yoga, projects himself into Kubera, the god of wealth, and controls him so as to be able to take his wealth and decamp. In 15. 26. 26–29 the ascetic Vidura, as he dies, rests his body against a tree, and enters the body of Yudhisthira who is thus dowered with Vidura's many virtues. The Sage, having left with Yudhiṣṭhira his powers, obtains the Sāṁtānika's worlds. But, as a rule, the art is to enter the empty body of a dead person, or of a person who has himself decamped from his own body. That is the permanent type. Thus, in Kathākoça, p. 38 ff., Prince Amaracandra enters another's body in order to feign death, and thus test the faith of his wife Jayaçrī who had but just married him by svayaṁvara. When she is about to join him on the funeral pyre he recovers his body by his magic.

The intricate story of Yogananda, or the Brahman disciple Indradatta, who became king Nanda by entering his dead body by Yoga, is told, Kathās. 4. 92 ff.; and in the fifth chapter of Merutuṅga's Prabandhacintāmaṇi, p. 271. In the version of the Kathāsaritsāgara the celebrated Hindu Grammarian Vararuci, together with his two pupils Vyāḍi and Indradatta, wishes to learn from Varṣa a new grammar that had been revealed to him by the god Kārttikeya. Now Varṣa asks a million gold pieces for the lesson. The price is rather stiff, and they know no way except to rely on the liberality of king Nanda of Oudh. When they arrive in Oudh Nanda has just died. They devise that Indradatta shall enter for a short time Nanda's body, and that he shall again withdraw therefrom as soon as he has granted the million. Indradatta then enters Nanda's body; Vyāḍi watches over Indradatta's empty shell; Vararuci makes the request for the money. But the wise minister of the defunct king, Çakaṭāla by name, reflects that Nanda's son is still a boy, that the kingdom is surrounded by enemies, and decides to retain the magic Nanda (Yogananda) upon the throne. He therefore orders all corpses to be burned,[20] including Indradatta's, and the latter's soul, to its horror, is thus compelled to reside in the body of Nanda, a Çūdra, whereas it is, in truth, that of a Brahman.

[20] For this featûre, namely, the burning of temporarily abandoned bodies, see Benfey, Pañcatantra, I. 253; II. 147.

In the Prabandhacintāmaṇi king Nanda of Pāṭalīpura dies, and a certain Brahman enters his body. A second Brahman by connivance comes to the renovated king's door, recites the Veda, and obtains as reward a crore of gold-pieces. The prime minister[21] considered that formerly Nanda was parsimonious, whereas he now displayed generosity. So he arrested that Brahman, and made search everywhere for a foreigner that knew the art of entering another body. Hearing, moreover, that a corpse was being guarded somewhere by a certain person he reduced the corpse to ashes, by placing it on the funeral pyre, and so contrived to carry on Nanda as monarch in his mighty kingdom as before. Benfey, Das Pañcatantra, I. 123, quotes Turnour, Mahāvaṅso, Introduction, p. XLII, to the effect that Buddhist sources report of Candragupta, the founder of the Māurya dynasty, the same story. Candragupta's body was occupied after his death by a Yakṣa, named Devagarbha.

In the Vampire-story in Çivadāsa's recension of the Vetālapañcaviṅçati, 23; Kathāsaritsāgara, 97; Oesterley's "Baitāl Pachīsī," 22; "Vedāla Cadai," 22,[22] the Vampire relates how an old and decrepit Pāçupata ascetic abandons his own shriveled body and enters that of a young Brahman who has just died, and later on throws his own body into a ravine. In the Hindī version of the Vampire stories ("Baitāl Pachīsī," 24), but not in the classical versions, there occurs an unimportant variant of the same story.

In Kathās. 45. 47, 113, the Asura Maya tells Candraprabha that he was, in a former birth, a Dānava, Sunītha by name, and that his body, after death in a battle between the Devas and the Asuras, had been preserved by embalming. The Asura Maya proposes to teach Candraprabha a charm by which he may return to his own former body, and so become superior in spirit and strength.

In the Hindustani "Bhaktimāl"[23] there is a merry story about Çaṁkarācārya, who has entered into a learned disputation with a Doctor named Mandan Misr. The latter's wife had crowned the

[21] Çakaṭāla (or Çakaḍāla) is his name in the same text, p. 306, and in another Jain text, Pariçiṣṭaparvan 8. 50.

[22] Babington in "Miscellaneous Translations from Oriental Languages," Vol. I. Part IV, p. 84.

[23] See Garçin de Tassy, "Histoire de la Littérature Hindoui et Hindoustani," II. 44.

heads of the two disputants with wreaths; Mandan Misr's wreath faded first, and Çaṁkara declares that he has conquered, and that Mandan Misr must become his disciple. But the wife remonstrates, on the plea that her husband is only half, she herself being the other half: he must conquer her also. She enters into a disputation with him particularly on the Art of Love (Ras-Schaster), in which he, a Brahmacārin, is quite inexperienced. In order not to have an undue advantage she gives him a month's time for preparation. Çaṁkara enters the body of a king who has just died, committing his body to the care of his disciples. In the time of a single month Çaṁkara gathers a fund of experience in the art sufficient to down the woman in her own domain.

A Buddhist novice kills a serpent in order to enter its body, according to Burnouf, "Introduction à l'histoire du Buddhisme," I. 331, and Stan. Iulien, "Mémoires," I. 48; see Benfey, Das Pañcatantra, I. 124.

F. W. Bain, "A Digit of the Moon," pp. 84 ff., tells the following, presumably spurious, story, based upon sundry echoes from Hindu fiction: A king's domestic chaplain (purohita) is smitten with an evil passion for another man's wife. He gets the husband interested in the art of entering another's body, takes him one night to the cemetery, and there each by the power of Yoga abandons his body. The Purohita enters the body of the husband, who in turn is obliged to put up with the Purohita's body that is left. By chance he returns not to his own home, but to the house of the Purohita.

His wife's illicit love for the Purohita has in the meantime driven her to his house, and as a result, she now showers unaccustomed endearments upon her own husband in the guise of the Purohita. The Purohita, in the meantime, has gone to the house of this dissolute woman, where he passes the night, cursing his fate because of her absence. In the morning the Purohita leaves the house before the woman's return, and arrives at his own house where he finds the husband asleep in his own bed. After mutual recriminations they return to the cemetery and change back their bodies. Then the husband realizes the import of what has happened and brings both the Purohita and his own wife before the king's officers. But the Purohita says: "I have not touched your wife." And the wife says: "Was it not yourself that I embraced?" And the situation, in the manner of the Vampire-stories, remains a puzzle.

The most important aspect of our theme is that which tells how a certain king, either Mukunda or Vikrama, was tricked out of his body by a wily companion. In both versions figure a parrot, and a devoted and observant queen; and in both stories the king finally regains his own body. Nevertheless, the two types of story show very individual physiognomies. The Vikrama story, in an essentially Hindu form, has been accessible since a very early date (1817) in "M. le Baron Lescallier," Le Trône Enchanté, New-York, de l'imprimerie de J. Desnoues, No. 7, Murray-Street, 1817. This, as the translator explicitly states, is a translation from the Persian "Senguehassen Batissi," which in its turn is a version of the Hindu cycle of stories best known (though not exclusively so) under the names of "Siṅhāsanadvātriṅçikā," or, "The 32 Stories of the Throne Statues"; or "Vikrama Carita, the History of King Vikrama."[24] Benfey traces the Vikrama version, or echoes from it, through five Western story collections, all of which are certainly based upon Hindu models, because they contain the feature of the parrot, or, in the case of the Bahar Danush, of the sharok bird (the maina, Skt. çārikā[25]). But, as far as Hindu literature is concerned, Benfey knew only a Greek rendering of the Mukunda story in Galanos' translation of the Hitopadeça.

The Mukunda version was made accessible to Europeans considerably later than Lescallier's Vikrama version. Galanos, "Χιτοπαδασσα ἢ Παντσα Ταντρα," pp. 20 ff., rendered it into Greek in 1851 (see Benfey, l. c., p. 4), and Benfey translated it from Galanos in Pañcatantra, Vol. II., pp. 124 ff. Since then Hertel found the original of Galanos in the Bühler manuscript of the Pañcatantra;

[24] See A. Loisseleur Deslongchamps, "Essai sur les Fables Indiennes," p. 175, note 5 (who draws attention to "1001 Nights," LVII–LIX); Benfey, Das Pañcatantra, p. 123. The Hindu classical versions of the Siṅhāsana do not, as far as I have been able to find out, contain the story; see especially their summary, as made by Weber, "Indische Studien," XV, pp. 447 ff.

[25] See my paper, "On Talking-Birds in Hindu Fiction," Festschrift an Ernst Windisch, pp. 349 ff.

see WZKM. XIX. 63 ff. He also brought to light two briefer versions of the same story, one in Meghavijaya's recension of the Pañcatantra, ZDMG. LII, pp. 649 ff.; the other in the Southern textus simplicior of the Pañcatantra, ZDMG. LXI, p. 27. The story pivots about a proverbial (nīti) stanza, to wit:

"That which belongs to six ears is betrayed."
"Not if the hunchback is present."
"The hunchback became a king,
The king a beggar and vagabond."[26]

King Mukunda of Līlāvatī, returning from a pleasure grove to his city, saw a hunchback clown performing his tricks before a crowd. He took him with him in order to make merry over him, and constantly kept him by his side. The king's Minister desiring to consult with the king, saw the hunchback and recited part of the metrical adage:

"That which belongs (is known to) to six ears is betrayed."

But the king continued the stanza:

"Not if the hunchback is present."

On a certain day a Yogin turned up; the king received him under four eyes, and learned from him the art of entering into a dead body. The king kept rehearsing to himself the charm in the presence of the hunchback who, in this way, learned it also. It happened that the king and the hunchback went out to hunt; the king discovered in a thicket a Brahman who had died of thirst. Eager to test his power, he muttered the charm he had learned and transported his soul into the body of the Brahman. The hunchback immediately entered the body of the king, mounted his horse,

[26] The original of this verse as given by Hertel, WZKM. XIX. 64, is: ṣaṭkarṇo bhidyate mantraḥ kubjake nāiva bhidyate, kubjako jāyate rājā rājā bhavati bhikṣukaḥ. Very similar is the verse quoted from Subhāṣitārṇava, 150, by Böhtlingk, "Indische Sprüche," 6601: ṣaṭkarṇo bhidyate mantraç catuṣkarṇo na bhidyate, kubjako jāyate rājā rājā bhavati bhikṣukaḥ. Hertel cites yet another version from the southern textus simplicior of the Pañcatantra, ZDMG. LXI, p. 27, note 2, to wit: ṣaṭkarṇaṁ bhidyate mantraṁ tava kāryam ca bhidyate, kubjo bhavati rājendro rājā bhavati bhikṣukaḥ. Cf. also Böhtlingk's "Sprüche," 6602 and 6603 (from various sources); they do not mention the kubjaka, "hunchback."

and said to the king: "Now shall I exercise royalty; do you go wherever on earth it pleases you." And the king, realizing his helplessness, turned away from his city.

Because the trick king spoke irrelevantly in the presence of the queen, she suspected him and consulted the aged Minister. He began to distribute food among needy strangers, and, as he himself washed their feet, he recited:

"That which belongs to six ears is betrayed."
"Not if the hunchback is present,"

and asked each mendicant to recite the other half of the stanza.[27] The true king heard of this; recognized in it the action of the queen, returned as a mendicant, and, when the Minister recited as above, he finished the stanza:

"The hunchback became a king,
The king beggar and vagabond."

The minister was satisfied with this evidence, and returned to the queen whom he found wailing over a dead pet-parrot. He advised her to call the false king and to say: "Is there in this city a magician who can make this parrot utter even a single word?" The fake king, proud of his newly won art, abandoned the royal body, entered that of the parrot, and the true king recovered his own. Then the Minister killed the parrot which had been reanimated by the hunchback.

Meghavijaya's version (ZDMG. LII. 649) is a straight abbreviation of this story. Yet briefer and somewhat tangled is the version reported by Hertel from the South-Indian textus simplicior of the Pañcatantra; see ZDMG. LXI. 27 ff. This version is clearly secondary to that of Galanos; the names are all changed, and the hunchback figures as an attendant of the king, being called

[27] On divided stanzas as a means of recognition see the story of Bambhadatta, p. 18, lines 30 ff. (Jacobi, "Ausgewählte Erzählungen in Māhārāṣṭrī"), and cf. my essay on Mūladeva, *Proceedings of the American Philosophical Society*, LII. (1913), 644. On the completion of fragmentary stanzas see Tawney's translation of Prabandhacintāmaṇi, pp. 6, 60; Hertel in ZDMG. LXI, p. 22; and, in general, Zachariae in "Gurupūjākāumudī," pp. 38 ff.; Charpentier, "Paccekabuddhageschichten," p. 35. Çloka as deus ex machina in Parçvanātha Caritra 2. 660 ff.

Kubja, "Hunchback;" *i. e.*, the word has become a proper name without relevance of any sort. The story is, moreover, dashed with motifs that had nothing to do with it originally: The king learns the art from a sorcerer. Kubja overhears the charm. The king sees a female hañsa-bird in distress, because her mate has been shot by a hunter. The king, out of pity, enters the male hañsa's body;[28] Kubja enters the king's body, usurps the kingdom, but is flouted by the queen. The king abandons the body of the hañsa, enters that of a beggar, and consults with the sorcerer. The latter tells the story to the king's minister. The minister advises the queen to kill her parrot, and to tell the fake king that she will receive him, if he reanimates the parrot. The false king enters into the parrot and is slain.

All versions of the story with King Vikrama in the center are clearly marked off from the Mukunda story. They supplant the hunchback by a magician (Yogin) and do not pivot about the stanza, "That which belongs to six ears is betrayed." As far as I know there are four versions of this story, to wit: Lescallier's, alluded to above; a version which appears in a manuscript of the Vetālapañcaviñçati, edited and translated by Uhle in ZDMG. XXIII. 443 ff.; a very brief summary in Merutuñga's Prabandhacintāmaṇi, p. 12; and a full and brilliant version in Pārçvanātha Caritra, 3. 105–324.[29] Moreover this tale has great vogue in Hindu folk-lore, where it is usually blended with other parrot stories and with other Vikrama stories: see Frere, "Old Deccan Days," pp. 102 ff. (Vicram Maharajah Parrot); J. H. Knowles, "Dictionary of Kashmiri Proverbs," p. 98 (§§ 4 and 5); Anaryan (pseudonym of F. Arbuthnot) in "Early Ideas, Hiṇdoo Stories," pp. 131 ff., where the story is ascribed to the Prākrit poet Hurridas (Haridāsa);[30] Butterworth, "Zig-Zag Journeys in India," p. 167: "The parrot with the soul of a Rajaḥ."

[28] For this trait of the story see Rāmāyaṇa 1. 2. 9 ff.

[29] Deslongchamps, l. c., states that the story occurs, "avec d'autres détails, dans le recueil sanscrit qui a pour titre Vṛhat-Kathā" (voyez le *Quarterly Oriental Magazine de Calcutta*, mars 1824). Vṛhat-Kathā is doubtless intended for "Kathāsaritsāgara," but the story is not there. The *Quarterly Oriental Magazine* is not accessible.

[30] That the story did exist in some Prākrit version seems to be likely,

Lescallier's version of the story, a little uncertain as to its make-up, differs not only from the Mukunda story, but also from the three remaining versions of which we have the Sanskrit text. Since the book is very rare, the following digest may be acceptable: A Yogin (Djogui) named Jéhabel (Jābāla or Jābali?) starts out with the avowed purpose of tricking Vikramāditya (Békermadjiet) out of his body, so that he may rule in his stead. He takes with him a dead parrot. He obtains an audience with the king, and after effusively praising him, says that he has heard that Vikrama possesses fourteen arts (vidyās), one of which is the capacity to transplant his soul into a dead body, and thus to revive it. He begs for an ocular demonstration of this art: Vikrama is to pass his soul for a moment into the body of the dead parrot. After some remonstrance Vikrama consents, and they go to a room whose every opening the Yogin carefully shuts, on the plea that complete secrecy is desirable. Vikrama enters the body of the parrot which immediately shows every sign of life; the Yogin occupies Vikrama's body. Then he attempts to seize the parrot in order to slay him. Vikrama, unable to escape from the closed room, resorts to the supreme being, making what the Buddhists call the saccakiriyā, or "truth-act," or satya-çrāvaṇā, or "truth-declaration":[31] "O almighty God, as king I have done good to all men, I have treated generously and benevolently all who have resorted to me, I have solaced the unfortunate, and none, not even animals, have suffered exactions or injustice at my hands. Being without reproach, I do not comprehend for what fault I am thus punished!" No sooner has he uttered this prayer than a violent gust of wind throws open every aperture of the room. The parrot escapes, and settles upon a Samboul (Çālmali) tree in the great garden of Noulkéha,[32] where he becomes king of the parrots.

because a stanza which occurs at the end of several manuscripts of the Vikrama Carita states that formerly the Vikrama collection existed in the Māhārāṣṭrī language; see Weber, Indische Studien, XV, pp. 187 ff.

[31] Pārçvanātha Caritra, 3. 267. This motif of Hindu fiction, best known by its Buddhist name of saccakiriyā, is one of the most constant. Many illustrations of it are in my hands (including the trick-saccakiriyā), but the theme is in the competent hands of Dr. E. W. Burlingame, who hopes soon to publish an essay on the subject.

[32] Also printed Noutkéha.

The Yogin embalms his own body, buries it secretly, and then proceeds to impersonate Vikrama. One day the parrot reconnoitres the palace, and flutters about the head of the trick king, who is afraid that he will peck out his eyes. He therefore issues a proclamation to the hunters of his domains that he will pay a gold mohur each for parrots, in the hope that he will in this way get rid of the parrot inhabited by Vikrama. As many as are brought to him he promptly orders to be roasted. Now a certain hunter, Kalia by name, spreads a net under the tree inhabited by the royal parrot. The latter deliberately flies into the net, and is followed by all his tribe of parrots. Then he asks Kalia to release them all, on the plea that he will manage to obtain a thousand mohurs as his own price. The hunter is impressed with the royal parrot's accomplishments, and enters upon his scheme.

In the meantime the queens of the palace show repugnance to the usurper, and refuse him the proper marital attentions, so that he is led to cast his eyes upon the daughter of his treasurer Ounian, who is, of course, flattered by this distinction, and promises him his daughter in marriage. One day the maiden with her attendants goes to bathe in a certain bathing tank, passing and repassing on the way the house of the hunter Kaliah. The parrot, hanging in his cage outside, enchants her by his sayings and songs, so that she finally buys him at the exorbitant price of a thousand mohurs—the price which the parrot had set upon himself. When she takes him to her own apartments he notices there the signs of festal doings. He asks her what is the occasion, and she tells him that she is to be married to the king in four days. The parrot breaks out into hilarious laughter, believing that he sees a way to revenge himself on the Yogin. When the treasurer's daughter asks him to explain his hilarity, he tells her that she is making a mistake in marrying the king, since as his wife she would share his affection with a thousand others. She asks what she is to do, and he tells her as follows: "Buy a young deer, small and weakly. On the marriage day, when you are conducted to the palace, take him with you and tie him to the foot of your bed. When the king comes, tell him that you love the deer as a brother, and that marital intimacies must therefore not take place in his presence. The king, angry because you repel his advances, will kick the deer and kill him. You will then break out in lamentations over the death of the deer, your brother, and insist that you cannot endure caresses unless your eyes behold the deer alive, if only for a moment."

In due time all happens as prearranged. The amorous trick king, to please his new queen, enters the body of the dead deer, and immediately the parrot, who manages to be present, reoccupies his own body. Vikrama then mercifully enables the wicked Yogin to reenter his own body. Shamed and contrite he is allowed to go his way.

The story in this form is unquestionably less well motivated than that of the Vetālapañcaviṅçati, or Pārçvanātha Caritra, below. Especially, the manner in which, in the latter account, the Yogin is tempted by circumstances to enter upon his perfidious career is important and primary; the relation of the parrot king to his own queen is worked out much more artistically than in the Persian version.[33]

The remaining three versions are strikingly unitarian as to plot, but differ each from the other in some details, in style, and in extent. Merutuṅga's version is little more than a table of contents of the little Epic as told in Pārçvanātha Caritra (both are Jain texts), although the wording differs a good deal. Merutuṅga (Bombay, 1880) is presumably not very accessible; I give here the brief text of the original:

atha kasmiṅç cid avasare parapurapraveçavidyayā nirākṛtāḥ sarvā api viphalā kalā iti niçamya tadadhigamāya çrīparvate bhāiravānandayoginaḥ samīpe çrīvikramas taṁ ciram ārarādha, tat pūrvaprasevakena kenāpi dvijātinā rājño 'gre iti kathitam, yat tvayā māṁ vihāya parapurapraveçavidyā guror nādeyā, ity uparuddho nṛpo vidyādānodyataṁ guruṁ vijñapayāmāsa, yat prathamam asmāi dvijāya vidyāṁ dehi paççān mahyam, he rājan ayaṁ vidyāyāḥ sarvathānarha iti guruṇodite bhūyo-bhūyas tava paççāt tāpo bhaviṣyatīty upadiçya nṛpoparodhāt tena viprāya vidyā pradattā, tataḥ

[33] A story similar to that of Lescallier, but differing in many particulars, is told in "Les Mille et Un Jours" (Petis de la Crois), Vol. I., p. 281 (jour 57).

pratyāvṛtāu dvāv apy ujjayinīṁ prāpya paṭṭahastivipattiviṣaṇṇaṁ rājalokam avalokya parapurapraveçavidyānubhavanimittaṁ ca rājā nijagajaçarīra ātmānaṁ nyaveçayat, tad yathā,

bhūpaḥ prāharike dvije nijagajasyāṅge 'viçad vidyayā,
vipro bhūpavapur viveça nṛpatiḥ krīḍāçuko 'bhūt tataḥ.
pallīgātraniveçitātmānaṁ nṛpe vyāmṛçya devyā mṛtim,
vipraḥ kīram ajīvayan nijatanuṁ çrī(vi) kramo labdhavān.

itthaṁ vikramārkasya parapurapraveçavidyā siddhā.

Tawney's translation, "The Prabandhacintāmaṇi, or Wishing-stone of Narratives," pp. 9, 10, reads: Then, having heard on a certain occasion, that all accomplishments are useless in comparison with the art of entering the bodies of other creatures,[34] King Vikrama repaired to the Yogin Bhāiravānanda, and propitiated him for a long time on the mountain of Çrī. But a former servant of his, a certain Brahman, said to the king, "You ought not to receive from the teacher the art of entering other bodies, unless it is given to me at the same time." Having been thus entreated, the king made this request to the teacher, when he was desirous of bestowing on him the science, "First bestow the science on this Brahman, then on me." The teacher said, "King, this man is altogether unworthy of the science." Then he gave him this warning, "You will again and again repent of this request." After the teacher had given this warning, at the earnest entreaty of the king, he bestowed the science on the Brahman. Then both returned to Ujjayinī. When the king reached it, seeing that his courtiers were depressed on account of the death of the state elephant, and also in order to test the science of entering another body, he transferred his soul into the body of his own elephant.

The occurrence is thus described:

The king, while the Brahman kept guard, entered by his science the body of his elephant;
The Brahman entered the body of the king; then the king became a pet parrot;
The king transferred himself into the body of a lizard; then considering that the queen was likely to die,

[34] For the tradition that Vikrama became an adept in all sorts of magic, see Jülg, "Mongolische Märchen," p. 217.

The Brahman restored to life the parrot, and the great Vikrama recovered his own body.

In this way Vikramāditya acquired the art of entering another body.

It requires no sharp attention to note that this brief account reads like a digest of some such story as either of the following two. Especially the unmotivated passage of the king from parrot to lizard, and the still less clear mention of "the queen, likely to die" point to a fuller narrative. As against this the change in some proper nouns is of no significance, since it is a constant factor in the repetition of stories. One verse of the final summary, a sort of versus memorialis of the main points of the story, is repeated almost verbatim at the end of the Vetālapañcaviṅçati version, to wit:

vipre prāharake nṛpo nijagajasyāṅge 'viçad vidyāyā,
vipro bhūpovapūr viçeṣa[35] nṛpatiḥ krīḍāçuko 'bhūt tataḥ.

Uhle's prose version, edited and translated excellently from a single manuscript in ZDMG. XXIII. 443 ff., is again, a drier handling of some such version as that of the Pārçvanātha. The events of the two stories are alike step by step, but they are narrated here succinctly and with avoidance of all rhetoric. Though the Pārçvanātha introduces episodes, secondary moralizing, and much ornamentation, it represents a closer approach to the prime form than Uhle's version which, again, is not very much more than a table of contents. Inasmuch as Uhle's version is reflected step by step that of Pārçvanātha it need not be summarized, especially as the publication is readily accessible. In one or two points Uhle's version is readily improved in the light of Pārçvanātha's. Thus the passage, p. 446, l. 15, avameva asmāi dātavyā, which Uhle very doubtingly renders, "Give him only the lowest (Science)!" must mean, "Give him (namely the Brahman) the (Science) first!" In the immediate sequel the Science is, in fact, bestowed upon the Brahman first: tadā īçvareṇa *brāhmaṇāya rājñe ca* parakāya-praveça-vidyā dattā; cf. Pārçvanātha 3. 140, 141. Read in Uhle's text

[35] Uhle's manuscript has the word in this form; he makes out of it and the next word the compound viçeṣa-nṛpatiḥ. Merutuṅga's vipro bhūpavapur viveça is the true reading.

prathamāiva for avameva.—Read in Uhle's text, p. 448, l. 10, with the manuscript, ayaṁ mamopari caṭiṣyati, "he will hang down on the top of me;" in Pārçvanātha 3. 183, the same idea is expressed, mā mamāstu tadārohe pāpasyopari cūlikā, "he shall not mount as a tuft upon wretched me!"—On p. 448, l. 4, read mānavatī for 'mānavatī. This contrasts the word with amānavatīnām in l. 1: All the women of the seraglio are without pride, hence consort with the king; Queen Surasundarī alone is mānavatī "self-respecting" (cf. pativrata in l. 18).—On p. 450, l. 18 the word mṛnmayam is brachylogy for mṛnmayam iva: the false king, seeing the distress of Surasundarī, realizes that he can never really enjoy his royalty; his royal body, therefore, seems to him no better than clay. Note the phrase niṣkamalaṁ rājyam in the parallel passage, Pārçvanātha 3. 300.[36]

The most important version of the Vikrama story, as indeed of all stories that deal with our theme as a whole, is that told in Pārçvanātha Caritra (3. 105–324), edited by Shravak Pandit Hargovindas and Shravak Pandit Bechardas (çrāvakapaṇḍita-haragovindadāsa-becaradāsābhyāṁ saṁçodhitam). Benares, "Vīrasaṁvat," 2348 (A. D. 1912.)

The Pārçvanātha's account of Vikrama's adventures as a parrot is one of the best specimens of çloka-fiction. It is in modern Kāvya style and a worthy, if not the best link of the Vikrama epopee. It does not seem to have belonged to the "Vikrama-Carita" (Siṅhāsana), as it does not occur in any recension of that work. The Persian version which we know from Lescallier's "Le Trône Enchanté" (above), may be a loan from the Vikrama tradition at large. The story is likely to have been very popular among the Jains: one wonders whether it occurs in the Triṣaṣṭiçalākāpuruṣa Carita. I should, in any case, hardly think that it is original here.[37]

[36] Uhle prints several times para*kāyā*praveça for para*kāyā*praveça, following, I presume, his manuscript.

[37] The blatant Prākritism vidhyāyati, Sanskrit back-formation from vijjhāyati, "become extinguished," in 3. 297, is hardly sufficient to suggest a Prākrit original. The Pārçvanātha familiarly employs forms of this verb: 1. 489; 3. 297, 361, 893; 6. 609, 858, 1322; 8. 243, 385. See Johanssen, IF. III. 220, note; Zachariae, KZ. XXXIII. 446 ff. In 8. 243, correct vidhyāyapati to vidhyāpayati.

In Pārçvanātha it is, rather curiously, not made to illustrate āudārya, the standard moral quality of Vikrama, but rather his vinaya, or tactful conduct, which furnishes part of the text of a very long preachment (with excellent stories) in behalf of the four "worldly" virtues (lāukikā guṇāḥ): vinaya, "tact;" viveka, "discretion;"[38] susaṁga, "keeping good company;" and susattvatā, "noble endurance," from 3. 97 to the end of the chapter.

The following is a translation in full of this version of

Vikrama's Adventures in the Body of a Parrot.

Vikrama and His Queen Kamalāvatī (105–108).

There is in India, in the land of Avanti, a city named Avantī, resplendent with men and jewels gathered there from sundry strange lands. In that city there governed Vikrama, a ruler of the earth, of noble form, and he, though his own power was unrivaled (advāitavikrama),[39] kept extoling the accomplishments of Viṣṇu (Trivikrama). That king, though lavish with his wealth, was free from haughtiness; though endowed with might, was tolerant; and, though he himself was instrumental in exalting noble men, yet he was sincerely modest before them that deserved honor.[40] His was a beloved Queen, Kamalāvatī[41] by name, fashioned, as it were, by a skilful poet. She had many noble qualities: strength (of character), graciousness, sweetness, loveliness, and more.

Vikrama Extols the Glories of His Kingdom, and is Acclaimed by a Visitor (109–118).

One day that monarch, beholding his court that was like the palace of Indra, rejoiced exceedingly and asked those who were

[38] Vinaya, together with viveka, often, *e. g.*, Çālibhadra Carita 1. 21. A person having such virtues is called mahāpuruṣa, according to a pair of çlokas cited in a foot-note to the same text, 2. 2: udāras tattvavit sattvasaṁpannaḥ sukṛtāçayaḥ, sarvasattvahitaḥ satyaçālī viçadasadguṇaḥ, viçvopakārī saṁpūrṇacandranistandravṛttabhūḥ, vinītātmā vivekī yaḥ sa mahāpuruṣaḥ smṛtaḥ.

[39] Advāita, "unrivaled,' is punningly the name of Viṣṇu. The second meaning is: "And he, having power equal to Viṣṇu's, nevertheless kept praising Viṣṇu." The passage puns also thrice on the name of Vikrama.

[40] Note the play upon āunnatyam and vinataḥ.

[41] "Like a lotus."

present in his hall of audience: "Ah, tell me! Is there anywhere any accomplishment, science, wealth, or intelligence so marvelous as not to be found in my kingdom?"[42]

Then a certain visitor, skilled in polite accomplishments, his face blossoming out with joy, saw his opportunity, and declaimed aloud: "Long have I roamed the treasure-laden earth, but I have not beheld a union of the rivers of glory and knowledge like unto thee. In Pātāla (Hades) rules Vāsuki,[43] O king; in heaven Çakra (Indra). Both these, invisible as they are, are realized by the mind through thy majesty, O Ruler of the Earth! Wise men say, O Lord, that heaven is the goal of noble men. But even there is but one moon; in thy kingdom they are counted by the thousand![44] No wealth is that wealth, worthless is that accomplishment,[45] ignorance is that understanding which does not inhere in thee! Fragrant with the fulness of thy worth, controlling by thy might the surface of the earth,[46] thou doest now stand at the head of kings, as does the syllable *om* at the head of the syllables. Thou art wise with the mind of Vācaspati;[47] at thy behest the people enjoy life; gladly to thee bow the chief rulers of the circles of the earth. The warriors of thy enemies cannot endure thy scent any more than that of an elephant in rut. This thy host of dear wives is lovely with their bodies bent with the burden of the God of Love."[48]

[42] For this sort of boastful inquiry cf., *e. g.*, Jacobi, "Ausgewählte Erzählungen aus dem Māhārāṣṭrī," p. 39; Leumann, "Die Āvaçyaka-Erzählungen," II., 8. 3 (p. 15).

[43] The beautiful king of the serpents.

[44] The pun of the original cannot be reproduced perfectly: kalāvān, "moon," literally "having phases," means also "having accomplishments"; the implied plural kalāvantas means "having accomplishments," and at the same time punningly "moons." Sanskrit poets rarely neglect the opportunity of this double entente; see, *e. g.*, Kathās. 34. 163; 35. 114; the present text, I. 373; Çālibhadra Carita, I. 100.

[45] Sanskrit pun: niṣkalā, lit. "without accomplishment" (kalā).

[46] Sanskrit pun: vikramākrāntabhūtalaḥ, "with Vikrama astride over the surface of the earth."

[47] The Lord of Speech or Wisdom.

[48] I suspect that anañgabhara, "carrying the God of Love," is a kenning for "breasts," to wit, "with their bodies bent by the weight of their breasts."

The Visitor Points Out Vikrama's Single Shortcoming, Namely, Lack of the "Art of Entering Another's Body," and Vikrama Starts Out to Obtain It (119–124).

"You have here, my lord, that which exceeds magic,[49] wonderful in its mystery. Only one art, namely the 'Art of entering another's body,' is not found here." The king eagerly said: "Where is this found? tell me quickly!" And he replied: "On the mountain of Çrī, your Majesty, in the keep of a man, Siddheçvara."[50] The king dismissed the assembly, put his minister in charge of the affairs of the kingdom, and, eager to obtain this science, went out from the city by night. Putting aside such pleasures of royalty as were his; not recking the hardships of the road; thirsting after new experience; courage his sole companion, he went rejoicing. For low men strive for gratification of the body; average persons for increase of wealth. Superior men, on the other hand, strive for some wonderful end.[51]

And as he thus steadily proceeded on his way, as if drawn by the reins of his persevering spirit, the mountain of Çrī soon hove in sight.[52]

Vikrama Finds the Master of the Art, Obtains His Favor, and Meets a Rival (125–133).

There, in a certain place, the king perceived the Master of magic, of tranquil countenance, Siddheçvara by name. Joyfully he made obeisance, and then spake: "Through the mere sight of thy person I have attained my purpose, O Lord of Sages! The moon unasked is sure without stint to delight the world. Therefore I shall worship thy two lotus feet, union with which was difficult to obtain. Permit it!" And when he was not forbidden he did as he had said.

Now a certain Brahman had been on the spot a long time ahead

[49] The rather despised indrajāla.

[50] Lord of Magic.

[51] The same text, 1. 421, with a different turn: tundasya bharaṇe nīcās tuṣṭāḥ svīyasya madhyamāḥ, uttamā bhuvanasyāpi satāṁ svaparatā na hi. Similarly also 7. 121.

[52] In the third pāda read perhaps tasya for yasya.

of him in order to acquire the Science, but the very devotion he showed became a plague because of his constant importunity. As seed sown in a clear field comes up quite by itself, thus[53] also other good deeds prosper; covetousness alone results in misery. The Master was delighted with the king's pleasing and disinterested[54] services, such as preparing his couch, or washing his feet. Even stone idols, to whom devotion is paid with intent mind, straightway show delight.[55] How much more so do sentient beings! So the Master said: "Noble Sir! From your tactful conduct I know you to be some ornament of men, interested in foreign lands. I am delighted with your good breeding, so accept from me the 'Art of entering another's body,' in order that I may feel that I have discharged my debt for your devotion."

Vikrama Induces the Master Against the Latter's Inclination to Bestow the Art upon the Brahman, after That Receives it Himself (134–144).

Upon hearing this Vikrama, indifferent to his own interests, perceiving the disappointment of the Brahman who had come long before him, reflected with rising compassion: "How can I go away, carrying with me the Art, as long as this Brahman Guru who has been here a long time is, poor man, without hope? Hence I will make the teacher bestow the Art on him." And he said: "Reverend Sir, show me thy favor by bestowing the Art upon him who has long served thee zealously." Sadly the Guru replied: "Do not give a serpent milk to drink. He is unworthy, and with an unworthy person the art works great mischief. Think how, once upon a time, a Master of magic, seeing the bones of a lion, made the body of the lion whole and undertook to give him life; how, warned by his people, he nevertheless in his madness gave him life; then the lion slew him."[56] In spite of this reminder the king, intent upon another's interest, fervently embraced the Master's feet, and prevailed upon him to bestow the art upon that Brahman. Out of respect for

[53] Read tathā for yathā.

[54] Yāñcārahitāiḥ, literally "free from importunities."

[55] Thus in 7. 642, a stone idol of a Yakṣa, when implored, gives sweetmeats to a hungry boy.

[56] This refers to a familiar fable: see Benfey, Pañcatantra, I. 489; II. 332.

the command of the master the king himself also accepted the art, and the Magician expounded to him plainly the rules for its application.

The Brahman, though he had not been dismissed by the Master, was anxious to depart. Not so the king, even though he was given permission, because he was burdened with his affection for the Master. For noble men, after they have been laden with a pack[57] of accomplishments, do not turn their backs upon their benefactor, like peacocks upon a pool. But the Master dismissed the king, reluctant though he was, saying: "You have your affairs to regard, whereas I must devote myself to pondering on the Law (dharma)."

Vikrama and the Brahman Return Together to Avantī (145–149).

The king, having prepared himself for the execution of the Magic Art, and having taught the Brahman to do the same, arrived, perfect in the art, at his own city, accompanied by the Brahman. Out of friendly feeling he told the Brahman his own history: the ocean, though deep, because it is clear, displays its jewels. He passed the day in hiding, but at night, leaving the Brahman outside, he entered the city alone, in order to observe the state of his kingdom. Delightedly he noted that the people of the city everywhere were engaged in their usual pleasing occupations, such as celebrating in the temples of the gods, with song, festival, and drama, and if anyone happened to be worried by evil omens, such as sneezing[58] or stumbling, he propitiated the omen by exclaiming, "Long live Vikrama!"

Vikrama Enters the Body of the State Elephant that Has Just Died, and the Brahman Basely Usurps His Body and Kingdom (150–160).

Then the king observed that the people within the palace were upset because the state elephant had died. He returned to where

[57] It is not possible to reproduce the double meaning of kalāpa, which means both "bundle" and "peacock's tail"; noble men do not turn the knowledge which has been given them so as to show it as a tail to their benefactor; peacocks do turn their tails towards the pool which has refreshed them. It is rhetorical vakrokti.

[58] On various aspects of the sneeze as an omen see Henry C. Warren's paper in PAOS. XIII, pp. xvii ff.; and Tawney, "Translation of Kathākoça," pp. xx, xxii, and 75.

the Brahman was, and said to him: "Friend, look here, I have a mind to disport myself by means of my Art: I shall enter into the elephant so as to see something of what is going on within the palace. Do you here act as guardian beside my body, so that, with your help, I shall clearly recognize it." Thus he spoke, there left his own body, and entered into the carcass of the elephant. Then the prince of elephants as formerly disported himself blithely. Not only was his own elephant thus revived by the king, but also the entire royal court which had collapsed at its death was given life anew. Many jubilant festivals were set afoot for the prince of elephants, and these performances gave pleasure to the king even though he was occupying a strange body.

Then that base-souled man who had been set to watch the king's body, violator of faith, betrayer of friend, reflected: "Of what use to me is my own wretched body, plagued by racking poverty: I will enter Vikrama's body and serenely rule the kingdom!" Thus he did. The false king entered the palace quivering like an animal of the forest, because he did not know where to go. Holding on to the arm of the minister who met him in a flurry, he sat down on the throne in the assembly hall; the king's retinue bowed before him. The assembled multitude cried: "Fate has restored to life the king of elephants, and the king of men has returned again. This is indeed sugar falling into milk."[59]

The False King's Bahavior and First Encounter with the Queen (161–173).

But the false king did nothing for those who craved his customary conversation and favors, because he did not know their names, business, or other circumstances. The Queen's favorites came on rejoicing, but they did not find him, conditioned as he was, in the mood for sport, dalliance, or coquetry. The minister who had conserved the mighty kingdom obtained no audience; neither did the chief vassals, nor yet the citizens receive their meed of honor. When they saw the king in this condition they wondered: "Has some god or demon in the guise of the king taken possession of

[59] The same figure of speech, çarkarādugdhasaṁyogaḥ, in Pārçvanātha 6. 1349.

the vacant throne? Yet this does not tally, because his feet touch the ground and his eyes wink.[60] The king's mind must be wandering for some reason." The minister then concluded that, if the king's mind, inflamed by separation, was to be assuaged, that task could only be accomplished by the nectar of Kamalā's speech, and ordered a female attendant to conduct him thence. The false king then reflected: "Ah, what pleasant lot is mine, that has brought me to this station, hard to attain even in imagination!"

The Queen arose in confusion, and along with other ministrations, prepared for him the throne. But when she looked at the king again she fell to the ground as if in a faint. Her attendants raised her and asked: "What does this mean, your Majesty, tell us?" And the king also said: "How is it, your Majesty, that you are struck in a faint at my arrival?" On hearing his voice she was greatly pained and thought: "He looks like my beloved, yet afflicts me as an enemy!" Artfully she answered: "Your Majesty! At the time when you started upon your journey I uttered a fond prayer to Caṇḍī for your happy return: 'O Goddess, only after paying honor to thee, shall I look with my eye upon my beloved!' Now, having failed to do so before seeing you, Caṇḍī felled me to the ground. Therefore I shall let you know myself, O king, the time suitable for paying devotion to the goddess." Then the king, thus answered by the queen, went out of the palace.

Vikrama in the Body of the Elephant Escapes from Avantī (174–187).

At this time the Minister was adorning the state elephant[61] for the royal entry,[62] so that the people should see their sovereign at length returned. Also, that the king, seeing his city full of jubilant citizens, should become himself again, and commune with all as of old. Now the menials who were painting the ornamental marks on

[60] Similar personal characteristics of the god are frequently alluded to; they belong to the regular apparatus of fiction. See Nala 5. 23 = Kathās. 56. 272; also Kathās. 32. 31; 33. 178. See Tawney's "Translation of Kathāsaritsāgara," Vol. I, p. 561, note.

[61] Now inhabited by Vikrama.

[62] So we must translate rāja-pāṭyāi: the word is not quoted in the Lexicons.

the elephant kept saying one to the other: "Too bad, our Lord has become as one distracted by his journey to a strange land!" Then that prince of the elephants, hearing this, reflected in great perturbation: "Alas! What is this, woe me! The Brahman is certainly disporting himself as king in my body. Because, though warned by the Master, I yet induced him to bestow the Art upon this vilest of Brahmans, therefore this consummation has speedily come about. Because I forgot the precept taught me from childhood on, not to be too confiding, I nevertheless reposed trust in this man, therefore some trick of fate has surely taken place. The lowly may be raised up by fate; the lofty may be made insignificant—this very experience has brought him fortune, and robbed me of the same. All possessions on earth, elephants, dependents and the like, follow the body: since my body is gone all that is mine has come to belong to another. Just as eye-witnesses observe in this world even so it goes with a man in the next world. Therefore wise men arrange for good deeds to go with them as their true companion karma. In any case I shall now watch for an opportunity to make my escape: he shall not mount as a tuft upon wretched me!"

Having arrived at this decision the elephant raised up his ears, curved his trunk, and began to run swiftly, so that a great tumult arose. He was pursued by foot-soldiers, horsemen, and others by the thousand, but, as he ran more and more swiftly, they gave up the chase in disgust. Tired out he reached a distant forest and reflected dejectedly: "Compare now my former state of royal rule by a mere contraction of my eyebrow with this flight of mine! However, this plight is not a bit too sore for a fool who has taken up with a rogue!" Engaged in such reflections the king was assailed by the pangs of hunger, thirst, and the ocean of his regrets.

Vikrama Meets a Parrot-hunter, Enters the Body of a Dead Parrot, and Induces the Hunter to Take Him to Avantī to Be Sold as a Parrot of Price (188–195).

He reached the shade of a banyan-tree, which appeared to him like an only friend, and, when in time he had become composed, he saw a man standing there among the trunks of the banyan tree, engaged in killing parrots with a sling-shot.[63] The king, worried by his great body, hard to sate and unwieldy, considered: "What use is this body to me? Surely scope of action is more advantageous to success! Therefore I shall enter into the body of a parrot!" And thus he did.

Then the parrot said to the hunter: "Friend, what do you want to be killing so many parrots for? Take me to Avantī, and you surely will get a thousand ṭanka-coins for me; you must, however, give me assurance of personal safety." The hunter on hearing this gladly promised the parrot security and then took him in his hand. Next he fed him on meal[64] and water, put him at his ease, and then went to Avantī, where he took stand on the king's highway. When the people asked the parrot's price, the hunter said it was a thousand; he recites whatever Çāstras people ask for. Then they offered even more than the price asked, but the hunter, at the bidding of the parrot, refused to accept. Finally he demanded an exorbitant price.

Queen Kamalāvatī Buys the Parrot, Engages Him in Brilliant Conversation, and Makes Dispositions for His Comfort (196–209).

At this juncture some attendant maids belonging to Queen Kamalāvatī arrived. The parrot who knew well their dispositions, when accosted by one of them, recited in a sweet voice: "Pierced by the arrow of thine eyes, O graceful lady, one deems one's self happy and lives; not pierced one dies: here is a marvelous Science of Archery! Now do thou in turn recite something, that I may repeat it after thee in the manner of a pupil." But she retorted: "Thou art thyself a veritable Guru. Of whom shouldst thou be the pupil?"

Then the maid, delighted, went and reported to the Queen: "O Mistress! never before have I seen or heard a parrot so highly cultivated." The queen, enchanted by her report, concluded that Fate had furnished the parrot as a means by which she might divert

[63] Dhanurgolikā: the word recurs in the same text, 1. 317, in the form dhanurgulikā. This compound is not in the Lexicons.

[64] Cūrṇi for cūrṇa; so also this text, 1. 386; 7. 351.

herself with the art of poetry. Eagerly she addressed her: "Woman, go with speedy feet, pay the man his price, and bring hither the parrot prince!" Thus the servant did, and the hunter, contented, went to his home. She put the parrot into the lotus of her hand, and brought him into the presence of the queen.

When he saw Kamalāvatī joyfully coming to meet him the parrot extended his right wing, and chanted sweetly: "O Queen, in order to uphold thy weight, as thou restest on his left arm, Vikrama holds the earth as a counter-balance on his right arm."[65] The queen replied smiling: "O parrot! what you say amounts to this, that one cannot, unless he rules the earth, drag the load of a woman. Very pointedly have you stated that we impose a great burden: what wise person would not be pleased with a statement of the truth?" When she had thus out of modesty deprecated the parrot's flattery in description of herself, she put him in a golden cage furnished with agreeable resting places. She herself kept his abode sweet by washing and fumigating, and fed him on choice rose-apples, pomegranate seeds, and myrobalans. And whatever other things he desired to eat or drink she brought to him, and she constantly regaled herself with the nectar flow of his conversation.

Kamalāvatī and the Parrot Engage in a Contest of Riddles and Charades (210–227).

1. A Charade on the Mystic Formula oṁ namaḥ siddham uttaram.—The queen bid him recite some riddles, and without further ado the parrot, for mental diversion, recited: "On what do ascetics in contemplation ponder, and what is ever performed for a Teacher? What manner of thing do lofty men obtain, and what do pupils first recite?"

When the queen, thus asked, puzzled long, and did not know, the parrot gave the answer:—oṁ namaḥ siddham uttaram.[66]

2. Riddle on the Rounding of the Lips in Pronouncing Labials.—

[65] His right wing symbolizes Vikrama's right arm in the following passage. It is a common conceit that the king bears the burden of the earth; *e. g.*, Prabandhacintāmaṇi (Tawney's Translation), p. 107.

[66] The formula is, of course, treated analytically: in the fourth question the adjective uttaram which in the formula qualifies siddham is taken as a noun in the sense of "answer." The other three are: (1) The sacred syllable om; (2) namaḥ, "obeisance"; (3) mystic perfection.

The parrot next propounded the following riddle: "It does not inhere (lag) in nāga and nāringa; on the other hand it does inhere in nimba and tumba.[67] When one says, 'inhere' (laga) it does not inhere; when one says, 'do not, do not inhere' (mā mā, sc. laga) it inheres mightily.[68] What then is the answer?" When the queen had thus been questioned by the parrot, she reflected a moment and said: "Ah, I know; it is the rounding of the lips (in the pronunciation of labials)."

3. Riddle of the Painter's Brush.—"By it[69] serpents are rendered poisonless, gods are bereft of might, lions are rendered motionless; yet children carry it in their hand—what is it?" asked the queen. The parrot at once knew and answered: "Hear, your Majesty, I know it:—A painter's brush."

4. Riddle of the Fly and the Spider.—"A hero that slays elephants,[70] mounts lions, plagues soldiers, him, your Majesty, I have beheld bound in the house of a weaver."[71] When she had heard this riddle, propounded by the parrot, she guessed and laughingly exclaimed: "I have it, this hero is plainly the fly!"

5. A gūḍhacaturthaka, or Trick of Supplying the Fourth Verse of a Stanza.[72].—"A host of serpents to look like lotus-roots; black

[67] It is quite impossible to reproduce the ingenious trickery of this statement: na laged nāga-nāringe has two distinct values: the first as above; the second meaning is "the sound na inheres in nāga and nāringa." When taken in that sense the second pāda becomes yet more tricky: "again it inheres in nimba and tumba," which is precisely the reverse of the truth, because na does not inhere in these two words. That is part of the catch: the labials mb is what inheres in the two words.

[68] The rounding of the lips in pronouncing ṃ in the word mā.

[69] The text reads yathā, which must be corrected to yayā.

[70] Alluding perhaps to the familiar fable in which a fly helps slay an elephant, Benfey, Pañcatantra I. 241; II. 95.

[71] Text, kolikagrhe = kāulikagṛha. Cf. kolikagardabha in Divyāvadāna, 12. The weaver here is, of course, the spider.

[72] The text prints this and the next charade as follows:

mṛṇālābhaṁ ahivyūham añjanaṁ kṣīrasannibham |
nabhaḥ karpūrasaṁkāçaṁ rājñyā gūḍhacaturthake || 219 ||
iti pṛṣṭe çukaḥ prāha karoti yaçasā mahān |
doṣo 'pi guṇatāṁ yāti viṣam apy amṛtāyate || 220 ||
["mitrāṇi çatravo 'pi syuḥ" iti çukena gūḍhacaturthake pṛṣṭe rājñī caturthapadaṁ prāha—anukūle vidhāu nṛṇām"]

collyrium to resemble milk;[73] a cloud to look like camphor"—when the parrot was asked by the queen to supply the missing fourth verse, he answered—"a great man through his influence contrives to make."

6. Another gūḍhacaturthaka.—"Even sin assumes the nature of virtue; even poison acts as nectar; even enemies may become friends"—when the parrot thus asked the queen to supply the missing fourth verse she answerd—"when destiny is favorable to men."[74]

7. Riddle on the letter ā.—"Even a beggar (kṛpaṇa) is fit to be honored by a king (by lengthening the interior *a* of kṛpaṇa to *ā* so as to make it kṛpāṇa, 'sword'); even the noble (udāra) is beset with greed (by shortening the *ā* of udāra to *a*, so as to make it udara, 'belly'); by whose presence or absence even he who is addressed by name (ākhyāta) is not known (akhyāta)." When the parrot was thus questioned he answered:—"The letter ā (ākāraḥ)."

8. Riddle on the Syllable dhi(k), or dhikkāra, Treated as dhikkāra.—"With (the prefixed syllable) ā it expresses sorrow (ādhi);

It should be printed as follows:
mṛṇālābham ahivyūham añjanaṁ kṣīrasannibham |
nabhaḥ karpūrasaṁkāçaṁ—rājñyā gūḍhacaturthake
iti pṛṣṭe çukaḥ prāha—karoti yaçasā mahān || 219 ||
doṣo 'pi guṇatāṁ yāti viṣam apy amṛtāyate |
mitrāṇi çatravo 'pi syuḥ—

iti çukena gūḍhacaturthake pṛṣṭe rājñī caturthapadaṁ prāha—
anukūle vidhāu nṛṇām || 220 ||

For this kind of entertainment see Zachariae in "Gurupūjākāumudī," pp. 38 ff.

[73] See Böhtlingk's "Indische Sprüche," 7568: nāñjanaṁ çuklatāṁ yāti, and cf. ibid., 2146.

[74] "When destiny is favorable to men" = anukūle vidhāu nṛṇām. The sentiment of this speech is expressed from the opposite point of view in Pārçvanātha, 2. 792–3:

pratikūle vidhāu kiṁvā sudhāpi hi viṣāyate,
rajjuḥ sarpībhaved ākhubilaṁ pātālatāṁ vrajet.
tamāyate prakāço 'pi goṣpadaṁ sāgarāyate,
satyaṁ kūṭāyate mitraṁ çatrutvena nivartate.

"When fate is adverse nectar turns to poison, a rope turns serpent, a mole-hole leads to inferno. Light turns darkness, a puddle in the footstep of a cow turns ocean; truth becomes guile, and friendship vanishes in hostility." Cf. Böhtlingk, "Indische Sprüche," nr. 4226.

with (the prefixed syllable) vi it is pondered by pious men (vidhi, 'religion'); with (the prefixed syllable) ni it is desired by people (nidhi, 'treasure'); by itself it makes no sense (dhi, which is no word)."[75] When the queen was thus asked by the parrot she answered:—"The syllable dhik (dhikkāraḥ)."[76]

9. Riddle on the Syllable na.—"That which is at the beginning of night (first syllable of naktam, 'night'), at the end of day (last syllable of dina, 'day'), and different from evening;[77] though it is in the interior of the mind (mānasa, which has the syllable na in the middle) it is somehow not[78] perceived." When the parrot had been thus questioned by the queen he answered:—"The syllable na (nakāraḥ)."

10. Riddle on the Compound īhālaṁkārasaṁgatam, "a Combination of Effort and Rhetoric."—The next needs to be before the eye, to wit:

lakṣmī-kheda-niṣedhārtha-brahma-cakrāṅga-çarmaṇām,
ke çabdāḥ vācakāḥ khāntaṁ brūhi kiṁ ṇāntaṁ ichasi.
arthinām kā sadā citte[79] kā dagdhā kapinā purā,
ikṣuyaṣṭeḥ kim ichanti kiṁ ca haṅsasya sundaram.
sukavīnāṁ vacaḥ kīdṛg çukena viṣame kṛte,
iti praçne yadā rājñī nāvadad mūḍhamānasā.
ekadvisarvavarṇānāṁ paripāṭīkrameṇa saḥ,
çuka evottaraṁ cakre īhālaṁkārasaṁgatam.

The trick of this riddle is (1) To divide īhālaṁkārasaṁgatam into single syllables each of which furnishes a word, disregarding vocalic fusion; (2) to divide it into pairs of syllables, each pair being a word; (3) to allude to the word as a whole: (1) "What

[75] The last passage, kevalas tu nirarthakaḥ, seems to hold a second meaning, to wit: "by itself it has an unmeaning letter ka."

[76] Merutuṅga's Prabandhacintāmaṇi, p. 156, has a similar charade, in which the prepositions ā, vi, and sam are prefixed to the word hāra.

[77] The trick here appears to be as follows: pradoṣo, "evening," does not contain the syllable na; therefore it is different from na. Yet evening should be at the beginning of night and end of day. Hence the catch: "That which is at the beginning of night, the end of day, and yet something else than evening."

[78] Again a catch: lakṣyate na kathaṁcana, with second meaning, "na is somehow perceived."

[79] Text, erroneously, cite.

words express the goddess Lakṣmī (ī); distress (hā); forbidding (alam); Brahma (ka); part of a wagon (ara, 'spoke'); protection (sam); next tell the letter which follows the letter kha (in the kavarga of the Hindu alphabet, namely ga); do you wish also the letter which follows the letter ṇa (in the ṭa-varga of the Hindu alphabet, namely ta). All this makes up the theme ī + hā + alaṁ + ka + ara + saṁ + ga + tam. = īhālaṁkārasaṁgatam." (2) "What is ever in the mind of those who desire?" (Answer: īhā "effort"); what city was burned by the monkey? (Answer: Laṅkā, in Ceylon); what do people desire of sugar-cane? (Answer: rasam 'juice'); and what is beautiful in the haṅsa-bird? (Answer: gatam, "its gait").[80] This again makes up the theme: īhā + laṁkā + rasaṁ + gatam. (3) "What sort of a word of skilled poets is this?" Thus the parrot had put this tangled riddle, and when the Queen, her mind bewildered, did not answer, the parrot with successive arrangement of the word into single syllables, two syllables, and all its syllables gave the answer: īhālaṁkārasaṁgatam ("a compound of effort and rhetoric").

Salutary Instruction (*Hitopadeça*) *by the Parrot* (*228–233*).

Then the queen asked the parrot: "Recite some well-spoken words devoted to salutary instruction!" The parrot, thus requested by the queen, then replied: "Listen! A deed that is done after careful deliberation; speech that is well-weighed; passions completely under control never work mischief. Thought charged with rectitude; speech adorned with sweetness; and a body inclined with courtesy do not belong to ignoble men. Wrath of noble men endures but one moment; their vow for as long as it is set. But their responsibilities in the world last as long as life itself. Self-praise and abuse of others; envy of the good qualities of noble men; and inconsequent chatter drag one down low. Speech without malice towards others; serene dignity of countenance; and a mind discreet about what it has heard, these qualities lead a man aloft."

[80] The gait of the haṅsa is considered beautiful. A graceful woman is haṅsagāminī, Manu, 3. 10. In 7. 603 of the present text five animals are said to be conspicuous for their graceful gait: haṅsa, elephant, bull, krāuñca-bird, and crane. Cf. Böhtlingk, "Indische Sprüche," 7360.

Discretion Illustrated by the Simile of the Three Skulls (234–238).[81]

"Thus a certain king of yore caused his wise men to make the test of three skulls[82] that had been brought by a stranger from another land. On that occasion a thread put into the ear of one of the skulls came out of its mouth: the price of that skull was a farthing (kaparda), because it would blab what it had heard. Again, a thread put into the ear of the second skull came out at the other ear: the price of that skull was a lakh, because it forgot what it had heard. But the thread inserted into the ear of the third skull went straight down the throat: that skull was priceless, because what it heard remained in its heart. Conforming with this, O Queen, who that has ears and hears reference to another's guilt does not become discreet in mind?"

Kamalāvatī, the Parrot Protesting, Adopts Him as Her Husband (239–245).

Now Kamalā's soul was so delighted by this discourse of the parrot, that she made the following promise: "I shall certainly live and die together with thee, O parrot!" But the wise parrot answered her: "Say not so, beloved wife of a king! Of what account am I, a wee animal, beside thee, beloved of Lord Vikrama? Moreover, O Queen, thy husband, out of love for thee will come and go; how canst thou avoid fond intercourse with him?" Upon hearing this Kamalā, sighing deeply, exclaimed: "O paragon of parrots, my eye tells me that my beloved has returned from abroad, but my mind says not. Disturbed by this, I shall devise some answer and dismiss the king. But you, as a husband, shall afford me delight, that do I here declare!" Then the king-parrot, filled with a great joy, reflected: "The Art called Entering another's body has been of profit to me, for how else could I have tested the heart

[81] Cf. R. S. Mukharji, Indian Folklore, p. 36; S. Devi, The Oriental Pearls, p. 115; E. J. Robinson, Tales and Poems of South India, p. 328. A mere allusion to the test of the three skulls, which is not entirely explained in the story, may be found in the Kathāprakāça; see Eggeling in "Gurupūjākāumudī," p. 120 ff. Cf. also the Prākrit verse quoted from the Vikrama Carita (126) by Weber, Ind. Stud. xv. 345.

[82] Trikapālīparīkṣaṇam; not in the Lexicons.

of the queen? Moreover, judging from this show of feeling other delights shall be mine.!"

The Parrot at Kamalāvatī's Request Preaches the Law (246–252).

The queen again addressed the parrot: "I am vastly pleased with thy nectar-sprinkling speech; do thou then tell something of the Essence of the Law." Then the parrot said: "Listen, O Queen, I have heard from the mouth of the Master that it is meritorious to benefit others, sinful to oppress others. No moral obligation compares with abstention from doing injury, no vow with content. Nothing makes for purity as does truth; no ornament is there the like of virtue. And it has been well said: Truth is purity; ascetic practice is purity; control of the senses is purity; pity of all living things is purity. Purification by water holds but the fifth place. To cast away filth of mind, that is a bath indeed; to bestow security from injury, that is a gift indeed; to know truth's essence, that is knowledge indeed; to extricate the mind from the senses, that is contemplation indeed. Even the householder[83] who constantly eats food in faith may through purity of mind attain to the law; without it, even ascetic practice is in vain. For it has been said: The mind of man alone is the instrument of bondage or release;[84] in bondage it clings to the senses, but in release it casts them away."

Episode, Illustrating the Superiority of Soul-purification over Meritorious Deeds (253–286).

"Thus once upon a time a wise king heard that his brother, a Sage, had arrived at a part outside of the city; then he went there followed by his retainers. The king, adorned with the bloom of his hair that bristled from joyous emotion,[85] paid his respects to the Sage, listened to the law from his mouth, then returned to his palace. The chief queen, longing in turn to greet her brother-in-law, the Sage, took leave of the king in the evening, and made the following vow: 'I must in the morning, sur-

[83] In Jain religion the lay householder (gṛhin, gṛha-vāsin, çrāvaka, etc.) is distinguished from the professional ascetic (yati). The religious obligations of the former class are less stringent than those of the latter.

[84] Bondage in saṁsāra; release in nirvāṇa.

[85] Horripilation with the Hindus is a symptom of joy as well as of fear. In literature it is almost always connected with joy.

rounded by my retinue, salute this Sage, Soma by name, and not take food before he has been feasted.' Now on the road between the city and the park there was a river. When she arrived there by night the river was flooded, and flowed too deep for crossing. At that the queen was perplexed in her mind, and in the morning asked her husband how then she might obtain her heart's desire. The king replied: 'Queen, let not such a thing worry you, because it is easily managed. Go cheerfully with your retinue! On the hither bank of the river remember first to call upon the River Goddess, join your hands in supplication, and with pure mind recite: "O Goddess River, if my husband has practised chastity since the day on which he paid his devotions to my brother-in-law, then promptly give me passage!"'[86] Upon hearing this the queen reflected in surprise: 'Why now does the king, fifth Protector of the World, say such an absurd thing? Since the day of his devotion to his brother I have become pregnant by him with a son; that wifely state of mine he knows full well. But why be in doubt when the test is at hand, particularly since devoted wives should entertain no doubt about a husband's statement. Because a good wife that doubts the instruction of her spouse, a soldier that of his king, a pupil that of his teacher, a son that of his father break their vow.' Thus the queen reflected, and went with her equipment and train to the bank of the river, where the face of the earth was crowded with the assembled people. There she called upon the River Goddess, paid honor to her with a pure mind, and openly made the truth-declaration,[87] as told her by her husband. At once the river banked its waters to the right and to the left, became shallow, gave passage, and the queen crossed to the other side.

"She thought herself favored, and then paid proper respect to the Sage. And when she had received his blessing the Sage asked the devoted wife in what manner she had crossed the river. She told the whole story, and then asked the Lord of Sages how her husband's inconceivable chastity was valid. He then said: 'Hear Lady! When I took vow, from that time on the king also, intently eager for holiness, became in his soul indifferent to earthly matters. But as

[86] The notion that rivers may be induced by prayer to furnish passage is a very old one in India; see Rig-Veda 3. 33. 9; 4. 19. 6.

[87] Satyaçrāvaṇā = the Buddhist saccakiriyā; see above, p. 16, note.

there was no one available to bear the burden of royalty, he kept performing his royal acts in deed but not in thought. Thus it has been said: A woman devoted to another man follows her husband;[88] thus also an ascetic devoted to the truth follows the saṁsāra.'[89] Therefore, though he is in this wise leading the life of a householder, the king's chastity is valid, because his mind is unspotted, even as a lotus that stands in the mud.'

"The queen then paid reverence to the Sage, and having attained to supreme joy went to some spot in the forest and pitched her camp. She had a rasavatī-pudding[90] prepared for herself and train, ordered the Sage to be supplied with the same, and thus fulfilling her vow, ate of it herself. She then went to bid adieu to the Sage, and asked him how now she was to recross the river. The Sage replied with tranquil voice: 'You must say to the River Goddess: "If that Sage since taking his vow has steadily lived in fast, then make passage for me!"' The queen in renewed surprise went to the bank of the river, recited the words of the Sage, crossed the river, and arrived home. She narrated everything to the king, and asked: 'How could the Sage be in fast, since I myself entertained him with food?' The king replied: 'You are simple, O Queen, you do not grasp the spirit of the law: the lofty-minded Sage is indifferent to both eating or non-eating. Even though the Sage in the interest of the law eats pure food that he did not prepare or order to be prepared, nevertheless that is said to bear the fuit of an unbroken fast. Mind is the root, speech the crown, deed the branch-expansion of the tree of the law: from the firm *root* of that tree everything springs forth.'

"When the queen had comprehended this lofty-mindedness of her husband and brother-in-law, in full sympathy[91] she purified her own mind also." The parrot then said: "This essence of the law which I, the parrot, have proclaimed to you illustrating it by story, that verily is illumination[92] by light. The mind even of noble

88 See the story in Benfey, Pañcatantra, II. 258, in which this idea is employed to trick a confiding husband; cf. ibid., I. 371.

89 These rather loose parallels are intended to illustrate the paradoxical contrast between the king's action and state of soul.

90 According to Böhtlingk's Lexicon rasavatī is curdled milk with sugar and spices; see Tawney's Translation of Prabandhacintāmaṇi, pp. 156, 157, 196.

91 Anumodanā, fem., not in the Lexicons.

92 Dhavalana, abstract noun from dhavalaya, not in the Lexicons.

women, as long as it derives knowledge from natural disposition alone, is quite sure to go astray like a conceited Paṇḍit."

Kamalāvatī Divines that the Parrot is Vikrama, Whereupon the Latter Abandons His Body and Enters into the Body of a House-lizard (287–299).

When the queen had heard this clear and substantial speech[93] of the parrot, she thought that there was no one quite like him in fulness of knowledge: "My faltering mind was under delusion: this is the king, here speaks his voice!" While the queen was thus rejoicing sleep descended upon her. Then the king in the guise of a parrot, noticing there a dead house-lizard,[94] entered into it, that he might test whether the queen would virtuously keep her word. Soon the queen, waking of herself, and seeing the parrot-prince lie soundless, began to rouse him with hundreds of tender endearments: "Speak, O parrot! why dost thou not to-day pour nectar into my ears? Thou who hast awakened[95] me, shall I in turn awaken thee? Abandon sleep, arise, recite the morning prayer! Wherefore this darkness of sleep on the part of noble beings that make shine the torch of their knowledge? Why dost thou to-day not give answer, how didst thou wax wroth with me? Since thou preservest thine own form shall I not forsooth suspect deception even in thy sleep?"

When the parrot, urged by such and other words did not wake up she arose in distress, and touched him with her hand. Even so he did not breathe; then the queen fell in a faint. Soon coming to herself she wailed and exclaimed: "Woe me, O parrot, why has this wretched fate[96] overtaken thee? O evil destiny, tell me why he, who is like a sandal-tree,[97] has been consumed by thy fire? Even a

[93] The original here contains an untranslatable metaphor: suvivāraṁ sagarbhaṁ ca vacaḥ. Her utterance is compared to a womb wide open (suvivāra) and containing an embryo (sagarbha); cf. sagarbhavacana in this text, 7. 294.

[94] Gṛhagodhaka, not in the Lexicons.

[95] The double meaning of the original, which means both "awaken" and "enlight," must be left to the guess of the reader of a translation.

[96] Dāivakam.

[97] Sandal-wood is the emblem and quintessence of coolness; its consumption by fire marks an extreme. See Kathās. 31. 23; "Indische Sprüche," 340, 663, 1763, 2215, 5278, 7360.

forest-fire is quenched[98] by constant streams of water, but thou wert not deterred by the hundredfold flow of the nectar of the parrot's speech. Ah me! O king of birds, slain am I, to whom the stream of thy words had given life! Alas! I spoke falsely for a moment in order to delay thy death."[99] Thus speaking she, with resolution caused by the parrot's death, bathed and anointed his body, and endeavored to perform the other duties suitable to the occasion.

The False King, Stricken with Remorse at Kamalāvatī's Despair, Enters the Body of the Parrot, Whereupon Vikrama Returns to His Own Body (300–305).

The false king, upon learning all this from the queen's attendants, exclaimed in consternation: "Alas, alas, this entire kingdom, without Kamalā,[100] will be profitless to me: I must go and restore her to life!" He did as decided, but when she would not at all be restored, he once more asked: "O Queen, if I assure you that the parrot is alive, will you then also live?" And when she had assented he thought his desire fulfilled: he determined to endow the parrot with life, carry him to some other place, release him, and, thus having kept his promise to the queen, reënter his own body. After deciding upon his course he abandoned his body in a retired spot, entered the parrot and disported himself. The king, in turn left the body of the house-lizard, and entered his own body. And when he had taken on his body, resplendent like a mighty mass of cloud, Vikrama, the king, quickly went into the presence of the queen.

Kamalāvatī Excuses Her Failure to Fully Recognize Vikrama in the Parrot (306–313).

At sight of him Kamalāvatī grew radiant as a garland of lotuses,[101] and was adorned with loveliness. And the completely

98 Vidhyāyati, Sanskrit back-formation from Prākrit vijjhāyati; see p. 21, note.

99 She blames herself for speaking to the parrot as though he were alive at a time when she had no good reason to doubt his death, and to act accordingly, as she now proceeds to do.

100 Niṣkamalam: pun upon Kamalā, the pet (hypocoristic) name of the queen, and some meaning of kamala; either "without lotus," or "without wealth." The play of words cannot be reproduced in a translation.

101 The original for "garland of lotuses," kamalāmāla, puns on the name of the queen.

faithful wife was embodied in the queen who had been distracted by the arrival of a strange man, but promptly became herself again at the arrival of her own husband. When she perceived that his speech, his gait, his habit, and his regard were just as before, she fell crying at his feet and then quickly rose and clung to him. Then she exclaimed: "Life, my Lord, became one grief when you were absent in a strange land, and yet another grief when you appeared in a delusive form. Wretched woman that I am, how I was deceived by a false story, and what sort of test could I apply through my knowledge of strange countries?[102] What, under such circumstances, I did accomplish, being a mere woman, is wholly due to your favor, born of the graciousness of your feet. Now do you, first of all, explain to me without omission each of the shapes you assumed." The king replied: "Your dearly beloved parrot yonder shall narrate to you." The queen then said: "Your majesty! what purpose is there in an affair that death has taken in charge? The parrot whom I have just now looked upon has become violently repulsive to me."

Vikrama Generously Forgives the Treacherous Brahman, and is Reunited with Kamalāvatī (313–324).

The king took the parrot in his hand and said: "What have we here, O Brahman?" The parrot replied: "That which befits them that deceive their teacher, their king, and their friend. My king art thou, because thou rulest men; my teacher, because thou hadst the Science bestowed on me; my friend, because thou didst put confidence in me: all that has been cut off by me as if by excision.[103] The king answered: "Look here, Brahman, why do you speak thus beside the mark? Your conpanionship[104] has enabled me to pass the troublous experience of the Science." The Brahman replied: "Full well thou knowest, O King, what sort of companionship was mine.

[102] She means to say that she had no means of quizzing the fake king about his experiences during his absence.

[103] Luptaṁ lopavad mayā, seemingly a grammatical pun: "has been elided by me as if by elision."

[104] Lalitāñga forgives the injuries done him by the wicked Sajjana for the same reason, namely, former companionship, Pārçvanātha, 1. 293. See the same trait in the story of Mūladeva, *Proceedings* of this Society, Vol. LII., p. 643.

O thou great ocean of propriety and virtue! Me that has strayed from my own house and body, the tricker of friend, sovereign, and teacher, it does not, O Protector, befit thee to see and to touch! There is no noble wife like unto Kamalā, no great man like unto thee, and no base-souled creature like unto myself. Do thou then rule thy kingdom a long time; as for me, seize me by the left foot and cast me somewhere that I may devote myself to a better life.[105] All this shall serve thee as a lesson in the wickedness of men!"

The king heard him, his heart was softened by pity, he forgot the evil deed, and said: "See here, ours is the same Science; how then can I seize you by the foot? Go whither you desire, enjoy wealth somewhere while doing good to others in deep devotion to the law!" After he had thus dismissed him, Vikrama ruled his kingdom in Kamalā's society, happy in heart, devoted to the performance of the law. Thus the Science obtained by him through tactful conduct led to a happy issue, but the very same Science imposed great misery upon the Brahman who was wanting in that same virtue.

[105]Karma seve.

NAMING AMERICAN HYBRID OAKS.

By WILLIAM TRELEASE.

PLATES I–III.

(*Read April 13, 1917.*)

Two methods of designating hybrids are sanctioned by the International Botanical Congresses of Vienna and Brussels—employment of a compound trivial name composed of the names of the two parent species, separated by the conventional × sign, or use of a new trivial name in a binomial preceded by the same conventional symbol. Taking a now well-known oak hybrid as illustration, the first method would cause it to be referred to as either *Quercus alba* × *Prinus* or *Q. Prinus* × *alba,* and the second as × *Q. Saulii.*

Various qualifications of the first procedure have been proposed or put in practice now and then to show which is the male and which is the female parent species, or to indicate by use of the symbol > or < which parent is more closely resembled by the hybrid. The first of these is possible only when hybridization has been effected artificially or when the mother plant is known, so that uniformity in its use and therefore general comparability is impossible. As a fact no effort has been made to indicate the resemblance to either parent in the majority of cases; nor is it likely that different observers would reach identical conclusions in this respect for many specimens of hybrids because, among other things, no agreement exists as to which of several non-concordant characters is to form the basis of judgment. Amplification of this composite name method permits the similar designation of secondary and tertiary or higher hybrids, but in an increasingly cumbersome way, so that the polynomial indication of such forms becomes very quickly a confused symbolically abbreviated description rather than a name. Even in the simple case of such a first cross as has been taken for illustration, every rectification of error in the names applied to either parent species entails a change in each of the hybrid designations. For instance, if Professor Sargent's conclusion is to be accepted[1] that the specific name *Prinus* must be applied to the cow oak, and not to the rock chestnut oak, so that the name *montana* is to be restored for the latter, the permissible designations of this hybrid at once change to *Q. alba* × *montana* and *Q. montana* × *alba*. This sort of double correction must be applied every time that the name of either parent is dragged into the lamentable whirlpool of nomenclatorial debate, which in this particular branch can be made hopelessly confused and voluminous by even a fraction of the permutations that are likely to be made.

Binomial designation of each hybrid—simple, secondary or of a higher order—offers escape from some of the difficulties attending the multiple-name method. A binomial applied to a hybrid at once falls under the procedure customary with ordinary specific binomials, and no matter what changes the trivial names of the parent species may undergo its own applicability rests solely on the basis of priority. In case of a change of generic names it is merely dragged about with the species it is derived from, and in the rare instances of what are or may come to be considered bigeneric hybrids it does not itself suffer change in the new connection and may cease to be dragged about, even, so soon as such hybrid genera are given uniformly definite names of their own, such, for instance, as *Lælio-Cattleya,* applied to the hybrid between the orchid genera *Lælia* and *Cattleya.* Its position is even more stable than that of varietal or subspecific trivial names, the treatment of which prescribed by international conventions is not followed uniformly in different countries or by different writers.

One inherent defect in such binomial designation of hybrids requires serious consideration. The scientific name of a species or variety stands for an assemblage of individuals no two of which may be alike but which possess characters of agreement by which they differ from other assemblages of individuals to which they are related in the genus they represent as species or in the species they represent as varieties: it stands clearly for a morphological concept. In contrast with this, the binomial applied to a hybrid ap-

[1] *Rhodora.* 17: 40, 1915.

pears to be an expression of parentage, which may be supported by morphological characters when its individual representatives meet this test of mutual resemblance and difference from other named assemblages, but which falls to the ground when they differ so much among themselves as to make a diagnostic description impossible. This is the case frequently, and the now commonly known Mendelian laws of segregation prepare one for the expectation that in some cases, at least, purely dominant and recessive seedlings of a known hybrid will be no longer other than reversions to one or other parent form if raised from self-fertilized seeds.

Obviously the application of binomials to hybrids is in a different category from the use of such names for species or varieties: it is not a matter of taxonomy, the stability of which is generally recognized as dependent upon a morphological basis: but a phase of nomenclature, a means to the end of convenient reference to the various kinds of things. There is so much to be said in its favor that botanists are coming to employ it generally. A special difficulty and source of confusion inherent in the designation of hybrids under any method lies in the fact that their parentage is more commonly assumed from their characters or inferred from circumstantial evidence than actually known. Whatever the method, synonymy must grow with every mistake made in this respect: but the remedy for this lies with those who are responsible for reporting the parentage of supposed hybrids, as, elsewhere, it lies with those who are responsible for segregating species or other formal groups.

Such a case as that of Bartram's oak, × *Quercus heterophylla,* presents an interesting aspect of the question. This was named by Michaux as though it were an ordinary species. Subsequent botanists have regarded it as a cross between *Q. Phellos* and *Q. velutina.* The behavior of seedlings from trees taken to be representative of *heterophylla* has led to the conclusion that these were a cross between *Q. Phellos* and *Q. rubra.* On this evidence, they have been given by Schneider the binomial × *Q. Hollickii.* If the purpose were to name the idea of a possible cross, this would obviously be necessary, since the idea of the cross between *Q. Phellos* and *Q. velutina* would have been called × *Q. heterophylla.* As a matter of fact, the name was given to a definite plant form, and follows that form whatever changes of theory or knowledge its parentage may undergo. For this reason, × *Q. Hollickii* passes into synonymy as a mere equivalent of the earlier name × *Q. heterophylla;* and the latter does not in any way affect the naming, on its own merits, of a hybrid between *Phellos* and *velutina* whenever that is brought to light. Such a plant is believed to be that which is here called × *Q. dubia,* though some doubt attaches to its parentage. If an error has been made, × *Q. dubia* in its turn will still stand for this form if it can be identified, which is less certain than for *heterophylla;* and a real hybrid between *Phellos* and *velutina,* if ever found, will finally be given a definite name quite irrespective of these efforts. A somewhat comparable case is afforded by × *Q. runcinata.*

In my study of the American oaks, briefly summarized recently,[2] I have had to account for a considerable number of hybrids, some of which have been described or even figured, occasionally as species in the ordinary use of the term, and some of which have been made known by reference to specimens more or less generally distributed by their collectors. No collective treatment of these forms has ever been made: they are not to be found severally assembled in any herbarium that I have seen, being inserted sometimes under one parent, sometimes under the other—now under one name, now under another for the parental species—and exceptionally under binomials of their own. The following table accounts for everything of this description that I have encountered either in herbaria or in publications on *Quercus;* it is published partly to call attention to the general desirability, as I see it, of designating hybrids by binomials, and partly to facilitate a workable assemblage of oak materials in herbaria.

Lest misapprehension arise, it should be stated that what is here called *Q. rubra* is the common red oak of the eastern United States; though, following Professor Sargent's suggestion of a current misidentification, Mr. Ashe proposes replacing this name by *Q. maxima,* and using *rubra* for what is here called *Q. cuneata*—the *digitata* or *falcata* of many writers.

[2] Proc. Nat. Acad. Sci. 2: 626. 1916.

Quercus alba × *bicolor* = × Q. Jackiana
× *macrocarpa* = × Q. Bebbiana
× *montana* = × Q. Saulii
× *Muehlenbergii* = × Q. Deami
× *prinoides* = × Q. Faxoni
× *Prinus* = × Q. Beadlei
× *stellata* = × Q. Fernowi

Q. arizonica × *grisea* = × Q. organensis

× **Q. Ashei** n. nom. (*Q. Catesbæi* × *cinerea*)

× **Q. Beadlei** n. nom. (*Q. alba* × *Prinus*)

× Q. BEBBIANA Schneider (*Q. alba* × *macrocarpa*)

× Q. BENDERI Baenitz[3] (*Q. coccinea* × *rubra*)

Q. bicolor × *alba* = × Q. Jackiana
× *macrocarpa* = × Q. Schuettei

× **Q. blufftonensis** n. nom. (*Q. Catesbæi* × *cuneata*)

× Q. BRITTONI Davis (*Q. ilicifolia* × *marilandica*)

× **Q. caduca** n. nom. (*Q. cinerea* × *nigra*)

× **Q. carolinensis** n. nom. (*Q. cinerea* × *marilandica*)

Q. Catesbæi × *cinerea* = × Q. Ashei
× *cuneata* = × Q. blufftonensis
× *nigra*[4] = × Q. Walteriana

Q. cinerea × *Catesbæi* = × Q. Ashei
× *cuneata* = × Q. subintegra
× *laurifolia* = × Q. sublaurifolia
× *marilandica* = × Q. carolinensis
× *nigra* = × Q. caduca
× *? velutina* = × Q. podophylla

Q. coccinea × *ilicifolia* = × Q. Robbinsii
× *palustris* = Q. ellipsoidalis f.,—not a hybrid.
× *rubra* = × Q. Benderi

[3] Resemblance to either parent is here indicated by use of the trinomials × *Q. Benderi coccinoides* and *Q. Benderi rubroides*, and one of the many forms possible of the former is indicated in the name × *Q. Benderi coccinoides* f. *volvato-annulata*.

[4] *Q. sinuata* Walter, usually taken to have designated this hybrid, is held to apply properly to what Small has called *Q. austrina*.—Ashe, *Proc. Soc. Amer. Foresters.* 11: 89. 1916.

Q. cuneata × *Catesbæi* = × Q. blufftonensis
× *cinerea* = × Q. subintegra
× *Phellos* = × Q. subfalcata
× *velutina* = × Q. Sudworthi

× **Q. Deami** n. nom. (*Q. alba* × *Muehlenbergii*)

Q. Douglasii × *Garryana*

What has been taken for, possibly, this cross scarcely appears to be more than *Q. Douglasii.*

× Q. DUBIA Ashe (*Q. Phellos* × *? velutina*)

Q. dumosa × *Engelmanni*

Specimens distributed for this hybrid scarcely appear to be more than *Q. dumosa.*

Q. ellipsoidalis × *velutina* = × Q. palæolithicola

Q. Emoryi × *grisea*
× *pungens*

Neither of these appears to show evidence of *Q. Emoryi* as a parent.

Q. Engelmanni × *dumosa* (See *Q. dumosa*)

× **Q. exacta** n. nom. (*Q. imbricaria* × *palustris*)

× **Q. Faxoni** n. nom. (*Q. alba* × *prinoides*)

× **Q. Fernowi** n. nom. (*Q. alba* × *stellata*)

Q. Garryana × *Douglasii*

See note under *Q. Douglasii.*

Q. georgiana × *marilandica* = × Q. Smallii

× **Q. Giffordi** n. nom. (*Q. ilicifolia* × *Phellos*)

Q. grisea × *arizonica* = × Q. organensis
× *Emoryi* (see note under *Q. Emoryi*)

× Q. HETEROPHYLLA Michaux (*Q. Phellos* × *rubra*)

× **Q. Hillii** n. nom. (*Q. macrocarpa* × *Muehlenbergii*)

× Q. HOLLICKII Schneider = × Q. heterophylla

Q. ilicifolia × *coccinea* = × Q. Robbinsii
× *marilandica* = × Q. Brittoni
× *Phellos* = × Q. Giffordi
× *velutina* = × Q. Rehderi

Q. imbricaria × *marilandica* = × Q. tridentata
× *palustris* = × Q. exacta
× *rubra* = × Q. runcinata
× *velutina* = × Q. Leana

Q. Kelloggii × *Wislizeni* = × Q. moreha
× Q. Jackiana Schneider (*Q. alba* × *bicolor*)
Q. laurifolia × *Catesbæi* = × Q. Mellichampi
× *cinerea* = × Q. sublaurifolia
× Q. Leana Nuttall (*Q. imbricaria* × *velutina*)
× Q. ludoviciana Sargent (*Q. Pagoda* × *Phellos*)
Q. macrocarpa × *alba* = × Q. Bebbiana
× *bicolor* = × Q. Schuettei
× *Muehlenbergii* = × Q. Hillii
Q. marilandica × *cinerea* = × Q. carolinensis
× *georgiana* = × Q. Smallii
× *ilicifolia* = × Q. Brittoni
× *imbricaria* = × Q. tridentata
× *nigra* = × Q. sterilis
× *Phellos* = × Q. Rudkini
× **Q. Mellichampi** n. nom. (*Q. Catesbæi* × *laurifolia*)
Q. montana[5] × *alba* = × Q. Saulii
× Q. moreha Kellogg[6] (*Q. Kelloggii* × *Wislizeni*)
Q. Muehlenbergii × *alba* = × Q. Deami
× *macrocarpa* = × Q. Hillii
Q. nigra × *Catesbæi* = × Q. Walteriana
× *cinerea* = × Q. caduca
× *marilandica* = × Q. sterilis
× **Q. organensis** n. nom. (*Q. arizonica* × *grisea*)
Q. Pagoda[7] × *Phellos* = × Q. ludoviciana
× **Q. palæolithicola** n. hybr. (*Q. ellipsoidalis* × *velutina*)

A form in foliage resembling *Q. coccinea,* or the *coccinea*-like *ellipsoidalis,* with fruit of the larger *ellipsoidalis* or *coccinea* type, but buds large and hairy as in *velutina.*—The type from Winnebago County Illinois (*Bebb*).

Q. palustris × *coccinea* = Q. ellipsoidalis f.,—not a hybrid.
× *imbricaria* = × Q. exacta
× *rubra* = × Q. Richteri

[5] The rock chestnut oak, commonly called *Q. Prinus.*

[6] Commonly written *Q. Morehus,* but evidently an adjective name based on Moreh—the Scriptural "land of Moriah," and consequently to be brought into agreement of gender with the feminine tree name *Quercus.*

[7] Though *pagodæfolia,* applied by Ashe to this species, has priority in varietal use, it gives way under the international rules to Rafinesque's specific name *Pagoda.*

Q. Phellos × *cuneata* = × Q. subfalcata
× *ilicifolia* = × Q. Giffordi
× *marilandica* = × Q. Rudkini
× *Pagoda* = × Q. ludoviciana
× *rubra* = × Q. heterophylla
× *? velutina* = × Q. dubia

× **Q. podophylla** n. nom. (*Q. cinerea* × *? velutina*)

This is *Q. petiolaris* Ashe, a preoccupied name.

× **Q. Porteri** n. nom. (*Q. rubra ?* × *velutina*)

Q. prinoides × *alba* = × Q. Faxoni

Q. Prinus[8] × *alba* = × Q. Beadlei

Q. pungens × *Emoryi* (See note under *Q. Emoryi*)

× **Q. Rehderi** n. nom. (*Q. ilicifolia* × *velutina*)

× Q. Richteri Baenitz (*Q. palustris* × *rubra*)

× **Q. Robbinsii** n. nom. (*Q. coccinea* × *ilicifolia*)

Q. rubra × *coccinea* = × Q. Benderi
× *imbricaria* = × Q. runcinata
× *palustris* = × Q. Richteri
× *Phellos* = × Q. heterophylla
× *? velutina* = × Q. Porteri

× Q. Rudkini Britton (*Q. marilandica* × *Phellos*)

× Q. runcinata Engelmann (*Q. imbricaria* × *rubra*)

The current idea that this is a cross of *Q. cuneata* with *Q. rubra* seems less probable than the parentage here indicated; and *cuneata* does not occur where the type material was collected.

× Q. Saulii Schneider (*Q. alba* × *montana*)

× **Q. Schuettei** n. hybr. (*Q. bicolor* × *macrocarpa*)

A form with twigs of *Q. macrocarpa* and sometimes corky-winged, foliage variously intermediate but prevailingly suggestive of *bicolor*, and subsessile small fruit of the *bicolor* type but with the cups sometimes short-fringed and then resembling small-fruited forms of *macrocarpa*.—Cf. *Proc. Amer. Philos. Soc.* 54. pl. 1.—The type from Fort Howard, Wisconsin (*Schuette*, September 28, 1893).

× **Q. Smallii** n. nom. (*Q. georgiana* × *marilandica*)

Q. stellata × *alba* = × Q. Fernowi

× **Q. sterilis** n. nom. (*Q. marilandica* × *nigra*)

[8] The cow oak, commonly known as *Q. Michauxii.*

× **Q. subfalcata** n. nom. (*Q. cuneata* × *Phellos*)

This is *Q. falcata* Ashe, a preoccupied name.

× **Q. subintegra** n. nom. (*Q. cinerea* × *cuneata*)
× **Q. sublaurifolia** n. nom. (*Q. cinerea* × *laurifolia*)
× **Q. Sudworthi** n. nom. (*Q. cuneata* × *velutina*)
× Q. TRIDENTATA Engelmann (*Q. imbricaria* × *marilandica*)
Q. velutina × *cinerea* = × Q. podophylla
× *cuneata* = × Q. Sudworthi
× *ellipsoidalis* = × Q. palæolithicola
× *ilicifolia* = × Q. Rehderi
× *imbricaria* = × Q. Leana
× *Phellos* = × Q. dubia
× *rubra* = × Q. Porteri
× Q. WALTERIANA Ashe (*Q. Catesbæi* × *nigra*)
Q. Wislizeni × *Kelloggii* = × Q. moreha

From the foregoing list, I have omitted *Q. hemisphærica* Willdenow and *Q. hybrida* Small, as I am frankly in doubt as to their status. The latter (*Q. laurifolia hybrida* Michaux), supposedly a cross between *laurifolia* and *nigra,* seems rather to be a toothed form of *Q. laurifolia.* The former, comprising a great array of intermediates between *Phellos* and *nigra* as well as other forms not otherwise placeable, and in its extremes not distinguishable from these species, though I do not recall that it has been held for a hybrid seems more likely to include some hybrids in its complex than is true of *Q. hybrida.*

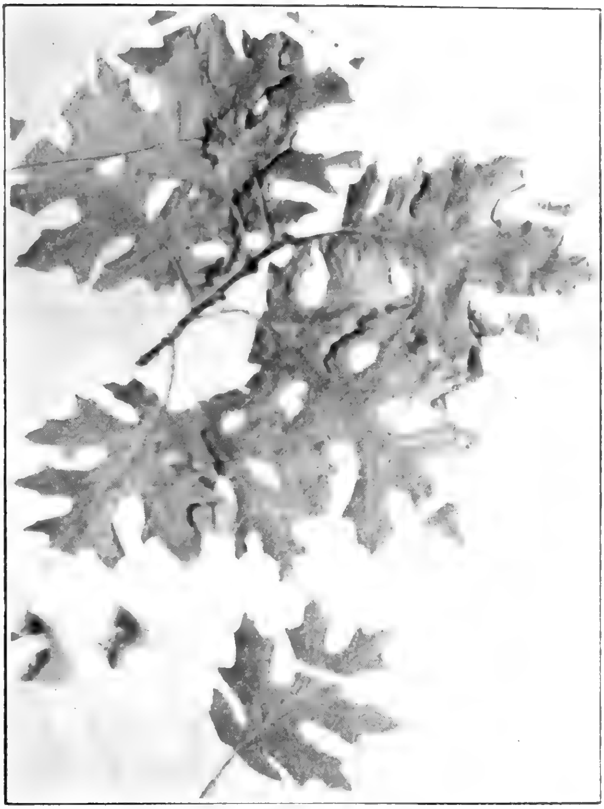
THE UNIVERSITY OF ILLINOIS,
MARCH 1, 1917.

EXPLANATION OF PLATES.

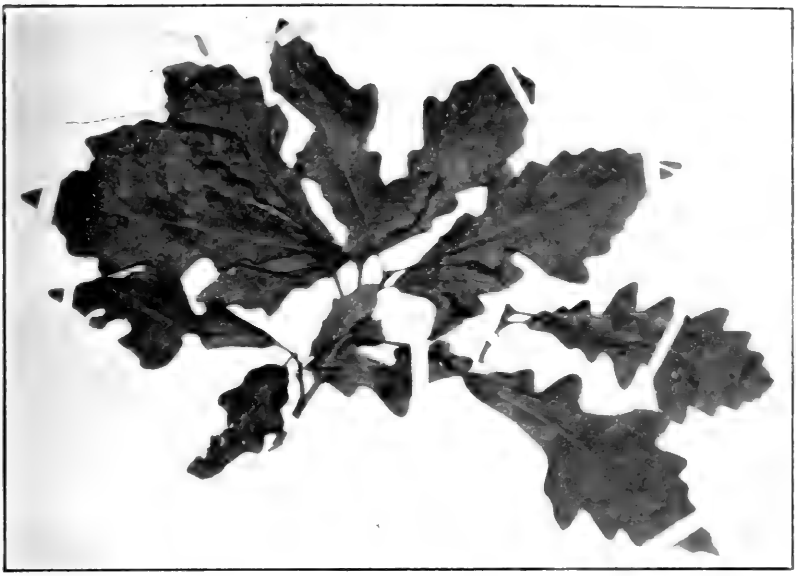
PLATE I. × *Quercus palæolithicola.* Type material in the Field Museum. The upper figure about one third natural size; the lower of natural size.

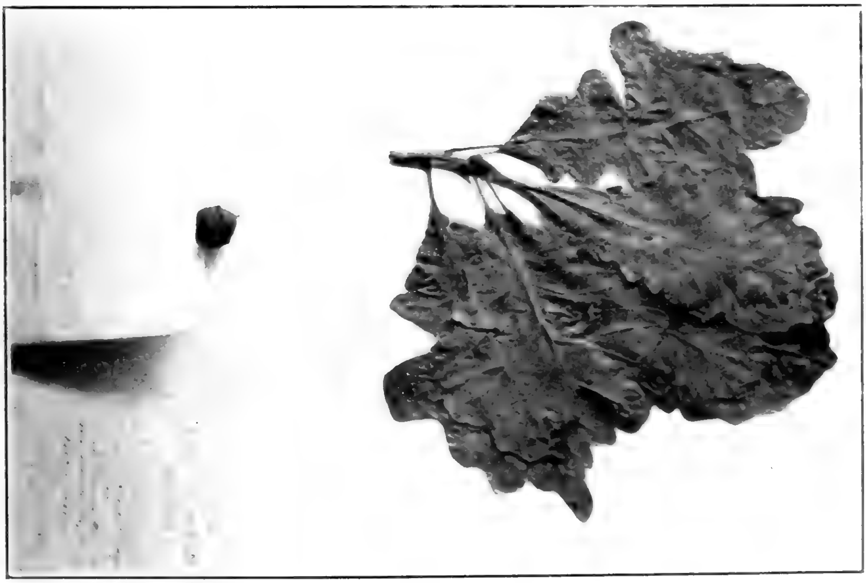
PLATE II. × *Quercus Schuettei,* about one third natural size. The upper sheet, in the United States National Herbarium, with foliage approaching that of *Q. bicolor;* the lower, in the Field Museum, with foliage and fruit more as in *Q. macrocarpa.*

PLATE III. × *Quercus Schuettei.* The upper figure a representation of the type sheet, in the Field Museum, about one third natural size; the lower a fragment of this specimen, of natural size.

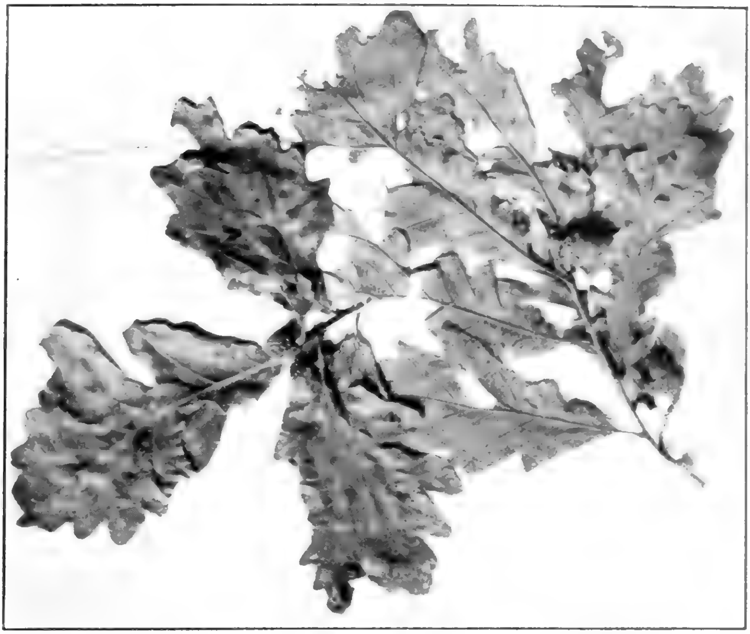


QUERCUS PALÆOLITHICOLA





QUERCUS SCHUETTEI



QUERCUS SCHUETTEI

INTERRELATIONS OF THE FOSSIL FUELS.*

II.

By JOHN J. STEVENSON.

(*Read April 14, 1917.*)

THE CRETACEOUS COALS.

Coal of Cretaceous age occurs more or less abundantly in many countries. The original areas in which it was formed vary from mere patches to thousands, even hundreds of thousands of square miles; but these greater areas have been broken by erosion into isolated basins, or better into isolated fields, sometimes widely separated. The coal seams are not confined to a single horizon but are present throughout the Cretaceous at localities where proper conditions existed. The several regions have so many features in common as well as so many in contrast that a detailed description of some typical areas, though tedious, is necessary for proper understanding of the relations.

Europe.

In western Europe, coal is confined almost wholly to the Wealden but in central Europe the Upper Cretaceous contains deposits of more than local importance.

Coal in thin seams has been observed at some places in England but the quantity is significant. The Wealden of the Dorsetshire coast and of the Isle of Wight has no coal. Mantell[1] states that, at Brook Point on the Dorset coast, a sandstone ledge in Lower Wealden encloses trunks and large branches of trees, mostly petrified. Webster, at an earlier date, had seen these stems, of which some had been converted into a jetlike substance. Mantell, observ-

* Part I. appeared in these *Proceedings*, Vol. LV., pp. 21–203.

[1] G. A. Mantell, "Geological Excursions round the Isle of Wight," 3d ed., London, 1854, pp. 203–206, 238, 239, 242.

ing that all the stems are prostrate, thought them a fossil raft, remains of an ancient pine forest, transported by a river and buried in the delta sands and muds, as is the case with rafts of the Mississippi River. But the description of conditions leads one to hesitate before accepting the reference to rafts. The Mississippi rafts, as described in European works of Mantell's day, were not the rafts as they were. It is not probable that the rafts of the Atchafalaya and Red River would produce deposits such as those under consideration. The features[2] are more like those observed along the Athabasca and some other North American rivers, where great masses of driftwood occur, the interstices being filled with silt and sand. Mantell emphasizes the presence of ripple markings in the Wealden; slabs of sandstone, clay and limestone on the Isle of Wight are often covered with them. Imprints of annelid and molluscan trails, of crustacean claws, of pectoral fins of fish as well as of feet of reptiles have been obtained. The formation is of essentially fresh-water origin. Lyell,[3] in describing the Lower Wealden or Hastings sand, remarks that one finds at different heights in the section strongly rippled slabs of sandstone. Some of the clay beds had been exposed, for sun cracks are abundant. A red sandstone, near Horsham, contains innumerable traces of a plant, apparently *Sphenopteris,* with stems and branches disposed as if they are standing erect on the place of growth, the sand having been deposited gently around them. Similar conditions have been observed elsewhere in this formation.

Some coal has been found in the Wealden of France, but it is of little importance. The lignites of Simerols[4] suffice as illustration. The area is small, with radius of about 25 kilometers. The section at one locality shows (1) clay, 0.90; (2) lignite, 2.50, at times without partings, but at others divided into two or three benches; (3) shale, 0.70; (4) lignite, friable, not mined, 1.50; (5) carbonaceous shale, 0.80; (6) lignite, compact, 1 to 1.50; total, 7.90 meters. This deposit, at times only 4.60 meters thick, underlies

[2] See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.,* Vol. L., 1911, pp. 548–551.

[3] C. Lyell, "Elements of Geology," 6th ed., New York, 1866, pp. 350, 351.

[4] Arnauld, "Des argiles lignitiferes des Sarladais," *Bull. Soc. Geol. France,* II., Vol. 23, 1866, pp. 59–63; Meugy, the same, pp. 89–96.

marine Cretaceous, but is of fresh-water origin, the animal remains being indeterminate bones with shells of fresh-water mollusks. Plant remains and silicified stems are in the clays. The lignite is described as compact, blackish brown and lusterless.

The Wealden of Hanover, that portion equivalent to the Hastings sand of England, has coal seams, which in many places have economical importance. The region[5] has been studied by several geologists, each having in view the study of some special features. The area has extreme length from east to west of about 160 miles and an extreme width of about 120 miles from north to south. Exposures are not continuous, for erosion has removed the Wealden from extensive spaces, while in others the surface rocks belong to later formations. According to Credner, it reaches from the Harz Mountains westward to the Holland border, where it passes under a thick cover of diluvium. The exposed areas are isolated and at times are so widely separated that sections have little resemblance. The Wealden consists of clays, marls, sandstones and coal beds; the colors are from white to gray, with rare bands colored by oxide of iron. Dunker states that the coal usually resembles the older black coals, the plant materials have undergone much greater change than in brown coal, and distinct woody structure is rarely recognizable. Some mines yield a coal comparable to the best in England; a sample, analyzed by Regnault, gave carbon, 89.50; hydrogen, 4.83; oxygen and nitrogen, 4.67; ash, 1. This type is dense, brilliant, with uneven to conchoidal fracture and in appearance resembles anthracite. It is closely jointed and usually has a blackish brown streak. But there is lignite in the Wealden, with woody structure and reddish brown streak. A sample from Helmstadt, analyzed by Varrentrapp, yielded carbon, 68.57; hydrogen, 4.84; oxygen and nitrogen, 19.87; [ash, 6.72]. Dunker thinks this brown coal derived from conifers, cycads, lycopods and ferns.

In the Osterwalde, a very different type, the Blätterkohle, is

[5] W. Dunker, "Monographie der Norddeutschen Wealdenbildung," Braunschweig, 1846, pp. xi–xxviii, 2, 21; Heinrich Credner, "Ueber die Gliederung der oberen Juraformation und der Wealden-Bildung im nordwestlichen Deutschland," Prag, 1863, pp. ix, 47–54, 132, 138, 133, 138–141; C. Struckmann, "Die Wealden-Bildungen der Umgegend von Hannover," Hannover, 1880, pp. 14–28, 30–36.

found in the same section with other coals, some of them belonging to the "black coal" type. This Blätterkohle consists chiefly of *Abies linki* and *Pterophyllum lyellianum,* whose densely packed leaves and twigs, mostly brown and transparent, become flexible, when soaked in water; coalification is extremely imperfect. Dunker thinks that lycopods and ferns are the chief constituents of the black coals, as no remains of other plants have been discovered. It may be noted in passing that the Blätterkohle bears great resemblance to the conifer peat of the Fichtelgebirge,[6] as described by Reinsch, and to the "coarse" coal of the Carboniferous; in the latter the conversion is complete. It must not be forgotten that David discovered equally flexible remains of plants in the Permo-carboniferous of New South Wales.

The coals vary in quality; partings thicken and at times the whole seam becomes carbonaceous shale; occasionally masses of silicious matter, limestone or pyrite become so abundant as to render the deposit worthless. In some mines, a waxy substance, clear or dark yellow, occurs, which Dunker thinks may be hatchettin.

Near Bückeburg and Schaumburg, the Wealden sandstone is 120 to 150 feet thick and contains 4 coal seams, of which two are workable. On the Osterwalde, the thickness is not far from 450 feet and 18 seams were seen, mostly thin or too poor in quality to justify mining, the greatest total thickness of coal being 9 feet. Well-marked coal seams, in nearly every case, have a black clay roof and floor, the latter occasionally passing into Brandschiefer or cannel shale. The roof clay, at times, contains abundance of plant impressions and even becomes coaly—a true faux-toit. In the upper part of the section there are two seams consisting mostly of the black coal, but this, in part, is continuous with brown coal, containing pieces of wood-like anthracite.

The plants enumerated by Dunker include 2 species of *Equisetum,* 26 of ferns, 10 of cycads, 5 of conifers and one palm, *Endogamites,* now taken to be *Sedgwickia.* One species of *Equisetum* occurs abundantly in a sandstone, where the stems are more or less nearly vertical. Stems of trees were observed at many localities;

[6] See "Interrelations of the Fossil Fuels, I.," *Proc. Amer. Phil. Soc.,* Vol. LV., 1916, p. 54.

those replaced with sandstone or oxide of iron show no trace of structure, but those from the coal resemble *Pinus*. He believes that much of the coal is derived from conifers.

Credner reports that the sandstone is 540 to 550 feet thick on the south slope of the Diester range, 8 to 12 miles south from Hannover, where it consists of alternating clay shales, marly shales, sandstones and stone coal; the chief mass is a yellow, fine-grained sandstone with little cementing material. The section shows 16 coal seams, of which 11 are less than 10 inches thick and have "bad coal." Three beds, 2 feet, 1 foot 6 inches and 1 foot respectively, are of "workable" thickness and yield good coal. Clearly, the periods when coal accumulation was possible, were of brief duration and the general conditions were not such as to encourage formation of good coal; the total thickness is little more than 15 feet, of which less than one third is good. The fauna is fresh-water, *Unio, Paludina, Cypris, Lepidotus* and *Sphærodus* being the prevailing forms; *Cyrena* is not rare. The flora consists of ferns, cycads, conifers and palms.

The Osterwalde area is farther west; its resources had been developed after Dunker's examinations were made. The Wealden sandstone is approximately 500 feet, but the conditions are not the same as in the Diester area. The "workable" coal seam, one foot thick and 28 feet above the base at Diester, is here in the same position, but only 8 inches thick. Within 72 feet above it are 3 seams, the thickest being 6 feet 9 inches, all absent from the Diester section. Near Minden, 7 miles farther west, the coal is thicker. Meanwhile the character of sediments has been changing, for the sandstone, predominating at Diester, is insignificant here. The change continues westward: at Bentheim and Ochtrup, on the Holland border, one finds only clays and limestones about 800 feet thick; the limestones yield *Melania* and *Cyrena*. According to Credner's descriptions, it is evident that the coal decreases in the direction of finer sediments. The thick coals of Minden are associated with the one noteworthy sandstone of that area. Both Dunker and Credner note abundance of sphærosiderite in the rocks associated with coal seams.

Studies by Dunker and Credner were mostly in the region west from Hannover; Struckmann gave information respecting other areas and added to that respecting the western. The coal-bearing deposits equivalent to the Hastings sand are his Middle Wealden; his Lower Wealden is equivalent to the Purbeck beds of England, now placed in the Jurassic. The whole Wealden of Struckmann is only 15 meters thick under the city of Hannover; the Hastings sand is thin but contains an unimportant seam of coal. At Neustadt, 10 miles farther northwest, the sand is still present, though very thin, and holds thin coal, which has been utilized. At 24 miles west-northwest, the sand is insignificant, almost wholly replaced by a thick, often bituminous clay and marly shale, shale, rich in pyrite, but holding some coal.

The Hastings sand increases southwardly. At 10 miles west from Hannover, thick beds of sandstone appear; on the Diester, south from that city, as well as on the Süntel ridge at the southwest, sandstone prevails; but at Osterwalde, sandy and clayey shales are abundant, though there are prominent beds of sandstone. Struckmann compares several sections, I., on the Diester by Credner; II., farther west by himself; III., on Osterwalde by Credner; IV., at Rehburg, northwest from Hannover, by himself:

	I.	II.	III.	IV.
Sandstone	118.63	124.33	47.00	6 to 7
Clays, marls, sandy shale, soft sandstone	40.00	37.62	110.00	114.00
Coal, worthless	2.06	0.87	3.00	0.00
Coal, workable	1.31	0.84	2.50	0.23
Total, meters	162.00	163.66	162.50	120.00

In I., there are 12 worthless seams and three workable; in II., 3 worthless and one workable; in III., 6 worthless and 5 workable; in IV., one workable.[7] In III., sandy shales or very slightly consolidated sandstones, but in IV. clays and marls make the greater part. These observations by Struckmann show that the source of sediment was south from Hannover and that the sand flats decreased toward the west and north, giving place to less coarse materials. The coal seams are irregular and it is evident that many of them are of insignificant lateral extent. Sphærosiderite is abun-

[7] It would appear that in these calculations any seam yielding good coal and more than ten inches thick is thick enough to be mined.

dant. The fauna is fresh-water. The flora at Osterwalde consists of ferns, cycads and conifers, but two forms, an *Anomozamites* and a *Spirangium*, are wanting there, though they are extraordinarily abundant on the Diester.

Hosius[8] discovered plant remains and fragments of coal in the Wealden sandstone near Vreden in Westphalia about 35 miles west-northwest from Munster.

The Upper Cretaceous is almost wholly marine in England, France and western Germany, so that coal occurs rarely and in small quantity; but farther east, in Saxony, Bohemia, Silesia and Moravia, the limestones and marls are replaced with sandstones at several horizons and coal deposits are present, which in some areas have much economic importance.

The Löwenberg basin in southern Silesia is at about 25 miles from the border of Saxony and Bohemia. According to Scupin,[9] the coal of this basin has been regarded as either stone or Pech coal; it is deep black, lustrous and has conchoidal fracture, but gives a very dark color to solution of caustic potash. It is of merely local importance, as the greatest thickness is little more than a half meter, yet at one time the annual output was 60,000 Centner. Near Klittsdorf, a sandy brown coal contains remains of wood; near Löwenberg, coal, 6 inches thick, is exposed and lower down in the section is a mass of coal and sand, containing 6 inches of good coal, but in greatest part is mixture of coal and sand in about equal proportion; at another exposure the composition is clay and fragmentary coal. Scupin thinks that this confused mass must be allochthonous and suggests that it may represent a washed out swamp. Two lower beds, 10 and 3 inches thick, were pierced in a boring and a notable quantity of sphærosiderite was found in the intervening rocks.

The Cenomanian coal of Bohemia is usually unimportant. Naumann says that the Lower Quadersandstein occasionally contains layers of clay shale rich in conifer and dicotyledonous remains, with nests and layers of mostly unworkable coal. v. Andrian gives the section obtained near Chrudim, about 60 miles east-southeast from Prag: (1) Coarse sandstone, with fossils, 24 feet; (2) dark clay

[8] Hosius, *Zeitsch. d. d. Geol. Gesell.*, Vol. 12, 1860, p. 61.

[9] H. Scupin, "Die Entstehung der Niederschlesischer Senon-Kohlen," *Zeitsch. f. pr. Geologie*, 1910, pp. 254–257.

shale, with plant remains and coaled stems, 4 to 5 feet; (3) moderately coarse sandstone, 2 to 3 feet; (4) coarse conglomerate, 2 to 4 feet. The dark shale of this region section contains near Skutsch, 12 miles farther west, a bed of worthless Pechkohle, which is rich in Bernstein. Reuss, in a letter to Beyrich, stated that a mass of Bernstein, several inches long and of brownish yellow color had been obtained as Skutsch, which is very near the Moravian border.[10]

In Moravia, according to Reuss,[11] the coaly substance, to which the Lower Quader beds owe their color, is sometimes collected into nests or even into beds of workable thickness. At a mine, west from Mährens-Trubau and about 50 miles southwest from Chrudim, he saw a seam of thinly laminated Moorkohle [a peat-like brown coal] 4 feet thick, brownish-black and containing làminæ of bright black Pechkohle. It slacks readily on exposure and is high in ash. Grains of honey-yellow Bernstein, some as large as a pea, are scattered through it. The roof and floor are blackish-gray shale. In older mines near Utigsdorf, farther south, Reuss saw two coal seams, 1 foot 6 inches and 3 to 4 feet thick. Coal of the upper bed is brown-black, with shaly structure, rather bright fracture and contains much resin. The coal of the lower bed is black, rather crumbling, contains numerous layers of Faserkohle as well as many lumps and half-inch layers of Pechkohle. Bernstein is less abundant than in the upper bed. Roof and floor of both beds are dark, more or less sandy.

Coal has been mined for many years in Lower Austria, near Grünbach, at a score of miles south from Vienna and near the border of Hungary. The deposits are in the Gosau formation, which is taken to be of Turonian or Senonian age. Cžjžek[12] states that the seams are all thin south from Grünbach, but become thicker north from that city. The Alois tunnel, 1,200 feet long, intersects 21 seams of which only 3 are workable, the others being from 2 to 10 inches thick. The workable beds, all within vertical distance of

[10] Reuss, *Zeitsch. d. d. Geol. Gesell.,* Band III., 1851, p. 13; F. v. Andrian, *Jahrb. k. k. Geol. Reichsanst.,* Vol. XIII., 1863, p. 207.

[11] A. E. Reuss, "Beiträge zur geognostichen Kenntniss Mährens," *Jahrb. k. k. Geol. Reichsanst.,* Vol. V., 1851, pp. 727–731.

[12] J. Cžjžek, "Die Kohle in den Kreideablagerungen bei Grünbach," *Jahrb. k. k. Geol. Reichsanst.,* Vol. II., Pt. 1, p. 144, Pt. 2, pp. 107 et seq.

60 feet, are the *Caroli*, 2 to 3 feet, very irregular in thickness, but its coal is much prized, as it is low in ash and clean, the bed being without a parting. *Jodahofer*, 3 to 4 feet, is usually quite regular, but at times the intervening rocks disappear and this unites with the Caroli, the thickness increasing greatly and occasionally reaching 10 feet. *Antoni*, 2 to 2 feet 6 inches, is in 3 benches with clay partings, each 2 inches. The coal is soft in top and bottom, but in the middle bench it is hard. The roof is black slate, 1 foot, which burns well. As described by Cžjžek, it is a cannel-shale, a mud very rich in organic matter.

The coal is pitch-black, with bright luster and black-brown streak. No woody structure is visible to the unaided eye. Occasionally one finds pieces which retain the form of branches, but all trace of fiber has disappeared. Analyzed by Schrotter, the composition is: Carbon, 74.84; hydrogen, 4.60; oxygen [and nitrogen], 20.56; water at 100° C., 6.57; ash, 6.92. Reasoning from this analysis, Cžjžek concludes that the character of a coal has some relation to its age. The Tertiary coal at Brennberg has only 60 to 70 per cent. of carbon, while that from the Lias at Fünfkirchen has 85 to 86 of carbon and only 8 to 9 per cent. of oxygen.

Passing over into Hungary, one finds, according to Hantken,[13] important development of Cretaceous coals in the province of Bakony and in the western mountains. The areas are insignificant in comparison with those of the Lias, but the beds are little disturbed, mining is simple and the output is large. The important mines are near Ajka in Bakony, where the Cretaceous consists of two marine formations separated by a fresh-water formation with coal seams. The fauna contains some brackish-water forms but fresh-water types predominate. There are at least 25 seams of coal, of which one near the top and another near the bottom are workable. The upper or Bernstein Flotz is always divided into several benches and the coal is inferior. In one part of a mine this bed is 2.93 meters thick with 4 benches of coal aggregating 1.70 of coal, while in another part it is 2.43 meters thick and in 6 benches, but the thickness of coal is practically the same, 1.72 meters. The lower

[13] M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in der Ländern der ungarischen Kröne," Budapest, 1878, pp. 174, 176–179, 197, 198.

bed averages about 2 meters. Sometimes it is without partings but at others it is broken by two, 20 to 50 centimeters thick. Occasionally, one of the other beds is thick enough for mining, but in all cases the thickness shows much variation. The coal is of very fair quality; in the Barod area, moisture is from 8.2 to 10.4 per cent. and the ash is from 7.1 to 15.7 per cent.

In the Lower as well as in the Upper Cretaceous, coal seams accumulated on border areas, where the sediments show proximity to land. The character of the deposits, the lens-shaped coal seams and the fresh-water fauna associated with them seem to justify the suggestion that the coal was formed in swamps on great irregular river plains. For the most part, these had a comparatively brief existence and were subject to frequent floods carrying muddy water.

Australasia.

Molengraaff[14] reports that he saw thin seams of coal at various horizons in the Cretaceous along several rivers in central Borneo. These are without economic importance. The associated sandstones frequently contain grains of coal.

Coal is present in the Cretaceous of eastern Australia, though very rarely in economic quantity. As the conditions appear to be much the same throughout, it suffices to consider the phenomena in Queensland as described by Jack.[15] Cretaceous deposits cover a great part of that province, where they are divided into the Upper or Desert Sandstone and the Lower or Rolling Downs formation.

The Desert Sandstone formation, now remaining in barely one twentieth of its original area, consists mostly of thin flags, whose surfaces are covered with a network of raised lines, crossing each other at all angles, which clearly represent filled sun cracks. The same sands show tracks and burrows as well as indeterminate remains of plants. Cross-bedding is quite characteristic of the thicker layers. Pebbly deposits occur occasionally and, at one locality, Gibb saw an angular quartzose grit which passed into brecciated

[14] G. A. F. Molengraaff, "Geological Explorations in Central Borneo," Eng. ed., Leyden, 1902, pp. 202, 217, 241, 250, 277, 318.

[15] R. L. Jack and R. E. Etheridge, Jr., "Geology and Palæontology of Queensland," Brisbane, 1892, pp. 397–403, 511–536, 551, 558.

conglomerate. Silicified stems of trees and of bamboo-like plants were observed in many beds. On top of a small table-land in western Queensland, H. Y. L. Brown discovered a grove of fossil stumps standing erect. Thirteen are large, the greatest diameter being 4 feet and the usual height is 4 feet 6 inches. Many of the stumps are hollow and fragments lie in all directions. "The matrix having been denuded, they stand as evidence of how trees have degenerated in size in this part of the country since Cretaceous times."

The features of this formation throughout are those of a vast flood plain, subject to frequent overflow and to frequent changes in direction of drainage. As one should expect, the coal deposits of the Desert Sandstone are lenses of moderate extent and commercially unimportant. Within the Cooktown region, seams were seen 6 and 15 inches thick; the bottom of the latter is crowded with quartz granules. The coal is worthless; four samples from the Cooktown region gave 9.65, 19.02, 30.20 and 36.53 per cent. of ash. The coals vary from semi-bituminous to high-grade bituminous, though in the description of this region, no reason for this difference appears. Pellets of coal were seen frequently in rocks associated with the coal.

The Rolling Downs formation is mostly marine, with intercalated deposits, which may be of fresh-water origin. The higher rocks on the Upper Flinders River contain bands of ferruginous sandstone with markings which are suggestive of reptilian footprints. Farther up the river are thick-bedded sandstones, with grits, pebbly grits and conglomerates. These hold coal seams, one of which is in five benches with 22 inches of coal and a total thickness of 4 feet 9 inches. Other but thinner seams were seen in this neighborhood. The coal is very good and cakes. Near Winton, borings have passed through some seams of coal, but all are thin, none exceeding 2 feet, and the coal in the several seams varies, the ash being from 4.58 to 20.34 per cent. Some seams, 3 feet thick, have been observed elsewhere in Queensland, but they are merely lenses, marking sites of swamps occupying depressions in sandy river plains.

Identifiable remains of plants are rare in the Queensland Cretaceous, only two forms having been recognized. One of them belongs to *Glossopteris* and was found in the Desert Sandstone. Etheridge cannot distinguish it from *G. browniana* and *G. ampla,* which abound in the Permo-carboniferous of Queensland and New South Wales. The important coal deposits of New Zealand, in the lower part of the Cretaceo-Tertiary, occupy some extensive areas in the South Island and a less important area in the North Island. The South Island was studied in detail long ago by Hector[16] and his associates. Hector examined Nelson district, the northern part of the island. The coal-bearing rocks at the Collingwood mine, in the extreme north, rest on 105 feet of conglomerate and are 250 feet thick. They are mostly thick-bedded clayey sandstones with interbedded carbonaceous shales, which have 6 coal seams, from 1 to 4 feet thick. But the coal is broken badly by partings. On the Ngakawau River there is a seam, 16 feet thick and yielding good caking coal, which burns freely with a sooty flame. In the lower canyon of Buller River, he saw a bed of compact brown coal, at least 16 feet thick, underlying brown micaceous sandstone and overlying a conglomerate or breccia of great thickness, which has a few thin seams of coal. The thick seam, which has much fossil resin, varies in composition; samples from different parts of the bed have from 33.45 to 46.85 per cent. of volatile combustible matter in the pure coal. The ash in raw coal is about 7 per cent. A seam, 20 feet thick, is mined on a branch of Buller River; its ash is remarkably low, varying from 0.98 to 1.19 per cent. The coal in some parts of the seam is compact, with bright luster and splintery fracture, but in others it is dull, with fracture like that of brown coal, and resembles jet.

In the Grey River area, the southwest corner of the district, the basal rocks are conglomerate and breccia, succeeded by 200 to 800 feet of sandstones, grits and shales with beds of anhydrous caking coal. Above these is a non-persistent conglomerate. Where this last is absent, the sandstones pass gradually into sandy clays with marine fossils and nodular clay iron-stone. Immediately below these marine beds and resting on the conglomerate or, in its absence,

[16] J. Hector, "Geological Survey of New Zealand," 1872, pp. 129–141, 158–165.

on the sandstones, is a seam of inferior coal, the "upper bed," which is a pitch coal, containing much resin and little constitutional water. The thick bed on Grey River, 16 feet, contains 64 to 68 per cent. of fixed carbon, while another seam, on the coast, has but 38.55 per cent. Hector described the latter as a very superior pitch coal, but its chemical composition suggests cannel; and it was recognized as such by Campbell,[17] who notes its variations in thickness. Within its small area, he saw it 4, 6, 16, 4, and 2 feet. At the border, it thins away to nothing. Cannel is the prevailing type in this bed. Another bed, resembling splint, contains pebbles of sandstone.

A more detailed study of the Buller Coal Field was made by Cox and Denniston.[18] At Coalbrookdale in Waimangawa Basin, Cox saw two coal seams, 5 and 18 feet thick, separated by 34 feet of sandstone; but at a short distance away they become 6 inches and 11 feet 6 inches. The upper bed quickly disappears but the lower one thickens northwardly until it becomes 40 feet, beyond which it decreases. Still farther north, beginning at Mount Frederick in the Ngakawau Basin, this lower seam is 5, 25, 37, 40 and, at center of the basin, 53 feet; thence it thins away in all directions, the last measurement being 6 inches. Other beds show similar variations. Southwardly from the Waimangawa Basin, the conditions are the same. Descending a stream from Mount Williams, Cox saw an outcrop of shale; at a little distance beyond, this became a coal seam, 3 feet thick, but worthless because of numerous shale bands. Followed southwestwardly, this, the lower coal seam of other basins, became 3, 8, 20, 40, 20, 20, and 25 feet. But southward from the last measurement the seam thinned away until no trace of it could be found.

Denniston's descriptions and his numerous sections show the lens form of the coal seams, thickest at center and thinning away to disappearance toward the margins of the basins. He notes that coal of the lower seam is not the same throughout a basin. In one area the upper portion is tender but the lower is hard; in another, the prevailing type is splint or cannel, hard, compact, jetlike, burning

[17] W. D. Campbell, New Zealand Geol. Survey, Reps. for 1876–7, pp. 31–40.

[18] S. H. Cox, N. Z. Geol. Survey, Reps. for 1874–6, pp. 17–29, 106–119; R. Denniston, the same, pp. 121–171.

with a candlelike flame and showing little tendency to cake. The descriptions by Cox and Denniston make clear that the basins were contemporaneous but not connected.

The district of Canterbury, embracing the middle eastern part of the island, was examined by Haast.[19] The Malvern Hills area, about 30 miles west from Christchurch and embracing not far from 180 square miles, exhibits his Great Brown Coal Formation, which, in the Table of Formations of 1879, is placed at base of the Cretaceo-Tertiary. The coal seams are numerous, usually thin and always variable. Occasionally, nodules of retinite are numerous. The intervening rocks show great irregularity in structure. Sandstones have abundance of tree trunks, whose thick bark has been replaced with clay ironstone, while the interior tissue has been replaced with "woodstone" or filled with black shaly material.

The extensive district of Otago, embracing the southern part of the island, was examined by Haast, McKay and Hutton.[20] In Haast's area the lower part of the column has near the base a mass composed of subangular fragments of schists and containing irregular seams of coal, 6 to 15 inches thick. Higher up, the rock becomes a conglomerate with well-rounded pebbles of quartz. The thin-bedded sandstones and shales following this conglomerate have only thin seams, but in the upper part of the column there are beds of conglomerate separated by thinner shales and sandstones, which hold important coal seams.

Coals are mined on Green Island. Near one of the shafts, McKay saw a bed of fossilized roots "sticking in an old soil, just as they grew." At another locality, a workable coal seam underlies beds containing *Belemnitella*.

According to Hutton, the area of Cretaceous coals is small in Otago. The most important field is near Shag River, where there are at least 6 workable seams, yielding the best of brown coal. The seams are thin in the Mount Hamilton field, rarely exceeding 10 inches, but the coal is bituminous. The highest sandstone there contains at base an angular block of sandstone, 8 by 3 feet, resting on

[19] J. Haast, N. Z. Geol. Reps. for 1871–2, pp. 1–88.

[20] J. Haast, Reps. for 1871–2, pp. 148–153; A. McKay, Reps. for 1873–4, pp. 59, 60; F. Hutton, "Geology of Otago," Dunedin, 1875, pp. 44, 100–103.

a thin seam of coal. He conceived that it had been floated in, attached to the roots of a tree, "wherefore the coal beds are formed partly from driftwood."

The coals of New Zealand for the most part are lignitic or sub-bituminous, but no woody structure is mentioned by any observer.

Greenland.

The existence of coal in the Cretaceous of western Greenland was made certain by the work of White and Schuchert[21] during 1897. Their observations were made chiefly on the Nugsuak Peninsula. The Komé or lower division, as exposed near Kook, consists of shaly or laminated sandstones with thin beds of dark shale containing much carbonaceous matter, so abundant at times as to make the shale combustible, but not enough to justify one in calling it coal or lignite. The whole succession is so irregular that sections are not comparable. The plants are conifers, cycads and ferns with some indeterminate leaves of dicotyledons. Near Ugarartorsuak, all divisions of the Cretaceous were examined. The Komé, in a section of 270 feet, has 20 feet of "thin coals with shaly partings and 2 bands of carbonaceous shale." Another section of about 305 feet, belonging to the Atane or middle division, has several beds of coaly shale, a coal seam, 1 foot 6 inches and a mass of "thin sandstones and coals," 10 feet. The flora differs from that of the Komé as, besides cycads, conifers and ferns, it has 8 species of dicotyledons. A third flora, in still higher beds, is related to the second and both seem to be related to the Upper Cretaceous. Dark beds with huge ferruginous concretions, have fossils of types characterizing the Montana of western United States.

A dark shale, 75 feet thick, seen near Ata on the southerly shore of the peninsula, has leaves and large fragments of tree trunks with an invertebrate fauna, which Stanton takes to be the same with that of the highest beds on the north shore and equivalent to Cenomanian. The highest division of the Cretaceous, Patoot of Heer, is exposed near Patoot, where the lowest beds are at 470 feet above the sea. The fossils are of Senonian age and some of the plants are

[21] D. White and C. Schuchert, "Cretaceous Series of the West Coast of Greenland," *Bull. Geol. Soc. Amer.*, Vol. 9, 1898, pp. 343–368.

allied to Laramie forms. The authors suggest that, at least in part, the Patoot may be a transition formation; no unconformity was observed between Cretaceous and Tertiary; all conditions indicate that sedimentation was continuous. Near Patoot, at 1,170 feet above the base of this division, there are occasional bands, ferruginous, containing ferns, conifers, and dicotyledons, with erect stumps and abundance of silicified wood.

North America.

Cretaceous deposits are present on the Atlantic and the northern Gulf coasts of the United States, but they contain no coal and the occurrences of lignite have interest only for the paleobotanist. The important area is in the west-central region, where the deposits originally extended from the 95th meridian westward for not far from 1,000 miles, and from Lat. 25° in Mexico northward for not less than 2,100 miles, in all not less than 2,000,000 square miles. These figures are merely approximations and the area of greatest extent may have been considerably larger. The continuity of these deposits was destroyed by post-Cretaceous erosion, following the Rocky-Mountain revolution.

Belief that Cretaceous deposits were practically continuous throughout this vast area is of comparatively recent data. The prevalent conception until within little more than 20 years, was that the Rocky Mountains had existed during Cretaceous time. There seems to be little room for doubting the general accuracy of conclusions that those mountains mark lines of successive foldings but proof of their existence as elevated areas is wanting. Willis[22] thought that the earliest Cretaceous deposits of his district were laid down on a surface of Carboniferous and Algonkian rocks, which was a plane, primarily a peneplain and afterwards a surface of marine planation. The first period of compression may not have begun until after close of the Cretaceous. Incidental reference to the conditions indicates similar conception on the part of some later observers; but the first clear analysis of the evidence, known to the writer, is that by Lee,[23] who has discussed the phenomena observed by him-

[22] B. Willis, "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 338, 339.

[23] W. T. Lee, U. S. Geol. Survey, Prof. Paper, 95-*C*, 1915, pp. 56–58.

self and others in New Mexico and Colorado. He recognizes peneplanation in the southern Rocky-Mountain region prior to the beginning of the Upper Cretaceous. The evidence all indicates that the interior continental sea extended from Utah and Arizona eastward over the present site of the Rocky Mountains.

The source of sediments was at the south and west, as appears from discussions by Lee, Stone and Calvert and Stebinger,[24] as well as from sections by many other observers. The coarser materials are in the southern and western parts of the area, while, toward the east, land and border-land conditions disappear, so that the rocks become shales with more or less of limestone. But toward the close of the Cretaceous, land and shore deposits extended far east, indicating perhaps a long period of comparative stability prior to the great mountain-making period of the Tertiary. The vast area, reaching in some places almost to the Mississippi, was apparently at first almost a peneplain, over which the early Cretaceous sea advanced to the western border.

During and after the Rocky-Mountain revolution, erosion was so energetic that, in New Mexico, Arizona, Utah and Colorado, the Cretaceous was broken into isolated "fields" or "basins," separated in many cases by ranges showing Archean rocks at thousands of feet above the general altitude of the region. But this greatly disturbed area becomes narrower toward the north, so that, in much of Wyoming, the continuity is broken only by comparatively short ridges around which the Cretaceous rocks outcrop. Still farther north, the undulations in by far the greater part of the area are gentle and sedimentation appears to have been continuous into the Tertiary; the greatly disturbed region on the western side trends toward the northwest and becomes very narrow. During the Cretaceous, deposition was practically continuous, there being only local unconformities, so small vertically and horizontally as to be surprising, in view of the vast area under consideration. There are, however, great variations in thickness which seem to be due to differential subsidence. The conditions favoring accumulation of coal were repeated many times in the region of coarser sediments and

[24] W. T. Lee, Prof. Paper, 95-*C*; R. W. Stone and W. R. Calvert, *Econ. Geol.,* Vol. V., 1910; E. Stebinger, Prof. Paper, 90-*G,* 1914.

the formation of offshore deposits was marked by an assemblage of fossils which survived the changing conditions and reappeared at several horizons.

It was to be expected that during the period of reconnaissance surveys, coal groups belonging near the base of the Upper Cretaceous should be correlated with others elsewhere, which are in highest formations of the series. One familiar with the facts, as now understood, is not astonished by the contradictions, when he considers the conditions under which the earlier work was done. During recent years, detailed studies by geologists of the National surveys of the United States and Canada have done so much toward removal of uncertainties, that it is possible to present a comparative table of formations, which, as a generalization, is near enough to the truth for purposes of this study.[25]

The first systematic classification of the western Cretaceous was presented by Hall and Meek.[26] Hall had financed an expedition to make collections between the Missouri River and the Mauvaises Terres, Meek being in charge. The succession, based chiefly on Meek's observations, is

Eocene, Tertiary Formation, clays and sandstone, etc., containing remains of mammalia, 250 feet.

Cretaceous Formation,

5. Arenaceous clay, passing into argillaceous sandstone, 80 feet.
4. Plastic clay, with calcareous concretions containing numerous fossils. This is the principal fossiliferous bed of the Cretaceous on the upper Missouri, 250 to 300 feet.
3. Calcareous marl, containing *Ostrea congesta,* scales of fish, etc., 100 to 150 feet.

[25] The writer would not neglect acknowledgment of his great indebtedness to the writings of W. T. Lee, T. W. Stanton, N. H. Darton, F. H. Knowlton, E. Stebinger, R. W. Stone and W. R. Calvert, of the United States Geological Survey and to those by D. B. Dowling, of the Geological Survey of Canada. Several of these students have been unreserved in communicating unpublished material; but they must not be held responsible for conclusions offered by the writer, some of which may appear to them far from correct.

[26] James Hall and F. B. Meek, "Descriptions of New Species of Fossils, from the Cretaceous Formation of Nebraska," *Mem. Amer. Acad. Arts and Sci.,* 1856, p. 405.

2. Clay containing few fossils, 80 feet.

1. Sandstone and clay, 90 feet.

The thicknesses were purely tentative, as the party, owing to unexpected complications, were compelled to make a remarkably rapid reconnaissance. Several years later, Meek and Hayden published an amplified section, based on examinations and collections made by Hayden while associated with the Raynolds expedition.[27] In this memoir, geographical names were applied to the several formations, Fox Hills beds, No. 5; Fort Pierre group, No. 4; Niobrara division, No. 3; Fort Benton group, No. 2; Dakota group, No. 1.

The Fort Union or Great Lignite Group, which overlies the Fox Hills, was placed in the Tertiary. This grouping was based on the fossil remains, not on the lithological features and it was applicable apparently throughout the eastern part of the Cretaceous region. In the early 70's discussion arose respecting the relations of some coal deposits which had been referred to the Fort Union; the term "Laramie" was introduced for the deposits in dispute, to be employed without committing the writer to either Tertiary or Cretaceous age. Studies in more recent years made necessary a change at the base of the column. Darton's examination of the Black Hills in northeastern Wyoming showed that the Dakota is complex, that the middle and lower portions carry Lower Cretaceous forms, while the upper portion belongs to the Upper Cretaceous. Some years afterward, the same author, and later Lee and Stanton, discovered fossils with similar relation in the same beds within New Mexico. These lower beds were correlated with the Kootenai of Canada.

When, however, an attempt was made to apply the Missouri River section to the country west from the 106th meridian, serious difficulty was encountered. The character of the deposits was wholly different. The matter was complicated by the fact that the earlier explorers did not recognize that the great erosion was due to post-Cretaceous elevation of the mountains and by the other fact that they did not know that a grouping of fossils, resembling that of the Fox Hills, occurs in that region low down in the column. In

[27] F. B. Meek and F. V. Hayden, *Proc. Acad. Nat. Sci.*, Philadelphia, 1861, citations from pp. 419, 432.

the later work, exigencies made necessary the study of economically important districts and the temporary ignoring of intervening districts. The column was divided for descriptive purposes, largely on the basis of lithology and local names were introduced, which were utilized in other districts, but not always in the same sense. At an early date, the difficulty in determining boundaries of formations at the west was recognized; the Fox Hills and the Pierre were combined as the Montana and the Niobrara and Fort Benton as the Colorado. In this study, the Meek and Hayden classification is employed as it is based on palæontological ground and enables one to recognize changes in physical geography. As modified by later studies it is

Laramie
Montana { Fox Hills, Pierre }
Colorado { Niobrara, Benton }
Dakota
Kootenai.

Each of the several formations is coal-bearing in areas of greater or less extent, but barren or nearly so in others of greater extent. They will be described in the order of age. Literature dealing with the coals of the western Cretaceous is voluminous, but it consists largely of preliminary studies with land classification as the object. Much of the region is very sparsely settled, as it is agriculturally arid, and systematic mining is confined to narrow strips along the railways. For the most part, explorers must depend on natural exposures, which are indefinite. At the same time, one cannot refrain from grateful acknowledgment of the skill exhibited by not a few of the observers, for the mass of information is so great as to prove an embarrassment in preparation of this review.

The Laramie, Lance, Edmonton.

The post-Cretaceous erosion spared only scattered areas of Laramie in the southern districts, but farther north, where the region of orogenic disturbance was restricted more and more to the far western border and deposition was apparently continuous in the plains, Laramie covers or underlies great spaces.

In the present state of knowledge, one may not assert or deny the existence of Laramie beds in the important Trinidad-Raton field of Colorado and New Mexico. Lee's discovery of an unconformity by erosion in the mass, formerly regarded as Laramie, has made the relations of the Raton formation, that above the unconformity, somewhat uncertain. The plant remains appear to have Tertiary affinities. The report by Lee and Knowlton on this field is still unpublished. It would appear that the Laramie is present in the isolated coal field on the Arkansas River, near Canyon City, Colorado. Stevenson[28] in his first report referred all the coals of this field to the Laramie; but at a later date, he restricted that formation to the upper part, 880 feet, which is in accord with the later measurement by Washburne. This later observer obtained plant remains which show that the rocks are equivalent to a part, at least, of the Laramie as recognized farther north in the Denver Basin. The coal seams are irregular in occurrence and appear to be mere lenses. The sandstones and shales are so variable that vertical sections, less than 100 yards apart, are wholly dissimilar.

The Denver Basin extends along the eastern foot of the Front Ranges almost to the northern boundary of Colorado. The Mesozoic deposits were studied by Eldridge.[29] The Laramie, 600 to 1,200 feet thick, consists mostly of sandstones in the lower, but of clays in the upper part. Coal seams in the higher beds are thinner and much more irregular than those in the lower division, which is about 200 feet thick. *Ostrea glabra,* according to Eldridge, occurs in the lower division, so that in the writer's opinion this sandstone is closely allied to the Fox Hills, to which it is lithologically similar. Sections throughout show great variation in the rocks as well as in the coal seams, so that in any district, strict correlation of coals in different mines is possible only where the workings are continuous. The coal seams of the lower division are from 3 to 14 feet thick. A seam,

[28] J. J. Stevenson, U. S. Expl. W. of 100th Mer., Vol. III., 1875, pp. 393–397; *Proc. Amer. Phil. Soc.,* Vol. XIX., 1881, pp. 505–521; C. W. Washburne, U. S. Geol. Survey, Bull. 381, 1910, pp. 341–378.

[29] S. F. Emmons, W. Cross, G. H. Eldridge, U. S. Geol. Survey, Monog. 27, 1896, pp. 51–74, 323–369.

mined in the Lafayette district, is 14 feet thick at the outcrop; but within 500 feet a parting appears, which increases northwardly to 10 and at length to 25 feet. The splits remain good in this direction, but southwardly, as the parting increases, the lower split is broken more and more by slates until it becomes worthless. The coal in some seams is not the same throughout; one bench may be hard, another soft. In one bed, the upper bench yields softer coal than the lower, which is complex, consisting of: Bright coal with conchoidal fracture, 6 inches; crushed coal, 6 inches; fibrous coal, 36 inches. The coal of the Denver Basin often has woody structure and contains silicified tree trunks, knots and branches. It is resinous at many places.

D. White[30] states that, while the coals of this Basin are relatively persistent, they vary greatly in thickness. The topography of the floor reveals shallow "swales" or ponds, occasionally extending a mile or more, in which the coal is thicker. The floor at Lafayette is a bluish sandy underclay, containing numerous roots in place, probably an old swamp soil; resting on this is a bed, 8 to 30 inches thick, of dark carbonaceous clay, or lignitic mud, filled with flattened stems, lying in all directions, some of them very large and many are much compressed. The roof is sandstone with no transition from the coal.

In general, the coal is essentially xyloid, there being apparently more wood than in the lignite of Hoyt and Rockdale in Texas, though less than in that of Wilton and Lehigh in South Dakota—all of them Eocene. The quantity of jetified wood is large but the branches and limbs are compressed to thin lenses. Mineral charcoal is abundant, often in large fragments. A log was seen, 14 by 5 inches in section, jetified in the interior, while the outer portion had become mineral charcoal; but another specimen was hollow, containing mineral charcoal in the interior, while the outer portion was jetified. Irregular lumps of yellow resin are numerous and at times this material has been squeezed into the joints.

The coal at Marshall, 10 miles from Lafayette, is at the same horizon, being regarded as one of the splits of the main Lafayette seam. Silicified wood is abundant and well-preserved, showing

[30] D. White, "The Origin of Coal," Bur. of Mines, Bull. 38, 1913, pp. 20–23.

grain and rings distinctly. The lower part of the bed is more conchoidal, less xyloid and has higher percentage of fixed carbon than the upper, suggesting, as White says, that it represents a more matured peat. He could obtain no data respecting the floor of this bed, but roots were found under two coal seams in a railway cut, the sandy floor of one being undoubtedly an old soil.

Thiessen's[31] microscopic study of the Lafayette and Marshall coals proved that, generally speaking, the type of vegetation and the conditions during accumulation must have been very similar to those during the Eocene in Montana and Dakota, though the proportion of woody materials is somewhat less and the compression is greater. The resin is darker than that of the Dakota lignite. The débris contains the reticulated bodies observed in the pith of certain fossil wood and present in all Tertiary and Cretaceous coals which Thiessen has examined. Fungal hyphæ and spores are abundant, the former especially in material of herbaceous origin. Spores and pollen exines compose not more than 5 to 10 per cent. of the mass.

A notable area of Laramie has escaped erosion in the northern part of the San Juan Basin within New Mexico and Colorado. On the eastern outcrop, according to Gardner,[32] coal seams are very thin or are wanting; but on the western outcrop, Shaler saw along the Rio Chaco several coal seams which occasionally become workable, with a maximum thickness of 3 to 6 feet. Farther north, on the San Juan and Plata Rivers, he saw the Carbonero seam with maximum thickness of 50 feet; but it is variable, for at one locality it is little more than 6 feet and is broken by three partings. Beyond the Colorado line, near Carbon Junction, the thickness increases to about 100 feet; the partings are very numerous, but there are some bands of clean coal, 4 to 5 feet thick. The bed divides toward the west; at 3 miles southeast from Durango, Shaler saw three seams, 7, 30 and 15 feet, in a vertical space of less than 200 feet, which he believes to be splits of the Carbonero.

Apparently no part of the Laramie has escaped erosion in the great Uinta Basin of northwestern Colorado; or, at least, if any still remain, its rocks are so similar to those of the Pierre that no

[31] R. Thiessen, Bur. of Mines, Bull. 38, 1913, pp. 241–243.

[32] J. H. Gardner, Bull. 341, 1909, p. 388; M. K. Shaler, Bull. 316, Pt. 2, 1907, pp. 385, 386, 395, 396, 400, 404.

separation can be made. The coal deposits of this region were referred to the Laramie by the earlier observers; the later observers have proved that they in the Pierre.

Laramie coals are important in the Green River Basin of southwestern Wyoming. The Cretaceous section in the outlying coal field of Coalville in northeastern Utah has on top 2,500 feet of mostly sandy beds, with leaves and fresh-water shells, but no coal. This rests on 1,650 feet of sandy beds with marine fossils.[33] At about 30 miles northeast, one reaches the Laramie area of Uinta County, Wyoming, where the Laramie, according to Knight and Veatch,[34] is more than 5,000 feet thick in the southern part of the county. There, as in the Coalville field, one is near the western border of deposition and the formations are thick. Schultz found only 2,800 feet remaining in the northern part of the county. The lower portion of the column for several hundred feet contains marine fossils and it must be referred to the Fox Hills; but Laramie leaves are abundant in the higher deposits. The Tertiary coals of Evanston overlie the Laramie uncomformably. Coal seams are numerous in the Laramie and at times they are workable, but the thicker seams of the Tertiary render them unimportant.

The Rock Springs coal field in Sweetwater County is about 50 miles farther east, only Tertiary deposits being at the surface in the intervening space. Schultz[35] gives the thickness of Laramie as 3,900 to 1,500 feet, the variation being due to extent of erosion. The lower part of the section is clearly Fox Hills; the Laramie beds are sands and clays with little coal. The marine sandy beds persist eastwardly and the Laramie rocks retain their features, finer in grain, more argillaceous and without important coal beds. In southern Carbon County, Ball and Stebinger[36] find an extreme thickness of 4,000 feet, but the formation thins away southward. The lower part of the column for about 400 feet must be assigned to the

[33] C. H. Wegemann, Bull. 581-*E*, 1915, p. 161.

[34] W. C. Knight, "Southern Uinta County, Wyoming," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 542–544; A. C. Veatch, Bull. 285, 1906, p. 333; A. R. Schultz, Bull. 316, 1907, p. 217.

[35] A. R. Schultz, Bull. 341, 1909, p. 259; Bull. 381, 1910, pp. 223, 227.

[36] M. W. Ball and E. Stebinger, Bull. 341, 246, 253; Bull. 381, pp. 190, 193, 204.

Fox Hills. The coal seams are irregular except in the northern part of the district, where beds were seen, 8, 6 and 4 feet thick. Whether these belong to Fox Hills or to Laramie cannot be determined from the sections. In the southern portion of the basin, within Colorado, the Laramie is 900 feet thick according to Fenneman[37] and Gale, consisting of alternating sandstones and shales, with indications of 20 lignite seams distributed irregularly in the upper two thirds. The writer regards the lower third as belonging to Fox Hills and thinks that the thick coal seam near Craig, 8 feet, is in that formation.

Northward from the Green River Basin, areas of Laramie are comparatively unimportant. On the west side of the Bighorn basin, lenticular coal beds were seen by Woodruff at many places in the lower part of the formation. Washburne found 150 to 700 feet between the Eocene and the Pierre formation, massive sandstones and shales; in this, taken to be Laramie, there are thin and variable coal beds. The only workable seam is near Garland where 4 feet of clean coal had been worked; but the seam quickly breaks up in all directions and becomes worthless. The Buffalo coal field, east from Bighorn Mountains, shows great irregularity in deposition during the Laramie, but the coal seams, though varying in thickness and quality, can be traced for considerable distances. In the Sussex coal field, 30 miles farther south, Wegemann found the Lance formation, 3,200 feet thick and resting on the Fox Hills. The coals are unimportant except in two localities, where seams occasionally become workable. Wegemann's descriptions seem to make clear that the coals are mere lenses and the better coal is in the middle portion of the lens. Winchester measured about 2,450 feet of Lance beds in the Lost Spring coal field, which is on the western border of the great Tertiary lignite area. There are traces of the coals seen farther west, but only carbonaceous shale was found. The Fox Hills, Lance and Fort Union appear to be conformable in this region. The highest rocks in the Black Hills area of northeastern Wyoming are sandstones, shales and lignites, in all about 2,500 feet, as determined by Darton. That student hesitated to identify these beds as Laramie, because it was not possible to determine whether or not they are conformable to the underlying Fox

[37] N. M. Fenneman and H. S. Gale, Bull. 285, 1906, p. 288.

Hills. The relations of the Lance formation have been subject for much discussion; the testimony of plant and animal remains is contradictory. In no inconsiderable area, the Lance is conformable to the Fox Hills. Winchester in a recent note, summarizing results obtained by himself and his assistants, in eastern Wyoming, states that Lance overlies Fox Hills. It is subdivided into three members; a lower undifferentiated portion, 425 feet thick; a middle, lignite-bearing portion, the Ludlow, at least 350 feet; and an upper marine member, the Cannonball, 225 feet. The marine fauna of the Cannonball is very similar to but not identical with that of the Fox Hills, while flora of the Ludlow cannot be differentiated from that of the Tertiary Fort Union.[38]

The eastern half of Montana is a rolling plain covered with Tertiary and later deposits, the mountains of states at the south having disappeared. Anticlinals have brought up the highest members of the Cretaceous. The Lance, taken by the writer as the eastern extension of the Laramie, has at base the Colgate sandstone, which is 90 to 175 feet thick and contains no coal except at one locality, where Hance saw a lens only a few hundred yards long. The upper part of the Lance, about 500 feet, has variable seams of lignitic coal, but all are lenticular. Some observers note great irregularity in the deposits, which appear to be fresh-water throughout.[39]

West from the 109th meridian, one approaches the mountain region and finds the whole Cretaceous exposed. In northern Fergus County, the Lance appears to be present, but the relations of the beds are not altogether clear. Near the Crazy Mountains in Meagher County, Stone found 1,200 to 2,800 feet of shales and sandstones, which he places in the Laramie; but the Lennep sandstone, at the base, 200 to 400 feet thick, is known now to be Fox Hills. Lenses of coal, a few inches thick and of insignificant horizontal extent, are present in the Laramie. Not far westward from this district shore conditions prevail and a continuous formation,

[38] E. G. Woodruff, Bull. 341, 1909, pp. 202, 205; Bull. 381, p. 173; C. W. Washburne, Bull. 341, pp. 167, 169, 181; C. H. Wegemann, Bull. 471-*F*, 1912, pp. 26, 30; D. E. Winchester, Bull. 471-*F*, p. 58; *Journ. Wash. Acad. Sci.*, Vol. VII., 1917, p. 36; N. H. Darton, Prof. Paper 65, 1909, p. 58.

[39] W. R. Calvert, C. F. Bowen, F. A. Herald, J. H. Hance, Bull. 471-*D*, 1912, pp. 13, 21, 48, 49, 91.

the Livingston, occupies the whole interval from near the base of the Pierre to the lower portion of the Fort Union.[40]

In Teton County, on the Canadian border and near the western boundary of the Cretaceous, Stebinger saw 980 feet of clay, clay shales soft gray to greenish gray cross-bedded and rippled sandstones with coal seams and some lenticular limestones. Apparently, the succession from Lower Cretaceous to the top of the Eocene is conformable throughout. This mass, placed by Stebinger at top of the Cretaceous column, is shown by tracing to be the St. Mary formation of Dawson in Alberta. Its sandstones contain fossil wood. Coal seams occur at top and near the bottom, but they are too thin and uncertain to be of economic importance. The persistence of a coal horizon near the base proved, as Stebinger observes, the existence of widespread though transient coal-forming conditions soon after deposition of the great Horsethief (Fox Hills) sandstone. The coal seams improve near the Canadian border.[41]

Passing over into Canada, Dawson in southeastern Alberta placed a great mass of deposits in the Laramie, but later studies have made evident that only the lower division should be referred to that formation. This, the St. Mary beds, is, at least in part, the same with the Edmonton of Dowling and with the Lance in Wyoming and Montana. The formation, about 2,800 feet thick, is of freshwater origin except at the base and in its upper portion has sandstones which are cross-bedded, rippled and with worm borings.[42] Dowling[43] measured about 3,000 feet on Oldman River, mostly sandstone with sandy shales and some thin coals at the base. In the Sheep River district, two seams were seen near the Foothills, but farther east on Sheep River there is only one. Tyrrell[44] studied a large area in eastern Alberta between the Red Deer and North Saskatchewan Rivers. At the south near Red Deer River, he saw two important coal seams near the top of the formation, each about

[40] R. W. Stone, Bull. 341, pp. 82, 84; R. W. Stone and W. R. Calvert, *Econ. Geol.*, Vol. V., 1910, pp. 551–557, 652–669, 741–764.

[41] E. Stebinger, Bull. 621-*K*, 1916, pp. 124, 127, 128, 145.

[42] G. M. Dawson, Geol. Survey of Canada, Reps. Prog. 1882–83–84, Part *C*, pp. 36–72.

[43] D. B. Dowling, Summ. Reps. for 1903, pp. 142–149; the same, for 1914, p. 47.

[44] J. B. Tyrrell, Rep. Prog. for 1886, Part *E*, pp. 56, 60–63, 132.

10 feet thick; but he did not find them persistent. In the North Saskatchewan portion of the area, the important coal is also near the top of the formation. The chief seam was seen first near Wintering Hills as a bed of carbonaceous shale; but farther north it becomes coal and increases steadily until it becomes 25 feet thick. Several seams were seen in the lower portion of the formation, but the most persistent horizon is about 160 feet above the Pierre. Cross-bedded sandstone was observed at many localities.

About twenty-five years later, when the region had been opened up, Dowling[45] reported upon the Edmonton District, a portion of the area studied by Tyrrell. There he found about 700 feet of Laramie (Edmonton, St. Mary), a succession of shales and sands, too often merely clays and sands, a brackish-water formation between the marine Pierre and the fresh-water Pashkapoo of the Tertiary. It is rich in coal seams, which increase from south to north. The important coal horizon is near the top of the formation and it has been followed from the Red Deer to the Pembina River, becoming thicker toward the north and northwest. Three seams were seen on the Pembina, of which the highest is 26 feet thick; on the north Saskatchewan, a seam, belonging to the same coal group in the upper part of the formation, is 25 feet. Below the middle of the formation, Dowling saw another coal group; some of its seams are lenses of moderate extent, while others have been traced by borings under a considerable area; but they vary greatly in thickness and may be lenses. Dowling is evidently far from certain that the main seam of the region is persistent.

McConnell[46] states that the Laramie in northern Alberta has numerous seams of inferior lignite and ironstone. Rose reporting on the Lance of southwestern Saskatchewan, refers to the formation as a transition from the marine Fox Hills to the fresh-water Fort Union. The rocks are slightly consolidated and the seams of lignite are unimportant.

[45] D. B. Dowling, Memoir 8-*E*, 1910, pp. 13, 16, 18, 27, 28.

[46] R. G. McConnell, Ann. Reps., Vol. VI.-*D*, 1893, p. 53; B. Rose, Summ. Reps. for 1914, pp. 64–67.

The Fox Hills, Lennep Sandstone, Horsethief Sandstone.

In this study the transition beds from the marine Pierre to the fresh-water Laramie are taken to be the Fox Hills. At very many localities, where the higher members of the Cretaceous have escaped erosion, this transition formation is a shore or offshore deposit of more or less coarse materials, with fossils, mostly marine but accompanied at times by brackish-water forms. Within some basins, coal seams of great economic importance are present, while in others, coal is wanting or in such small quantity as to possess only geological interest.

Reports on the San Juan Basin to which the writer has access, give no details sufficing to determine whether or not the Fox Hills is present in any considerable part of the Basin; but a section by J. H. Gardner, cited and discussed by Lee,[47] shows that it exists in the northern part. The Pictured Cliffs sandstone, 394 feet thick, mostly gray sandstone, contains marine fossils to the top. It underlies 79 feet of brackish to fresh-water beds, in which coal seams, 4 and 12 feet thick were seen at 4 and 57 feet from the base. Lee includes these in the "Laramie," as there appears to be uncertainty respecting the relations of some parts of the column. No coal has been reported from the Pictured Cliffs sandstone.

The existence of Fox Hills is equally uncertain in the Uinta Basin of western Colorado. Fox Hills conditions recurred at various horizons in the Pierre of this basin, as they did in central New Mexico, so that the earlier observers recognized both Fox Hills and Laramie in the Pierre beds. But there is no room for doubt that the formation exists in the southeast prong of the Colorado portion of the Green River Basin; for there Gale[48] found the basal sandstone of the "Laramie," resting on the Pierre, with a marine fauna. The thick coal bed at Craig apparently belongs in the Fox Hills. About 50 feet of this formation has escaped erosion in North Park, Colorado, where it rests on the great mass of Pierre shale. There Beekly obtained marine shells and the fucoid *Halymenites major* from this sandstone; but no coal is present.[49]

[47] W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, pp. 587–591.

[48] H. S. Gale, Bull. 341, pp. 287, 295.

[49] A. L. Beekly, Bull. 596, 1915, p. 46.

The relations are sufficiently clear in the main portion of the Green River Basin with Wyoming. In Uinta County, the basal 200 feet of "Laramie" with alternating marine and land deposits includes among others the great Adaville-Lazeart coal seam, 10 to 84 feet thick; Veatch's brief summary of the coals gives no details respecting the accompanying rocks. Schultz found in the Rock Springs field of Sweetwater County a yellowish white sandstone at base of the "Laramie," overlain by sandstones, clays and coal beds; in some places fossils abound. The basal sandstone rests on the upper member of the Pierre. The coal of this Fox Hills is inferior and is no longer mined. Smith reports that in northeastern Carbon County, marine fossils are present up to 500 feet from the base of the "Laramie," which, he says, is a common condition in southern Wyoming and northern Colorado. Here as in other parts of the basin, a great sandstone is at the base. Coal is present in the Fox Hills, but the beds are unimportant, the thickest being only 18 inches. Veatch[50] separates the beds with marine fossils in east central Carbon from the Laramie and places the great white sandstone with its overlying beds in the Pierre. No occurrence of coal is noted. Ball and Stebinger in southern Carbon place the sandstone and the overlying beds in the Laramie, but state that marine fossils have been up to 400 feet above the sandstone. They give no details respecting the character of the beds and apparently they saw no coal.

The Raton-Trinidad coal field of New Mexico and Colorado is at the eastern foot of the Front Ranges. The earlier students regarded the coal-bearing rocks as conformable throughout and placed them in the Laramie. The numerous unconformities observed were thought to be merely local variations, characterizing deposits on the rudely level strand area. Lee, however, has proved that the irregularities are far greater than imagined by his predecessors and that a great unconformity by erosion separates the column into the Raton and Vermejo formations, the former most probably of Tertiary age. The Vermejo, resting on the Trinidad sandstone, is taken by the writer to be Fox Hills but Lee is inclined to regard it

[50] A. C. Veatch, Bull. 285, 1906, p. 333; Bull. 316, 1907, pp. 246, 248; E. E. Smith, Bull. 341, pp. 225, 228, 229; M. W. Ball and E. Stebinger, Bull. 341, pp. 246, 247; Bull. 381, 1910, p. 193.

as somewhat older. At the same time, in view of conditions farther north along the eastern foot of the Front Ranges, the writer feels compelled to abide by his opinion expressed 35 years ago, that in large part, at least, the rocks belong to the Fox Hills. The basal sandstone known now as the Trinidad sandstone (Halymenites sandstone of Stevenson), contains some marine fossils with great abundance of the fucoid, *Halymenites major;* the overlying beds, with extreme thickness of about 500 feet, are prevailingly sandstone with interbedded shales and coal seams. The rocks have fossil leaves, which are older than Laramie and a few marine fossils have been seen. The coal seams are numerous but are indefinite, varying so greatly in thickness and relative position that correlation, especially of the higher ones, is not possible. All are excessively variable in the New Mexico portion of the field, but some of them attain importance in modest areas and are mined extensively. In the northern or Colorado part of the field there are from one to 8 seams in the 250 feet above the Trinidad sandstone. This group is persistent and consists of lenses, which frequently are workable. Near Sopris, the seams "thicken and thin out characteristically," they are broken by partings and the coal is dirty. Near Trinidad, the coal is sometimes without a parting. The accompanying rocks are as variable as the coals. Near Pictou, 3 seams are mined. At the outcrop, the intervals are 15 and 30 feet; but at 2,500 feet in the mine, the upper and middle beds have united and the interval to the lower one is but 20 feet. The coal seams are not persistent and resin is found in the northern part of the field.

	I.	II.	III.	IV.	V.
Coal	4 ft. 0 in.	0 ft. 8 in.	0 ft. 10 in.	4 ft. 0 in.	4 ft. 0 in.
Bone or shale.	0 ft. 4/5 in.	7 ft. 0 in.	21 ft. 10 in.	24 ft. 0 in.	7 ft. 0 in.
Coal	3 ft. 4 in.	1 ft. 8 in.	3 ft. 0 in.	5 ft. 0 in.	0 ft. 8 in.
Parting......	thin	0 ft. 2 in.	14 ft. 0 in.	13 ft. 0 in.	25 ft. 0 in.
Coal	2 ft. 1 in.	5 ft. 0 in.	6 ft. 0 in.	9 ft. 0 in.	0 ft. 3 in.
Clay or shale.	1 ft. 4 in.	0 ft. 4 in.	8 ft. 0 in.	12 ft. 0 in.	22 ft. 5 in.
Coal	0 ft. 10 in.	2 ft. 0 in.	1 ft. 0 in.	1 ft. 0 in.	blossom
Total......	11 ft. 7 in.	16 ft. 10 in.	54 ft. 8 in.	68 ft. 0 in.	58 ft. 11 in.
Total of coal	10 ft. 0 in.	9 ft. 4 in.	10 ft. 10 in.	19 ft. 0 in.	4 ft. 11 in.

On the northern side of the Raton plateau, a sandstone at 70 feet above the Trinidad coal bed, contains many weather-beaten tree trunks along with worm borings and impression-like *Halymenites.* The extreme instability of conditions on the sandy flats, where coal accumulated, is shown by variations in the Trinidad coal bed, mined at Engle and Starkville. Stevenson's measurements are given in the preceding table.

These measurements are all within 3 miles from the first and the position to the Trinidad sandstone precludes all probability of error in correlation. The Trinidad sandstone is practically without coal.[51]

Fox Hills conditions are distinct farther north on the Arkansas River in the Canyon City coal field. Stevenson visited this field in 1873, but the movements of the party, to which he was attached, were so rapid as to give opportunity only for errors. He visited it again in 1881 and Washburne examined it in detail during 1908. These observers recognized the Trinidad sandstone, from which Stevenson, in both visits, obtained *Halymenites.* The Vermejo formation is about 500 feet thick, including the basal sandstone and its uppermost member is a massive sandstone, 145 feet, containing abundant *Halymenites.* According to Washburne, this member, nearer the mountains, loses its marine fossils, is less massive, is cross-bedded and has all the characteristics of a fluviatile deposit.

The coal seams are numerous and some are important. One, resting on the Trinidad sandstone, is 3 ft. 4 inches thick with at times shale, at others, sandstone as the roof, the less thickness being under the sandstone. The shale is 0 to 7 feet thick, showing that the erosion followed deposition of the shale. Sandstone "rolls" were seen by Washburne in a bed about 275 feet above the Trinidad sandstone. These extend for long distances and the sandstone passes through the roof clay, often through the coal to the floor. These "rolls" have rounded bottom, curved sides and the trend is toward northeast throughout the mine. The current bedding in the "rolls" indicates a northeast flow for the streams. Resin occurs in the lowest coal seam.

Fox Hills has been recognized in the Denver Basin by Eldridge

[51] J. J. Stevenson, U. S. Geog. Expl. W. of 100th Mer., Vol. III., sppl., 1881, pp. 102 ff.; G. B. Richardson, Bull. 381, 1910, pp. 385, 386, 395, 411; W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, p. 611. It is unfortunate that Lee's elaborate report on the Raton coalfield is still unpublished.

and by Fenneman,[52] who assign to it a thickness of 800 to 1,200 feet. These observers recognized no coal in the Fox Hills, as they took the important coal seams of the basin to be Laramie. But Stevenson[53] saw coal in rocks of Fox Hills age at 5 miles southeast from Evans, about 40 miles north from Denver. From a sandstone overlying coal he obtained *Ammonites lobatus, Cardium speciosum, Mactra alta, Mactra warreniana, Lunatia moreauensis* and *Anchura*. The *Halymenites* is abundant.

The deposits in western Wyoming, which earlier observers termed Fox Hills, are known now to belong to the Pierre, but the formation is present in some areas. The "Laramie" in the northeastern part of the Bighorn Basin, 150 to 700 feet thick, is apparently Fox Hills. It is mostly a massive sandstone but contains some seams of coal, occasionally workable though of quality inferior to that from older formations. East from Bighorn Mountains, the Fox Hills was recognized in the Lost Spring field by Winchester, in the Sussex field by Wegemann and in the Black Hills by Darton, but no coal is reported from any locality, except one, where Wegemann saw a deposit of "unusual variability in thickness and quality."[54]

The Fox Hills is known in northwestern Montana as the Horsethief sandstone described by Stebinger, as the Lennep sandstone of Stone and Calvert in the central part of the state. Stebinger traced the Horsethief sandstone across the Canadian boundary and proved its continuity with the Fox Hills of Dawson. He describes the sandstone as 360 feet thick, buff, coarse, massive and much crossbedded in the upper half, but becoming slabby and more or less shaly toward the base. Usually the fauna is brackish, *Ostrea, Corbicula, Corbula,* and *Anomia*, but at some horizons it is marine of the litoral type, *Tancredia, Cardium* and *Mactra*. In his paper of 1914, he shows that the Horsethief sandstone was at one time continuous from the Teton district at eastern foot of the Rocky Mountains to

[52] G. H. Eldridge, Mon. 27, 1896, pp. 69, 72, 73; N. H. Fenneman, Bull. 265, 1905, p. 33.

[53] J. J. Stevenson, *Amer. Journ. Sci.*, Vol. XVII., 1879, pp. 369–372.

[54] C. W. Washburne, Bull. 341, p. 169; D. E. Winchester, Bull. 471-*F*, 1912, p. 58; C. H. Wegemann, the same, pp. 25, 32; N. H. Darton, Prof. Paper 65, 1909, p. 57.

the Black Hills on the Wyoming border. No coal, aside from some insignificant lenses, has been seen in this northern extension of the Fox Hills; and the conditions are the same in Alberta.[55]

The Pierre Formation.

Thus far the tracing has been comparatively simple. The Laramie and Fox Hills mark the closing portion of the Cretaceous and conditions appear to have been much the same in each throughout the whole region. But during the Pierre, conditions near the source of sediments were wholly different from those in the great area beyond. On the eastern side, the rocks are almost wholly shale and without coal, while on the western and southern sides there are great deposits of sandstone and sandy shale with, in some areas, important coal seams at several horizons. At the east, the fossils are marine but at the west and south there are marine and brackish as well as fresh-water horizons. The offshore and strand conditions, marking strife between advancing land and the sea, are evident from the recurrence of a fauna allied to that of the Fox Hills as well as of sections showing a succession like that of Fox Hills and Laramie, a gradual transition from marine to continental deposits. In the description of widely separated areas, local terms based on lithological features became necessary, but the resulting confusion has been removed by the labors of the students listed on an earlier page and the relations are now well understood, though in some areas there still remains uncertainty as to the planes of separation.

In Alberta, Montana and northern Wyoming the Pierre is divided into Lewis or Bearpaw shale, Judith River formation, Claggett shale and Eagle sandstone: the last, overlying shale. This order, descending, is distinct from the Bighorn Basin of Wyoming northward into Alberta, but, at a short distance westward, where one approaches the western limit of Cretaceous deposition, some modifications in nomenclature and grouping become necessary. Farther south in Wyoming, Colorado and New Mexico, the succession is given as Lewis shale, Mesaverde formation and Mancos shale. The term, Mesaverde, is indefinite; it is the sandstone member of the Pierre and is more or less coal-bearing. In some extensive areas it

[55] E. Stebinger, Bull. 621-*K*, 1916, p. 125; Prof. Paper 90-*G*, p. 62.

embraces practically the whole of the Pierre, while in others it but the middle portion. Mancos is another lithological term, designating the mass of shale underlying the Mesaverde, so that in many districts it includes the Lower Pierre as well as the Niobrara and Benton. The significance of the several terms will appear in description of the districts.

The Pierre in the Parks of Colorado and east from the meridian of the Front Ranges of Colorado consists mostly of shales, becoming sandy toward the top, with irregular lenses of limestone and, in the upper portion, huge calcareous and ferruginous concretions. Sandstone is wholly unimportant except in the Boulder district of the Denver Basin, where Fenneman saw,[56] at one third way from the base, the Hygiene sandstone, which is several hundred feet thick west from Berthoud, but only 250 feet at the north end of the district. The thickness of Pierre in this region is not fully determined; Eldridge gives 7,700 to 7,900 feet in the Denver Basin, but Fenneman gives only 5,000 in the Boulder district of that basin. Near Canyon City on the Arkansas River, oil-borings found 4,500 feet, while farther south on the eastern border of the Raton-Trinidad coal field, the thickness appears to be considerably less.

But the change is startling between the southern termination of the Raton field and Cerillos, a distance of about 100 miles in west of south direction. At Cerillos, one is on the same meridian with the Park area of Colorado, where the Pierre is almost wholly shale, whereas here it is largely sandstone. Some small isolated coal fields remain farther south. The Engle, unimportant from the economic standpoint, has coal-bearing rocks, which as Lee[57] has shown, rest on deposits of Benton age. Wegemann found similar conditions in the Sierra Blanca field about 80 miles west-northwest from the last. Both authors are inclined to refer the coals and associated rocks to the Mesaverde, because the general conditions resemble those observed farther north in the Cerillos field. In the absence of conclusive information, the writer is inclined to suggest that the coals may be of Benton age. The Sierra Blanca area is not far from 120 miles south from the Cerillos field and by so much

[56] N. M. Fenneman, Bull. 265, 1905, pp. 31, 32.

[57] W. T. Lee, Bull. 285, 1905, p. 240; C. H. Wegemann, Bull. 541-*J*, p. 10.

nearer the source of sediment. One should expect to find in that direction the same conditions as appear on the western border, where important coals occur in the Benton.

The Cerillos coal field, a few miles south from Santa Fe, New Mexico, has been examined by several geologists whose conclusions are not in agreement.[58] Stevenson thought that the coal-bearing group belongs to the Laramie; Johnson referred it to the Fox Hills; but Lee recognized the true relations and determined that it is Mesaverde, the Middle Pierre in this field. The coal group is about 1,200 feet thick and rests on Mancos shale, of which the top 150 feet carries Pierre fossils. The basal rock of the coal group is a sandstone, 300 feet thick and without coal. It has an assemblage of fossils which suggests Fox Hills conditions. The coal seams are numerous but variable. The sections of one bed at four openings, as given by Stevenson, are

Coal	1 ft. 2 in.	Thin	Streaks	Absent
Clay	1 ft. 3 in.	6 ft. 0 in.	12 ft. 0 in.	8–10 ft.
Coal	2 ft. 3 in.	2 ft. 5 in.	4 ft. 7 in.	3 ft. 10 in.
Coaly shale	3 ft. 5 in.	Absent	Absent	1 ft.

In one mine the coal has been replaced with sandstone in a space 75 feet wide and several hundred feet long, a case of contemporaneous erosion. Gardner[59] saw an apparently similar replacement in the Omera field, east from Cerillos. At 500 feet from the outcrop in a mine, the roof descended and cut out the coal. In 1879, Stevenson noted a ripple-marked sandstone and an underclay with roots.

The only information available for present purposes, respecting coal fields between Cerillos and the great San Juan Basin at the west, is contained in Lee's publications.[60] The Hagan field directly west from the Cerillos differs notably from the latter. The most striking difference is due to increase of Mesaverde at expense of the

[58] J. J. Stevenson, U. S. Geog. Expl. W. of 100th Mer., Vol. III., Suppl., pp. 147 ff.; *N. Y. Acad. Sci.*, Vol. XV., 1896, pp. 105 ff.; D. W. Johnson, *Sch. Mines Quart.*, Vols. XXIV., XXV., 1903; W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 642, 658; Bull. 531-*J*, 1913; Prof. Paper 95-*C*, 1915, p. 41.

[59] J. H. Gardner, Bull. 381, 1910, p. 448.

[60] W. T. Lee, Bull. 389, 1909, pp. 5–40; *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 622–642.

underlying Mancos. The lower portion of Mesaverde in Cerillos is the great sandstone, 300 feet thick; but in Hagan it is about 900 feet, mostly sandstone, without coal and with Pierre fossils at several horizons. The coal group immediately overlying it is 180 feet thick with 5 coal seams, of which one has local importance. This averages about 3 feet in a small area and underlies a massive coarse sandstone, cross-bedded and containing petrified wood. Thin streaks of coal were seen in higher parts of the column. The whole thickness is about 1,850 feet and the upper half has no marine fossils. The Tijeras coal field, at 25 miles southwest, gives clearer evidence of land conditions. The lower portion of the Mesaverde is only 700 feet thick, but it contains 3 coal beds, 2 inches to 3 feet thick, proof that the broad sand flats were free from sea-invasion long enough to permit accumulation of peat in the hollows of their irregular surface. The lithology changes above the uppermost marine sandstone. Exposures are such as to make measurements indefinite, but the presence of what the writer takes to be the Cerillos coal group is distinct, for two coal seams, 3 feet and 1 foot 6 inches, were seen. This upper portion contains no marine forms. The basal deposit is a massive sandstone, 115 feet thick.

The Rio Puerco field, beyond the Rio Grande, is about 25 miles west from Hagan and Tijeras. Lee gives 1,700 feet as the thickness of Mesaverde, but thinks that the upper part has been removed by erosion. The Mancos (Colorado) shales are but 1,113 feet, whereas they are 2,350 feet at Cerillos. The Mesaverde has many horizons of marine fossils even to the top; but, at about 300 feet from the top as here exposed, it has a coal group, 185 feet, with 16 coal seams, all very thin; and another, about 100 feet thick, with one of the beds 6 feet thick, at 450 lower. Some of the sandstones contain fossil leaves in abundance. At the base is a massive marine sandstone, the Punta de la Mesa sandstone of Herrick and Johnson,[61] which is 77 feet thick. The former existence of another coal-bearing group is shown at the top of the column, where Lee found at some localities a shale with thin coal. At the same time it seems probable that the upper coal group represents that at Cerillos. Lee's suggestion that the 300 feet of marine sandstone and sandy shale at

[61] C. L. Herrick and D. W. Johnson, *Bull. Univ. New Mex.*, Vol. II., p. 6.

the top of the section may represent the Lewis shale is very far from improbable: there appears to be good reason for believing that the Mesaverde of Rio Puerco includes the whole of the Pierre, whereas at Cerillos, Mesaverde is Middle Pierre.

Pierre deposits are exposed on the borders of the great San Juan Basin. Information is lacking for the southern prong of this basin but is fairly abundant for the main part, northward from Lat. 35° 30′, though comparatively few details have been published. Gilbert,[62] during the reconnaissance in 1873, measured a long section of Cretaceous at Stinking Spring, 12 miles west from Fort Wingate in New Mexico. This shows about 700 feet of yellow shales, yellow sandstones with coal beds, resting on 1,050 feet of sandstones and mostly sandy shales. Of the 7 coal seams, 3 reach workable thickness; one of them is triple, the benches being 4, 5 and 2 feet, separated by 5 feet and one foot of shale. There is no coal in the basal 200 feet. The Cretaceous in this region is one lithologically; "characterized by sands, by coal, by rapid alternations, by ripplemarks and by oysters, it is evidently an off-shore deposit." But fossils offer basis for subdivision; they are abundant in the lower 850 feet, which may be taken here as representing the shore facies of Colorado or lower portion of the Mancos, as that appears in the type locality.

Thirty years later, Schrader[63] made a reconnaissance of the eastern side of the basin, from Gallup, near Fort Wingate, to the northern border in Colorado. The section is longer than at Stinking Spring and during the 30 years interval the coal bed had become important. He found shales and sandstones, 2,000 to 3,000 feet thick, with the Upper Coal Group in the lower part; shales and sandstones, 500 to 800 feet, with the Middle Coal Group near the top; and 500 to 1,000 feet of Colorado shale, with the Lower Coal Group near the top. The Upper Coal Group is about 100 feet thick and contains 6 workable coal seams, 5 of which have fireclay floors. The Middle Coal Group appears to be the same with that of Gilbert's section. The coal seams throughout appear to be irregular.

[62] G. K. Gilbert, U. S. Geog. Explor. W. of 100th Mer., Vol. III., 1875, pp. 544, 549, 550.

[63] F. C. Schrader, Bull. 285, 1906, pp. 242, 254, 255.

Gardner[64] afterwards examined this line more in detail. Here he regarded the upper and middle groups of Schrader as Mesaverde (here evidently in part Lower Pierre), to which he assigns a thickness of about 1,000 feet east from Gallup. The coal seams are numerous but variable; "within a few miles, thin beds undoubtedly thicken to valuable properties and thicker beds thin to mere traces."

Farther north between San Mateo and Cuba, the Mesaverde, 1,200 feet thick, is coal-bearing throughout. Near the top is the first appearance of the Lewis shale, which contains much sandstone and sandy shale. There, one is little more than 40 miles northwest from the Rio Puerco locality, where Lee found marine fossils at top of the Mesaverde and thought that the deposits might be the equivalent of Lewis shale. No trace of that shale is reported from any locality farther south in the San Juan Basin. Along this portion of the outcrop, the Mesaverde coal seams are in two groups, separated by 300 feet of barren measures; the seams are all lenticular and in several instances have bony coal at top or bottom or both. Gardner's observations north and west from Cuba are important. At a little north from Gallina, 14 miles north from Cuba, the Lewis is 2,000 feet while westward it becomes only 250 near Raton Spring. Gardner thinks this westward change due to replacement with sandstone, which has been regarded as Mesaverde. The condition southeast from Cuba confirms the suggestion, for there the Mesaverde is but 719 feet, with no coal in the basal 300 feet and only coaly shale or thin coals at widely separated horizons in the upper part. The thinning is more notable beyond Gallina, where the Mesaverde is but 214 feet and contains 14 coal seams, of which only one is of workable thickness. The coal is subbituminous, occasionally resinous and the seams are variable to the last degree. The Mesaverde is limited, top and bottom, by massive sandstones which persist although the section is decreased. Lee[65] states that Gardner's collections from Lewis shale and from Mesaverde south and southeast from Cuba, are marine. He saw great numbers of petrified stumps and logs in the lower part of the Mesaverde near Cabezon, where the upper part of the Mancos has Pierre fossils.

[64] J. H. Gardner, Bull. 341, 1909, pp. 339, 343, 345, 366, 372, 377; Bull. 381, 1910, pp. 463, 470.

[65] W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, pp. 619–621.

It would appear from the observations by Lee and Gardner that, in this portion of the basin, the Mesaverde is again Middle Pierre. The sea area extended as a gulf southward as far as Cabezon's latitude and the sandy member of the Pierre must have disappeared at only a little way east from Gallina.

Shaler[66] examined the western outcrop in the San Juan Basin. He reports that Lewis shale, only 250 feet thick where first recognized at the south, becomes 2,000 feet farther north but diminishes to 1,600 feet at the northern outcrop. The Mesaverde, massive sandstone and thin interbedded shales and sandstones with coal seams at the south, shows the triple succession at the north, where the thickness is from 750 to 1,450 feet. He observed "horsebacks" and "rolls" in a Mesaverde seam near Gallup. Along the northern outcrop in Colorado, Cross and Spencer[67] found the highest member of the Pierre, named by them the Lewis shale, well defined. The Mesaverde, named by W. H. Holmes, is triple, the two great escarpment sandstones with between them a coal group of sandstones, marls and coal seams. The whole thickness in the La Plata quadrangle is barely 1,000 feet, that of the coal group being 600. The coal seams are variable and the authors look upon them as a series of lenses. The Mancos shale named by Cross, has Pierre fossils in the upper "several hundred feet," so that here also, one has the condition observed on the opposite side of the area, at Cerillos, where Mesaverde is the Middle Pierre. In the southern part of the San Juan Basin, it would appear that Mesaverde and Pierre are practically synonymous terms. Gardner's[68] observations are of interest in this connection. He traced the Mesaverde around the northern border from Durango, Colorado, to Monero, New Mexico. It is about 1,000 feet thick near Durango but decreases eastwardly, so that it is only 400 feet at the Piedra River, 60 miles from Durango. This is in accord with Schrader's observations and with those of Gardner in the Gallina area. One seems to be justified in suggesting that the Mesaverde disappears at a short distance east from the San Juan basin, giving place to the shales, which are present in

[66] M. K. Shaler, Bull. 316, Part 2, 1907, pp. 378, 414.

[67] W. Cross, "Telluride Folio, No. 57," 1899; W. Cross and A. C. Spencer, "La Plata Folio, No. 60," 1899.

[68] J. H. Gardner, Bull. 341, p. 353.

Colorado on both sides of the Front Ranges. Near Durango, three workable coal seams are present within a vertical distance of 110 feet, midway in the Mesaverde; these become insignificant toward the east and no workable seam was seen along the outcrop for more than 60 miles. But at Monero in New Mexico, three seams of workable thickness are present in a vertical distance of 100 feet above the basal sandstone.

The Uinta Basin extends from the westerly foot of the Wasatch Mountains in Utah into northwestern Colorado and has an area of not far from 10,000 square miles, being a little larger than the San Juan Basin. The Utah prong, known as Castle Valley, was examined by Taff and by Lupton, while Gilbert has given the section in the Henry Mountains about 50 miles southeast.[69] The highest Cretaceous beds in the Henry Mountains are the Masuk sandstone and Masuk shale of Gilbert, the former containing coal seams; it is thought by Lupton to be most probably Mesaverde. Lupton made no detailed study of the Mesaverde in Castle Valley, but estimated the thickness as not far from 1,200 feet and notes that it contains several important coal beds in a section of 500 feet, beginning at 200 to 300 feet from the base. Taff notes the triple structure of the Mesaverde, the two sandstones separated by the coal group. The coals are numerous but are important only in the lower 250 feet of the group. The coal is massive, bright, clean, bituminous and contains much resin. Partings are usually insignificant, but Taff saw one in a thick coal seam, which increased from nothing to 16 feet within 2,000 feet. The roof and floor of the coal seams are often sandstone.

Richardson examined the southern side of the basin between Sunnyside, Utah, and Grand River, Colorado, known as the Book Cliffs coal field.[70] The thickness of the Mesaverde is given as 1,200 to 2,200 feet, the variation being due to erosion. The underlying Mancos shale contains Pierre fossils in the upper 250 feet and is nonfossiliferous for a great thickness below; so that the Mesaverde is not lower than Middle Pierre. The sandstones of the formation

[69] G. K. Gilbert, "Geology of the Henry Mountains," U. S. Geog. and Geol. Survey of the Rocky Mountain Region, 1877, pp. 4–10; J. A. Taff, Bull. 285, 1906, pp. 292–294, 298; C. T. Lupton, Bull. 628, 1916, p. 34.

[70] G. B. Richardson, Bull. 371, 1909, pp. 7–39.

are lenses and are the marked features of the Book Cliffs; the lower members contain *Halymenites major* and brackish-water forms are present at many horizons. The coal seams of economic importance are confined to the lower 700 feet but Richardson's section makes clear that the importance in each case is confined to a small area and that the seams must be lenses. Near Thompson, Utah, at the southern point of the field, there are 5 seams, beginning at 490 feet from the base; near Price canyon farther north, are 7 beds, beginning at 340 feet, while near the Colorado line 6 seams were seen in the basal 275 feet, the lowest being only 95 feet from the bottom. On the Grand River the section shows 10 seams in the lower 519 feet. No coal seam has been traced for more than a few miles; one, 21 feet 6 inches thick, where mined, proved to be a mere lens, which disapeared quickly toward the west. Seams important at the east disappear toward the west. There are coal horizons, not continuous beds.

The Grand Mesa coal field and smaller fields farther east have been discussed by Lee,[71] who has made the relations clear for the region east from Grand River. The Upper Mancos is rich in Pierre fossils and the Mesaverde is 600 to 2,500 feet thick, the variation being due to erosion preceding deposition of newer formations. The upper part or undifferentiated Mesaverde, about 2,000 feet thick, is of fresh-water origin, mostly sandstone and contains little coal. It rests on the Paonia shale, closely allied to it lithologically, and about 400 feet thick. This has plant remains, fresh-water mollusks and important coal beds. Underlying this and separated from it in a considerable area by an unconformity, are the Bowie shales, 0 to 425 feet thick, with important coal seams and brackish-water as well as marine invertebrates. The basal deposit is the Rollins sandstone, usually about 100 feet thick, white, massive, with *Halymenites major* and marine invertebrates—evidently the basal white sandstone observed by Richardson in the Book Cliffs field.

Lee recognized a distinct unconformity below the Paonia; ordinarily, that formation rests on the Bowie, but for a considerable space in one portion of the region it overlies the Rollins. This leads

[71] W. T. Lee, Bull. 510, 1912, pp. 19, 37, 45, 81, 82, 86, 92, 95, 98, 106–109, 182, 188.

him to suspect that the unconformity may indicate a time interval and that possibly the Paonia and overlying rocks may not be older than Laramie. The unconformity is distinct, for the Bowie decreases from 425 feet on Grand River to nothing in the Rollins district; and it seems to be suggested on Grand River by the irregular contact between Paonia and Bowie at Palisades. It may be injudicious, it may savor of temerity for one who has not visited the localities to controvert the opinion of one who has examined the area in detail, especially when the latter is a model of accuracy in observation and caution in conclusion, but the writer feels compelled to believe another explanation not improbable. The vast area of Cretaceous deposition was subsiding until certainly toward the close of the Cretaceous as was the Appalachian Basin during Coal Measures time: but there were local crumplings as there were in the Appalachian. In the latter, these have left their records in deep stream valleys, filled with later deposits. Similar conditions have been observed in the British coal fields. It would be strange if evidences of local elevations or depressions were wanting in the vast subsiding Cretaceous region. The irregular contact on Grand River seems to indicate change in direction of drainage on the broad plain.

A serious argument in favor of assigning Laramie age to the Paonia and overlying deposits is the presence of a flora, which is described as containing Montana Laramie and even Post-Laramie forms, the Montana forms being few. The origin of a flora is a perplexing problem, but there seems to be no reason to suppose that it sprang into existence full-formed and without local forerunners, probably at many places. But, be that as it may, the Bowie and the Paonia appear to be continuous in the eastern part of the region described by Lee and no plane of separation has been determined. Farther north, just beyond the existing limits of the Uinta Basin, the Lewis shale has been recognized. It seems not unreasonable to suggest that in the southern part of this basin as in the southern part of the San Juan Basin, fresh-water sandstones may hold the place of the Lewis. The doubts must be dispelled by stratigraphy. The "Fox Hills" and "Laramie" of the earlier students have been placed in the Pierre, in spite of the remarkable resemblance to the later formations. If the deposits under consideration underlie the Lewis, they belong to the Pierre.

The undifferentiated Mesaverde on the western border of Lee's area consists chiefly of massive cliff-making sandstones, about 1,500 feet thick, containing deciduous and conifer leaves as well as *Sphærium, Physa* and *Goniobasis.* Within 22 miles eastward, of about 1,000 feet exposed, 700 feet are shales; it may be described as shale with thick partings of sandstone, while near Bowie in the Somerset district the shale feature becomes much more marked; but in Crested Butte district, the southeastern part of the basin, it consists of sandstones separated by layers of shale. The coal seams throughout are thin.

The Paonia shales, at several horizons, are rich in fossil leaves and fresh-water mollusks. The lowest coal seam, Cameo of Richardson, is at 4 to 10 feet above the great sandstone at top of the Bowie; in the western part of the area studied by Lee, this coal horizon seems to persist throughout the whole region. This coal is double at Rollins, 3 and 11 feet with parting of 2 feet. Thin seams are at 80,123 and 219 feet higher at Cameo on Grand River; but in the Rollins district 3 workable seams were seen in 108 feet above the base. Similar irregularity was observed in the easterly districts, so that one must look upon the coal seams as lenses. The quality is as variable as the quantity of coal. In one mine on the lowest seam, irregular masses of white sandstone descend from the roof and occasionally extend across the bed. Cross-bedded sandstone was seen midway in the section at several localities.

The Bowie shale, 420 feet thick on Grand River, has a sandstone, 100 feet, on top, cross-bedded, with worm tubes and *Halymenites.* Only one coal seam is there, about 430 feet below the Cameo bed; this is unimportant and thins away toward the south. There is no Bowie in the Rollins district, but it reappears farther east in the Somerset district, where, near Bowie, it is 405 feet and has the great top sandstone. The coal seams are numerous and at least 7 of them are "relatively thick," aggregating 38 to 43 feet in this district. The thickness of other seams has not been determined. The coals are exceedingly variable and they may be only extensive lenses; but some of them attain notable thickness. The Juanita bed is 12 feet in one mine near Bowie but 21 in another and 22 near Somerset; while at another locality, no trace of it could be found. At the Johnson prospect, on Minnesota creek, east from Paonia, 9 coal seams, 2 to 8 feet thick and with total thickness of 43 feet, were seen in the lower 300 feet of the Bowie. At the Simonton prospect, about 4 miles toward the south, the exposure shows this section, beginning at 37 feet above the Rollins sandstone: coal, 2 feet, 10 inches; shale, 10 inches; coal, 1 foot, 2 inches; shale, 5 inches; coal, 13 feet, 1 inch; shale, 6 feet; coal, 16 feet; bony coal, 2 feet; coal, 7 feet, 2 inches; in all 49 feet, 6 inches.

The presence of this great mass is perplexing. One cannot trace the section from the Johnson prospect and Lee concludes that the Simonton seam is due to the coalescence of 7 seams of the Johnson section, or that it is a merely local deposit. The Bowie becomes irregular in districts farther east, sometimes present, sometimes absent, and the coals are extremely variable in thickness and quality.

Lee's notes show that mineral charcoal is present in most of the coals. Toward the Elk Mountains, the region is greatly disturbed by plication and by eruptive rocks; the coal is from subbituminous to hard dry anthracite. The seams are thicker on anticlines than in synclines. In some localities, the stream channels, due to contemporaneous erosion, have been filled with white sandstone.

On the northwestern side of the Uinta Basin, there is a mass of deposits, 0 to 3,300 feet thick, which Lupton[72] places in the Mesaverde—the variation in thickness being due to erosion prior to deposition of the Wasatch beds. The lower half in this Blacktail Mountain coal field is marine, without coal and is mostly sandstone with sandy shale and some limestones. The upper half, apparently fresh-water, has coal with sandstones, thin-bedded and cross-bedded, as well as much sandy shale. This upper division has 21 coal seams in 1,500 feet, 7 inches to 15 feet thick. One seam has a maximum thickness of 21 feet with only a single parting, 2 inches. The coal is resinous at some places.

Gale[73] has given some notes respecting the northern outcrop. He reports the Lewis shale as about 1,000 feet thick and without

[72] C. T. Lupton, Bull. 471-*I*, 1912, pp. 27, 32, 33, 39, 41.

[73] H. S. Gale, Bull. 341, 1909, pp. 287, 289, 290, 299; Bull. 316, 1907, p. 273.

sandstone. The Mesaverde, 5,000 feet at the east, where erosion was less energetic, has three coal groups. The lowest is in the basal part of the formation and underlies a conspicuous white sandstone, which contains marine fossils. Gale's description suggests that this sandstone may be equivalent to the Rollins of Lee and that the lowest coal group may be in the Lower Pierre, included farther south in the Mancos shale. The coal seams are usually thin and where thick are worthless. The middle coal group, above the white sandstone, is unimportant west from the Utah line, but the seams become thicker toward the east, though they are irregular and at times are broken badly by partings of shale or bone. They become important in the eastern part of the basin; at Newcastle, there are 105 to 108 feet of coal in 7 seams, the thicknesses being 5, 8, 20, 5, 45–48, 18 and 4 feet respectively. One seam at Newcastle has a parting of soft coal at 4 to 6 feet from the floor and is troubled by "sandstone dikes." A seam at 40 miles south from Glenwood Springs has 7 to 10 feet of coking coal as the upper bench, but the lower bench is non-coking. The upper coal group is near the top of the Mesaverde; its coals are unimportant.

The Green River Basin, north from the Uinta Mountains, is mostly in Wyoming but the southeastern prong extends into Colorado and an outlier remains in Utah at the west.

The relations of the upper part of the long section in the Coalville coal field in Utah appear somewhat uncertain. The area was studied by Taff and later by Wegemann, the paleontological determinations being made by Stanton.[74] The boundaries of the several formations are still indefinite, but it is sufficiently clear that the region was near the source of sediment, for sandstone and sandy shale predominate in the upper 7,000 feet of the section. The upper 2,500 feet, prevailingly sandy, has yielded leaves and fresh-water shells. The succeeding 1,650 feet contains marine shells and rests on a white sandstone, 200 feet; below that is a coal seam. This, at 4,450 feet below the top of the Cretaceous, is irregular in occurrence as well as in its relations to the thick sandstones above and below it. It is double or triple at many localities, while at others

[74] T. W. Stanton, Bull. 106, 1893; J. A. Taff, Bull. 285, 1906, pp. 285–288; C. H. Wegemann, Bull. 581-*E*, 1915, pp. 163, 182.

it could not be found. At one locality, a seam belonging at or near to this Dry Hollow horizon underlies a bed of oyster shells, 20 feet thick. The quality of the Dry Hollow coal is good, but the bed is too variable, so that no mines of any importance were in operation at the time of Wegemann's examinations.

No coal of economic importance has been reported from the Pierre of Uinta County in Wyoming, but in southern Sweetwater County, where Gale[75] recognized Lewis, Mesaverde and Mancos, he saw in one exposure two seams, 8 and 10 feet thick, separated by only 25 feet. The coal is not persistent and, within a short distance, it becomes black shale with coaly streaks. The lower seam is separated by one foot of bone from a thick white sandstone. Farther north in the same county is the Rock Springs coal field, intersected by the Union Pacific Railroad. There Schultz[76] recognized the Lewis shale, without coal, and the Mesaverde, consisting very largely of sandstone with important coal seams. The "Laramie" of Schultz is not everywhere conformable to the underlying Pierre. The unconformity is especially marked on the south and west sides of the Rock Springs Dome, where the "Laramie" rests on the Rock Springs coal group, a hiatus of fully 2,500 feet; but the succession is complete and conformable throughout on the west side of the Dome. Elsewhere there appears to be no unconformity.

The important coal seams are in the Almond and Rock Springs groups, separated by 800 to 1,000 feet of mostly massive sandstone, more or less conglomerate in the upper third with pebbles of gray and black quartz. The Almond coal group, 700 to 900 feet thick, contains many seams of coal and of carbonaceous shale. The seams are variable, though less so than are those in the Rock Springs group, but the coal is comparatively poor and no works were in operation at the time of Schultz's examination.

The coals of the lower or Rock Springs group are black, with distinct bedding planes and do not slack on exposure. The coal-bearing portion is about 1,275 feet with 37 seams containing in all somewhat more than 110 feet of coal. Five seams have been opened

[75] H. S. Gale, Bull. 341, pp. 310–314.

[76] A. R. Schultz, Bull. 341, pp. 256–382; Bull. 381, pp. 214–281.

near Rock Springs, but most of the coal has been taken from numbers 1 and 7, at 481 and 743 feet from the top of the group.

Number 1 has many "rock-slips" or "horsebacks," long, slim wedges of white sandstone, protruding usually from the floor. They are smooth on one side, rough on the other and the coal is unchanged even at the contact. The roof and floor are brownish to white sandstone. The coal, at times, is 10 feet thick, but changes are abrupt. Partings thicken and the coal becomes worthless. In one mine the coal is 11 feet thick and clean, but in another, adjoining, the coal suddenly became worthless and, at a little distance beyond, it pinched out. Seam 3 shows similar complications. A band of shale appeared in one mine at 2 feet from the floor; within a short distance it thickened upward until the top bench became too thin for working; but within 200 feet the foreign matter almost disappeared and the upper bench was again more than 5 feet thick. Schultz's description shows that here is a channel originating during growth of the swamp and filled up before the growth ceased, so that the swamp covered it. Seam 7 is less inconstant than the others but it is far from free from troubles. The roof and floor are shale, the former black. One important mine was abandoned because the good coal was replaced with worthless stuff in an area of evidently great extent. The Rock Springs coal seams become unimportant southwardly and none has been discovered in the extreme southern portion of the field.

Tertiary deposits conceal the Cretaceous from the Rock Springs field to near Rawlins in Carbon County, where Smith[77] recognized the Lewis, Mesaverde and the shales of Lower Pierre. The Mesaverde, consisting of sandstones, shales and coal seams, is still distinct but is much thinner than in fields farther west. It consists of two massive sandstones separated by a mass of soft brown sandstones and white to gray shale. The Almond and Rock Springs coal groups have become insignificant. The coal seams in this area are on top and at base of the upper sandstone and just above the lower sandstone: four or more seams were seen in the upper zone, few were observed in the middle and 4 to 6 in the lower zone. The

[77] E. E. Smith, Bull. 341, pp. 220–242.

coal throughout is inferior and the seams, for the most part, are too thin to be mined.

Beyond Rawlins and still north from the Union Pacific Railroad, Veatch[78] studied the coal field of east-central Carbon County, where the Pierre consists of Lewis, Mesaverde and Lower Pierre, with a total thickness of almost 8,000 feet, not far from that given by Smith; but in both districts the thickness decreases greatly toward the north. According to Veatch, some important coal seams are present in the lower part of the Lewis, evidently those belonging to the highest zone of Smith. Seams in the middle zone of the Mesaverde occasionally become thick enough for mining, but they are irregular and not persistent. The southern part of Carbon County, where the subdivisions of the Pierre are as in the northern part of the county, was studied by Ball and Stebinger.[79] The thickness of Lewis and Mesaverde decreases eastwardly, becoming 1,600 and 2,000 feet. The Lewis has no coal. The Mesaverde still has the two limiting sandstones with the middle shale and sandstone member. The basal sandstone is white gray and brown, cross-bedded and, in the eastern part of the district, contains a limestone, 25 feet thick. The top sandstone is less distinctly cross-bedded and the layers are thinner. No workable coal seams were seen in the sandstone members, at the north, but the number and thickness of those in the upper sandstone increase toward the south. Some important seams are in the middle member near Rawlins, but they disappear toward the northeast. The coal is hard and bituminous. The sandstones of this member are irregular and the coal seams appear to be overlapping lenses.

The Yampa coal field, in Routt County of Colorado, is the extreme southeast part of the basin. One can recognize in the section by Fennemann and Gale,[80] Lewis, Mesaverde and the lower shales, Mesaverde being Middle Pierre; the relations are more allied to those of the western than to those of the northern part of the basin. There are three coal groups, which in some portions of the field are in a vertical space of 2,000 feet, the lowest being about

[78] A. C. Veatch, Bull. 316, 1907, pp. 244–366.

[79] M. W. Ball and E. Stebinger, Bull. 341, pp. 243–355; Bull. 381, pp. 186–213.

[80] N. M. Fenneman and H. S. Gale, Bull. 285, 1906, pp. 226–239.

1,200 feet from the base. Each coal group has 2 to 3 workable coal seams, but the number and thickness of the seams vary from place to place. At the time when this field was examined, the population was sparse and none but insignificant mines had been opened. In the eastern part, coal seams, 4 to 10 feet thick, were exposed in both the middle and the lower group; but the upper group is ill-exposed. Farther west, seams of greater thickness were seen, one near Lay being 20 feet, with a parting of 15 inches midway. There, the three coal groups are in a vertical space of not more than 800 feet. Many seams have shale roof and floor and one is clearly between sandstones. A faux-toit was seen in many openings and either bone or dirty coal is the usual parting. A faux-mur is recorded in but one instance.

The irregularity in thickness of the Mesaverde in the Yampa field may be due to the eastward disappearance of shore conditions. At 25 miles east from the boundary of the Yampa field, Beekly's[81] sections on the west side of North Park show no evidence of Mesaverde, while at 25 miles farther east in the same Park, the Pierre is represented by about 4,500 feet of shale, wholly like that beyond the Front Ranges in Colorado and New Mexico. It is sandy on top and passes into a marine sandstone, shown on east side of the Park—apparently the Fox Hills. Some thin sandstones were seen in the lower part of the formation but no trace of coal is reported by Beekly.

Northward in Wyoming and east from the Medicine Bow Mountains about 60 miles east of north from the exposures in North Park, the section by C. E. Siebenthal, cited by Darton,[82] shows about 5,500 feet of Montana rocks, divided at about 1,300 feet from the top by the Pine Ridge sandstone, 60 to 80 feet thick. The mass is practically shale throughout, there being in all only 127 feet of sandstone in the upper 1,332 feet and 35 feet in the underlying 4,150 feet. The formation contains marine fossils at many horizons, the highest being within 140 feet from the top. It is difficult to determine a positive plane of separation between Pierre and Fox Hills in this region so that authors frequently employ "Montana" or

[81] A. L. Beekly, Bull. 596, 1915, pp. 20, 43, 45.

[82] N. H. Darton, *Bull. Geol. Soc. Amer.*, Vol. 19, 1908, 459, 460.

"Pierre-Fox Hills" to designate the whole mass. Just above the one persistent sandstone, Pine Ridge of Siebenthal, is a coal bed and others, unimportant, are in the succeeding 560 feet of black shale; but in the overlying beds no coal was found. It may be that the upper part of the section, including the Pine Ridge sandstone, is equivalent to Mesaverde, Lewis and Fox Hills, the coal being in the Mesaverde.

Farther west in Fremont County, north from Sweetwater, the lower shales are 2,250 to 3,000 feet, increasing eastwardly, while the upper division, of which erosion has spared 550 feet, has at base a sandstone, 200 to 250 feet thick. Overlying this is a bed of carbonaceous shale, which occasionally contains a seam of coal. Here the Mesaverde conditions are distinct for the overlying mass consists of "sandstones, with intercalated gray shales, sandy shales and coal beds." The lowest coal is 8 feet thick at 10 miles east from Lander.

The Pierre is without coal[83] in the Black Hills and is wholly shale. The Sussex field at 100 miles southwest from the Black Hills has, according to Wegemann, 4,650 feet of Montana rocks, of which he refers the upper 700 feet to the Fox Hills. The Pierre has a sandstone, 175 feet thick, at about 1,000 feet from the base and, at 2,300 feet, another sandstone, the Parkman of Darton's Bighorn section, 350 feet. This sandstone contains masses of petrified wood with shells of turtles and bones of *Trachodon*. In the shaly portions near the base, it has thin seams of low-grade bituminous coal, high in ash. Thin seams are associated in the southern part of the field with another sandstone, about 300 feet above the Parkman. The Pierre rocks are predominatingly shale. The fauna of the Parkman sandstone, according to T. W. Stanton, is similar to that of the Mesaverde in Colorado and of the Claggett in Montana.

The Bighorn Basin of north central Wyoming lies west from the Bighorn Mountains, occupying parts of several counties and extending into Montana. It was examined by Washburne and Woodruff and in part by Darton.[84] The indefinite relations of the upper

[83] N. H. Darton, Folios 127, 128, 1905.

[84] N. H. Darton, Prof. Paper 51, 1906, pp. 13, 58, 59; E. G. Woodruff, Bull. 341, pp. 204, 208–210, 215; Bull. 381, pp. 173–175, 178; C. W. Washburne, Bull. 341, pp. 168, 172–179, 187, 195.

part of the column near Bighorn Mountains are shown by the fact that Darton embraces the whole above his Parkman sandstone in a single formation, the Piney. Woodruff in the southeastern part of the basin found indefiniteness throughout, but the succession is suggestive of the section as recognized in Montana and northward, there being at base shales with Pierre fossils succeeded by two sandstone and shale members which he referred provisionally to the Eagle sandstone and Claggett shale of Montana, while he terms the higher beds merely Undifferentiated Montana. All become more shaly toward the east. Coal seams were seen in the upper division, but they are lenticular and unimportant: the quantity decreases toward the north. In the western portion, Woodruff recognized the Eagle sandstone of the Montana section, but none of the higher divisions could be identified. Coal seams in the Eagle are lenticular, but occasionally they are important. One near Gebo is 11 feet thick; in Grass Valley, a seam, 7 to 8 feet, is mined, but within a fourth of a mile toward the west it is too thin to be worked, while, at an equal distance toward the south, it becomes much thinner and so broken by partings as to be worthless. Similar variations in the Eagle coals were observed elsewhere within this portion of the field. Farther south in the Buffalo Basin no coal has been found in the Eagle. The Undifferentiated Montana has some coal seams but they are wholly unimportant.

In the northeastern part of the basin, extending into Montana, Washburne was able to recognize all members of the Pierre as they had been determined in Montana—Bearpaw shale, Judith River Formation, Claggett shale, Eagle River sandstone, the last resting on Colorado shale. The Bearpaw, evidently the Lewis of localities farther south, is marine, 150 feet thick and without coal; the Judith River variegated clays and sandstone, 300 to 400 feet, has abundance of leaves and bones but seems to be without coal; the Claggett, 400 to 500 feet, consists of massive gray to yellow sandstone with interbedded shales and has marine fossils in many portions; the Eagle, 150 to 225 feet, has two or three massive sandstones. The upper part of the Colorado shale, for 1,000 feet, is without fossils, but it differs lithologically from the shales below and it may be taken as, at least in part, representing the lower shales of the Pierre as in the southern portion of the Bighorn Basin. Coal is present in the Claggett and the Eagle. The Claggett seams are very thin, nowhere exceeding 21 inches, and in all cases the coal is so dirty as to be worthless. The Eagle seams are of capricious distribution. There are workable beds in the southeastern corner of the basin, but they disappear northwardly before Bighorn County is reached and are replaced with yellow sandy shales. Black shales appear north from the city of Basin and these near Garland contain very thin seams of coal. Elsewhere in that neighborhood, these coal horizons are marked only by black shale with coaly streaks. An anticline near Silvertop, close to the Wyoming-Montana line, brings up the Eagle. There is but one workable seam in that formation on the Wyoming side, but there are two beyond the line in Montana. The Bridger coal field is west from the anticline and extends along the Chicago, Burlington and Quincy railroad to beyond Bridger in Montana. Some important coal deposits are in the Montana portion, but none in Wyoming, and all trace of coal disappears at a short distance west from the railroad. The Eagle coals are all well-jointed and show no woody structure. They illustrate well the irregularity of coal deposits in an extended area.

The eastern part of Montana is a rolling plain, the mountains of Wyoming, Colorado and New Mexico having become insignificant, as the disturbed area is confined to the western border; but mountain-making was energetic there, west from the 109th meridian, and the whole section of Cretaceous is shown at many localities. In this disturbed area, one is west from the Bighorn Basin, as well as the western boundary of Colorado and New Mexico, so that conditions should bear resemblance to those observed in Arizona, Utah and western Wyoming.

The most southerly coal field is that near Electric, in Park County, about 100 miles west from Bridger. There as well as in some petty areas at the north, Calvert[85] was unable to recognize the subdivisions of the Pierre and grouped the section, about 1,000 feet, as Montana. The upper portion, about 330 feet, consists of sandstone and shales with some carbonaceous shale but no coal; the middle portion, about 230 feet, is largely sandstone and sandy shale

[85] W. R. Calvert, Bull. 471-*E*, 1912, pp. 28–66.

with several beds of dark shale and some seams of coal; the lower portion, about 370 feet, and without coal, is sandstone except 78 feet of sandy shale at the top. Four coal seams were seen in one section, three of them thick enough to be mined; but the coal is very dirty; that from the best contains 20 to 24 per cent. of ash and the washed coal, utilized in making coke, retains 21.71 per cent. This Montana of Calvert rests on a mass of shale and sandstone containing Colorado fossils throughout; which makes probable that basal member of the section may be equivalent to the shales of the Lower Pierre and that the coal-bearing member may be at the Eagle or Mesaverde horizon, there being Mesaverde fossils throughout. The "Montana" beds underlie conformably the Livingston formation, a mass of andesitic material. Calvert found similar conditions in the Livingston coal field farther north in the same county, except that his Montana beds are thinner. There are not less than 3 seams of coal, 2 to 20 feet thick; but they vary rather abruptly in thickness and the coal is of uncertain quality. Two samples from one mine gave 8.77 and 17.5 per cent. of ash; analyses of samples from other mines yielded 8.44, 10.92, 10.99, 14.9, 27.53 and 31.51 per cent. in air-dried coal. Cross-bedded sandstones were noted by Calvert in both fields.

Newberry[86] noticed that coal near Bozeman, in the Livingston field, contains a large quantity of yellow, translucent, almost amber-like resin. Weed[87] examined the same fields at an earlier date and called especial attention to the uneven floor of the coal seams. This as well as the occasional disappearance of the coal led him to believe that the coal seams had been formed in depressions of the surface. He found *Unio* in beds associated with the coal seams of the Electric coal field.

In Meagher County, north from Park, Stone recognized the four formations. The Bearpaw shale, marine throughout, has no coal; the Judith River, brackish and fresh water, has some lenses of coal, usually very thin and of short lateral extent; when of workable thickness, their coal is apt to be dirty. The Claggett, marine and brackish, appears to be without coal. The Eagle has coal, but

[86] J. S. Newberry, *Ann. N. Y. Acad. Sci.*, Vol. 3, 1884, p. 245.
[87] W. H. Weed, *Bull. Geol. Soc. Amer.*, Vol. 2, 1891, pp. 349–364.

it is uncertain both as to quantity and quality; when a seam becomes thick it has much foreign matter and is in great part worthless. Stone could not determine whether or not the Eagle coals are lenses; but the quality is inferior with from 17 to 37 per cent. of ash. Here, as in districts farther south, the rocks are mostly sandstone and sandy shale.

The Lewistown coal field in Fergus County is about 60 miles north-northeast from the Meagher area and its western limit is near the 110th meridian. Calvert[88] found no rocks newer than the Claggett, which like the underlying Eagle, consists of sandstone and sandy shale; cross-bedded sandstones are characteristic. The only coal seam is in the Eagle, at 10 feet from the base. It is merely a coaly layer. Bowen[89] examined the Cleveland field, about 80 miles east of north, and the Big Sandy field at an equal distance west of north from Lewistown. In both fields the Judith River and the Eagle are characterized by irregularity of the deposits and the sandstones are often cross-bedded, occasionally ripple-marked. The Eagle becomes shaly in the eastern field. Thin seams of impure coal were seen in the Judith River within both fields; the Eagle has similar streaks in the southern part of Big Sandy but no coal was seen in the northern part of that field nor in the Cleveland field. The Eagle coal is usually bony.

The Milk River coal field is north from the Cleveland and extends to the Saskatchewan line. Pepperberg[90] states that the Judith River coals, all near top of the formation, are lenses, which become thinner and poorer toward the east. The variation in thickness is abrupt; a lens, 9 feet thick, decreased to a fraction of an inch within a short distance along the outcrop. The quantity of bone is a serious drawback in many mines, so that the product is inferior, because of high ash. The coal is subbituminous and contains mineral charcoal as well as resins. All deposits in the Judith River are lenticular and the sandstones are locally cross-bedded. Some streaks of coal were seen in the upper part of the Eagle, but they are insignificant. The sandstones of both formations have become much less prominent.

[88] W. R. Calvert, Bull. 341, p. 110; Bull. 390, pp. 32, 34.
[89] C. F. Bowen, Bull. 541-*H*, 1914, pp. 45–47, 60–65, 77–80.
[90] L. J. Pepperberg, Bull. 381, pp. 85, 86, 94.

Teton County is very near the western boundary of Cretaceous deposition in Montana. It reaches the border of Alberta and the coal-bearing area is between meridians 112° 30′ and 113°. Stebinger's[91] report on this area and his general discussion of the Montana Cretaceous have done much to solve serious problems in correlation. The succession in the Teton coal field is St. Mary River formation, correlated with the Laramie; Horsethief sandstone, 225 to 275 feet, which Stebinger has shown to be same as the Lennep sandstone and the Fox Hills; Bearpaw shale, with characteristic features of the formation, 490 feet; Two-Medicine formation, 1,950 feet, gray to greenish gray and whitish clay shales, with some sandstones, which are important in the basal 250 feet; Judith River leaves, mollusks and bones of reptiles are present; it is apparently continental in origin, there being evidence of only one marine invasion, and that is at about 200 feet from the base. The formation includes Judith River, Claggett and the upper or coal-bearing portion of the Eagle. The marine deposit near the base contains the Claggett-Fox Hills fauna, indicating deposition in a retreating sea. Within the disturbed region on the western side of the county, one finds it difficult to distinguish this formation from the St. Mary; the conditions during deposition must have been very similar in both. Virgelle sandstone, 220 feet, the basal sandstone of the Eagle, is gray to buff, coarse, cross-bedded sandstone, becoming slabby to shaly in the lower half.

Two-Medicine and Virgelle, traced northward into Alberta, prove to be the Belly River formation, described by G. M. Dawson. The Two-Medicine is characterized by extreme irregularity of the beds; sections only a few hundred feet apart are wholly dissimilar. Fossil wood is distributed throughout the formation, knots and entire sections of compressed trunks of trees are of common occurrence. The continental deposits, except the Fox Hills, become thinner toward the east, so that in the Black Hills of northeastern Wyoming the Pierre is represented only by marine shales.

No coal aside from petty lenses was seen in the Virgelle; the Two-Medicine has three coal zones, one at the base, another at 250

[91] E. Stebinger, Bull. 621-*K*, 1916, pp. 126, 127, 131, 140, 144; Prof. Paper 90-*G*, 1914, pp. 61–68.

feet higher and a third at the top, but coaly material is present in other portions as carbonaceous shale. The highest coal is found in the northern part of the county, but it disappears south from Valier, about 50 miles from the International Boundary and no trace of it has been found farther south in a distance of not less than 50 miles. It is thin in Teton County but increases toward the north beyond the boundary and is 6 feet thick at Lethbridge, where the coal is good. The seams of the middle zone are thin and yield only impure coal, while the lower zone has two seams which are persistent in the Valier district on the easterly side of the county. The upper one is 2 feet 6 inches, with 2 feet of coal, while the lower one, with extreme thickness of 5 feet 8 inches, contains only 8 inches of clean coal. These seams vary much in thickness, but the upper one is mined. Samples of clean coal gave 14.07, 13.9, 14.5 and 28.6 per cent. of ash.

Dowling,[92] in his synopsis of conditions in the western states of Canada, says that the depressions, in which Mesozoic rocks were deposited, appeared in the Rocky Mountain area, where Triassic and Jurassic beds are found. The Jurassic sea invaded a narrow depression, now elevated as the Rocky Mountains and the Foothills. Land conditions prevailed during part of the Lower Cretaceous, but occasional submergences extended to a short distance toward the east, whereas in the United States they extended as far east as the Black Hills of Wyoming. More general submergence eastwardly came in the Upper Cretaceous, while on the western side there is evidence of shallowing during the earlier periods. Marked proof of shallowing on that side is evident during the Montana, for land conditions are shown by the coal seams and by the type of sediments, but marine conditions prevailed at the east. Submergence followed and the sands at the west were covered with marine shale. The closing part of Cretaceous time was characterized by emergence, with brief periods of submergence, as shown by land and shallow water conditions, giving an abundant flora and a brackish-water fauna: this closing stage is the Edmonton-St. Mary formation. The vast accumulations unsettled the equilibrium of the area whence they had been derived and, toward the close of the

[92] D. B. Dowling, Geol. Survey of Canada, Mem. 53, 1914, pp. 32, 33.

Eocene, crustal movements followed, which formed the Rocky Mountains. But the energy was expended in a narrow area so that at the east, even in the Foothills, one finds nothing exposed below the Middle Cretaceous.

The conditions noted by Dowling are very distinct in southern Alberta. McEvoy, in the mountain portion of the Crowsnest coal field, found the Upper Cretaceous merely a mass of sandstone and conglomerate, 7,000 to 8,000 feet thick and without coal. In another part of the Rocky Mountain area, near the International Boundary, McConnell saw no coal in the upper part of the section, which contains great beds of conglomerate, some of them 150 feet thick. It seems to be impossible to differentiate the formations in this area; but McLearn, at a short distance eastward in the Foothills, recognized the Bearpaw and the Belly River, the latter being the equivalent of Judith River, Claggett and Eagle.[93] The sea-invasion during Claggett did not reach much of southern Alberta and did not extend so far westward as did that during the Bearpaw. No coal was seen in the basal sandstone of the Belly River formation, but 4 thin seams were seen in the overlying 50 feet of clay and shale. The higher deposits are sandstones and shales, alternations of "sand bottoms and clay bottoms" with *Unio* and gastropods in the sands and gastropods in the clays. The faunules are fresh-water. Mackenzie[94] saw no coal in the Allison (Belly River) formation on Oldman River, where it is 2,000 feet thick and consists chiefly of sandstones, massive to shaly and often cross-bedded.

Dawson[95] examined an extensive area within southeastern Alberta, mainly along the Bow and Belly Rivers, but reaching into the Milk River region near the International Boundary. He offered tentative names for the formations. The Pierre shales, 750 feet thick, contain intercalated beds of sandstone, which increase toward the mountains. A coal zone was seen at the top on Bow River and another at the base on Belly River; the latter was seen also at several

[93] J. McEvoy, Ann. Reps. Geol. Survey Canada, Vol. XIII., 1900, Part *A*, pp. 84–88; R. G. McConnell, the same, 1886, Part *D*, pp. 16, 17; F. H. McLearn, Summary Report, 1914, pp. 62, 63.

[94] J. D. Mackenzie, Summary Report for 1912, pp. 235–246.

[95] G. M. Dawson, Geol. Survey of Canada, Reps. Prog. for 1882–83–84, Part *C*, pp. 36, 52, 62, 69, 71.

places on St. Mary River. At the mouth of the latter river, in a section by R. G. McConnell the lower zone has 3 coal seams in a vertical distance of 132 feet, the thickest being from 3 feet to 3 feet 6 inches. This zone is persistent and its coal is mined on Belly River. The Belly River formation has few thick coal seams; its sandstones are gray to yellow, hard and the surfaces often show ripple marks and worm trails. In one case, the ripples indicate movement toward S. 36° W. The "Lower Dark Shales" of Dawson were seen on Rocky Ridge in the Milk River region. Dowling[96] has shown that the Pierre shale is the Bearpaw, the Belly River of southeastern Alberta is the Judith River and the lower dark shales of Rocky Ridge are the Claggett. Evidently he places the coal of Dawson's Pierre in the upper or fresh-water part of the Belly River. The area within Alberta, in which the Belly River with its important coal seams is exposed, is not less than 24,000 square miles; its presence has been proved by borings in a great area, where it is deeply buried under later formations. In a report on the Sheep River Oil and Gas field, Dowling has emphasized the increasing thickness of Bearpaw toward the east; in the Foothills, it is 650 feet, on Red Deer River, east from Calgary, 750, on the Cypress Hills, 900 and on Sheep River, about 1,200 feet.

The coal seams of the Pierre formations become unimportant north from the latitude of Edmonton. They are few and thin, sometimes wholly wanting, as appears from observations by G. M. Dawson,[97] Dowling, Tyrrell and McConnell. Dawson found no seam thicker than 6 inches on Pine River. The associated rocks are sandstone and sandy shale, the former cross-bedded and ripple-marked. On Smoky River he saw a soft massive sandstone, with abundant fragments of plants, which in one place are "distinctly representing the base and roots of a tree, and evidencing a terrestrial surface. Overlying this is a thin carbonaceous film which, at a short distance up the river, becomes a seam of lignitic coal, two and a half inches in thickness." The Dunvegan sandstone of Peace River, regarded as the Belly River formation, has no coal.[98] It disappears toward the east and is not present on Athabasca River.

[96] D. B. Dowling, Mem. 53, 1914, pp. 28–31, 51, 53.

[97] G. M. Dawson, Rep. for 1879–80, Part *B*, pp. 117, 118.

[98] R. G. McConnell, Reps., Vol. VI-*D*, 1893, p. 53.

The Colorado Group.

The Niobrara and Benton are sufficiently distinct in the region of the Front Ranges and eastward as far north as Wyoming. The Niobrara consists of black shales and limestones weathering to chalky whiteness; while Benton is mostly shale, but with bands of sandstone and more or less persistent limestones. Farther west, however, the deposits answering to the Niobrara-Benton time interval lose the limestones and the mass becomes practically continuous as shale, though varying much at different horizons. The term Colorado Shales finds application in those areas, where Niobrara cannot be recognized and where Benton conditions, as shown at some places by the continuing fauna, remained comparatively unchanged. The term Mancos was introduced in southwestern Colorado, to designate the shale mass between the Mesaverde (Middle Pierre) and the Dakota. It is a lithological term for use in the field and includes Lower Pierre as well as Niobrara and Benton.

The Colorado interval is represented by marine deposits in by far the greater part of the Cretaceous area, but in New Mexico the isolated coal fields give abundant evidence that the mainland was not far distant, as coarse deposits make their appearance, while farther west in the same state as well as in Arizona and Utah one finds conditions such as characterized the Middle Pierre, marking the strife between land and sea, sandstones and coal beds being the especial features.

The relations of deposits in the southernmost fields of New Mexico are somewhat obscure, the areas being very small and isolated. But there is little room for doubt farther north in the Cerillos and other fields southeast from the San Juan Basin. Lee[99] obtained a detailed section of the Mancos in the Cerillos field. The upper portion is distinctly Pierre and the lower portion, about 2,200 feet, is certainly Colorado in the lower 1,200 feet. One finds here the several subdivisions of the Benton, as recognized east from the Front Ranges, but the limestones of the Niobrara interval have disappeared. A sandstone, Tres Hermanos of Herrick and Johnson,[100]

[99] W. T. Lee, *Bull. Geol. Soc. Amer.*, Vol. 23, 1912, pp. 623, 631, 658, 651–654.

[100] C. L. Herrick and D. W. Johnson, *Bull. Univ. New Mex.*, Vol. II., p. 13.

20 feet thick and about 82 feet from the base, is hard, quartzose, cross-bedded and in thin irregular layers, which have rippled surfaces with worm borings and indefinite markings. Of especial interest are impressions very similar to *Halymenites major,* associated with an offshore fauna. At the base of the Benton are conglomerate, 5 feet and carbonaceous shale, 5 feet, with a few inches of coal at the top.

The Tres Hermanos sandstone is 90 feet above the base and only 5 feet thick in the Hagan field, west from Cerillos; though so much thinner, it has the same features. The thin coal bed and its overlying conglomerate, seen in Cerillos, appear to be wanting. A Benton fauna is present in the lower 670 feet of the section. Conditions are practically the same in the Tijeras field. In the Puerco field no coal was seen at base of the Benton, but a conglomerate, 5 feet thick, with pebbles of quartz and chert, recalls that overlying the coal in Cerillos.

In the southwest corner of the San Juan Basin, as Gilbert[101] has shown, the Colorado is represented by mostly sandstones for 180 feet at the base, containing 3 coal seams about midway, while above are 380 feet of carbonaceous and clay shale underlying sandstones and sandy shales. The whole thickness is not far from 850 feet. The coals are not persistent and they were seen in only one section. Elsewhere they are replaced with carbonaceous shale. Winchester[102] says that in the Zuni Mountain region, a few miles south from the locality of Gilbert's section, the Mancos is 60 per cent. sandstone. This sandstone decreases northwardly as do also the coal seams, which disappear in the northern part of the area examined by him.

The Mancos shale is thin in the main portion of the San Juan Basin, the whole thickness, according to Gardner,[103] being not more than 800 feet. Coal seams occur in the upper 500 feet, where the rocks are sandy; there are no coals in the lower part, where clayey beds prevail. The coal seams are usually thin, though occasionally reaching 3 feet, are double or triple and often contain much bone. One seam at times becomes workable, with 3 to 5 feet of sub-

[101] G. K. Gilbert, U. S. Geog. Explorations, etc., Vol. III., 1875, pp. 550, 551.
[102] D. E. Winchester, *Journ. Wash. Acad. Sci.,* Vol. IV., 1914, p. 300.
[103] J. H. Gardner, Bull. 341, pp. 366, 369, 373, 375; Bull. No. 381, p. 462.

bituminous coal which contains much resin. Eastwardly along this southern border no workable seams occur, while farther north along the eastern outcrop only traces of coal were seen. The sandstone decreases in that direction. Lee appears to have found no coal in the Colorado beds along the northeastern border of the basin, but he was able to recognize the Tres Hermanos sandstone.

In Arizona the near approach to the source of sediments is manifest. The most southerly fragment of Cretaceous is the Deer Creek coal field,[104] about 150 miles southwest from the southern termination of the San Juan Basin, near the junction of the Gila and San Pedro Rivers. In the lower or southern part of the field, according to Campbell, 400 to 500 feet of coarse greenish gray sandstone with some shale rest on the Carboniferous limestone. The fossils are imperfect and suffice only to prove Cretaceous age. Three coal seams, much broken and thin, were found in a shaft within the basal 60 feet. The coal is poor; the best has 34.78 per cent. of ash. The Pinedale coal field is about 100 miles north from the Deer Creek area. There Veatch[105] found about 500 feet of deposits containing Benton fossils as determined by T. W. Stanton. The two coal seams are near the base, 10 to 15 feet apart, and are only 25 feet above rocks of Pennsylvanian or Permian age. The seams are 12 and 3 feet thick, but coal from the upper one is very bad, having 54 per cent. of ash. The lower one has some good coal with only 10 per cent. A much more extensive field is that of the Black Mesa[106] in the northeastern corner of the state. The Cretaceous is about 700 feet thick and coal seams were found near the base as well as above the middle. The lower group is within the basal 55 feet and its seams are 7 and 15 feet thick. The upper bed yields a fairly good coal, bituminous and with about 14 per cent. of ash. The lower seam is a worthless mass of shale and coal. The higher beds show numerous seams 2 to 12 feet thick; the coal is evidently inferior, but in default of better material it is used as fuel.

Benton deposits are present in isolated areas within Utah as far west as the 113th meridian along the Arizona border. Almost 45

[104] M. R. Campbell, Bull. 225, 1904, pp. 241–258.
[105] A. C. Veatch, Bull. 431, 1911, pp. 239–241.
[106] M. R. Campbell and H. E. Gregory, Bull. 431, pp. 229–238.

years ago, Gilbert discovered in Washington County a mass of shale about 635 feet thick, including at base a coal group, somewhat more than 130 feet thick, with 5 seams, 4 inches to 4 feet thick. Howell, in Park County, next east, found two coal groups, separated by 500 feet of barren measures, containing Benton fossils. The lower coal group is capped by an oyster bed 1 to 5 feet thick. Thirty-five years later, Richardson examined some small fields in Washington, Kane and Iron Counties.[107] The coal seams are from 50 to 500 feet above the assumed base of the Cretaceous and they are lenses. Ordinarily only one workable bed appears in a section but in some cases there are as many as six. In the Harmony field, only 600 feet of Cretaceous remain, containing 6 seams of coal and shale, 7, 11, 6, 11, 17 and 6 feet respectively, with 4, 5, 4, 7 and 4 feet of coal. At best this coal is very poor, two air-dried samples having 22.89 and 33.96 per cent. of ash. The seams are similarly lenticular in the Colob field. In this field on the North Fork of Virgin River, Richardson saw, at about 100 feet above the basal conglomerate, a coal seam with this structure: carbonaceous shale with fossils; bituminous coal, 2 feet 5 inches; cannel, 5 feet 6 inches. This seam disappeared quickly toward the north, east and southeast; but a similar seam was found at 10 or 12 miles toward the southeast. The cannel at these localities is brownish black with dull greasy luster. The violatile is very high and the hydrogen in dried coal is practically twice as much as that in the ordinary coals. D. White examined it under the microscope and ascertained that its structure and composition are essentially those of high-grade cannel. The Colob coals are better than those of the Harmony field and have from 10 to 15 per cent. of ash. They vary from low grade bituminous to subbituminous. In many cases a coal seam overlies or underlies fossiliferous limestone.

Lee examined a small field in Iron County, north from Washington, where he measured a section of 1,200 feet in which sandstone predominates. The coal seams are in a group of shales and thin limestones, about 150 feet thick, beginning at nearly 800 feet from the basal conglomerate. The fossils are of Benton age. One coal

[107] G. K. Gilbert, U. S. Geog. Explor., etc., Vol. III., pp. 158, 159; E. E. Howell, the same, p. 271; G. B. Richardson, Bull. 341, pp. 379–400.

bed is divided by bands of limestone containing brackish-water mollusks. Another has marine limestone roof and floor, with marine fossils, but one of its partings has *Physa, Planorbis* and other fresh-water forms, related to those of ponds and streams. Several of the sandstones are cross-bedded.[108]

Lupton examined the Emory coal field in in the southern part of Castle Valley, about 40 miles northwest from the Henry Mountains, which had been studied by Gilbert.[109] At approximately 600 feet from the base is the Ferron sandstone, regarded by Lupton as equivalent to Gilbert's Blue Gate sandstone. It is 800 feet thick at the southwest but becomes thinner toward the northeast until at north end of the valley it is but 75 feet. This sandstone holds all the Benton coal seams, but these are confined to the southern part of the valley, disappearing toward the north as the sandstone decreases in thickness. Local unconformities which one must accept as evidence of contemporaneous erosion, occur within this sandstone. The coal-bearing area is a narrow strip about 33 miles long. Fourteen coal horizons were recognized but the deposits are lenticular and correlations are uncertain. The variations are abrupt; in one case, from one to 20 feet within a very short distance. Many of the seams are injured seriously by partings. The coal is low grade bituminous of very fair quality, with color and streak black, and contains resin. In portions it is thinly laminated, but at times the dull layers are several inches thick and resemble cannel.

The most easterly locality in the southern part of the Uinta Basin,[110] at which the Benton coals have been recognized, seems to be that on the Gunnison River about 60 miles east from the Utah-Colorado line. There Lee found at base of the Benton a succession of sandstone and shale with maximum thickness of about 80 feet. The lenses of coal, a few inches to 3 feet thick, occur in the shales. Near the junction of Gunnison and Grand Rivers, 5 deposits of coal, one to 3 feet thick, were seen, but these lenses are too indefinite in extent and contain too much carbonaceous shale to justify mining. The ash in air-dried coal varies from 6 to 34.5 per cent. The sand-

[108] W. T. Lee, Bull. 316, 1907, citations from pp. 361–373.

[109] G. K. Gilbert, "Geology of the Henry Mountains," 1877, pp. 4–10; C. T. Lupton, Bull. 628, pp. 30, 31, 47–74, 78.

[110] W. T. Lee, Bull. 510, 1912, pp. 24, 25, 68.

stones are more or less flinty, are cross-bedded, ripple-marked and locally conglomerate. These coals have been placed in the Dakota by several students, but the presence of fossils confirms Lee's reference to the Benton. The Ferron sandstone cannot be recognized in this part of the basin and the coals of Castle Valley are wanting.

No observer has noted the existence of Benton coals on the northern side of the Uinta Basin within Colorado, but they have been recognized in two outlying fields along the northwestern border in Utah, which have been described by Lupton.[111] The western or Blacktail Mountain coal field is almost due north from the Emery field. The Mancos formation is about 2,650 feet thick. The upper part, 1,450, consists of shale; the middle, about 250 feet, is chiefly sandstone and has coal seams; the lower part is sandstone and shale. The shales increase and the sandstone decreases toward the east; the upper shale is but 800 feet thick in the western part of this field. Four coal seams were seen, 3 to 11 feet thick, but extremely variable. The coal is very similar to that from the Mesaverde, though 3,500 feet lower in the column; some of it is very good, with but 3 per cent. of ash and 10 per cent. of water in the air-dried coal. In the Vernal coal field, 30 miles farther east, the Mancos is not far from 2,500 feet thick, but the upper or shale division is 2,100 feet and the lower or sandy division is about 400 feet, with some coals near the top. It is quite possible, as suggested by Lee, that these coals are at same horizon with those of the Ferron sandstone. They are irregular but in some cases yield a good coal.

The Coalville coal field, about 30 miles northeast from Salt Lake City, Utah, was examined by Wegemann.[112] There, at somewhat more than 1,600 feet from the base of the Cretaceous section at Coalville, is the important coal seam known as the Wasatch. The roof is sandstone, locally conglomeratic, with sometimes a thin shale intervening. It appears to be quite regular. The floor is shale or sandstone and is irregular, there being "rolls" which occasionally cut out as much as 5 feet of the coal. The coal seam is from 5 to 14 feet thick but as a rule, the variations are not abrupt. The coal as mined at Coalville is of excellent quality. It is stated

[111] C. T. Lupton, Bull. 471-*I*, 1912, pp. 13, 35, 44.

[112] C. H. Wegemann, Bull. 581-*E*, 1915, pp. 161–184.

that work was abandoned in one mine because the bed thinned abruptly, the coal being cut out by a "sand roll" or deposit of coarse sand and gravel in the roof of the bed. At about 850 feet below the Wasatch seam, thin coals were seen, which are known as the Spring Canyon beds. The coal is impure and worthless; it is possible that these belong at a Bear River horizon.

The Coalville field is an outlier of the Green River Basin, which is reached in Uinta County of Wyoming near the 111th meridian or nearly 100 miles west from the Utah-Colorado line and probably 25 miles east from the meridian passing through Emory in Castle Valley field of Utah. The relations of the lower part of the section were a source of much perplexity, as the fresh-water fauna had led to the belief that it belonged to the Laramie or possibly even to the Tertiary. Its place in the column was determined by Stanton[113] who showed that it intervened between coarse sandstones and conglomerates below and well-defined Colorado above. Knight[114] recognized an important coal-bearing formation in the southern part of the county, which he named the Frontier. It consists of thick sandstones with coal beds and it may be practically equivalent to the deposits containing the Wasatch seam at Coalville. At a later date Veatch reported upon the southern and Schultz[115] upon the northern part of the county. The thickness of deposits in this area is enormous; Veatch assigns not less than 2,000 feet to the Niobrara, 4,200 to the Benton and 0 to 2,400 to the Bear River. The Frontier sandstone formation, the upper part of the Benton, is about 2,400 feet thick, consists of alternating sandstones and clays, with numerous coal seams. The important coals are the Kemmerer group near the top, consisting of 3 seams within a vertical distance of 90 feet; the highest bed has an extreme thickness of 5 feet, the main Kemmerer is from 5 to 20 feet thick in the mines, but along the outcrop, the variability is much greater, for at some localities between the mines it is very thin, at times absent. At 550 feet below the main Kemmerer is the Wilson bed which is not

[113] T. W. Stanton, "The Stratigraphic Position of the Bear River Formation," *Amer. Journ. Sci.*, Vol. XLIII., 1892, pp. 98–115.

[114] W. C. Knight, "Coalfields of Southern Uinta County, Utah," *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 542–544.

[115] A. C. Veatch, Bull. 285, pp. 333, 337, 340; A. R. Schultz, Bull. 316, p. 215.

present in the southern part of the field, but is 5 feet 8 inches at Kemmerer, where it yields a coking coal. The Carter bed is 1,300 feet below the Kemmerer and the Spring Valley, 1,475. The last, 5 to 6 feet thick, is apt to be dirty.

The Bear River coals are occasionally thick, as much as 6 feet, but the coal is so dirty as to be worthless. This formation, 2,400 feet on the western side of the county, is only 100 feet at the east side. The Frontier coals are bituminous, of high grade, with low ash and water content; the Coalville coal is subbituminous.

The Frontier sandstone does not outcrop in the Rock Springs field; in northern Carbon County Smith saw it with all the lithological features observed in Uinta County, but without coal. It is 900 feet thick in the southern part but only 500 in the northern part of his district; showing a great decrease toward the east. The Bear River is only 30 feet thick, but this has some thin and worthless streaks of coal. Veatch[116] in the eastern part of the same county found 400 to 800 feet of Frontier, but no coal, while the coaly streaks in shales overlying the Dakota are thin and worthless. Woodruff saw thin streaks of coal, 6 to 8 inches, below the middle of the Colorado, in Park County of Wyoming, almost due north from the Rock Springs coal field. No observer has reported the occurrence of coal at the Frontier horizons at any locality in Montana or in Alberta or anywhere east from the 109th meridian in Wyoming or the 108th in Colorado, but the lowest coal horizon, that resting on the Dakota, reaches to the 105th in Carbon County of Wyoming and, in northern New Mexico, along the southern border, it is present occasionally to near the same meridian. In New Mexico it extends northwardly for only a short distance.

The Dakota.

The Dakota or basal member of the Upper Cretaceous is a sandstone, more or less massive and locally conglomerate in the eastern or Rocky Mountain region. It is often cross-bedded and sometimes ripple-marked. At some localities farther west it contains much conglomerate. The thickness rarely exceeds 200 feet. Land

[116] E. E. Smith, Bull. 341, p. 226; A. C. Veatch, Bull. 316, p. 247; E. G. Woodruff, Bull. 341, p. 203.

conditions existed at few localities and in by far the greatest part of the region no coal occurs. The thin lenses, referred by some writers to this formation, belong rather to the Benton.

The Kootenai.

The Dakota, as described by the earlier students in the Front Range region of Colorado and New Mexico, consists of two sandstones separated by shale of variable thickness. Darton's collections in the Black Hills of northeastern Wyoming proved that the Dakota of that region is complex, that only the upper sandstone is Upper Cretaceous, the other deposits belonging to the Lower Cretaceous. He was convinced that a new name was necessary and offered Cloverly formation as substitute for Dakota. At a somewhat later time Darton, Lee and Stanton discovered somewhat similar conditions in Colorado and New Mexico. In Montana, this formation proved to be practically equivalent to the Kootenai formation of G. M. Dawson, which is important in the Rocky Mountains region within Alberta and British Columbia. This earlier name has been accepted throughout; but in some localities it appears to include the upper sandstone or Dakota. The Kootenai has not been recognized in Colorado and New Mexico west from the Front Ranges except in the Park area of Colorado, where it was seen by Beekly. Elsewhere the "Dakota" sandstone rests on a mass of clays containing some sandstones, the Morrison formation, of which the relations are not wholly clear, though in recent years the paleontologists have shown increasing inclination to regard it as Lower Cretaceous. It has no coal.

The Kootenai is recorded as coal bearing nowhere south from the Black Hills, where Darton gives the succession, as Dakota sandstone, 10 to 100 feet; Fuson shale, 10 to 100 feet; Lakota sandstone, 25 to 300 feet; forming the Cloverly formation of his earlier publications.[117] The Lakota, mainly sandstone, contains the coal. The sandstones are mostly hard, massive, coarse and cross-bedded; but in many places they are slabby, ripple-marked and locally they are conglomeratic. Lenses of coal occur near the base and at times

[117] N. H. Darton, Folios 127, 128, 1905; Prof. Paper 51, 1906, pp. 50–53; Bull. 260, 1904, pp. 429–433; Prof. Paper 65, 1909, pp. 12, 40–48.

attain commercial importance. Two are near Aladdin, one of them, 2 feet to 3 feet 6 inches, the other, 10 feet above, being thinner. The extreme thickness is at a little way north from Aladdin where the lower lens becomes 8 to 9 feet; but both thin away, being replaced with impure coal, before disappearance. The coal at Aladdin is soft and bituminous, as it is also at Sundance. In the Cambria district, on southwest side of the region, there is an oval space of about 10 square miles, in which the coal averages 5 feet, but, in the surrounding area, the thickness decreases, the coal becomes impure and carbonaceous shale replaces it. On the southern slope of the Black Hills, a coal bed, 5 feet thick near Edgemont, is distinctly local; it quickly disappears toward the southeast, giving place to sandstone; while toward the northwest, it becomes merely a coaly shale. There is little coal on the easterly side of the Black Hills, only thin lenses of coal and coaly shale were seen, and these are confined to the northerly portion. The thick bed near Aladdin has a bone parting somewhat more than one foot thick, which, in appearance, closely resembles cannel; it has 38.69 per cent. of ash. The upper part of the Lakota holds much petrified wood; cycad stems are numerous at several localities.

Darton recognized his Cloverly formation on both sides of the Bighorn Mountains in north central Wyoming, where, in much of the region, the Dakota sandstone appears to be wanting. Streaks of coal were seen occasionally in the Lakota, but they offer no promise of economical importance. Fisher[118] saw Lakota coal in the drainage area of No Wood creek at the westerly base of Bighorn Mountain. It is less than 50 feet above the Morrison formation and is found within a considerable area. One opening was in a bed divided by a parting of 2 inches into benches, each 4 feet; but the coal is a lens and thins away rapidly on all sides. The coal is dark with dull earthy luster, conchoidal fracture and resembles carbonaceous shale; but it is bituminous coal with not more than 11 per cent. of ash. Fisher suggested that the formation might be Dawson's Kootenai. No coal was seen by Woodruff within the southwestern part of the Bighorn Basin and the formation appears, according to Darton, to be barren in central western Wyoming, but

[118] C. A. Fisher, Bull. 225, 1904, pp. 355, 362.

coal, too thin to be worked, was found by Washburne in the northeast part of the Bighorn Basin near the Montana line.[119]

Calvert reports that, in the Electric coal field, Park County, Montana, the Kootenai is 577 feet thick and with same general structure as that of the Cloverly. The Fuson, 230 feet, consists of variegated shales, limestones and thin sandstones; the Lakota, 249 feet, has a coal bed, one foot thick and underlying a conglomerate sandstone; but it seems to be local. In the Livingston coal field of the same county, the Kootenai is 540 feet thick and apparently has no coal. In the Crazy Mountains coal field of Meagher County, north from Park, Stone found the Kootenai only 235 feet thick with variegated sandstones in the upper half and variegated shales in the lower half. The lowest of the sandstones is coarse and has layers of conglomerate; it overlies one foot of black shale; no coal is reported.[120]

Calvert[121] found 512 feet of Kootenai in the Lewistown coal field of Fergus County, where the upper part is variegated shale with two massive, cross-bedded sandstones, 8 and 25 feet thick; the lower part, 147 feet, is coarse sandstone, locally conglomerate, with sandy shale. The workable coals of the Kootenai in this field are in the lower portion at 60 to 90 feet above the base and underlie a massive cross-bedded sandstone. In some districts only one seam is present but in others there are several. The seams are distinctly lenses, separated by unproductive spaces. The thickness seldom exceeds 5 feet and ordinarily the coal is divided into benches by partings of shale or bone. The roof is shale or sandstone and the floor is shale or clay; in many cases a bench-bone is at top or bottom of the coal. A dull, lusterless coal, resembling cannel, was seen at several places but especially in the Mace mine, where it occurs as lenses within the coal, the largest being 200 feet long. The coal is accepted as bituminous, but the percentage of ash varies greatly.

The Great Falls coal field in northern Cascade County, west

119 E. G. Woodruff, Bull. 341, p. 203; C. W. Washburne, the same, p. 170; N. H. Darton, *Bull. Geol. Soc. Amer.*, Vol. 19, pp. 447–449.

120 W. R. Calvert, Bull. 471-*E*, pp. 34, 53, 58; R. W. Stone, Bull. 341, p. 80.

121 W. R. Calvert, Bull. 341, pp. 110, 113, 117, 119; Bull. 390, pp. 56, 61, 72, 74.

from Fergus and north from Meagher, was examined by Weed and afterward by Fisher.[122] The Kootenai, 400 to 500 feet, according to Fisher but about 750 according to Weed, was formerly regarded as Dakota; but J. S. Newberry in 1887, cited by Weed, determined that it is Kootenai. The Dakota was not recognized. The individual deposits are inconstant, sandstones and shales alike being lenses. The coal horizon is about 60 feet from the base and the seams are clearly lenses. Weed has described the coals in detail. The great coal seam, with extreme thickness of 12 feet in Sand Coulée district, splits toward the west into two beds, which, where last seen, were separated by 25 feet of shale. The seams are usually divided and the benches often differ in quality of the coal, coking and non-coking being found within the same bed. Picked samples from one bed had barely 10 per cent. of ash, but one from the middle part of the bed had 27 per cent. Official samples, collected by Fisher, give from 16 to 23 per cent. of ash. As in sampling of the coal, nothing is taken which ought to be removed in mining, it is certain that this fuel, as it reaches the consumer, must be decidedly inferior in quality.

Stebinger[123] gives about 2,000 feet as the thickness of Kootenai in the Teton coal field, which, like the Great Falls field, is near the western boundary of Cretaceous deposition in Montana. The formation is practically without coal, there being only some black shale with 6 or 8 inches of coal.

The Kootenai shows great variation in thickness within Alberta. Dowling,[124] summarizing observations made by himself and others in various parts of the province, states that the maximum deposition was near the axis of the Rocky Mountains, where the base is a great bed of sandstone, succeeded by sandstones and shales with many seams of coal. In the Elk River escarpment, it is 3,600 feet, but at Blairmore, toward the east, it is but 750; northward, near Banff, it is 3,900 feet, but in Moose Mountain, east from the main range, it is only 375 feet. Farther east, the formation is unim-

[122] W. H. Weed, *Bull. Geol. Soc. Amer.*, Vol. 3, 1892, pp. 302, 303, 313–321; C. A. Fisher, Bull. 356, 1909, pp. 22, 50, 51, 52, 77, 78.

[123] E. Stebinger, Bull. 621-*K*, 1916, p. 124.

[124] D. B. Dowling, Geol. Survey Memoir, 53, 1914, p. 27.

portant owing to thinning of the beds; it has not been recognized in Manitoba.

In Alberta, the Kootenai is fully exposed only in the more disturbed portion of the Rocky Mountains area and the more important coal deposits, for the most part, are west from the Mountains in British Columbia. Mackenzie[125] measured about 700 feet of Kootenai on Oldman river in southern Alberta, in the Foothills region. The rocks mostly arenaceous. An overlying sandstone formation was assigned to the Dakota. A Coal Measures group, about 200 feet thick, is in the upper part of the Kootenai, where the sandstones increase in coarseness. Near Blairmore, five coal seams were examined; the total is about 40 feet, but two of the beds are poor and shaly; elsewhere the quantity of coal is less.

The Crowsnest coal field[126] is farther west, in and beyond the Mountains, and the greater part is in British Columbia. In Crowsnest pass, within Alberta, McEvoy gives a section of 4,736 feet, which he regarded as wholly Kootenai. The coal bearing portion begins at 1,170 feet from the base and is 1,847 feet. The coal is 198 feet, somewhat less than in the main field farther west. McLearn[127] states that the lower part of the Kootenai in this region contains abundant remains of plants and erect stems of trees.

Dowling[128] examined a small area of Kootenai on the North Saskatchewan river, about the 55th degree and near the 118th meridian. There, behind the Brazeau Hills, he saw 5 coal seams within a vertical distance of 631 feet. The lowest and highest, with somewhat more than 12 feet thickness, yield worthless coal, but the second and third, with about 23 feet of coal, are good, though the ash is rather high, being from 12 to 15 per cent.: the grade is semi-bituminous.

Malloch[129] reported upon an extensive district farther west, on the headwaters of the Saskatchewan, Bighorn and Brazeau Rivers, and within the outlying ridges of the Rocky Mountains. The thickness of Kootenai is 3,658 feet, which is unexpectedly great, as

[125] J. D. Mackenzie, Summ. Rep. Geol. Survey, Canada, pp. 239, 243, 244.

[126] J. McEvoy, Ann. Rep., Vol. XIII., 1900, Pt. *A*, pp. 84–88.

[127] F. H. McLearn, Summ. Rep., 1915, p. 111.

[128] D. B. Dowling, Summ. Rep. for 1913, pp. 150, 151.

[129] G. S. Malloch, Memoir 9–2, 1911, pp. 25, 31–33, 52, 53, 59, 60.

farther south in the foothills the formation is thin. In the basal 700 feet, there is a ripple-marked sandstone as well as shales and sandstones with impressions of rain drops. Sandstones and shales are irregular throughout and clear evidence of contemporaneous erosion was observed at several localities. Some thin beds of conglomerate were seen but they are indefinite and are clearly local.

Twenty-one coal seams were seen in a section of 2,760 feet, from 2 inches to 9 feet thick; in another section of about 1,100 feet in the upper part of the formation, 7 seams were seen, with total thickness of about 26 feet, while in a third of nearly 1,300 feet, there are 8 seams with total thickness of more than 52 feet, besides other seams less than 3 feet thick. Comparison of the sections make clear that the seams are lenticular. The coal throughout is bituminous and, with rare exceptions, is coking. The quality is excellent, ash and sulphur being low.

Malloch thinks that the shales, sandstones and conglomerates are of fluviatile origin. Absence of roots in the floor of coal seams leads him to suggest that these may have developed in bogs within choked oxbows or on coastal plains. The quantity of coal decreases rapidly eastward from the mountains.

Some Chemical Features of Cretaceous Coals.

No substance resembling the pyropissite of Sachsen has been mentioned by any observer, the only allied material being that seen by Dunker in the Hannover region, which he thought might be hatchettin. Resin of one sort or another occurs commonly; it is termed Bernstein, retinite, walchovite or simply resin by various authors. It is in grains or in lumps several inches long in the Lower Quader coals of Bohemia and Moravia; at one locality in Hungary it is so abundant as to give the local name to a coal seam; there is much in New Zealand; in North America, resins are characteristic features of coals in the Laramie, the Fox Hills and the Pierre as well as in those of the Benton. The color is from honey yellow to dark yellow and according to Thiessen is rather darker in the Fox Hills coals of northern Colorado than in the Eocene coals of the Dakotas. Resins appear to be wanting in bituminous coals of high grade; at least, no note is made anywhere respecting their existence in such coals.

Cannel has been reported from numerous places. Often it evidently is little more than highly carbonaceous mud, forming a faux-toit, faux-mur, or a thick parting, which may be regarded as roof and floor to the benches which it separates; but typical cannel is by no means rare. A great cannel lens was seen by Hector and by Campbell in one portion of the Buller coal field in New Zealand and Denniston has referred to what are clearly localized cannel deposits in coal beds. Hector has given the proximate analysis of the lens as water, 6.20; ash, 3.60; volatile matter, 61.41; fixed carbon, 38.58. Within the United States and western Canada, cannel has been described from Laramie, Benton and Kootenai horizons.

Cannel was discovered in the Benton of the Colob field, Utah, by Richardson, whose description shows that it is the lower bench of at least two lenses occurring at the same horizon. The material was studied microscopically by D. White, who recognized it as a typical cannel. At a later date it was studied in detail by Thiessen,[130] who reported that it has the appearance and characteristics of cannel. Under medium enlargement, the coal is a dark, homogeneous mass, in which are embedded resinous particles, dark and light, with some large spore exines and cuticles, this embedded material comprising about one half of the whole. Under higher power, the enclosing material is shown to be like the "groundmass" of other coals, being in largest part a mass of closely packed very thin flattened particles, most of which are spore and pollen exines, with small fragments of cuticles. In great proportion, these are fragmentary and many are so macerated that they are unrecognizable; but even in this condition, the color and optical action are the same as in the recognized cuticles and exines. As all intergradations are present, he thinks it reasonable to conclude that the origin is the same. With this is the amorphous substance or binding material as in the débris of lignite. The darker resinous substances are the more abundant and, in color as well as in appearance, they resemble those of lignite. Many are cylindrical, having retained the shape of resin cells in the wood. Smaller particles enter into the

[130] R. Thiessen, "Origin of Coal," 1914, pp. 244, 245.

groundmass. The darker resins are deep brown in color and in general are opaquely glassy. The lighter resins are in striking contrast and tend to be more irregular in form. Besides charred cell fragments, few other bodies are present and none of them is in recognizable condition. In variety of constituents, this coal is very simple and thus approaches Paleozoic cannel very closely. It is so brittle that proper sections cannot be prepared. The analysis showed 67.61 of volatile matter and 32.39 per cent. of fixed carbon in the pure coal. The cannel is overlain by a thin bituminous bench, which has 60 per cent. of volatile to 40 of fixed carbon, making probable that the upper bench contains much spore material.

Cannel is said to be present in the Lakota sandstone of the Black Hills, at a Kootenai horizon, where it is in two benches, each about a foot and a half thick and overlain by bituminous coal. The proximate analysis suggests that this is more probably a bony coal, as the volatile is but 38.64 and the fixed carbon 61.46 per cent. in the pure coal; the ash is 24.16. Cannel is present in the Kootenai of the Elk River district of Alberta, the composition being 65.55 of volatile and 34.45 of fixed carbon; the ash is only 9.86 per cent.[131]

That coals of very different types may occur in the same vertical section is evident from conditions in the Wealden of Hannover. Dunker[132] states that in many localities the coal resembles the older black coals, there being no trace of woody structure and the streak is blackish brown. This type of coal was analyzed by Regnault; but lignite is present also, which preserves the woody structure and has reddish brown streak. A sample from Helmstadt was analyzed by Varrentrapp. The results are:

	C.	H.	O and N.
I..................	89.50	4.83	4.67
II..................	73.50	5.18	21.30

Beside these there is the Blätterkohle, composed of leaves and twigs of conifers and cycads, which is so little changed that the leaves become flexible when soaked in water. This type occurs in the same

[131] U. S. Bureau of Mines, Bull. 22, 1913, p. 194; D. B. Dowling, Geol. Survey of Canada, Memoir 53, 1914, p. 74.

[132] W. Dunker, "Monographie," etc., p. xiii.

vertical section with other coals, some of which are of the "black" type. No analysis of the Blätterkohle is given. Dunker conceives that the black coal was formed from lycopods and ferns, as no remains of other plants have been found in it; the lignite, however, seems to him to be composed of conifers, cycads, lycopods and ferns. The ash of the Wealden coals in Hannover, according to analyses made by Saurwein and published by Zincken,[133] appears to average high, for in most cases the percentage exceeds 13.

Cžjžek[134] has described the black coal with black brown streak mined near Grünbach in Lower Austria, which occasionally contains fragments of branches, retaining their form but showing no trace of fiber. This, belonging to the Upper Cretaceous, is a lignitic coal, for, as analyzed by Schrotter, it has carbon, 74.84; hydrogen, 4.60; oxygen, 20.56. The water and ash are very low. The important coals of Hungarian Cretaceous are in the middle or fresh-water formation consisting of marls and coal beds. Hantken presents no detailed analyses; the water and ash, for the most part, are less than 10 per cent.

The Cretaceous coals of Queensland are rarely thick enough to be workable; they occur as lenses scattered over a great area. The analyses reported by Jack[135] are all proximate; reduced to pure coal for fixed carbon and volatile they show:

	Water.	Ash.	Volatile.	Fixed Carbon.
I.	7.16	36.53	37.22	62.77
II.	8.25	19.02	41.82	58.17
III.	0.33	30.20	43.37	56.62
IV.	2.32	9.65	17.26	82.73
V.	8.30	2.80	42.26	57.73

The coal of No. V., belonging in the Lower Cretaceous, cokes well. The stratigraphic relations give no explanation for the low volatile of No. IV. There is no relation between ash and volatile, for the ash of III. is almost ten times that of V., but the volatile is almost the same in both coals.

133 C. Zincken, "Erganzungen zu der Physiographie der Braunkohle," Halle, 1871, pp. 4, 5.

134 *Jahrb. k. k. Reichsanst.*, Vol. II., Part 1, p. 144.

135 R. L. Jack, "Geology of Queensland," pp. 398, 532, 537.

The analyses of New Zealand coals are proximate. Hector has published those of samples taken from different parts of two important seams:

	Water.	Ash.	Volatile.	Fixed Carbon.
I.	13.93	7.16	46.85	53.15
II.	16.46	7.20	33.45	66.54
III	4.98	1.19	41.89	58.10
IV.	10.38	0.98	38.36	61.63

The difference in volatile of I. and II., from the same bed, is unusually great. Cox has given the results of numerous analyses of coals from the Buller field; the coal is bituminous and that from some mines is caking. The water content is very low, seldom exceeding 7 per cent. The ash is amazingly small, there being less than one per cent. in 9 of the 14 samples and only 4 exceed two per cent. Analyses of coals from Otago, as reported by Hutton, have in most cases very little ash. One cannot resist the suggestion that the samples may have been selected "average" lumps.[136]

Many thousands of analyses of coals have been made by the United States Bureau of Mines and a great number have been made for the Geological Survey of Canada. The samples consist of cuts across the whole bed, omitting such partings or benches as should be removed before shipment of fuel from the mine. For the most part, the samples have been taken from mines in successful operation or, if the region be undeveloped, from such seams as gave promise. The purpose of the sampling is to determine the commercial value of the property and the method is beyond doubt the best yet devised. But the student of geological relations should read the descriptive portion of Bulletin 22 in order to learn how far the analyses concern matters occupying his attention.

The Laramie coals. The Laramie formation, as defined in preceding pages, contains at most localities only thin seams of coal; but in the northern part of the San Juan Basin of New Mexico and Colorado as well as in the Edmonton region of Alberta, the

[136] J. Hector, New Zealand Reps. for 1871–2, pp. 132, 134; J. H. Cox, the same, for 1874–6, p. 25; F. W. Hutton, "Geology of Otago," 1875, pp. 101, 105, 110.

seams become thick and of economic importance. Two analyses of the great Carbonero seam have been published, I. near Fruitland, where the seam consists of bone, shale and coal, 12 feet, and at base 5 feet of coal, which was sampled; II. near Pendleton, where the thickness is 48 feet, but only 7 feet were included in the sample.

	Water.	Ash.	Volatile.	Fixed Carbon.	Sulphur.
I.	9.89	10.19	48.10	51.90	0.80
II.	8.30	8.25	42.61	57.39	0.80

The Edmonton coals are subbituminous and break up on exposure; but this disintegration is much less rapid if the fuel be stored under cover. Dowling has reported the results of numerous analyses, which show no serious variation in composition of the pure coal; it suffices to cite three from the upper group, which includes the great seam on Pembina River, and one from the Clover Bar group several hundred feet lower in the section.

	Water.	Ash.	Volatile.	Fixed Carbon.
I.	12.93	10.00	41.46	58.52
II.	13.78	6.86	40.33	59.66
III.	11.78	3.31	45.58	54.42
IV	17.28	7.30	47.30	52.70

Coals of the Clover Bar group appear to be less advanced in conversion than those of the higher group; three samples from different mines yielded 43, 45 and 47 per cent. of volatile. The ash rarely exceeds 8 per cent.[137]

The Fox Hills coals. The coals taken by the writer to be of Fox Hills age are irregular but they are better than those of the Laramie, within the United States; and in some extensive areas they are of great economic importance. Along the eastern base of the Front ranges, these coals are mined on large scale in several fields from New Mexico almost to the Colorado-Wyoming line; in much of the region the seams are broken more or less by bony partings, but these are separated readily and they have not been included in the samples taken for analysis. Of the analyses, Numbers I. to V. are

[137] U. S. Bureau of Mines, Bull. 22, p. 141; D. B. Dowling, Memoir 53, pp. 11, 18, 21, 47.

from the Raton-Trinidad field; VI. and VII. are from the Canyon City field; VIII. and IX. from the Boulder District; and X. is from Platteville, about 40 miles north from Denver.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 3294...	2.72	14.57	38.51	61.49	0.83	84.58	5.54	7.64	1.41
II. 3295...	3.45	16.67	40.14	59.86	0.91	83.62	5.77	9.06	1.55
III. 6595...	2.45	17.40	34.36	65.64	0.96	85.32	5.67	6.93	1.12
IV. 115D..	2.25	20.44	38.15	61.85	0.82	84.08	5.61	8.02	1.47
V. 7196...	3.88	13.73	33.18	66.82	0.57	84.56	5.34	7.97	1.56
VI. 6254...	9.89	6.21	42.05	57.95	0.52	76.30	4.77	17.33	1.08
VII. 6376...	5.44	12.10	46.12	52.88	0.87	77.67	5.96	14.18	1.32
VIII. 1523...	18.68	5.99	46.30	53.70	0.73	76.28	5.30	16.16	1.53
IX. 6836...	17.32	4.64	41.06	58.94	0.39	74.97	5.18	18.00	1.46
X. 6408...	28.90	5.02	43.63	56.37	0.70	73.19	5.19	19.51	1.41

The ash is high at the south, but the seams in the lower part of the Vermejo group yield a fuel so good for steaming purposes that the high ash becomes unimportant; the ash decreases northwardly and in the Boulder District it is about that of an ordinary good coal. But in the same direction the type of coal changes; in the Raton-Trinidad field, one finds usually a high-grade bituminous coal, that from some extensive mines yielding a strong coke; in the Canyon City field, the coal is still bituminous, but it does not cake and the oxygen is about double that in the Trinidad coals; in the Boulder District, the coal is distinctly subbituminous, is xyloid in appearance and disintegrates on exposure. There are no such violent contrasts between proximate and ultimate composition, such as have been recognized in some of the newer coals.

The Fox Hills as a coal-bearing formation is important in southwestern Wyoming; the Adaville seam of Uinta County has maximum thickness of 84 feet; at least a part of the Black Buttes coal group in Sweetwater County belongs here; the coal assigned to the Lewis in Carbon County is taken by the writer to be at a Fox Hills horizon. The seams become thin and unimportant eastwardly. The Adaville seam yields coal of almost the same composition at two widely separated mines, which differs little from that of the Boulder District in Colorado. The volatile in the coals of Uinta and Sweetwater Counties varies from 38 to almost 49 per cent., though in the coals compared the carbon is almost the same throughout The lowest percentage of carbon in either county is barely 73; usually it is somewhat more than 76 per cent. These coals are high in water but not in ash. They are classed as subbituminous and are not held in high esteem as better fuel from the Pierre is readily accessible.[138]

The Pierre coals. These attain great importance in the San Juan, Uinta and Green River Basins as well as in portions of Alberta in Canada. There are few localities whence coal, positively recognized as Lower Pierre, has been taken for official analysis. Probably the Hagan coal of Sandoval County in New Mexico belongs here, but the only available analysis is proximate. The Upper Pierre or the Lewis and the Bearpaw shales have no coal deserving consideration. The Middle Pierre or Mesaverde, as originally defined, is the productive formation. Its coals are mined in the Cerillos coal field, where all grades from bituminous to anthracite are obtained; and in various parts of the San Juan Basin. Of the analyses given here, I. and II. are from the Cerillos field, III. and IV. are from the southern part of the San Juan Basin, V., VI. and VII. are from the northern part.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 6153	5.70	5.99	2.47	97.53	0.78	93.84	1.99	1.96	1.34
II. 6154	3.76	4.89	37.67	62.83	0.62	82.49	5.78	9.86	1.25
III. 1307	10.79	18.66	47.94	52.06	1.79	78.06	5.70	13.10	1.35
IV. 1278	12.29	6.99	42.84	57.16	0.78	78.43	5.51	14.00	1.28
V. 5761	1.71	6.92	39.68	60.32	0.71	82.50	5.50	9.58	1.71
VI. 2121	3.04	9.66	44.70	55.30	4.03	81.01	5.99	7.27	1.70
VII. 537D	1.24	16.12	38.30	61.70	0.66	84.64	5.56	7.49	1.65

The sample III. consisted of slack and VII. represented the run-of-mine. II. and VII. yield a high grade coke. The anthracite of Cerillos is believed to be due to a sheet of andesite overlying the seam.

The Mesaverde coals of the Uinta Basin are in two groups, separated by a thick sandstone. The upper group, the Paonia shales, has many coal beds of which one or more may be workable at a given locality; the lower group, Bowie shale, contains important seams. In the southeastern part of this basin, the Paonia and Bowie cannot

[138] Bull. 22, pp. 137, 138, 69, 58, 59, 54, 55, 82 for Colorado-New Mexico; pp. 310, 319 for Wyoming.

be distinguished; yet in the western part the coals differ altogether. The Paonia coals are subbituminous, with 15 to about 20 per cent. of water, almost 17 of oxygen and less than 76 of carbon; whereas the Bowie coals have less than 4 per cent. of water, 9 to 12 per cent. of oxygen and from 79 to 83 per cent. of carbon. The Paonia coals are at times rather high in ash, but the coal mined from the Bowie is uniformly clean, the ash rarely exceeding 6 per cent.

The Mesaverde coals are important in Sweetwater County of Wyoming, within the Green River Basin. There, as in the Grand Mesa area within the Uinta Basin, the coals are in two groups, Almond and Rock Springs, which are separated by a greater interval than the Paonia and the Bowie. The Almond coals are lower in water than are those of the Paonia, but the oxygen is higher while the carbon is from 72 to 76 per cent. The Rock Springs coals have about 5 per cent. less of oxygen and the carbon varies little from 79 per cent. Farther north in Wyoming, within the Bighorn Basin, a coal is mined near Cody which has 21 per cent. of oxygen and only 71 of carbon.[139]

In Montana, the coal seams are more irregular than in southern areas, the lenses, for the most, are of less extent and the coal is apt to be dirty. The Judith River seams, or approximately the Upper Mesaverde, are of subbituminous coal with water from 10 to 25 per cent., 16 to 20 per cent. of oxygen and 72, 73 to 76 per cent. of carbon. But the coals of the Eagle sandstone are bituminous with 12 to 16 of oxygen and 76 to 80 per cent. of carbon. The ash usually is high, 13 to more than 16 per cent.

Dowling has published many analyses of Belly Rivers coals from Alberta. They are proximate but they represent a great number of localities The water rarely exceeds 5 per cent. in the Foothills region but in the Lethbridge-Medicine Hat region it increases eastwardly and, near Medicine Hat, it is about 20 per cent. The ash in beds of workable thickness is low, seldom exceeding 8 per cent. According to two analyses of Lethbridge coal, published by Stebinger,[140] that fuel is on the borderland between subbituminous and

[139] U. S. Bureau of Mines, Bull. 22, pp. 67, 140, 141 for San Juan Basin; pp. 55, 56 for Uinta Basin; pp. 313, 315, 316 for Green River Basin.

[140] E. Stebinger, Bull. 621-*K*, 1914, p. 138.

bituminous, but it is of better quality in respect of ash than the Montana coals at the same horizon.

The Benton Coals.—The published reports contain no reference to occurrence of coal in deposits representing the Niobrara time interval; the coal seams are associated with rocks containing Benton fossils. These coals are confined to the western part of the Cretaceous area within Arizona and Utah, though extending eastwardly for a short distance into New Mexico, Colorado and Wyoming. The coal in Arizona and New Mexico is rather high in ash, about 14 to 16 per cent., and the sulphur seems to be not far from 2 per cent., so that it is an inferior fuel. Analyses I., II. and III. are from Iron County, Utah, where the coal seams are often closely associated with marine limestones; IV. is from Emery County, where the coal is mined extensively; V. and VI. are from Uinta County, on the northwest side of the Uinta Basin.

	Water.	Ash.	Volatile.	Fixed Carbon.	S.	C.	H.	O.	N.
I. 5494....	4.93	13.04	45.40	54.60	8.19	76.82	5.56	8.29	1.14
II. 5304....	10.35	9.82	45.39	54.61	7.27	76.52	4.97	10.05	1.19
III. 5305....	14.19	9.92	44.00	56.00	7.10	72.83	4.77	14.18	1.12
IV. 12627....	4.00	5.93	45.4	54.6	0.44	81.01	5.64	11.52	1.39
V. 5510....	8.82	6.25	43.10	56.90	1.95	76.67	5.58	14.52	1.19
VI. 5513....	8.21	11.79	42.87	57.13	2.20	76.28	5.60	14.70	1.22

The carbon is highest at the west in Iron County, being more than 83 per cent. in the pure coal of I.; it is 78 in the pure coal of III., 81 in that of II. and 81 in the best coal from the Emery coal field. The sulphur in Iron County is so abundant as to suggest contribution by animals. V. and VI. are the upper and lower benches of a single bed and show improved conditions during formation of the upper bench. Lee has given analyses of the upper and lower benches of a bed in Delta County of Colorado; the upper bench has 6 per cent. and the lower bench 22 per cent. of ash. There, as in the Uinta County seam, the lower bench, though richer in ash, is poorer in volatile. The Frontier coals in Uinta County of Wyoming, in the Green River Basin, have excellent fuel in several of the seams. They are bituminous, low in ash and sulphur and have from 77 to almost 81 per cent. of carbon.[141]

[141] Bureau of Mines, Bull. 22, pp. 47, 139; for Utah, pp. 80, 193, 194; C. T. Lupton, Bull. 628, p. 80; W. T. Lee, Bull. 510, p. 201.

The coals of Dakota age are insignificant. The only ultimate analysis shows that in one case, at least, the coal is high-grade bituminous but with notable percentage of ash.

The Kootenai is without coal south from the northern border of Wyoming and there as well as in Montana the coal is not of high grade. In the Black Hills of Wyoming one finds extensive mines at or near Aladdin. In one of those the water is from 14 to 18, the ash from about 5 to 16 and the sulphur from 5 to 7 per cent., all in freshly mined coal. Within Montana, the Kootenai coals become important locally and are mined at many places in Cascade and Fergus Counties. In the former county, the water is but 3.5 to 7.5 per cent. but the ash is from 14 to 21. Sulphur is less than 3 per cent. The coal is bituminous, the carbon in pure coal being about 80 and the oxygen, barely 15 per cent. In Fergus County, the ash within several districts is from 10 to 17 per cent. of the air-dried coal; but only 3 out of 10 samples gave more than 10; the sulphur, however, is much greater than in Cascade, being 5 per cent. and upward. The percentage of carbon in pure coal is from 80 to 85 and that of oxygen 9 to 15. But one analysis shows only 75 of carbon with 19 of oxygen.[142]

The analyses published by Dowling[143] show regional variation in the coals of Alberta. The ash is highest in areas near the mountains, where three districts have 13 to 22, 10 to 20 and 8 to 17 per cent. In all other areas, it rarely exceeds 8 and is usually about 5. The water is about 3 per cent. Sulphur is in small quantity, there being one extensive region with barely a half per cent. The coal is bituminous and often is caking. Anthracite is obtained in disturbed districts.

In reading the results of analysis as given above, one is in danger of concluding that "clean" coal is the rule and "dirty" coal the exception. Emphasis must be laid on the fact that samples for analysis have been cut, for the most part, from mines in successful operation or from promising exposures. Lenses yield the best coal in the central portions; toward the borders, their coal becomes dirty and usually passes into carbonaceous shale. In many vertical sec-

[142] Bull. 22, pp. 305, 126, 127, 130–133.

[143] D. B. Dowling, Memoir 53, pp. 74–79.

tions, one observes that a large proportion of the seams are "dirty," and in reading descriptive notes of seams from which samples were taken, he finds that only in rare instances is a seam, upwards of 3 feet thick, clean throughout, while of thicker seams, a half or more must be rejected in sampling. Even in thinner seams, selection of samples requires no little skill. The testimony of observers, cited in preceding pages, proves that a very great part of the Cretaceous coal was formed amid conditions unfavorable to accumulation of clean coal. Generally speaking, foreign materials are in partings, but occasionally the mineral matter is distributed throughout so that it cannot be removed by washing.

SUMMARY.

The facts recorded in preceding pages may be grouped to make clear their bearing upon the matters at issue.

1. *The Distribution of Coal.*—One who reads reports covering an extensive area is liable to believe that caprice has determined the distribution of coal. The presence of coal at one locality gives no assurance that it will be found at the same horizon in others, for great barren spaces exist between productive areas, so that individual seams appear to have small areal extent; apparently, the total area on which coal was accumulating at any time was a comparatively insignificant part of the whole. There is, however, an evident relation between occurrence of coal seams and the prevailing character of the sediments, which would justify the assertion that in one locality coal may be present, and that in another it is almost certain to be absent. The descriptions seem to prove that coal seams accumulate only under conditions such as mark great river or coastal plains, where intervals of relatively rapid subsidence were followed by others, during which subsidence was slow; finer materials were deposited upon the coarser and coal accumulation began. But where the deposits are fine, such as those laid down at a notable distance from the source of materials and under a practically constant cover of water, coal is not present.

The relations are sufficiently clear in the Upper Cretaceous of Europe. Coal is of rare occurrence in England, France and western Germany, where the deposits, almost without exception, are marine and largely calcareous; but in a part of France, the closing stages are characterized by thick fresh-water deposits and thin seams of lignitic coal have been observed. Land deposits abound in eastern Germany and there coals are found, which at times attain economic[144] importance. The Hastings Sand of England, at base of the Wealden, is thought to be a delta deposit; if so, the areas remaining may mark, in greatest part, the submerged portions, as they contain no coal and the sand holds much driftwood. This formation has been recognized in France, where within small areas, some coal seams exist which have been mined. The Wealden is exposed within a large space in Hannover, reaching westward from the Harz Mountains to the Holland border, where it underruns newer formations. At this western limit, the deposits are fine clays or marls with important limestones, but no coal. Coarse deposits are reached farther east and with them the coal. The seams are usually thin and irregular, but occasionally one is more than 5 feet thick. In a section, toward the west, where shale, more or less argillaceous, predominates, a workable seam occurs, but it is associated with the principal sandstone of the section. The coals of New Zealand and Queensland either rest on sandstone or are separated from it by thin clay or shale.

The immense area of Cretaceous in the United States and Canada affords ample opportunity for comparisons. Each formation, with possible exception of the Niobrara, is coal-bearing. The chief source of detritus was at the west, though important contributions were received from the southern border, which probably lay in northern Mexico, not far from the international boundary.

The Laramie marks the closing stages of the Cretaceous and, where the succession is complete, deposition appears to have been continuous into the Eocene. Except in a portion of Alberta, where a brackish-water fauna is found, the rocks are of continental type; leaves abound in many beds and the animal remains are of river or pond forms. The conditions recall those observed on the great

[144] It should be noted that this term, "economic importance," has not the same signification everywhere: in the United States, a coal seam, less than thirty inches thick, is not thought to be workable, except in localities without railway communication. On the continent of Europe seams very much thinner have been worked.

plains of China. The drainage appears to have been irregular and shifting, the deposits are variable in form and composition, and except in a few localities, widely separated, the coal seams are thin. The periods, during which coal accumulation was possible in any locality, were usually brief; but in the northern part of the San Juan Basin, one seam attains the thickness of 100 feet and in the Edmonton district of Alberta the seams are not only thick but, unlike the seam in the San Juan, they yield coal of excellent quality.

The Fox Hills, underlying the fresh-water Laramie, is recognizable as a persistent sandstone with intercalated shales and coal seams. It resembles a low-lying strand of vast extent, frequently invaded for considerable periods by the sea, so that it has an off-shore fauna, which is of strangely persistent type. This is passage, from the continental conditions of the Laramie to the marine conditions of the Pierre. The coal seams, yielding better fuel than that from the Laramie seams, are thin and variable at most localities, but at times in considerable areas, some of them become thick and of great economic importance. Merely insignificant seams occur in the San Juan Basin except at the north, where two, 4 and 12 feet thick, are present in the shales immediately overlying the Pictured Cliffs sandstone. In the Green River Basin, the Adaville seam has a maximum thickness of 84 feet, but the seams become thin eastwardly and there are great spaces in which the formation seems to be barren. In central and eastern Wyoming as well as in Montana and Alberta, only occasional exposures of coal have been reported and those are unimportant. In the basins along the eastern foot of the Front Ranges in New Mexico, the seams are numerous and some horizons are extremely productive along this line of more than 300 miles; but the individual seams are variable to the last degree in thickness and quality, there being many spaces where the coal is either wanting or worthless.

The Pierre at the west and southwest is, for the most part, a mass of sandstone and sandy shale; toward the east, it becomes shale at top and bottom, while Middle Pierre or Mesaverde persists as a wedge of sandstone and shale thinning eastwardly until it becomes replaced wholly with fine shales and irregular limestones. This wedge thins away unbroken in Colorado and New Mexico but in Montana it is divided by shales into subordinate wedges, and these "fingers" disappear toward the east, giving place to marine shales. Coal seams are confined to the areas of sandstone and shale, there being none in the fine-grained marine shales, which extend from the longitude of central Colorado to the eastern border of the Cretaceous, except in the sandy strip along the southern border in New Mexico. In the sandstone wedges, land and marine conditions alternated, the former continuing for long periods at many localities, long enough to permit accumulation of thick coal seams. At the same time, the distribution of coal is indefinite. In the southern basin within New Mexico, the coal seams are important locally, but they are irregular and there are broad spaces, which are altogether barren. The story is similar in the Uinta Basin; coal seams are very numerous in the Mesaverde, but they are not persistent; portions of the column showing workable seams in one district are apparently without trace of coal in others. The features are the same in the Green River Basin; an extensive coal field in Sweetwater County of Wyoming has many lenses yielding coal of excellent quality, but at the same horizons in other counties there is either no coal or the seams are mere streaks. Farther east, the sandstones thin away and all traces of coal disappear. Elsewhere in Wyoming the distribution of coal is certainly capricious; here and there one finds a seam thick enough to be digged for local supply, but such exposures are separated by intervals of many miles. In Montana, coal occurs only in scattered spots, while the intervening spaces seem to be barren. Seams of workable coal are more numerous in Alberta and the lenses are larger; conditions favorable to coal accumulation existed in a large area. But there, as in the United States, the sandy coal-bearing formation thinned away toward the east and was replaced with shale, in which no coal is known.

The sandy deposits, containing Benton coals, reach only to the 109th meridian, aside from an isolated deposit in Colorado near the 108th. The most westerly localities at which coal has been found are in southwestern Utah, where the conditions are not in accord with the assertion that coal is present only in association with prevailingly coarse materials. In those fragmentary fields, the rocks are, in very large part, clays, clay shales and limestones, the last serving occasionally as roof or floor to coal seams. The area must have embraced not less than 2,000 square miles and its surface must have been a broad mud flat during formation of the coal seams. It was little above the sea-level. At 50 miles farther east, the conditions are wholly different, for there the coals are associated with sandy deposits, as they are farther north. The relations appear to give support to Gilbert's suggestion, offered more than 40 years ago, that the Wasatch Mountains were the source whence the sediments were derived. In that case, the conditions would be normal, for the sluggish streams, carrying only fine materials, would build up merely a mud flood plain, such as one sees at localities along the Atlantic coast, on which peat deposits are accumulating. The deposits are largely sandstone in northeastern Arizona, where they contain 3 coal seams near the base. Benton rocks in the southern part of the San Juan Basin have about 66 per cent. of sandstone and have 3 coal seams; but the sandstone decreases northwardly and the coal disappears. The condition is similar in the northern or main portion of the basin.

The Ferron sandstone of Castle Valley, Utah, at eastern base of the Wasatch Mountains, contains many and irregular coal seams, of which some are locally important; but these are confined to the southern part of the valley, where the sandstone is several hundred feet thick; no trace of them remains in the northern portion, where the sandstone has become thin. The Frontier sandstone contains several seams, yielding excellent coal, in Uinta County of Wyoming, but farther east the sandstone becomes thin and the coal disappears. The Bear River formation, of fresh-water origin, has numerous coal seams but it thins away rapidly toward the east.

The Kootenai has no coal in the southern portions, the first appearance being in the Black Hills region of northeastern Wyoming; there and in the Bighorn Basin of the same state the rocks are chiefly sandstone and contain patches of coal, which are sources for local supply; but they are far apart in Wyoming as well as in Montana, there being coal in only an insignificant part of the exposed area. In Alberta and the adjacent portion of British Columbia, the individual seams cover greater areas than in any part of the

United States and the quantity of coal in some fields is enormous, there being 198 feet in the Alberta section of the Crowsnest field. But the formation thins eastwardly and it has not been recognized in Manitoba.

The distribution of coal in the several formations of the Cretaceous is wholly similar to that of peat deposits on coastal plains.

2. *Structure and Other Characteristics of the Accompanying Rocks.*—Information respecting these topics is lacking for many districts but details given by observers in many others are all in accord and are sufficient.

The Wealden sandstones of England contain driftwood and often have rippled surfaces; the shales have sun cracks, while limestone slabs, in many cases, are rippled and are marked by trails. Stems of trees, replaced with silica or oxide of iron, abound in the rocks between coal seams. Grains of coal are in Wealden sandstones of Westphalia. The Upper Cretaceous of Borneo and Queensland has grains of coal in the sandstones. In Queensland, sun cracks, worm burrows and trails are notable features of the sandstones, which are cross-bedded at many places. Fragments of tree stems, usually silicified, characterize the sandstones of Queensland, New Zealand and Greenland.

Many observers report that the Laramie deposits in Colorado and Wyoming are extremely irregular, sandstones and shales being lenses. In Montana, the sandstones assigned to this formation are often cross-bedded, rippled and contain fossil wood. The Fox Hills sandstones are much cross-bedded in parts of Colorado and Montana. Fossil wood is reported from one locality in southern Colorado, where cross-bedding is not uncommon.

The Pierre sandstones show cross-bedded layers in the Cerillos field, where some of the beds are locally conglomeratic. Cross-bedded and rippled sandstones are in the southwestern part of the San Juan Basin, and petrified stumps and logs abound at at least one locality on the eastern border of the basin. In the Grand Mesa portion of the Uinta Basin, the sandstones and shales are so irregular in distribution that many times sections, separated by only a short interval, are unlike; cross-bedding in sandstones was observed frequently. Within Montana, the sandstones of Electric and Livingston fields are much cross-bedded, while in Cleveland and Big Sandy fields, rippled surfaces were observed and the shales and sandstones are in rude lenses. So also in the Milk River field where all deposits are lens-like and the sandstones are cross-bedded. In Teton County, the Two-Medicine formation is characterized by great irregularity of the deposits and fossil wood abounds; the Virgelle (Lower Eagle) sandstone is coarse and cross-bedded. The conditions in Alberta are similar; the Belly River sandstones have been described as cross-bedded, rippled and marked by trails; the same features were observed farther north on Pine River.

The Benton in New Mexico, has, near the base, the Tres Hermanos sandstone, cross-bedded, rippled and locally conglomeratic, which persists to the northeastern corner of the San Juan Basin. Similar features are recorded in the southwestern part of that basin as well as from localities in the Uinta Basin. The Dakota is usually more or less cross-bedded and holds local conglomerates. The Kootenai of New Mexico is cross-bedded and locally conglomeratic; it is rippled, cross-bedded, locally conglomeratic in the Black Hills, where petrified wood, chiefly cycads, is abundant. The conditions are similar in Montana, while in Alberta the same features were observed at many localities.

These features, characterizing the rocks of the several formations, indicate deposition in, at most, shallow water, as well as subsequent exposure to subaërial conditions. The rippling and cross-bedding were due to water movements in probably most cases, but it is possible that there has been too great readiness to accept this mode of origin as almost universally applicable. The writer has observed the ripple marks in rocks of several formations and has compared them with wind ripples seen by him in the sandy areas in the western states and in Russia and Prussia, as well as on broad river benches. The resemblance to fossil ripples, seen in many beds, is so great that the mode of origin must be the same for both. It may be also that some of the "cross-bedding" was due to wind action. The complex structure shown in many diagrams is precisely that of the æolian limestone of Bermuda and observable more or less distinctly in many dunes; the "current bedding" is clearly due to stream action. The presence of tree stumps and logs is evidence of shallow water and suggests the action of floods, which dropped their load on the broad surface, which was exposed during the intervals between floods.

3. *The Form of Coal Deposits.*—Cretaceous coal seams are lenses. No statement to this effect occurs in any of the older works, as nearly all students, prior to less than 25 years ago, held in a somewhat hazy way, that coal seams are continuous deposits. Comparison of sections in all fields proves that this conception was erroneous. The Wealden coals of Hannover are local, present in one section, absent in others, and in all cases they have small areal extent. There is a rather persistent coal horizon at the base, which seems to be made up of overlapping lenses. The Lower Quader has only nests of coal, which occasionally become workable; the Hungarian coals are well-defined lenses as are those of Queensland; and the detailed studies in New Zealand have proved lens form in the great seams.

The condition in North America is so marked that it has been noted by the great majority of observers during later years. Occasionally, a seam has an area so extensive that the describer is unwilling to commit himself as to the form. But it must be remembered that, even though the lenses have an area of hundreds or thousands of square miles, the general features are the same with those of smaller lenses, united by transgression to form the large one.

The Laramie coals are in lenses, usually small and thin within the United States; the great bed of the Saskatchewan in Alberta becomes only a thin deposit of carbonaceous shale in its southern extension. The Fox Hills seams are lenses, usually thin or impure, but locally important and workable in considerable areas. This feature is noteworthy in all districts along the eastern base of the Front Ranges in New Mexico, as well as the southern tier of counties of Wyoming. The Middle Pierre (Mesaverde) is probably the most productive formation with usually one or more workable seams; but its seams are like those of the newer formations. They are variable and uncertain in New Mexico; in the Uinta Basin, west from Grand River, portions of the section, containing workable coals in one district, are wholly barren in others; east from that river the coals are local, important here, unimportant or absent elsewhere; the Mesaverde coals of Green River Basin attain commercial importance in only one county; in Montana the lenses are usually small and thin; in Alberta, the coals are present in a great area, and often workable, but available details merely suggest, they do not prove that the seams are lenses.

Benton coals are present in only a small part of the Cretaceous area, but, wherever they have been studied, the lens form is characteristic. In southwestern Utah, in Castle Valley of that state, in Gunnison Valley of Colorado and in Uinta County of Wyoming, they are distinctly lenticular. The Dakota coals are merely insignificant lenses. The Kootenai is without coal south from northern Wyoming. There, within the Black Hills districts, coal lenses of typical form are present but they are all small, nowhere embracing more than a score of square miles. An occasional lens has been found in the Bighorn Basin. The lenses are few and unimportant in southwestern Montana; they become numerous and some attain workable thickness in Lewistown and Great Falls fields; but in Teton County, on the northern border, there are only insignificant nests. In Alberta, on the contrary, as well as in the adjacent part of British Columbia, the seams are numerous and the quantity of coal is enormous. Comparison of sections leaves no room for doubt respecting the lenticular form of the seams.

The lenses ordinarily show increase of foreign matters toward the borders, the coal is broken by fine partings and very often it becomes at last merely carbonaceous shale with laminæ of coal. Sometimes the lenses are connected by a stretch of black shale, but commonly no such bond exists and a barren space intervenes. These lenses, great and small, are similar to peat deposits on broad river plains and even more strikingly to those on coastal plains; at times, these are separated by broad spaces, forested; at others they are united by carbonaceous muds, while at still others, the peat of several lenses has become continuous by transgression.

4. *Contemporaneous Erosion.*—The effects of contemporaneous erosion are conspicuous. The curious intermingling of coal and débris, observed at one locality in the Loewenberg area of Silesia, seems to be explicable only by the supposition that it represents a washed out swamp. The presence of coal grains in sandstone may

signify that a coal seam in process of formation was exposed. Local conglomerates in many sandstones occupy the channelways of rapid streams; local unconformities between sandstone and shale suggest changes in direction of drainage. The coal seams themselves appear to have been subjected to subaërial erosion and to have been traversed by streams as in modern swamps. "Horsebacks" or "rolls" of the roof have been found wherever extensive mining operations have been carried on. They mark channel ways of varying width and depth, now filled with material like that of an overlying deposit; sometimes the material is the same with that forming the immediate roof, in which case the stream was probably contemporaneous with the bog; but not infrequently the channelway was excavated after the roof had been deposited. The conditions are commonplaces in modern deposits.

5. *Soils of Vegetation.*—Reports on areas of Cretaceous coal in North America give few instances where soils of vegetation have been observed in the rocks between coal seams. One must not forget, in this connection, that, generally speaking, observers have been compelled to depend on natural exposures, which are imperfect, and that the work has been done at cost of much personal discomfort. But the few illustrations available show that the condition is less rare than the record shows. A dense growth of *Sphenopteris,* in place, has been reported from the Wealden of England and a similar growth of *Equisetum* from that of Hannover. A grove of large trees exists in the Upper Cretaceous of Queensland, clearly in place of growth, where they were buried by drifting sand; an ancient soil in New Zealand contains roots in place. The Upper Cretaceous of Greenland has bands with ferns, conifers, dicotyledons, erect stumps and silicified wood. An old soil was seen on Pine River of Alberta in the Lower Kootenai, which contains erect stems, evidently in the place of growth.

6. *The Roof of Coal Beds.*—Coal seams may have shale, clay, sandstone, or limestone as the roof. In parts of some mines one finds shale as roof in one part, but sandstone in others; the variation being due, apparently, to local removal of the shale during or prior to deposition of the sandstone. It may be marine limestone or a detrital deposit containing marine fossils. Occasionally, a parting

of marine limestone serves as roof to one bench and as floor to the other. These limestones are thin but they are proof of submergence, due perhaps to change in course of drainage or to the breaking away of a barrier, which protected the swamp from sea-invasion, a by no means rare phenomenon on the New England coast. The roof is apt to be irregular.

7. *The Coal Seams.*—Where succession is undisturbed and deposition appears to have been continuous, the roof material ordinarily becomes more and more carbonaceous at the base and passes gradually into bone or into impure coal, with normal structure, a faux-toit. But the transition is abrupt in many cases where no evidence of disturbance by erosion is apparent; a condition which leads to the suggestion that a suddenly increased influx of mud or fine sand ended the bog's existence. In such cases the contact between coal and roof is irregular, defining the bog surface.

Accumulation of vegetable material was rarely continuous during long periods, though there are seams several feet thick, which are said to be unbroken by partings of any sort. Commonly, however, coal seams are divided into benches by partings of mineral charcoal, clay, sand or limestone, which indicate longer or shorter periods of interruption. In many cases, this interruption was not complete and the parting consists of bone or bony coal, at times closely resembling cannel; but when the parting consists of inorganic matter, it is proof of at least local cessation. The thickness of partings usually varies within narrow limits, but in some cases it is so great as to attract the attention of even a casual observer. Cžjžek notes the thinning away of a considerable interval and the consequent union of two important seams, with increased thickness of coal. In the Denver Basin, one parting increases from a mere film to 25 feet within a few miles; the partings in the Carbonero seam of the San Juan Basin thicken in one direction, so that the great bed, 100 feet thick, becomes three, with thicknesses of 7, 30 and 15 feet respectively, in a vertical space of 200 feet. Taff describes a parting, which increases from zero to 16 feet within 2,000 feet, the exposures being complete in one mine. The Trinidad seam, 11 feet thick near Trinidad, Colorado, becomes 58 feet within 3 miles by thickening of the partings. Lee has given details making almost certain that

7 coal seams, wholly distinct and separated by thick intervals, unite within 4 miles into one, 42 feet thick. Partings contain fossils; in southwestern Utah, Lee saw a limestone parting with brackish-water forms; at another locality a seam with marine limestone as roof and floor has a parting with fresh-water fossils. Clay partings frequently have remains of plants.

Benches of coal beds seams often differ so much as to make certain that conditions were not the same during the several periods of accumulation. One bench may yield caking, and another may consist of non-caking coal; in one, the ash may be unimportant while another may be so dirty as to be worthless; one may thin away to disappearance while others overlap it. Details respecting the benches are given only for districts where mining operations are on large scale, but enough is known to justify the old method of regarding benches as separate coal seams.

In a general way, Cretaceous coals vary from massive to laminated, the latter with alternating bright and dull laminæ—and these types are found throughout the whole section. Ordinarily, woody structure is not apparent to the naked eye, but it is distinct in many places. The Upper Cretaceous coal of Silesia is xyloid; a seam of Moorkohle is near Mährens-Trubau; the coal of the Boulder District is almost as xyloid as the Eocene coals of the Dakotas; it contains logs, carbonized, jetified or silicified. Most of the Wealden coal in Hannover is black and apparently without woody structure, but in the same section with the black coal one finds lignitic brown coal and even Blätterkohle, the latter being an accumulation of leaves and not related to the Blätterkohle of the lower Rhine region.

Few notes are available respecting microscopic structure of Cretaceous coals. v. Gümbel[145] studied only jet from Raschwitz in Silesia and coal from the Wealden of Hannover. Woody structure is well-preserved in the former; the latter contains numerous remains of leaves with clumps of wood cells and bark parenchyma, all easily recognized. Thiessen[146] examined coal from the Denver Basin, probably Fox Hills. So close is the resemblance to that

[145] C. W. v. Gümbel, *Sitzb. bay. Akad. Wiss.*, 1883, Math.-Phys. Kl. I., pp. 157, 160.

[146] R. Thiessen, "The Origin of Coal," pp. 241–245.

from the Eocene of Montana and Dakota that he believes the general conditions during accumulation were similar. Woody parts are more compressed in the older coal, but the canals of wood fibers are well shown and appear to be filled with resin. Resins form a large part of the mass, while spores and pollen exines compose not more than 5 to 10 per cent.; the "fundamental matrix" or binding material is derived, as in lignite, from cellulosic substances; all gradations are present from fibers to a homogeneous mass. The fibers are mostly xylum elements of plants, but whether of trees, shrubs or herbs is not always determinable.

8. *The Floor of Coal Seams.*—The floor may be clay, sandy or clayey shale, sandstone or limestone. Occasionally the transition from coal to floor seems to be abrupt, but in most cases there is a faux-mur. Even where this seems to be wanting, the basal part of the coal is, in most cases, higher in ash than that above; frequently the faux-mur is bone and occasionally it resembles the "coarse coal" of the Carboniferous. Limestone floors have been reported only from southwestern Utah, where they contain marine fossils. Bulging floors have been reported from many localities. They are due in some instances to irregularity of the surface on which the coal accumulated; in the Boulder District, petty swales were numerous, in which accumulation began and afterward crossed the low divides—after the manner so familiar in recent peat deposits. But "rolls" in the floor often mark the courses of streams crossing the swamp in its earlier stages.

American reports contain few references to the presence of roots in the floor; two notes have been given for the Trinidad-Raton area and D. White recognized characteristic underclays with roots in the Boulder District. But the scantiness of references in detailed reports indicates merely that the reporter did not look for the roots; Lesquereux,[147] long ago, asserted that most of the underclays are full of roots or rootlets. He visited exposures in the Raton Mountains, Canyon City, Golden, Marshall in Colorado and Black Buttes in Wyoming; at most localities, he found the shale containing such abundance of roots that these seemed to be a compact mass.

[147] L. Lesquereux, "On Formation of the Lignite Beds of the Rocky Mountains," *Amer. Journ. Sci.*, Vol. VII., 1874, p. 30.

The presence of roots in the floor is apparently the ordinary condition in much of Europe. Rzehak[148] says that the Wealden coals of Hannover are distinctly autochthonous, there being root-stocks in most of the underclays. Grand' Eury[149] states that he had found roots in the floor of Cretaceous coal at many places. At la Liguisse and les Gardies in the Causses there are many roots in place under the seam mined there. The Middle Cretaceous at St. Paulet shows roots in the marly mur of some coal seams; these he says are in place for some of them cross leaves of dicotyledons lying flat in the rock. In his later paper, he reports that, at Sarladais, roots in the mur give rise to stems. Similar conditions were seen in the Upper Cretaceous at Valdonne.

9. *The Fauna.*—Fresh-water forms predominate in the Laramie, the Judith River, the Bear River and occur occasionally in other formations; but for the most part the Cretaceous fauna is marine. Discussion of the faunas as such has no place here, but reference to some features is necessary.

The Lower Colorado fauna is characteristic throughout the whole region from western Utah to the eastern border; it is present in the limestone roof and floor of coal seams as well as in the occompanying shales and in the coal-bearing sandstones of Utah. The Pierre fauna abounds in the fine shales and occasional limestones, but it abounds equally in the Middle Pierre (Mesaverde) sandstones of New Mexico, where it is found in profusion at several horizons. The fauna is practically the same, be the rock sandstone or shale. The depth of water in western Utah was not great, for coal beds are numerous, one of them having a parting with fresh-water mollusks, though the roof and floor are marine limestone. The character of the rock and the numerous coal seams make the condition equally clear for the Mesaverde of New Mexico. The marine faunas give no support to the opinion that deep-sea conditions existed anywhere, but they make probable that the body of water, covering at times the greatest part of the Cretaceous area, was a very shallow sea. Fineness of sediments, in general, may be taken as indicating distance from the source of supply.

148 A. Rzehak, *Zeitsch. f. pr. Geologie,* Vol. XXII., 1914, p. 8.

149 C. Grand' Eury, Autun, 1902, p. 127; *C. R.,* t. CXXXVIII., 1904. 669, 741.

10. *The Flora.*—The Cretaceous coals are usually so far advanced in conversion as to give little information respecting the plants by which they were formed. Knowledge of the flora of the period is derived from fragmentary material found in the rocks; that has been transported, it represents mostly the upland vegetation and tells nothing about the swamp plants. In the United States and Canada, the coals are often rich in resins, indicating that conifers entered largely into their composition; such wood as has been recognized seems to confirm this conclusion. Cycads were abundant locally during the Kootenai but conifers and dicotyledons were predominant during the Upper Cretaceous, when ferns and lycopods appear to have been subordinate. Memoirs on European coals, consulted by the writer, usually contain little information upon the subject. Wood, fully recognizable, is present in the Upper Cretaceous coal of the Loewenberg region, but in the Grünbach coal, no structure is shown, though the stems and branches retain their form. The Wealden of Hannover contains abundance of conifers, cycads, lycopods and ferns; the plant remains in coal must be distinct there. Dunker thinks that the "black coal" of that region was derived from lycopods and ferns, because they are the only forms found in it; the lignitic brown coal is largely of conifer origin, as the stems occurring in it resemble *Pinus*.

11. *Chemical Relations.*—Discussion of the chemical relations of Cretaceous coals must be deferred until the older coals have been studied; but it may be well to call attention to some matters.

Like the Tertiary coals and some peats, these coals are resinous in many districts. Cannel is present at several horizons, with all features which mark the sapropels or Lebertorfs of later times. The carbon content is higher than that of Tertiary coals, but progressive enrichment with increasing age is less marked. In the Fox Hills the extremes of carbon are 73 and 84; in the Pierre, 71 and 84; in the Benton, 77 and 83, and in the Kootenai, 75 and 85. No note has been taken here of metamorphosed coals; anthracite is present at several horizons. No ultimate analyses of the Laramie coal are available and there are very few of the Kootenai. The variations are small compared with those in the Tertiary. In the Cretaceous as in the Tertiary, not all accumulations of vegetable materials had attained the same degree of enrichment before burial; the minimum of the Pierre rarely falls below 75, but there are seams with only 71 or 72. The condition is well marked in Hannover, where the "black coal" has 89 per cent. of carbon, the brown coal, 73, while the Blätterkohle is almost unchanged—the several types occurring in the same vertical section.

THE NAMES TROYAN AND BOYAN IN OLD RUSSIAN.

By J. DYNELEY PRINCE.

(*Read April 14, 1917.*)

The famous old Russian epic "The Tale of the Armament of Igor" (1185 A. D.), relating in striking form the exploits of the hosts of the ancient Russian Prince Igor Svyatoslávič, has been ably edited and translated by Leonard A. Magnus, LL.B. (Oxford University Press, 1915). The majority of the allusions in this poem are more or less clear historically, but the obscure references to Troyan and Boyan have been a matter of scientific discussion for over a century. The following brief exposition of this question may perhaps throw some additional light on the problem.

There are four references in the Igor-text to Troyan (cited by Magnus, p. xlix):

1. In the invocation to Boyan (lines 59 ff.), stating how Boyan might have sung on the subject treated by the author of the Igor epic:

O Bóyane soloviju starogo vremeni[1]	O Boyan, nightingale of ancient times,
aby ty sia polki uščekotal	had'st thou but warbled these hosts,
skača slaviyu po myslenu drevu	leaping, O nightingale, through the tree of thought,
letaya umom pod oblaki	flying in mind beneath the clouds,
svivaya slavy oba	interweaving the glories of both
poly sego vremeni	halves of this time,
rišča v tropu Troyanyu	rushing on the path of Troyan
čres pola ná gory	through the plains to the hills!

2. A reference to past events in connection with Troyan, lines 209 ff.:

Byli věči (or *sěči*) *Tróyani*	There have been the ages (or battles) of Troyan;
minula lětá Yaróslavlya	past are the years of Yaroslav;
byli polci Ól' govy	there have been the armies of Oleg.

[1] The system of transliteration herein adopted is based on the Croatian method, save that the Old Russian hard sign is indicated by ', and the soft sign by '.

3. Reference to the land of Troyan, lines 288 ff.:

V'zstala obida	Arose scandal
v silach Daž"boga vnuka	in the forces of Dažbog's offspring;
vstupila děvoyu	stepped like a maiden
na zémlyu Tróyanyu	on the land of Troyan.

4. Allusion to the period of Troyan, lines 569 ff.:

Na sed'móm věčě Tróyani	In the seventh age of Troyan,
vr'že Vsesláv zrebĭi	Vseslav cast lot
o děvicyu sebě lyubu	for a maiden dear to him.

It seems clear from the above four allusions that "Troyan" was used as the name of a country, thus: (1) the path of T. = the historical course of T.; (2—4) the "ages," probably not "battles" of T.; (3) land of T.; which settles the geographical sense. It is impossible to imagine that Troyan was a person from the above allusions.[2]

That the author of the Igor-Slovo[3] meant his own country "Russia" by "Troyan" seems quite evident, and this view has been advanced by many authorities, among them Magnus himself (op. cit., p. xlix), who notes, in connection with allusion No. 4 (see above), that there were just seven generations between the Scandinavian Rurik (Hrörekr), the founder of the first Russian dynasty, and the prince Vseslav herein mentioned. Such a deduction is comparatively easy, so far as the historical application of the term "Troyan" is concerned, but the problem as to the actual meaning of the term, apart from its application in the Slovo, is much more involved. Magnus (op. cit., pp. l–liii) cites five of the most generally held views, viz., (1) Troyan indicates some district outside of Russia; a view held only by few scholars; (2) Weltmann's opinion that "Troyan" should be read *Krayan* "borderland;" (3) "Troyan" is derived from the Roman emperor's name Trajan;

[2] The idea that Troyan was a divine person seems to have prevailed only in some of the later Slavonic myths (Louis Leger, "Mythologie Slave," p. 125), but this is probably an association with the Emperor Trajan, and not with the evidently geographical Troyan of the Slovo.

[3] The full title is: *Slovo o p'lku Igorevě, Igorya Svyat'slavliča vnuka,* "Narrative of the Expedition of Igor, of Igor son of Svyatoslav," grandson of Oleg.

(4) Troyan = Trojan, embodying the Russian tradition of Homer; and (5) Troyan was the transferred name of an ancient Slavonic pagan deity.[2]

Discussing these theories briefly, it should be noted that there is no evidence that the Troyan of our Slovo was other than a poetical name for Russia in its application by the poet. The fact that there is to-day a place called Troyan in Bulgaria and a Troyan near Smolensk, etc., is no proof that these localities are named from the same stem as the Troyan of the Slovo, which distinctly includes all the Russia of that day. Furthermore, the change of text, suggested by Weltmann, may be summarily dismissed as being too arbitrary (thus, also Magnus, p. 1).

It is highly likely that we have in the name "Troyan" a mixture of philological traditions, *i. e.,* that it is a combination-reproduction of the Roman "Trajan" and the Greek "Trojan," both which opinions are indicated above. In this supposed compound tradition, the Greek element must be regarded as predominating. Magnus cites (p. 1, from Sederholm) a *bylina*[4] of the reign of Catherine II., in which there is a direct allusion to the road of the emperor Trajan (*na doróge na Trayánovoï*), containing the *a* vowel (cf. also Magnus, loc. cit. on the miracle of Pope Clement), but the forms *Troyan tsar' Yermalanskiï* (=*rimlyanskiï* "Roman") occur in south Russian documents, and, moreover, there are other evidences of the Trajan tradition in northern and eastern Slavonic lore. This fact, in itself, is not sufficient, however, to account for the evident use of "Troyan," to indicate ancient Russia. Magnus holds (p. 1) that "Troyan" is derived from the numeral three (*tróye*), referring to the three Scandinavian brothers Rurik, Sineus and Truvor,[5] who founded Russia (Nestor 6370). Such an idea seems rather far-fetched, as Troyan is often used as a nickname for the third son, similarly to Latin *Tertius, Decimus,* etc. But there is

[4] The term *bylína* indicates the Russian folk-tale, of which thousands are still in existence, usually in rude meter. These productions are nearly always intoned in chant-form (Rimsky-Kórsakov, "Chants Nationaux Russes," Part 1, 1876).

[5] The names Rurik and Truvor are Slavonianisms, respectively, from Old Norse Hrörekr and Thorvardr (guardian of the gate). Many Old Russian names are pure Scandinavian (cf. Magnus, p. viii).

no historical evidence that Rurik was the third brother of the triad. In fact, in the legend, he always occupies the first place.[6]

It is much more probable that we have in the "Troyan" of the Slovo no distinctive Slavonic legend at all, but rather, as already indicated, the mixed tradition of the Roman "Trajan" and the Hellenic Homer. To this Magnus objects that the "landlocked state of mediæval Russia" could hardly have imported very much of this (Greek) tradition, as the road to Constantinople was blocked by Pólovtsi and Bulgars, and the Catholic powers of the northwest were all hostile. Magnus forgets, however, that the inherent tradition of the early Russian church was essentially Greek. Early metropolitans of Kiev, down to the period of the Mongol invasion, were usually Greeks who had been consecrated at Constantinople. The first important Russian metropolitan, who established the essentially Russian character of the church and nations, was St. Peter (1308–1328) of Vladímir. It is highly interesting in this connection to note that, in the first half of the twelfth century, a Russian writer excused himself before his sovereign for *not* having studied Homer, when he was young! The Chronicler of Volhynia (1232) cites a verse attributed to Homer, which has not been retained in our current version. Literate Russians of this period were evidently familiar with the tale of the Trojan war through the works of Tryphiodore, Kolouthos, etc. (Rambaud, "La Russie Épique," p. 408).

It is well known from Russian records that the father of Monomákh, Vsévolod, who had never been in foreign lands, knew no less than five languages. In the Slovo itself (lines 353–4) we read: *tu greci i moráva poyût slavu Svyatóslawlyu* "here the Greeks and Moravians sing the glory of Svyatoslav," showing that the author knew something about the Greeks.

In connection with the work of the Columbia University Slavonic Department, Dr. Clarence A. Manning has collected a number of possible Homeric and other Greek parallels with the Slovo, which show a very decided Hellenic influence on the formation of this poem;

[6] Note that in the year 862, Rurik as leader of the Variags (Varangians) was invited to defend the northern Russian princes.

they are incorporated herewith together with Dr. Manning's comments, as throwing an interesting light on the problem.

Slovo, 11: "as a gray wolf" = Il., x, 334: πολιὸς λύκος. Slovo 12: "as a dusky eagle" = Il., xxi, 252: αἰετοῦ-μέλανος.

Manning compares also the passage already cited above of the invocation of the poet Boyan, with Euripides, Helena, 1107 ff.: "thee who hast a tuneful seat in the leafy halls, thee I invoke, thee, most musical bird, mournful nightingale, come, O associate of my laments, trilling through thy tawny throat," etc. The resemblance between this passage and the Igor-lines is very striking, although, as Manning points out, it is doubtful whether Euripides was actually invoking Homer.

Slovo, 74: "offspring of Veles" (the ancient Slavonic cattle god); Theocritus, xxiv, 105, states that Linus, a mythical poet, was the son of Apollo. Slovo, 84: "swift horses" = Il., viii, 88; θοαὶ ἵπποι.

Slovo, 175: "the winds, scions of Stríbog" = Odyss., x, 1 ff.: "the winds, the sons of Æolus."

Slovo, 186–189: "the mad children blocked the fields with their shouting, but the brave Russians barred them with their crimsoned shields." With this, cf. Slovo, 435: "for these without shields with hunting-knives conquer the hosts by their shouting," and contrast Il., iii, 2–9: "The Trojans went with a shout and cry like birds, like the cry of cranes against the sky."

Slovo, 224: "To the Judgment Seat" (*na sud*); probably of Christian origin.

Slovo, 238: "(Russia) the scion of Dažbog"[7] seems to point to the Russians being a chosen people; an idea probably of Biblical origin, through the Biblical Greek.

Slovo, 374: "in my golden-roofed hall;" clearly a translation of the Byzantine χρῃσοκέραμος.

Slovo, 479: "On thy gold forged throne;" cf. Euripides, Phoen., 220: χρυσότευκτος.

[7] Dažbog, the rain or storm god, was probably the Russian equivalent of the Scandinavian Thor, who was the patron of the warlike Scandinavian founders of Russia (see above, note 5).

[8] The meaning of these lines is very obscure.

Slovo, 546–548: "the birds, O Prince, have been covering thy host with their wings and the wild beasts have been licking at their blood;" cf. Il., I., 4–5: "they made them a spoil for the dogs, a feast for the birds of prey."

In the Greek legend, Achilles was early associated with the Euxine and especially with the island of Leuke at the mouth of the Danube. Here he lived after death with Helen as his consort, along with other heroes. Leonymos of Croton was the first to sail thither to be cured of his wound by Ajax, and Helen told him to go to Stesichoros and say that she was angry at him for making her, in his poetry, elope with Paris (Pausanias, III., 19, 11–13); cf. Eurip. Andr., 1260 ff. Further east at the mouth of the Borysthenes (Dniepr), there was another island sacred to Achilles (Ἀχιλλήϊος δρόμος) mentioned by Herod, iv, 53; Strabo, vii, 307. Achilles also had a temple at Olbia (Dio. Chrys., xxxvi, 439 ff.). Furthermore, in the Crimea, there was a temple in which Iphigenia, daughter of Agamemnon, was placed by Artemis as priestess with the duty of sacrificing strangers (Her., iv, 103; Pausanias, I., 43, 1). This may have been connected with the account of the Scythian snake goddess (Her., iv, 9). We should note also that the maiden was one of the most important deities in the Chersonese (Minus, Greeks and Scythians, p. 543). She is probably identical with the Děvica, Slovo, 571. Helen is the symbol of discord also in the systems of St. Irenæus and the Gnostics (Rambaud, op. cit., p. 413).

There is every probability that Obida "discord" and Děvica "the maiden" of the Slovo represent the legend of Helen, child of the swan. Such legends could easily have been carried in a Byzantine form to the Russians by the ecclesiastics, in spite of their "landlocked" state in this early period, for the church was already there, as amply demonstrated in the Slovo. The objection that some aspects of this legend may have been inherent among the Slavonic tribes on the north shore of the Black Sea, and that the Greeks themselves may have borrowed some of their material, does not carry much weight, as the Slovo indications are too markedly Hellenic to admit of such a view.

The question remains to be solved, as to why the early Russians applied the term "Trojan" = "Troyan" to their own country and people. This use must have been suggested by the similarly sounding name Boyan, the legendary Slavonic poet, whose name appears only in the Igor-Slovo and there only six times (cf. Magnus, op. cit., xlvi). The allusions are as follows:

(1) Line 6: *po zamýšleniÿu Bóyanyu*	"according to the invention of Boyan."
(2) Lines 8 ff.: *Boyan bo věščiï ašče komu*	*chotyaše pěsn' tvoriti,* etc. Boyan, the seer, when for anyone he wished to make a song, etc.

(3) Lines 59–66: See above under the allusions to Troyan (1), where Boyan is described as "rushing on the path of Troyan."

(4) Line 74: *Veščeï Bóyane Vélesov vnuče*	O Wizard Boyan, scion of Veles!
(5) Lines 605–611: *Tomu věščeï (Bóyane)* *i pervoe pripěvku* *smyšleny reče:* *ni pticyu ni gub'cyu*[8] *ni pticyu ni gub'cyu*[8] *suda Božiya ne minuti*	To him, O seer Boyan, the first refrain with thought thou didst speak: neither the crafty one, nor the experienced, nor a bird, nor a minstrel(?) can escape God's judgment.
(6) Lines 745–747: *Reče Boyan i chody* *Svyat'slavy na Kogana:* *pěsnotvor"c az starago vremeni*	Boyan has told of the raids of Svyatoslav against the Kogan: the songmaker am I of olden time.

Magnus (pp. xlvi ff.) gives the chief opinions regarding Boyan; viz., (1) that Boyan is a common Bulgarian name, citing the quotation by Paucker of tales of a Tsarévich Boyan Simenovich. That our Boyan is connected with this legendary being is extremely unlikely, as there is no evidence that this Bulgarian Boyan was a noted poet. In fact, the Bulgarian name is probably an echo of our Boyan. (2) Boyan has been found in some of the later lists of pagan Slavonic deities. This use of Boyan is probably a mere deification of the poet mentioned in the Slovo. (3) Dubenski mentions a hymn of Boyan of Bus, in which the instructor of Boyan gives his name as a descendant of the Slovenes, the son of Zlogor, the long-lived minstrel of ancient tales. This hymn, as Dubenski points out, is of untrustworthy character, but in my opinion it embodies the tradition of the poet Boyan of the Slovo. (4) Magnus follows Weltmann's view, that Boyan is a contraction of some such phrase as *reče bo Yan* "then Yan spake," referring to the Yan mentioned by Nestor, as an aged man of ninety years, from whom the chronicler learned many legends. It is highly unlikely that so persistent a name as Boyan could be the result of such a contraction, as the nature of the particle *bo* was perfectly well known to chroniclers and copyists and it is improbable that it could have appeared in a fortuitous contraction without the knowledge even of an unintelligent copyist or recorder. Magnus seeks to show that the Yan alluded to by Nestor was born in the reign of Vladimir I. (1015 A. D.) and that he was a writer and took an active part in all the events of his day. In this way, he thinks, this Yan might well be described as "rushing on the path of Troyan" = "Russia." But surely no person, even in a life-time, no matter how long, could earn the right to be mentioned as covering the entire history of a nation. And yet this is how our Boyan of the Slovo is treated. Furthermore, there is no evidence that this Yan, although he was a writer, was a bard of such distinction as our Boyan is claimed to be in the above allusions to him in the Slovo, whose writer evidently regards Boyan as the one great poet of the world.

The most characteristic point about Boyan is the statement that he was a seer and, above all, a poet-singer, which naturally suggests the derivation of the name from *bayat'* "speak, relate" (from which we also have *basn'* fable). This is the opinion of Vyázemski and, I believe, the most reasonable theory in view of the apparent impossibility of other derivations of the name. Boyan has been variously derived from *boiti* = *vestí boï* "fight; carry on a fight"; and *boyát'sya* "to fear," neither of which roots seem to agree with the character of Boyan. It is highly probable that the name Boyan was a term deliberately applied to the function of this legendary person rather than a proper name of arbitrary meaning which happened to be the name of a poet. We may assume this to be the case, owing to the undoubted Hellenic influence seen in the Slovo and discussed above under Troyan. The ancient Slavonic world abounded in singers similar to the Celtic bards and the Scandinavian skalds, and, granted a word Boyan-Bayan = "singer, poet, sayer," already existing in the popular language, the author of the Slovo probably introduced the Troyan-epithet, to indicate Russia by assonance with Boyan. Boyan was for the author of the Slovo the poet *par excellence,* who had given the ancient norm of Russian song, the traditions regarding whom are unknown to the modern world. It is highly likely, therefore, that Troyan—having in itself a basis of "Trojan" with a possible superimposition of the later "Trajan" influence—was used for the country, of which the then known Boyan sang, *i. e.,* of Russia. Even if it be supposed that Boyan was Magnus's somewhat dubious Yan, the principle of association remains the same; viz., it was necessary to have behind the Slavonianized Hellenic influence of the Slovo poem some poet-name—and a name in assonance with Troyan would naturally suggest itself—so that, in a sense, our Boyan is really an echo of Homer himself, although perhaps not consciously Homer in the mind of the author of the Slovo. Vyázemski held that Boyan was unequivocally Homer, but it is not necessary to imagine that the ancient author of the Slovo had so direct a tradition, in order to account for the divine Boyan, who is especially made the descendant of the essentially Slavonic Veles, the god of cattle.

SYMPOSIUM ON AËRONAUTICS.

(*Read April 14, 1917.*)

I

DYNAMICAL ASPECTS

By ARTHUR GORDON WEBSTER.

In opening this symposium I can undertake to do no more than explain, in a most elementary way, the dynamical principles upon which artificial flight depends. It is difficult to do this without the use of differential equations, which would be out of place in a popular discussion, so that my treatment must confine itself to the merest outline. We must distinguish at the outset between *aëronautics* properly so-called, in which we have to do with airships, that is apparatus possessing natural sustentation through the buoyancy of the air displaced, which is at least as heavy as the airship, and *aviation*, which is the operation of apparatus that has no natural sustentation or buoyancy, being heavier than the displaced air, and, like a bird, possessing sustentation only when in motion. Unfortunately we have no generic term for the latter apparatus, corresponding to the recently coined French word "*avion*," and we are obliged to make use of the word aëroplane, although the term plane is not always accurate. While the principle of Archimedes, namely that a body is buoyed up with a force equal to the weight of the displaced fluid, this force acting at a point coincident with the center of mass of the fluid displaced, is sufficient for the study of the equilibrium of the airship, totally different principles are involved in connection with the aëroplane.

The first principle that we shall use is that of relative motion of the aëroplane and the air. It will be admitted that the forces involved are the same whether, as in the case of the kite, the object is at rest and the air in motion, or as in the case of the aëroplane the air is at rest and the object in motion in the direction opposite to that of the preceding case. We also notice that in both cases three forces are involved, first, the weight of the object, second, the action of the wind on the plane, and third, the pull of the kite-string or the thrust of the propeller. I may also say that it makes no difference whether the propeller pushes from behind, as in the first aëroplanes, or pulls from in front, as is now usually the case.

Since the time of Newton it has been known that the force of the wind on the plane is proportional to the square of the relative velocity, since it is proportional to the momentum destroyed in a given time, and this is proportional, for a given mass, to its velocity, while the mass arriving is again proportional to the velocity, so that the square is accounted for. Finally the influence of the angle made by the wind with the surface of the plane, the so-called angle of attack, must be known. We may assume that wind blowing tangent to a surface will slide along without exerting any force on it, although the action of the wind in supporting a flag shows that this is not so. But the wing of an aëroplane is made so smooth that for practical purposes we may neglect the tangential drag, and assume that the force is at right angles or normal to the plane. According to Newton, who treated the air like a stream of particles impinging on the plane, the force would have been proportional to

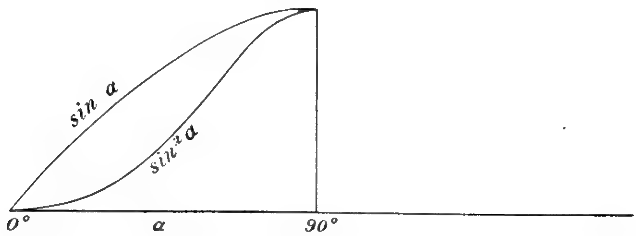


FIG. 1.

the square of the sine of the angle of attack, but we now know through the many series of experiments that have been made by Langley and others, that this law is not correct, and that it is much more nearly proportional to the first power of the sine. The difference is made apparent in Fig. 1, in which the vertical height of a point denotes the force, the horizontal distance the angle of attack of the plane, for both laws. We see that for small angles the sine law gives a much more rapid increase of force than the sine-square, which is a very important point in practice.

Beside the force at right angles to the plane the current tends to turn the plane about a certain axis, as we see if we drop a card with its long dimension horizontal. In falling it turns over and over even if started with its surface horizontal. This turning effect may be explained if we draw the stream-lines, which show at each point the direction of flow of the air. It is a proposition due to Bernoulli, that where the flow is fast the pressure is small, and where it is slow the pressure is great. In Fig. 2 where the

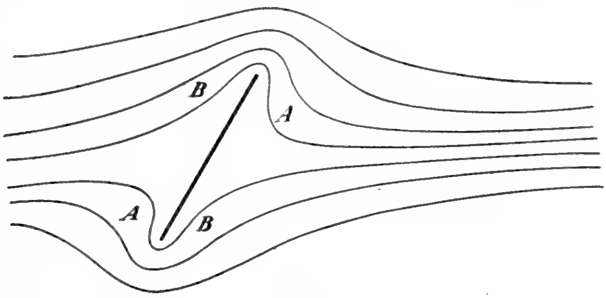


FIG. 2.

stream lines are far apart the flow is slower than where they are near together, just as a river flows most slowly where it is widest, so that the pressure is large in such points as *A, A,* and small at *B, B,* where the flow is rapid. Thus there is a tendency to turn the body in the direction of the arrow. We may express this turning property by saying that the effect of the air current on the plane is represented by a single force *R* applied at a point *P* called the center of pressure, not at the center of the plane, the position of *P* varying according to the angle of attack.

Much mathematical skill has been expended to determine the law of variation of the force with the angle, and the position of the center of pressure. Curiously enough if the air acts like a perfect fluid, and does not form vortices, it can be shown that there would be no force on an obstacle, but merely a turning moment. But if there are surfaces where the motion is discontinuous, on crossing which we pass from fluid that is moving to fluid that is at rest or moving less rapidly, the forces can be accounted for. Kirchhoff many years ago treated such motions, and Sir George Green-hill has followed him in working out a great number of cases with great skill. In Fig. 3 we see the flow past a cambered wing, with stream-lines continuous in Fig. *a,* causing no pressure, and in Fig. *b* with the stream splitting along the dotted line, part going up and

Fig. 3*a*.

part down, with discontinuity along the lines *AB, CD,* between which the fluid is comparatively at rest. From this assumption of the flow it is possible to calculate the thrust and the turning. But even this assumption about the flow is not true in practice, but the air forms vortices, which cause a calculation to be still more

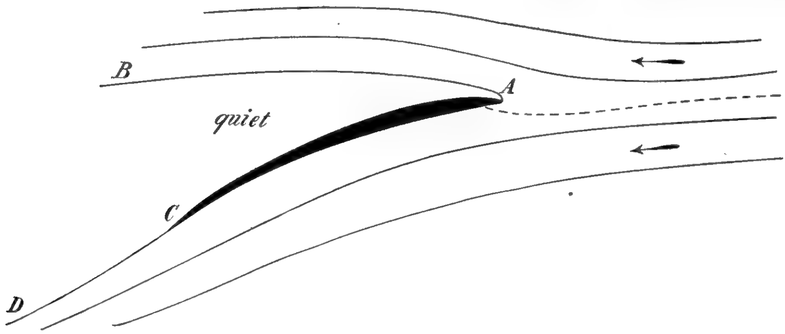


Fig. 3*b*.

difficult. Accordingly it becomes necessary to determine the laws of pressure by actual experiments on small scale models in wind tunnels, such as those of M. Eiffel in Paris, Professor Prandtl in Göttingen, Professor Joukowsky in Moscow, or that at the Massachusetts Institute of Technology used by Mr. Hunsaker in his experiments. In all these cases a steady stream of air is caused to flow through the tunnel by means of a blower, and the model is hung in the wind upon balances which enable the forces, their points of application and direction to be carefully measured for all angles of attack. We may expect in the next few years to see many such wind-tunnels constructed in this country, and large increases made in our experimental knowledge.

Suppose we now know the law of the force exerted by the air current on the plane, and the position of the center of pressure. We have now to apply an elementary principle of equilibrium of rigid bodies. If a body is submitted to the action of three forces the lines of action of these forces must pass through a common point. Thus if we consider a single plane supporting a machine, with the resultant pressure *R*, Fig. 4, with weight *W* concentrated at the center of gravity of the whole machine *G*, the thrust of the propeller *D*, which is nearly horizontal, must pass through the intersection of *R* and *W*. The second principle is that if we draw lines representing by their length and direction the three forces in

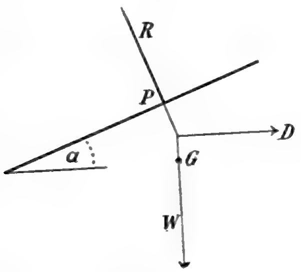


Fig. 4.

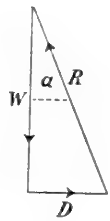


Fig. 5.

question, these lines must form a closed triangle, Fig. 5. Thus knowing the weight *W*, we may find *D*, the thrust required from the motor, as well as *R*, the force required, and a the angle of attack.

I shall illustrate the preceding principles by a very simple experiment, which I think well shows all the leading ideas involved in the dynamics of the aëroplane. I have here a heavy card fastened by a hook at the middle of one side to this rubber cord. I now need a very brave assistant, whom I request to hold the end of the rubber cord at the height of his shoulder. I strongly stretch the cord, holding the card in my hand, both card and string being horizontal. We are thus in a position to perform the Wilhelm Tell experiment, with the apparent probability that, since there are absolutely no upward forces present, the card will cut Walther's head off. On releasing the card you see that no such thing happens, but the card soars several feet above my assistant's head, although the cord is actually pulling down all the time. The reason is that on release the card immediately tips downward behind, and as it goes ahead with great velocity receives more than enough upthrust for its own sustentation, and is actually able to rise, although pulled down by the string.

I come now to perhaps the most important dynamical aspect of aviation, that is the question of stability of flight. Stability of equilibrium is a familiar notion, and exists when a system, if displaced, tends to return to its former position, generally performing small oscillations about it which die away, leaving it in its equilibrium position. Thus a pea at the bottom of a bowl is in stable equilibrium, but on top of a sphere, though in equilibrium, is unstable,

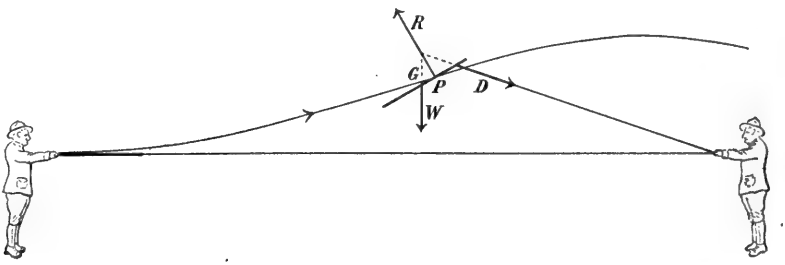


FIG. 6.

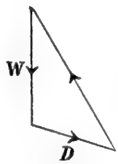


FIG. 6*a*.

because if slightly displaced it will not return, but will roll off. Stability of motion may be similarly defined. If an aëroplane is in flight, and is slightly displaced in position or direction, will it tend to resume its position or will it tend to leave it more and more? Consider what happens when it tips forward and downward. If the center of pressure moves forward when the angle of attack is less it will tend to turn the plane backward, so as to resume its former position. So far then the motion is stable. As it tips forward the angle of attack becomes smaller, the sustaining force becomes less, and the aëroplane sinks, but when tipped back again it rises once more. Thus the path oscillates about a horizontal line. But a rigid body has six ways of moving: forward and back, sidewise right and left, and vertically up and down, making three, together with three ways of turning, rolling about an axis fore and aft, pitching about a transverse axis, and yawing, or turning about the vertical. If any of these six motions are disturbed, how will the motion be affected? It is easily shown that a change in any of these six motions affects all the others, as already shown for pitching and rising. In treating this problem we use differential equations invented by Euler for problems in which we have to do with rotating axes of coördinates, and we are thus able to find the mutual connection of the different sorts of motion. Now if the disturbances are small, we are able to use the method introduced by Lagrange in his famous " Mécanique Analytique " for the treatment of small oscillations, which leads to the introduction of an algebraic equation of degree twice as great as the number of degrees of freedom of the system, in our case six, so that the equation would be of the twelfth degree. On account of symmetry, however, our equation reduces to degree eight, and falls apart into two equations of degree four. It is useless to undertake the general solution of these, but when we have the constants of a given apparatus, as determined by experiment, it is possible to solve the equations arithmetically with any desired degree of approximation. This is what has been done by various investigators, like Bryan and Bairstow in England, and Professor E. B. Wilson here. In fact when this work has proceeded to a certain extent, it is no longer necessary to have recourse to learned mathematicians, but it may be farmed out

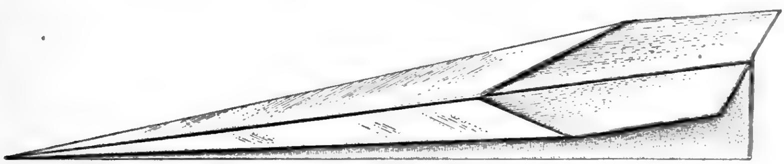


Fig. 7.

to computers, so as to be greatly expedited, and thus the design of machines may be greatly improved. I may say that machines generally gain more stability with greater speed, and that too great stability is not desirable, as it would lead to difficulty in steering or rising. At any rate the theory has now arrived at such a stage that we may hope to avoid such accidents as formerly occurred in great numbers owing to improper design.

I will conclude with a simple experiment showing the intrinsic stability possessed by a very simple aëroplane such as I learned to make when a schoolboy, which I am able to fold from a piece of paper before your eyes and to throw with a good deal of accuracy.

II

PHYSICAL ASPECTS.

THE AIR.

BY GEORGE O. SQUIER.

Everyone knows of course that if there were no atmosphere there could be no life, but probably very few fully realize its immense importance in almost every thing we do. In one condition it is invigorating and gives us a zest for hard work whether mental or physical, in another it leaves us depressed and incapacitated for efficient labor of any kind. Numerous manufacturing processes are radically affected by the amount of moisture in the air, and many others by its temperature. Power is transmitted by it; we communicate our thoughts one to another by vibrations of the air; and by its aid we have recently acquired our swiftest mode of travel. Obviously then a knowledge of the composition and physical properties of the air is of such vital importance as to justify most painstaking study and investigation.

In the past few years, for instance, several elements, helium, argon, neon, krypton, xenon, have been found in the atmosphere that previously were unknown and even unsuspected, for they were not required by the Mendeleeff table of the elements as then understood. One of these, argon, amounts to nearly one part in a hundred of the whole atmosphere, and yet through decade after decade of chemical investigations involving countless thousands of air analyses, it, and all its family of gases, remained undiscovered!

Recently, too, means have been found for drawing directly on the atmosphere for an inexhaustible supply of nitrogen compounds used in the production of powerful explosives, fertilizers and many other things of great value.

Not long ago even the most profound scientists believed that with increase of elevation the temperature of the air decreased more or less uniformly from whatever it was at the surface of the earth to absolute zero at an elevation of perhaps 30 to 40 kilometers. Now we know that this is not true, that at an elevation of only 10 to 12 kilometers at this latitude the temperature becomes substantially constant with respect to increase of altitude, and, what is of even greater intellectual interest, we can explain why it must be so. Only a little while ago no one could say why the clouds never rose higher than certain levels that were far below the known heights of the atmosphere. Now we do know why this is true, as we also know why clouds are more abundant at certain levels and less abundant at others.

We recently have learned how the velocity of the wind generally increases with altitude, and why it so increases. At last, and that quite recently, we have found a logical and experimentally supported theory of the electrification that gives the lightning flash, and with it we have acquired a clearer understanding of the mechanism of the thunderstorm.

These are only some of the comparatively recent discoveries in connection with the phenomena of the atmosphere, and opportunity lies near and inviting for many more.

The genesis of the ordinary cyclonic storm still needs much study and discussion. The relation of topography, nature of the surface, sunshine, etc., to air movements, both horizontal and vertical, need to be intensively studied because of their importance to the art of aviation, especially aviation as a means of commercial travel and as a sport. Through this investigation we may reasonably hope to acquire the art of soaring, and thereby realize the gentlest of all modes of travel.

The immediate problems of the atmosphere calling for solution are numerous, but I shall mention only one more. On the whole the earth is negatively charged. What then is the origin of this negative charge and how is it perpetually maintained?

War Department.
Office of the Chief Signal Officer,
Washington, April, 1917.

III

MECHANICAL ASPECTS OF AËRONAUTICS.

By W. F. DURAND, Ph.D.

Scope of Paper.

The present paper deals with heavier-than-air machines only. No attempt will be made to describe the present situation in comprehensive detail. The achievements of the past and the present condition of the art of aëroplane design, construction and operation must, for the most part, be assumed. The purpose of the paper will be rather to point out the more important problems pressing for solution, the elements in the broad problem of aëronautics which we may reasonably hope to improve, and so far as the author is able, to indicate the directions in which improvement may be sought.

The subject will be considered under the following general heads:

Structure of Aëroplane.
Power Plant.
Propulsion.

Structure of Aëroplane.

As a problem in engineering design the aëroplane presents the following features.

Required a structure coherent as a whole, provided with large flat or gently curved surfaces for realizing the necessary support, with suitable accommodation for the personnel, and with suitable structures for supporting a prime mover and for receiving the thrust of a propeller, fitted also with suitable auxiliary guiding surfaces for control in the air, and with suitable strength in all its parts to resist with a reasonable margin of safety the stresses to which it will be subject in the accidents of aërial navigation.

In its essence, however, the aëroplane is a wing or a combination of wings fitted with one or more engines and propellers.

The chief structural problems are therefore concerned with

(1) The design and construction of the wing.

(2) The design and construction of the members necessary and sufficient to join the wings together into a coherent structure suited to the purposes in view.

The wing again presents two problems. The *surface* and the ***framework*** necessary to give form and strength to the whole.

The amount of surface to be provided is dependent, according to well known laws, on the weight to be supported and on the speed at which support is to be realized. In the outlook ahead the insistent demand will be for the largest practicable size. We may therefore put the question bluntly, what is the largest attainable size, what elements tend to limit size and how may we hope to remove, in some measure, the effect of these limitations.

If we consider a series or family of aëroplane structures, homologous in all dimensions and differing only in size, we shall evidently find a ratio of surface to weight decreasing with increasing dimensions. The weights will increase as the cube of the linear dimension, the surfaces as the square, and hence the ratio of surface to weight will vary as the inverse ratio of increasing dimension. It follows that for such a series of structures the weight of the structure itself will tend to absorb an increasing part of the total weight which the surface should sustain at any given speed, and with corresponding reduction in the surplus lifting capacity available for power plant, crew, armament, express freight, etc.

Let x denote any linear dimension of the plane.

A the area.

W_1 the weight of the plane and auxiliary structures.

Then for a family of structures such as are here considered we shall have

$$A = Bx^2,$$

$$W_1 = Cx^3,$$

where B and C are two coefficients connecting respectively area with the square of x and weight with the cube.

At any given speed let the relation of total lifting capacity to area be expressed by the ratio m. Then if W = total lifting capacity we have

$$W = mA = mBx^2.$$

Denote the net lifting capacity by y. Then we shall have

$$y = W - W_1 = mBx^2 - Cx^3,$$

$$\frac{dy}{dx} = 2mBx - 3Cx^2 = 0, \qquad 1$$

$$x = \frac{2}{3}\frac{mB}{C},$$

and

$$y_m = \frac{4}{27}\frac{m^3B^3}{C^2}. \qquad 2$$

For such a series of structures therefore the maximum net lifting capacity will be given by a size determined by the value of x in equation (1) and the actual maximum net weight will be as in equation (2). For larger sizes of structure the weight required in the structure itself will increase more rapidly than the carrying capacity depending on area, and hence the net lifting power will decrease. It results furthermore that for such a family of structures there will be some size for which, all at a given uniform speed, the net carrying capacity will be zero, a size for which the total lifting capacity at the stated speed will be only just able to carry the weight of the structure itself.

We may now ask two important questions.

(1) What measures must be taken, in such a series of structures, to increase the maximum net carrying capacity?

(2) To what extent do these conclusions apply to a series of actual aëroplanes of continuously increasing wing surface?

Regarding question (1) the form of the expression for y_m shows that it varies directly with m^3, directly with B^3 and inversely with C^2. We must therefore seek to increase m and B and decrease C. We cannot hope to affect the value of B, the relation of area to linear dimension. We may, however, increase m by increasing the speed and decrease C by improved design or by developing materials stronger for a given weight than those now employed.

Regarding question (2) we may state the problem thus. For a series of aëroplanes of increasing area, how closely will the increase in weight vary with the $\frac{3}{2}$ power of the rate of area increase?

Broadly speaking the relation seems to hold within a significant degree of approximation. The weight of skin covering itself will increase as the surface. All structures subjected to cross breaking and in general all elements which tend to constitute the structure as a whole into a truss or girder will, except as the character of the design may change increase in their own linear dimension nearly with the overall increase in linear dimension, and hence in weight nearly as the cube of the linear dimension or with the $\frac{3}{2}$ power of the surface. Time does not permit any detailed analysis of this important problem, but broadly speaking we may expect that in a series of aëroplanes of the increasing area the weight will increase somewhat more rapidly than the area but somewhat less rapidly than the $\frac{3}{2}$ power of the area.

The practical question is this. To what degree of approximation in a series of aëroplane structures will the structural weight vary with the $\frac{3}{2}$ power of the area of wing? We know that for a given speed, wing area and gross weight vary nearly in direct linear ratio. Hence if the structural weight increases more rapidly than the area but somewhat more slowly than with the $\frac{3}{2}$ power, it is obvious that for any given speed there will be some area which will insure the maximum net lifting capacity and beyond this area the next lifting capacity will decrease.

Actual experience seems to indicate an increase in weight related to wing area according to an index lying between 1 and $\frac{3}{2}$ and varying somewhat irregularly according to the changing type of construction with increasing size. Hence we may conclude that for a given speed continued increase in size of wing alone will not insure indefinite increase in the net carrying capacity, but that instead there will be some area for which the net carrying capacity may be expected to reach a maximum, after which further increase in size at the same speed will involve a loss in carrying capacity.

It follows again that in order to increase carrying capacity the following steps are indicated.

1. Improvement in the elements of design and in the materials of construction.

2. The selection of such a size of wing as shall insure for the type of design and for such wing as an element in the structure as a whole, the maximum net carrying capacity.

3. Increase in speed to the upper limit practically attainable.

4. Increase in number of planes.

Recent experimental work with three, four and five planes seems to point to the multiple plane as perhaps the most immediate means of increasing carrying capacity. Or in other words, given the limitations imposed by structural materials and the upper limit of speed considered practicable and expedient, multiple planes seem to be the immediately remaining recourse for further advance in net carrying capacity.

Passing now briefly to the actual materials available, we may make a classification as follows.

Surface material (cotton or linen duck fabric).

Wing skeleton or structure—wood (spruce and mahogany), steel.

Struts and braces connecting wings in multiple—wood (spruce and mahogany), steel or special alloys.

Body or boat material: Framing: wood or steel. Covering: wood veneer or sheet metal.

Ties for serving as tension members in connecting wings to body or in multiple: steel wire, single or laid up in cable.

Fastenings: drop forgings, sheet steel, bronze.

The two fundamental problems are:

1. The development of materials furnishing more strength for the same weight.

2. The better disposition of the materials which we now have.

Passing the above classes of materials briefly in review, we may note as follows. There does not seem to be anything immediately in sight better than the materials now used for surfaces. With suitable treatment (usually coatings of celluloid dissolved in acetone with varnish finish) the material stretches tight, takes a smooth surface and has sufficient strength to support itself between the supporting ribs.

The surface does not form a large fraction of the total weight and saving here is not relatively as important as in the framework.

The substitution of metal for wood in the framing has long since attracted the serious attention of aëronautic engineers, and in certain recent designs the problem has been worked out with apparently a high degree of success. These results indicate the probability of an increasing use of steel for parts which have hitherto usually been made of wood. The peculiar qualities of stiffness and resilience combined with readiness of shaping and forming have combined to make wood broadly speaking the standard material for the skeleton or framing of the wings and body. It seems, however, a foregone conclusion that some parts now made of wood might with advantage be made of the best modern alloys combining strength with light weight. The extent to which this can be wisely done can only be determined by trial, but it seems probable that perhaps important savings in weight may be made by a judicious substitution of metal in certain elements of the structure.

The outlook for the future calls for new and improved metal alloys with certain of the physical characteristics of wood, as nearly as may be realized, and with proper form and proportion securing the development of the same strength with saving in weight.

The use of steel wire and cable for ties is standard and practically universal. These elements form a relatively small part of the total structural weight. It seems hard to imagine material superior to the best modern alloy steel wire, but there seems no reason for assuming that such material represents the last word in the wire-makers' art and if we may anticipate new and improved steel or bronze alloys, such material will provide the necessary tension elements with some slight saving in weight.

Fastenings have been made the subject of much study, experimental and otherwise, and the field is still open for further improvement. Here again the total weight is relatively small, but there may well be a chance to save something in weight and at the same time add to the security and integrity of the design as a whole.

Broadly speaking, there seems small ground for anticipating any profound change in the near future in the schedule of materials best available for the designer of aëroplane structures. Gradual advance there will be, and with it the designer of such structures must be quick to seize such advantage as he may.

Regarding a better disposition of the materials we now have, it may be assumed that there is a more promising field. It is peculiarly a field which must be worked in an experimental way, and while much has already been accomplished there is still room for further saving in weight through a better disposition of the elements of structure employed.

The problem is broadly; given an aëroplane structure exposed to the hazards of flight and involving baffling head winds, gusts, forced severe banking, diving, quick turning about various axes of motion and all in various combination, required a structure which shall present a substantially uniform factor of safety relative to the extreme stress, in any and all directions, to which it may be subjected.

This is obviously not a problem to be solved by theoretical methods or over the drawing board alone or even chiefly. It is distinctively a problem to be worked out primarily by experience supplemented by experiment, which is, after all, only experience realized under control conditions.

One of the future developments which should not be lost sight of lies this way and should comprise comprehensive studies of the combinations of structural elements available, always with the view of realizing more efficient results; that is, a more equable distribution of the strength realized with a corresponding saving in weight.

The problem of weight economy is vital in the science and art of aëronautics, and the possibilities of advance through a well-ordered program of experimental investigation on full sized forms should not be lost sight of.

Power Plant.

We pass next to the subject of the aëroplane power plant. We here meet the following principal problems.

1. The problem of fuel.
2. The problem of carburetion or preparation for combustion.
3. The thermodynamic problem of the transformation of the heat energy into mechanical work.

4. The problem of auxiliaries.
5. The problem of construction.

Gasoline stands preëminent as the standard fuel for aëroplane service. The chief objection is its high price. This will operate to produce a serious limitation in the economic application of the aëroplane and one of the most important problems with special reference to an extension of economic use is the development of prime movers capable of using cheaper grades of fuel. It will not be without interest, at this point, to note the fuel cost per ton mile for aëroplane service as compared with the same item for railroad and for marine transport. If we take an aëroplane with say 130 h.p. carrying 300 pounds of cargo at a speed of 60 m.h. we shall find with gasoline at 20 cents per gallon a fuel cost of about 30 cents per ton mile. This will compare with about $\frac{1}{10}$ cent in the case of a heavy freight train and with about $\frac{1}{40}$ cent in the case of say a 10,000 ton steamer. The fuel cost for merely carrying dead weight may therefore readily be from 300 to 1200 times as great as for railroad or marine carriage. This unfavorable relation between the economics of the fuel cost for aërial and for marine transport arises from certain relations which develop in the two cases between net cargo weight and gross weight, and between horsepower and gross weight.

Thus for the ship the net cargo weight may be, for moderate speeds, as high as 50 per cent. of the gross weight, while for the aëroplane as noted, it would be about 12 per cent. Again the ship requires for a speed of say 15 miles per hour, a horsepower of 5,000 or less, or not exceeding 1 h.p. for 4,500 pounds gross weight while the aëroplane requires something of the order of 1 h.p. for 15 to 20 lbs. gross weight. Again the fuel for the aëroplane engine costs from 5 to 8 times as much per horsepower hour developed as for the ship prime mover.

While the fuel represents by no means the whole cost it is an important item and it is clear that so long as the aëronautic engineer is limited to gasoline fuel the economic uses of the aëroplane must be seriously handicapped.

There are other fuels cheaper in character and developed to a point where they are satisfactorily employed in certain grades of internal combustion service, notably kerosene and distillate, and cheapest of all, crude oil which is used in engines of the Diesel type. The demands of aëronautic service are, however, insistent in regard to the holding of engine and machinery weights to the minimum and any attempt to use fuels other than gasoline must reckon with the possibility of increased weight. This limitation will apparently, at least under existing design conditions, rule out the Diesel engine from consideration.

With existing conditions of design and operation there seems to be nothing in sight as an immediate substitute for gasoline, and we cannot well see in what direction to turn for the ultimate solution of this problem. It is, however, none the less real and the economic extension of the aëroplane will depend in large measure upon the success or failure of efforts directed toward the development of a cheaper fuel.

Passing now to the problem of the carburetor only the briefest reference can be made to the principal details of this problem.

The primary function of the carburetor may be defined as the mixing of the gasoline in a finely divided state with the air necessary for combustion. Following this, on its way to the cylinder and on entering the cylinder, the liquid fuel becomes rapidly vaporized and ready for compression and ignition. The fundamental requirements are the following:

1. Fine subdivision of the liquid fuel.
2. A uniform or nearly uniform mixture by proportion of gasoline to air at varying motor speeds.

For aëroplane service, there should be, in addition, some adjustment, either automatic or manual, with reference to altitude and the consequent varying density of the air.

The function of the carburetor may be viewed under two heads.

1. Reliability.
2. Economy.

For aëroplane service a carburetor giving a nearly uniform mixture over a wide range of operating conditions is of special importance from the standpoint of reliability. When the life of the aëronaut may well depend on the degree of reliability with which the carburetor furnishes a nearly uniform mixture suited for ready ignition, the importance of this phase of the problem is apparent without further emphasis.

The best of present carburetors realize these conditions in high degree. The principal points still open for improvement are perhaps the following:

1. Improved means for atomizing the liquid fuel, looking especially toward the finest attainable degree of subdivision. This will aid both economy and reliability.

2. Improved means for covering a wide range of atmospheric conditions as regards density, temperature and humidity, and with a wide range of power developed under any combination of these conditions.

3. Improved means for atomizing the gasoline with the minimum drop in pressure through the carburetor. This will aid in decreasing the back pressure and will increase the net power developed per cycle.

Improvement in the carburetor is primarily dependant on experience. The interaction of the various controlling factors is so complex in character that cut and try methods based on the intelligent application of underlying principles seem to promise the most fruitful results in the improvement of this element of the internal combustion prime mover. The field is open and we may look confidently to the future to provide a standard form of carburetor which will secure the highest practicable results over the widest range of operating conditions.

We turn next to the thermodynamic aspect of the problem.

Under this head I shall only refer briefly to the character of thermodynamic cycle employed. As well known, the cycle at present universally employed is that based on the constant volume—adiabatic ideal. There remain open the constant pressure-adiabatic cycle and the constant temperature-adiabatic or Carnot cycle, or some combination of these.

The Diesel engine uses a cycle more or less intermediate between the latter two.

The constant pressure-adiabatic cycle has long been the ideal of engineers with special reference to sustained crank effort and the elimination of the explosive shock characteristic of the constant volume-adiabatic cycle. Thus far, however, structural and op tive difficulties in various details of the process have prevented wide use of this cycle. It is, however, just now the subject special investigation at the hands of engineers of insight and source and it may well be that the near future will open up to aëronautic engineer this cycle for practical use in engines for a plane service. If engines operating on this cycle can be mac success in the operative sense while at the same time keeping weights down to the limits reached with the type now employed may anticipate a wide field of usefulness for this cycle.

Under the head of auxiliaries the chief functions are igni cooling and lubrication. To these we may perhaps add, as rapidly approaching the status of common acceptance, some form of starting motor or device with wireless outfit, especially for military purposes.

Under ignition the insistent requirement is reliability, commonly assured, so far as auxiliary equipment is concerned, by magneto installation in duplicate.

Cooling is normally by water, except in the rotating type of engine, where air cooling prevails. The principal problems here relate to methods of circulating and cooling the water, security of joints and connections, minimizing loss of water by boiling and assurance of adequate supply for long life in air without going to needless excess weight in water carried.

The principal problems presented by lubrication are reliability and simplicity of means employed, usually some form of pressure or positive supply system.

Further references to problems presented by auxiliary equipment are more conveniently made under the next following head.

Under the general head of construction, time will only permit of brief reference to the following topics:

Materials.
Design.
Fabrication.

The materials employed are chiefly cast and wrought steel, cast iron for some few parts, aluminum and bronze. In order to reduce weights to a minimum forged steel is used for the cylinders or cylinder liners and generally for all parts receiving or carrying the direct load. Further progress here will wait on the skill of the metallurgist in furnishing steels of higher physical properties than those now available. Broadly speaking, the present aëronautic engine, in the most refined designs, exhibits a very near approach to the practicable limit with the materials at present available and further saving in weight must depend chiefly on the work of the metallurgist in developing new and improved materials for use.

The chief outstanding problems in the design of aëronautic engines are those dealing with the most effective disposition of the available materials of construction, and with the forms, proportions, arrangements and assemblage of the elements in such manner as shall secure the highest practicable degree of reliability of operation.

In the disposition of the materials with reference to the strength and stiffness required, the fundamental and insistent demand is the saving of weight. This problem is one to be studied partly by the application of mechanics and general engineering principles, and partly by experience. In any given engine there is no question but that there is a certain amount of redundant weight. The problem is to locate it. While, as already noted, the best of modern designs represent apparently a close approach to the ultimate attainable with existing materials, nevertheless the field of design with reference to further refinement is still open and will doubtless well repay further study. This road marks clearly one of the ways whereby future progress and improvement must come.

The principal problems dealing with improved reliability and with length of operative life may be enumerated as follows:

1. Oiling system and lubrication generally.
2. Means for securing all pipes and conduits, whether for oil, water or electric wiring, in such manner that jar and vibration cannot cause their rupture or separation at joints.
3. The reduction of vibration to a minimum by the careful balancing of rotating and reciprocating parts so far as practicable.
4. Adequate bearing surfaces especially for all principal parts, so that with a reasonable supply of lubricant there need never be danger of cutting or abrasion.
5. Adequate crank shaft size and adequate crank shaft bearings,

both in surface and in number, so that the shaft may be shielded from alternating flexure, a condition certain to result in early rupture.

6. Simplicity and directness of operation the valve gear.
7. Simplicity and directness of drive for all auxiliary machinery such as magneto, water and oil pumps.

In connection with the general problem of lubrication, one of the great problems, perhaps the one most important problem in connection with the aëroplane prime mover, relates to the possibility of developing metals of such physical properties or relations that they will operate in sliding relation without serious abrasion and without the need of constant lubrication, at least in terms of the practice found necessary with the materials now employed. Whether any such metals in pairs can be developed or whether the surfaces of metals will admit of treatment in any way which will reduce in marked degree the amount of lubrication required, is of course an open question; but the march of scientific and engineering progress is marked with many discoveries and developments seemingly far more remote from possibility than is this. In any event it is a field well worthy the most careful investigation, not alone for its importance in connection with aëronautic prime movers but also for the far-reaching influence which it would have throughout the whole field of engineering design. It represents moreover a serious need in the case of the aëronautic prime mover with reference to increased safety, simplicity and decreased cost of operation.

These problems, and others allied, all offer inviting fields for the research engineer, the designer and the inventor. It is, furthermore, difficult to overestimate their importance. Thus the rupture of a small oil pipe, perhaps ⅛ inch diameter, due to vibration resulting in a crystallization of the metal at a point of attachment, might result in the failure of lubricant to reach some important element of the engine, as a consequence of which the bearing heats, abrades, perhaps seizes, the engine stops and possibly disaster comes swiftly as a consequence. When safety of life may depend on continuous operation of the engine, no item or element bearing on reliability is too small to receive the most serious and earnest efforts on the part of those responsible for the design and construction of the prime mover.

It seems appropriate to note at this point, that until the margin of uncertainty or of unreliability is reduced far below where it now stands, the navigation of the air will be closed to the great mass of people who will prefer the safer if somewhat less thrilling mode by way of the solid earth or the water-borne boat.

PROPULSION.

The screw propeller has been universally adopted as the means for transforming the work developed by the prime mover into propulsive work.

In spite of its simple form the operation of the propeller depends on an astonishingly large number of variables, interrelated in complex and baffling ways, and thus far transcending all effort to bring them into practicable expression through the application of aërodynamic theory. The chief variables or conditions thus entering into the operation of a propeller may be listed as follows:

(*a*) Characteristics of the propeller as a geometrical body.

- (1) The diameter or general determining dimension.
- (2) The pitch of the helicoidal surface employed for the driving face. This may have two different modes of specification, viz.:
  - (*a*) The single value of the pitch if uniform, or the mean value if variable.
  - (*b*) The distribution of values if variable.
- (3) The form of the contour bounding the blade or helicoidal surface employed.
- (4) The area of the blade on the driving face.
- (5) The cross section or thickness of the blade. This may have two mode of specification, viz.:
  - (*a*) Areas of cross sections and their distribution radially.
  - (*b*) Forms of cross sections.
- (6) The character and finish of the blade surfaces.
- (7) The form and dimensions of the hub or central body carrying the blades.

(*b*) The characteristics of the adjacent structures such as parts of the aëroplane. These will influence the flow of air to and from the propeller and will thus affect the force reactions resulting from its operation under any stated set of conditions. These may be primarily specified by

(1) Dimension and form.

(2) Location with regard to propeller.

(*c*) The characteristics of the medium.

(1) Density.

(2) Viscosity.

(3) Character and extent of turbulence or departure from homogeneous conditions.

(*d*) The characteristics of operation.

(1) Speed of translation or speed of advance.

(2) Speed of rotation.

We have thus, without going too far into detail, some 14 variables or conditions, any one of which may exercise an important influence on the results realized from the propeller.

For many purposes and by way of approximate working formulæ, the operation of the propeller is related through empirical coefficients to the three most important of the above listed set of conditions; namely, diameter, pitch and the slip, which is directly expressible in terms of the relation between the speed of advance and the speed of rotation.

Aside from such approximate formulæ, in which the values of the coefficients drawn from experience must be so selected as to care for all variables other than the four directly represented, there seems to be no recourse save either in direct full size experimental investigation, or in model investigation. The limitations of full size experimental investigation are evident, and aëronautic engineers, following the lead of the naval architect, have turned to model experiments as furnishing the most hopeful means of dealing with the problem of the screw propeller.

The use of models presupposes the application of a law or principle of kinematic similitude, and regarding which it is unnecessary to speak in detail on this occasion. It will aid, however, in clarifying our present view to state the underlying assumption as follows.

The existence of a law of kinematic similitude assumes that for any given set of operating conditions for the full-sized body there will correspond a determinable set of conditions for the model and that the results realized for the model may be transformed into the results to be anticipated from the full-sized body by the application of determinable ratios which will be some known function of the relation between the two sets of conditions.

It should be noted further that this relation assumes that *all* of the conditions which may affect the result in question admit of definite expression in terms of mechanics and of definite numerical measurement in specific cases. This is not always possible especially with such factors as surface roughness or degree of turbulence.

Again the special conditions which are required for the model may be inconvenient or even impracticable as regards experimental realization.

These various conditions prevail in the case of air propellers. It is well known that we are only able to realize a practicable application of the law by neglecting the influence of the viscosity of the medium. This of itself, with the air propeller working in an indefinite medium and under loads and speeds which would permit the neglect of the influence due to the compressibility of the air and of the distortion due to thrust and centrifugal force, would make all speeds corresponding. This is equivalent to a reduction of the equation for the thrust of a propeller to the form

$$T = KD^2v^2.$$

Hence with such a relation the model may be run at any speed with the same percentage slip as for the full-sized propeller, and from the observed value of the thrust we may derive the factor K. The constant thus determined should then serve for any diameter so long as the shape and slip remain the same as for the experimental conditions.

If, however, allowance is to be made for compressibility and for distortion due to force loading, theory indicates, as is well known, that the tip speeds of both model and full-sized propeller should be the same.

The form of corresponding speed relation usually adopted for air propellers is in accordance with these indications. There remains, however, a margin of uncertainty regarding the influence due to the neglected viscosity and also a query as to the amount of error which would be introduced by using lower tip speeds for the model than for the full-sized propellers.

These two queries therefore stand out, representing two problems which press for solution and which lie at the foundation of the investigation of air propeller operation through the use of reduced size models.

We must therefore admit that the application of the law of kinematic similitude, in the form commonly employed, to experimental research on air propellers by means of reduced models, lacks full authority in rational theory, and as a result the real justification must come from experience. This means that the tests on models and their interpretation in terms of full-sized propellers must rest ultimately on carefully determined results given by the coresponding full-sized propeller. This does not imply, however, that all model measurements need to be checked by corresponding experiments on full-sized propellers, for if so there would be no object in the model experiments; but rather, that a selected number of experiments should be carried out, here and there over the field of propeller forms and proportions, thus establishing the presumptive degree of accuracy in model experimental work. With such margin of error known, model experiments could be used freely, with suitable corrections if necessary, and the results would then have all the accuracy which can attach to model experimental work corrected by reference to direct experiment on full-sized forms.

So much for the propeller itself. It must be remembered, however, that the propeller is but the connecting link between the prime mover and the aëroplane, and that no matter how excellent the propeller in itself, it must be adapted to the prime mover and to the aëroplane in order to secure a harmonious and efficient combination, or rather all three must be adapted each to the other, and it is in this lack of adaptation that much of the trouble with and inefficiency of the screw propeller in actual use arises. Thus no matter how efficient the propeller itself at a suitable value of the slip, if it is too small for the aëroplane, the slip will become excessive with corresponding loss in efficiency. Again if too large or if the relation between speed of advance, slip and torque are unsuitable, the propeller will perhaps hold down the motor to a rotative speed entirely too low and thus render impossible the development of the desired power. These and other relations are of course well known and are only mentioned here in order to emphasize the importance of the most careful inter-adaptation between the aëroplane, the motor and the propeller.

In this field there is still important work to be done in a more complete study of the characteristics of the aëroplane and propeller separately and when combined in their normal relation, all with a view of insuring a more perfect adaptation of the one to the other and of the prime mover to both.

The air propeller has thus far been normally made of wood and of the two-bladed form. Outstanding problems which are awaiting investigation relate to the best modes mechanically of making three and four blade propellers with the consequent saving of diameter for the same thrust, revolutions and slip; also to the practicability of propellers of light metal alloys instead of wood. Some work has been done along these lines and some hopeful indications have appeared.

A further problem, structually, relates to the thickness necessary for strength under the complex stress due to centrifugal force and air pressure, and also the distortion of the blade under these loads and the extent to which such distortion may modify the geometrical characteristics of the propeller itself.

Concluding we may in resumé sum up for the aëroplane as a whole, the insistent demands on the realization of which future progress must depend. These are:

1. Minimum weight of structure in relation to area of supporting surfaces and of power plant per unit of power developed. This will secure increased carrying capacity for fuel and supplies and for useful weight such as passengers, mail, etc., and this will serve as a factor in either long life in the air or heavy carrying capacity for short distance. On the other hand such extra weight carrying capacity may be put into additional power plant, engine and fuel, for correspondingly increased speed over shorter distances.

2. Maximum economy of prime mover and in applying its power for propulsive purposes. This will insure minimum consumption of fuel and supplies per unit of time or distance, and hence will serve as a factor in long life in the air or in large weight carrying capacity, or in added capacity of prime mover with corresponding increase of speed for shorter distances.

3. Reliability of operation. This embodies improved methods of control and navigation, and greater reliability in each of the many individual elements on which overall reliability in operation depends. These improvements are of special significance in the problem of lengthening the effective life in the air and broadly in the extension of the usefulness of the aëroplane especially in the arts of peace.

IV

AËROLOGY.

By WILLIAM R. BLAIR.

The treatment of this subject in one paper must necessarily be general. An attempt will therefore be made to cover the ground and indicate points of contact between aërological observation and aëronautics, leaving argument and details of methods to a fuller treatment of the subject which, it is hoped, may appear in the near future.

Fig. 1. Percentage of winds from each of eight directions for the year at selected stations.

Means of observations already reduced and compiled will be used in the discussion, not with the idea that these means will fully serve the aëronauts' purpose, but that they indicate standard conditions which to some extent show what may be expected at any time and place and should be in mind for comparison with the individual observations in the region navigated. These observations on the spot are of fundamental importance and in practice cannot be safely set aside for forecasts or the indications of means as to the upper air conditions.

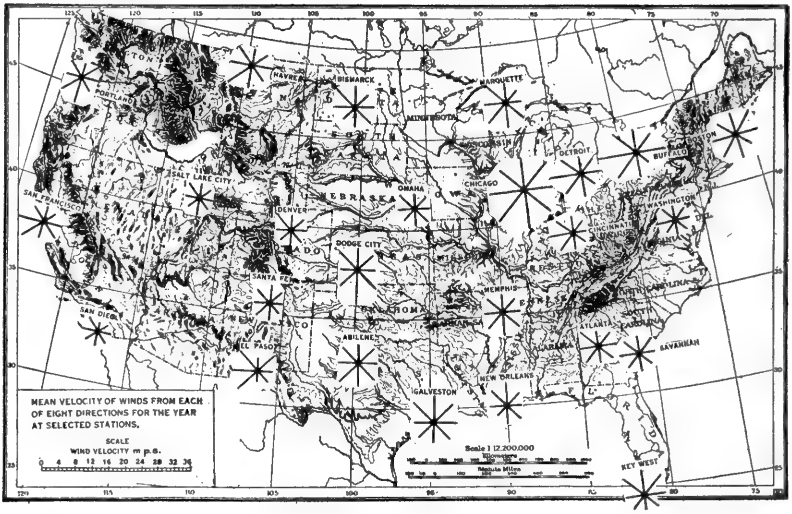


FIG. 2. Mean velocity of winds from each of eight directions for the year at selected stations.

Charts of means are in a sense the aëronauts' charts of the medium he navigates, but it must be kept in mind that these charts, in which results of observations are usually shown with reference to surface pressure distribution, are to be used with the current weather map.

Observations are made by means of kites, captive balloons and free balloons. Kites and captive balloons carry automatically recording instruments which record continuously temperature, pressure, humidity and speed of movement of the air. The free balloons used are of two sorts, sounding balloons and pilot balloons. The former carry an instrument which automatically records temperature, pressure and humidity of the air. Observations of air movement are obtained by means of continuous theodolite observations upon the balloons. In the case of sounding balloons, heights may be computed from the pressure record, and observations with one theodolite used with these heights to determine horizontal distance from the starting point. When pilot balloons are used, the rate of ascent can be fairly well determined by means of one of several formulæ, based upon the weight of the balloon, its resistance to the air and its ascensional force. It any case the position of a free balloon can

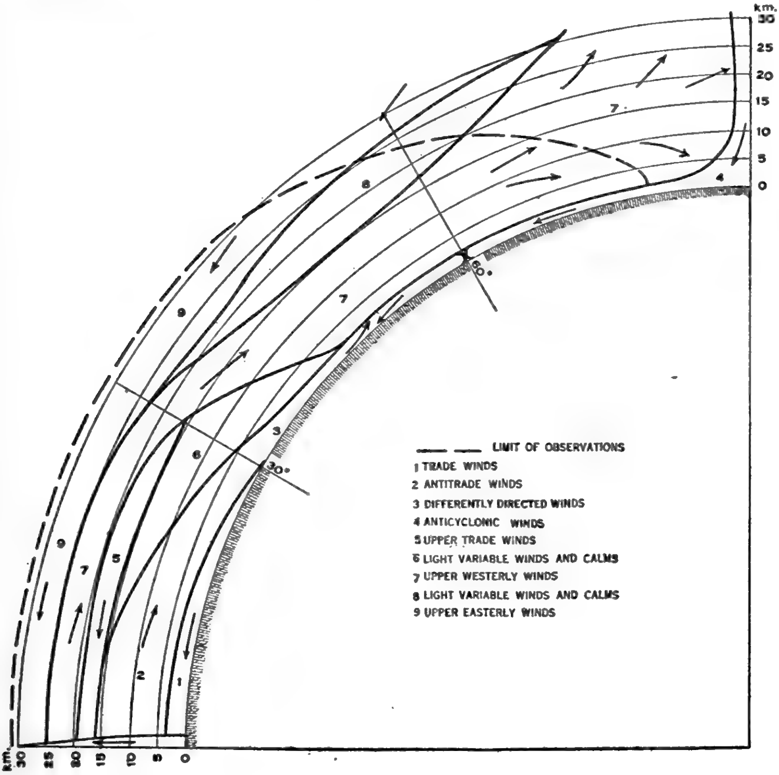


FIG. 3. Meridional section of the atmosphere.

be determined independently of the barometric pressure or of the ascensional rate of the balloon if a pair of theodolites, one at either end of a measured base line, is used. By means of any of these methods the observer is able to plot a horizontal projection of the balloon's path. From this plot may be read the wind speed and direction at any time during the ascension.

One of the first cares of the aëronaut is to put down suitable stations at which aircraft may be housed and repaired. It is important that these stations and their buildings be easily accessible to aircraft. A knowledge of the prevailing meteorological conditions is therefore of prime importance in the location of any station and in the orientation of its buildings. Among the climatic condi-

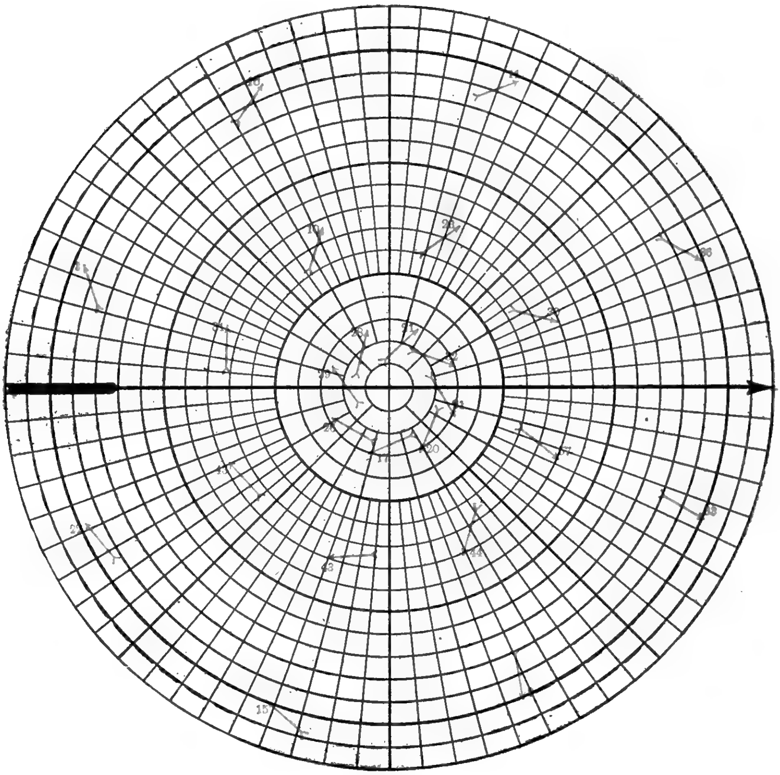


Fig. 4. Mean of Wind Observations in "Highs" at 526 Meters above Sea Level, 1907–1912.

tions that need consideration in this connection are cloudiness, rain, (including thunderstorm frequency), fog, humidity, temperature, pressure and wind. Of all these wind is the most important. It is an advantage to a station if the wind has a decidedly prevailing direction. Buildings housing aircraft can then be so oriented as to be easily accessible most of the time.

The Weather Bureau records can supply such information as that shown in Figs. 1 and 2 for many other stations than are here included. In addition to surface conditions it is well if a knowledge of free air conditions to heights well above neighboring trees, buildings, hills or mountains can be known before deciding on the location of a station.

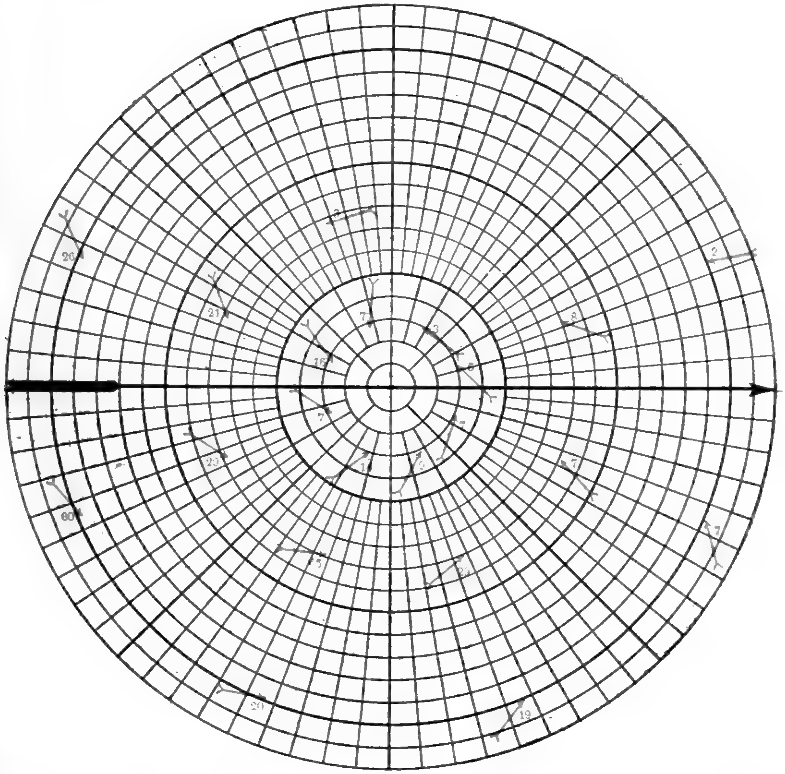


FIG. 5. Mean of Wind Observations in "Lows" at 526 Meters above Sea Level, 1907–1912.

The course to be pursued by a pilot flying between two stations should be governed by the structure of the atmosphere at the time and places in question. A knowledge of the relations that have been found to exist between surface and upper air conditions will be of value to the pilot, but cannot in general take the place of direct observations. By means of the observations, results of which could be available at the starting point of the course within half an hour after the observations were started, it would be decided whether

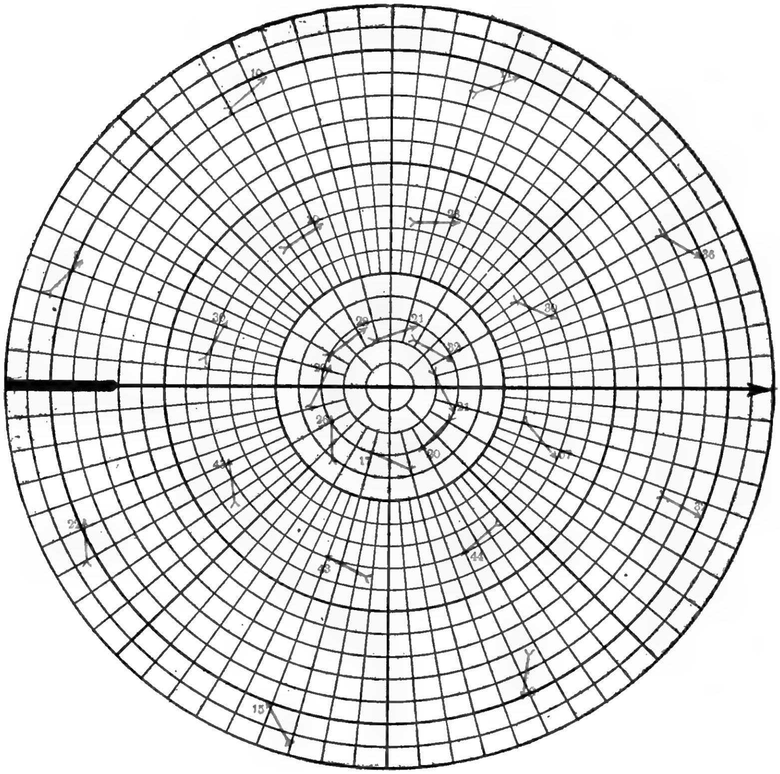


Fig. 6. Mean of Wind Observations in "Highs" at 1000 Meters above Sea Level, 1907–1912.

a direct course at the usual height or some deviation, lateral or vertical, from such a course should be made. Data sufficient for "laying" the course and determining beforehand the time required to travel it would be furnished by the observations. The pilot would to a great extent, if not altogether, be independent of having to see the earth's surface in order to know his direction and position at any time.

The different convective systems or circulatory systems of the atmosphere, together with the temperature distribution characterizing each, are of especial interest to aëronauts.

Fig. 3 shows a meridional section of the atmosphere, so far as it can be determined from observations now at hand. For the purpose

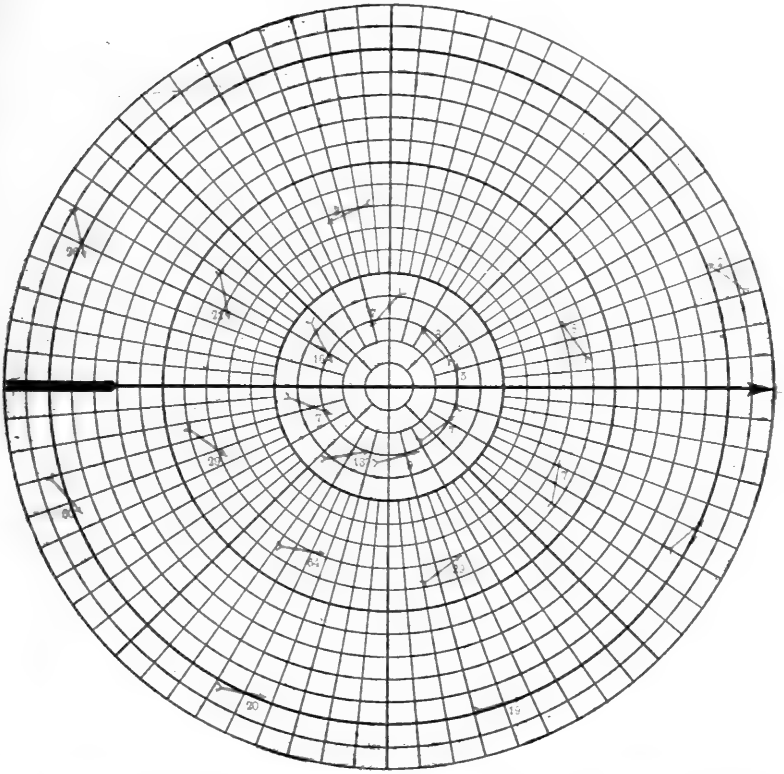


FIG. 7. Mean of Wind Observation in "Lows" at 1000 Meters above Sea Level, 1907–1912.

of this illustration the depth of the atmosphere shown is greatly exaggerated. The units of this general or planetary circulatory system in which the arrows point south are east winds having in the average a north component. Those units in which arrows point north are in general west winds having in the average a south component.

Especial attention is called to the fact that the air in west winds exerts a greater downward pressure than does the air in east winds. Aside from the fact that a gram mass moving from west to east exerts a greater downward pressure than does a gram mass moving from east to west, it is found that the air in west winds is in general dense for the level it occupies, while the air in east winds is light for its level. That air is heavy or light for the level it occupies depends upon its humidity and its temperature and on the fact that descending air heats at the adiabatic rate while condensation of the moisture in ascending air offsets to a greater or less degree the adiabatic cooling that accompanies the ascent. It is also true that, compared with moist air, dry air absorbs but little radiated

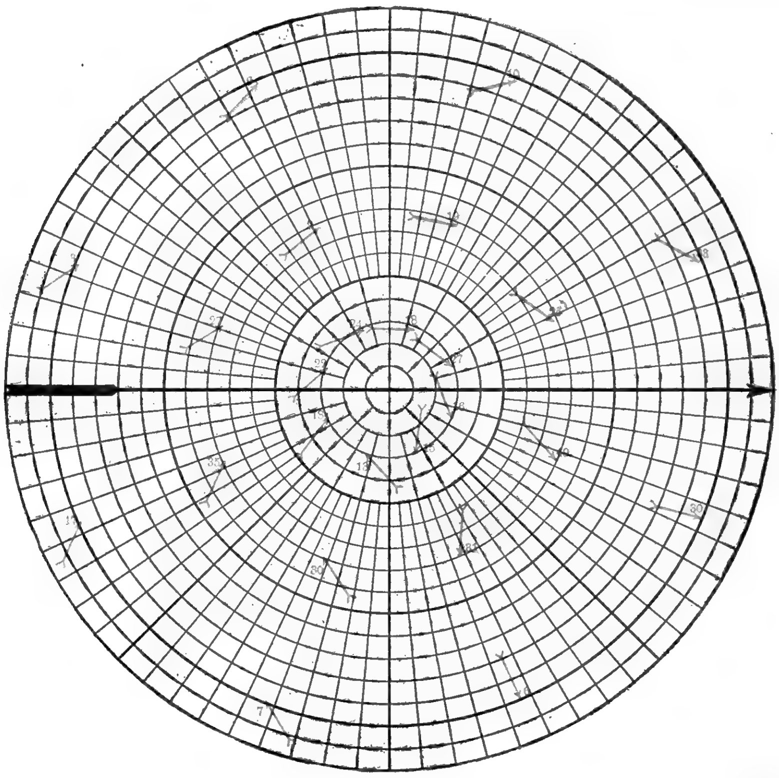


FIG. 8. Mean of Wind Observations in "Highs" at 2000 Meters above Sea Level, 1907–1912.

heat. This difference in adiabatic rates of cooling and heating effectively prevents the mixing of the airs in question. The west winds in general follow the irregularities of the bottoms, solid earth, water, or aërial, over which they flow and are in consequence gusty winds. East winds are not likely to be thrown into gusts by irregularities of surfaces below them. They are in general less gusty than are west winds.

Closely related to this arrangement of light and heavy airs is the fact that the two regions of traveling storms, the tropical hurricanes and the high and low pressure areas of middle latitudes, are found where air relatively dense for the level it occupies is flowing over

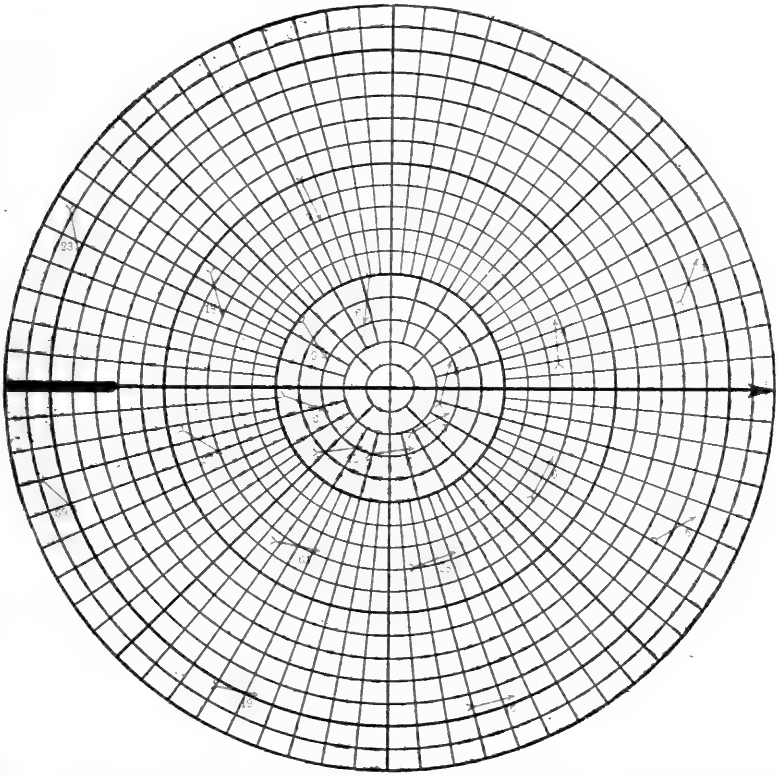


FIG. 9. Mean of Wind Observations in "Lows" at 2000 Meters above Sea Level, 1907–1912.

moister and, for its level, relatively light air. These storms are surface stratum phenomena, forming on the boundaries of warm, moist and cold, dry air masses and have approximately the speed and direction of the wind in the stratum immediately above them. The tropical hurricanes have the speed and direction of the antitrade winds where the latter flow over the trades, while cyclones and anticyclones have the speed and direction of the upper westerlies. The data seem to show that cyclonic disturbances form on the left side of oppositely directed, passing currents of air in the surface stratum, while anticyclonic disturbances form on the right side. The airs in these two sorts of currents are differently tempered and of different moisture content, the extent of these differences having to do with the intensity of the disturbances. These irregularities in pressure distribution behave toward the upper westerly wind, or, in the case of tropical hurricanes, toward the antitrades, as variations in the level of the surface over which they flow. The disturbances are thus communicated directly to the upper winds which

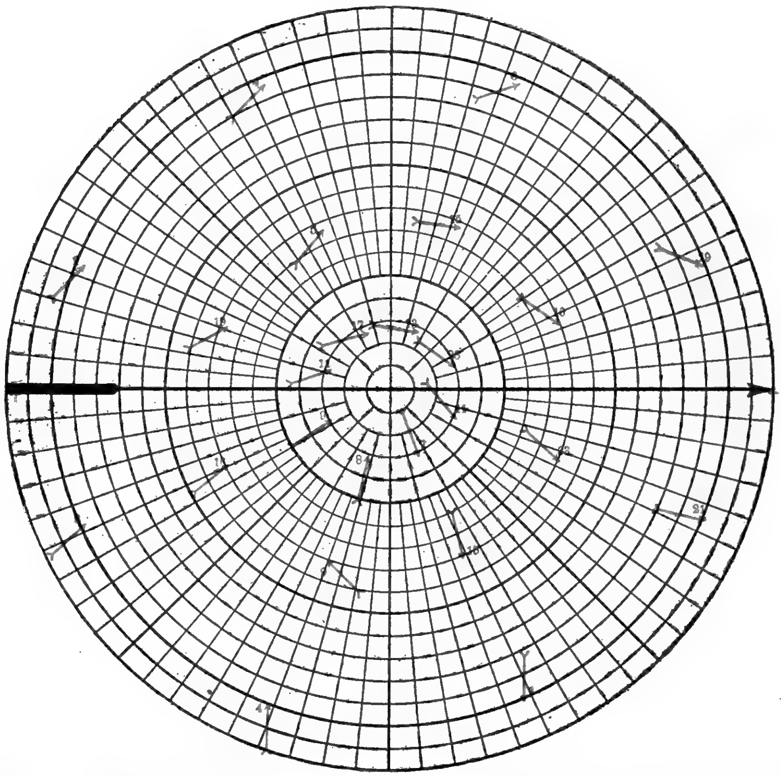


Fig. 10. Mean of Wind Observations in "Highs" at 3000 Meters above Sea Level, 1907–1912.

thus become gusty, just as do winds flowing over irregularities in the earth's surface. These gusts are accompanied by appropriate changes in pressure and temperature, and progress in the direction and with the speed of the wind in which they occur. They carry with them the self-sustaining disturbances of the lower or surface stratum which would otherwise be practically stationary phenomena.

Figs. 4 to 15 inclusive show the direction of the winds about centers of high and low pressure at the earth's surface and at levels above these centers. All winds, whatever their direction at the earth's surface, change direction with altitude in such a way as to become westerly by the time the four kilometer level has been reached. This tendency is shown by a comparison of surface winds

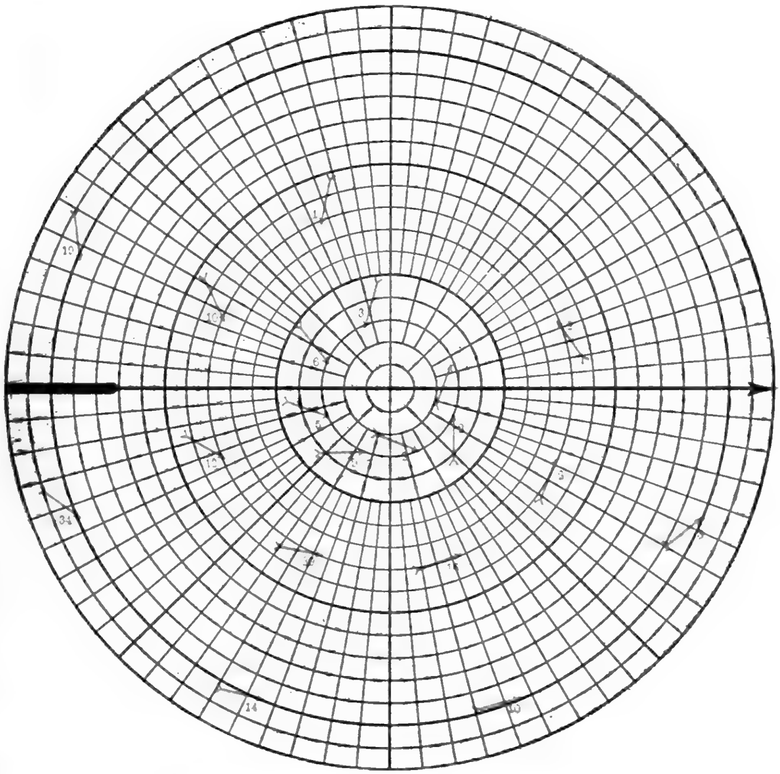


FIG. 11. Mean of Wind Observations in "Lows" at 3000 Meters above Sea Level, 1907–1912.

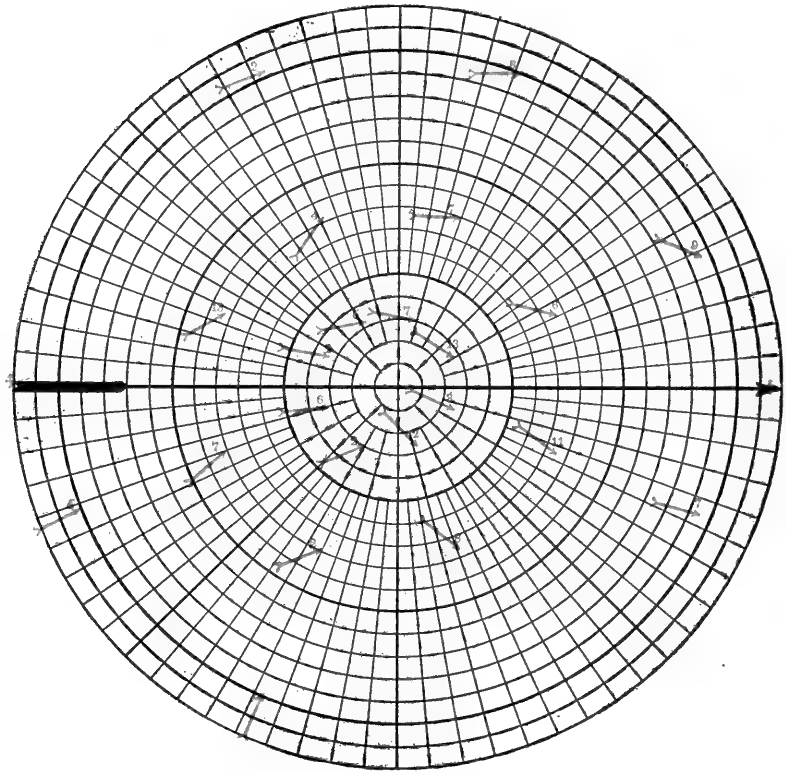


FIG. 12. Mean of Wind Observations in "Highs" at 4000 Meters above Sea Level, 1907–1912.

TABLE I.

TURNING OF WIND WITH HEIGHT.

Direction at Earth's Surface.	No. of Observations.	Clockwise, Per Cent.	Counter-clockwise, Per Cent.	None, Per Cent.
N. to ENE	31	45	35	20
E. to ESE	50	76	12	12
SE. to SW	474	94	2	4
WSW	46	76	7	17
W	109	51	12	37
WNW	298	41	29	30
NW	337	29	40	31
NNW	34	35	38	27

with those at the one kilometer level. By the time the three kilometer level has been reached, it is probable that isobars are no longer

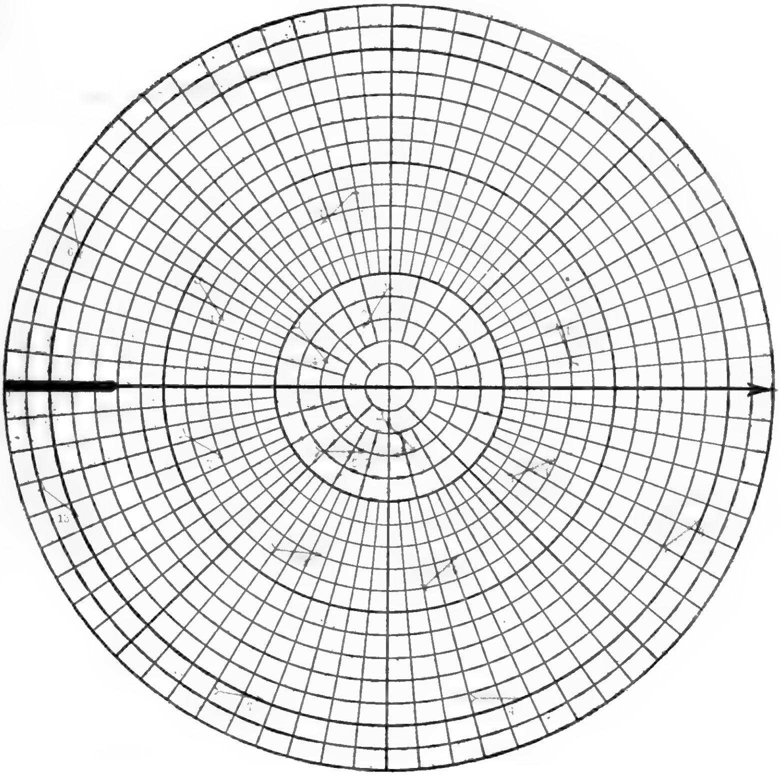


FIG. 13. Mean of Wind Observations in "Lows" at 4000 Meters above Sea Level, 1907–1912.

closed. The change in direction of the wind with height may be shown in a general way by Table I., based upon data obtained at the Mount Weather Observatory.

Tables II. and III. show frequency and speed, respectively, of winds at different levels above Mount Weather. Table II. indicates the decided increase in frequency of west and westerly winds with height. The increase in wind speed with height is rapid for the first 500 to 700 meters above the earth's surface, less rapid at higher levels.

In the study of any convective system the temperature distribution in the system is of prime consideration. The vertical distribution of temperature is of interest to the aëronaut, not only in connection with the filling and ascensional rates to be expected of balloons but also as the best available index of the condition of the atmosphere with respect to stability.

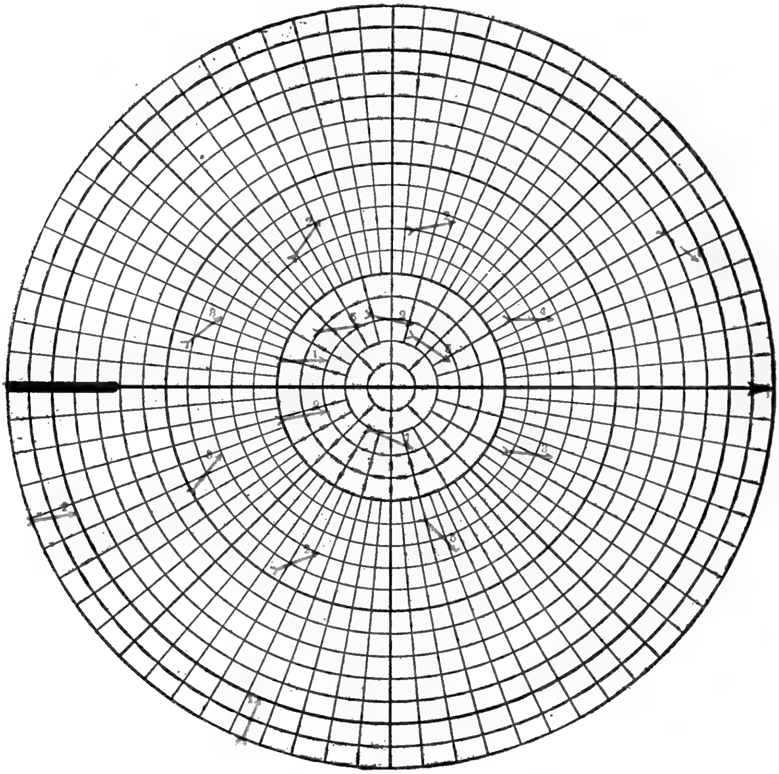


FIG. 14. Mean of Wind Observations in "Highs" at 5000 Meters above Sea Level, 1907–1912.

Fig. 16 shows the temperature distribution throughout the year up to the five-kilometer level. It is based on 5 years of observation at Mount Weather. The isotherms are farther apart vertically in the winter than in the summer months, indicating less stable atmospheric conditions in the summer months. The decrease in the amplitude of the annual variation of temperature with height is apparent; also, the difference in rates of rise and fall of temperature before and after the annual maximum.

Fig. 17 shows the vertical distribution of temperature to be expected in the different quadrants of the high-pressure area, based on five years of observation at Mount Weather, while Fig. 18 con-

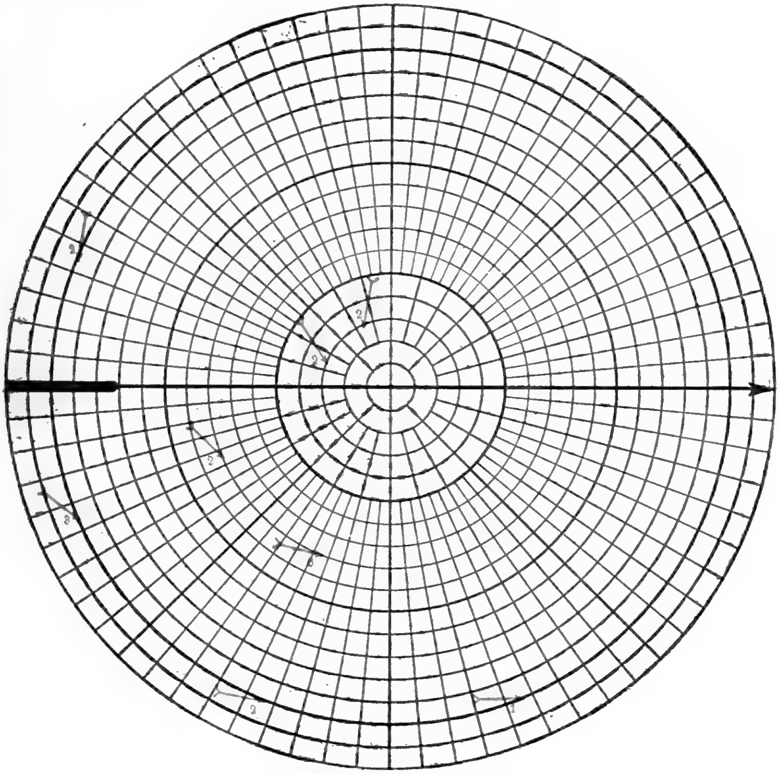


Fig. 15. Mean of Wind Observations in "Lows" at 5000 Meters above Sea Level, 1907–1912.

tains similar information for low-pressure areas. The temperature-altitude relation for a condition of neutral equilibrium in the atmosphere would be represented on one of these charts by a line drawn at an angle of 45° to the axes. Such a gradient is more nearly approached by average conditions in the high-pressure areas of the summer months than elsewhere, but the height to which it extends does not often exceed 1,500 meters in these latitudes.

Other convective systems than the planetary are in independent

TABLE II.

RELATIVE FREQUENCY (PER CENT.) OF WINDS FROM THE DIFFERENT DIRECTIONS OBSERVED AT EACH LEVEL.

Wind Direction.	Altitude of Each Level (Meters).											
	526.	750.	1,000.	1,250.	1,500.	2,000.	2,500.	3,000.	3,500.	4,000.	4,500.	5,000
N	0.2	2.5	2.2	1.7	2.0	2.8	2.2	1.9	1.8	...	...	...
NNE	...	...	1.1	1.2	1.8	1.6	2.2	1.9	1.2	1.9	1.7	...
NE	0.4	...	0.4	0.4	0.2	...	...	...	...	...	...	...
ENE	0.4	0.2	0.2	0.4	...	...	...	...	...	...	...	...
E	3.5	1.6	0.9	0.8	0.8	0.5	...	...	...	...	...	...
ESE	2.6	2.0	2.2	1.0	0.8	...	...	...	...	...	...	...
SE	14.1	3.2	2.4	2.1	0.8	0.2	0.3	...	...	...	...	...
SSE	9.6	10.6	6.2	3.7	2.0	0.9	...	...	...	...	...	...
S	7.5	12.4	12.4	9.0	6.4	2.5	0.8	0.7	...	...	...	...
SSW	0.7	6.5	7.6	11.5	10.4	8.8	7.8	5.6	3.6	1.0	...	...
SW	2.1	3.4	5.6	8.0	10.0	12.5	14.1	13.0	13.6	9.4	6.9	12.5
WSW	3.5	3.4	4.9	5.6	6.8	7.6	7.2	13.0	15.4	16.0	8.6	4.1
W	8.9	7.4	7.6	8.7	10.2	18.1	23.0	22.7	21.9	28.3	36.2	50.0
WNW	26.4	20.1	19.5	18.8	19.0	19.7	18.8	21.3	25.4	31.1	29.3	12.5
NW	17.0	19.4	19.3	19.5	19.2	17.8	18.3	14.5	13.6	8.5	12.1	8.3
NNW	3.3	7.2	7.6	7.5	9.4	6.9	5.3	5.6	3.6	3.8	5.2	12.5

operation. They are set up locally because of peculiarity of topography of the earth's surface or in its nature so far as ability to absorb and radiate heat is concerned. The variation in the intensity of insolation during the twenty-four-hour period also gives rise to a convective system which is of especial interest to the aëronaut. Figs. 19 and 20 show the temperature distribution up to the three-kilometer level accompanying the diurnal convective system, as it has been observed at Mount Weather on clear days. Fig. 19 is based on data for the summer half of the year and Fig. 20 for the winter half. The horizontal circulation that obtains in this convective system is not often in direct evidence. It usually manifests itself as a modification in the direction and speed of the wind prevailing at the time and need not now be further considered. The height to which turbulence in the air, caused by the heating of the earth's surface during the day, extends and the time of greatest activity in this stratum are shown to be, on the average, between 1.5 and 2 kilometers above sea level in the summer months, between 1 and 1.5 kilometers in the winter months. The height of the observing station on the Blue Ridge was 526 meters above sea level.

TABLE III.

Mean Velocity of Winds from Each of the 16 Points at Each Level. Year.

Wind Direction.	526 (Surface).		750.		1,000.		1,250.		1,500.		2,000.		2,500.		3,000.		3,500.		4,000.		4,500.		5,000.	
	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.	Number of Observations.	Mean Velocity, m.p.s.
N	1	2.8	14	9.2	12	11.9	9	11.3	10	9.6	12	10.4	8	10.5	5	14.5	3	13.2	...	...	...	...	...	...
NNE	...	...	...	...	6	12.8	6	10.7	9	9.4	7	10.1	8	10.3	5	13.9	2	14.4	2	17.2	1	24.5	...	...
NE	2	3.6	...	...	2	7.2	2	7.9	1	7.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ENE	2	4.7	1	8.5	1	10.2	2	10.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
E	20	5.6	9	8.7	5	10.4	4	8.1	4	8.0	2	15.0	...	...	...	...	...	...	...	...	...	...	...	...
ESE	15	6.5	11	7.4	12	9.3	5	9.8	4	10.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SE	81	8.0	18	9.3	13	9.1	11	9.3	4	9.9	1	9.0	1	18.3	...	...	...	...	...	...	...	...	...	...
SSE	55	7.7	59	10.9	34	11.7	19	9.4	10	7.2	4	10.4	...	...	...	...	...	...	...	...	...	...	...	...
S	43	6.5	69	12.0	68	10.8	47	13.4	32	14.0	11	12.5	3	12.5	2	12.8	...	...	...	...	...	...	...	...
SSW	4	5.7	36	11.5	42	14.0	60	14.4	52	14.9	38	16.2	28	17.4	15	19.1	6	22.8	1	24.6	...	...	...	...
SW	12	5.9	19	10.9	31	13.5	42	14.8	50	15.9	54	15.6	51	16.8	35	18.3	23	20.3	10	22.2	4	19.4	3	22.7
WSW	20	6.6	19	10.0	27	15.3	29	15.8	34	15.3	33	16.0	26	18.1	36	21.2	26	21.7	17	22.6	5	25.5	1	18.0
W	51	8.0	41	12.0	42	14.6	45	17.3	51	18.9	78	19.9	83	21.4	61	21.7	37	22.2	30	22.4	21	24.2	12	26.2
WNW	152	10.7	112	13.1	107	13.8	98	16.3	95	16.9	85	17.1	68	17.6	58	19.4	43	20.7	33	24.3	17	23.7	3	27.8
NW	98	10.0	108	13.3	106	12.4	102	15.4	96	16.4	77	18.1	66	19.3	39	20.1	23	21.1	9	19.7	7	24.5	2	23.7
NNW	19	6.8	40	10.9	42	12.9	39	13.5	47	12.9	30	13.8	19	14.5	15	17.5	6	22.2	4	21.6	3	22.3	3	25.7

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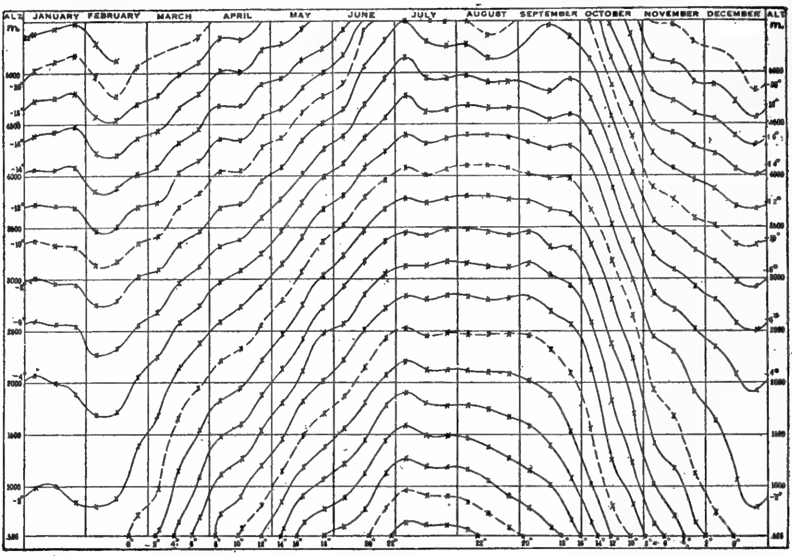

FIG. 16. Mean free air temperatures above Mount Weather, Va.

the station being 300 meters higher than the floors of the valleys on either side of the Ridge. Aërial navigation in this turbulent region is considerably more difficult than it would be outside the limits of the region.

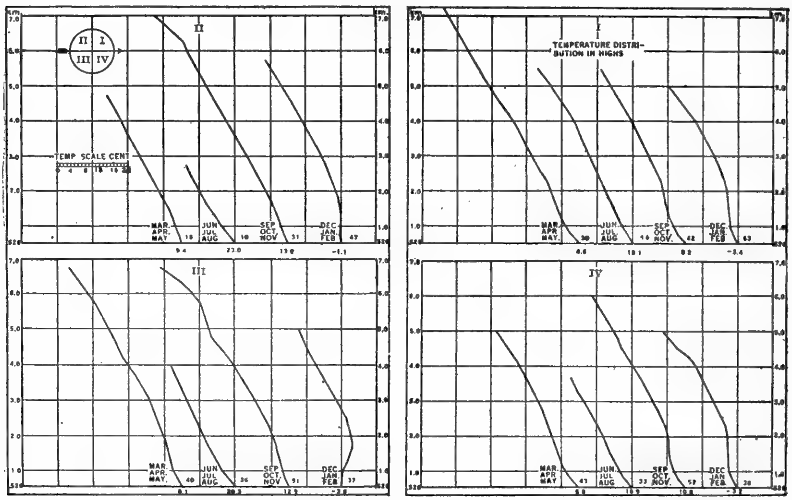

FIG. 17. Temperature distribution in highs observed at Mount Weather.

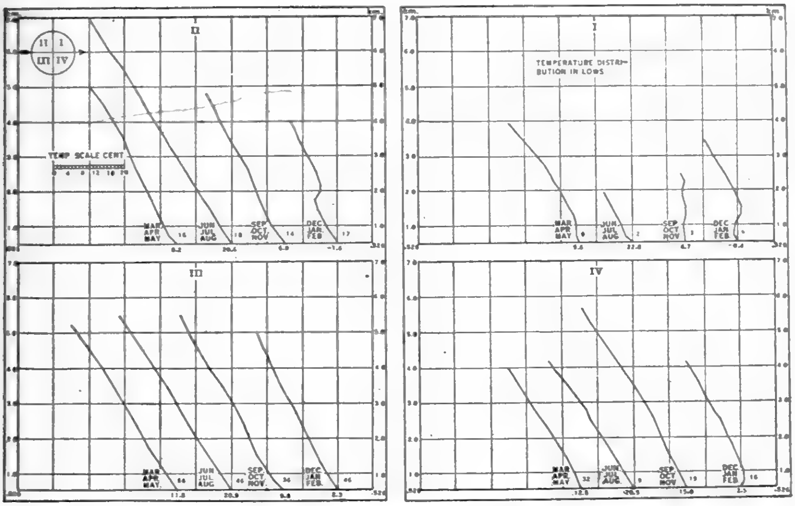

FIG. 18. Temperature distribution in lows observed at Mount Weather.

The gustiness of the wind is also a source of some difficulty to the aëronaut. This is especially true of surface winds because here the gusts follow each other at shorter and less regular intervals than do those occurring in winds at the higher levels. Each gust con-

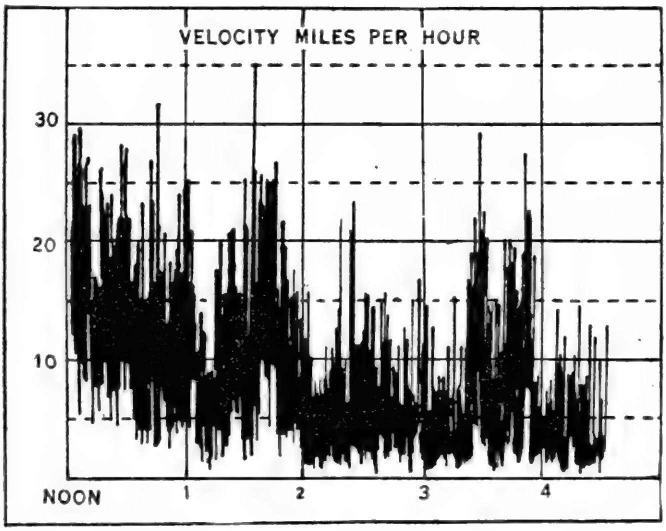

FIG. 22. Record of wind speed and force by pressure tube anemometer.

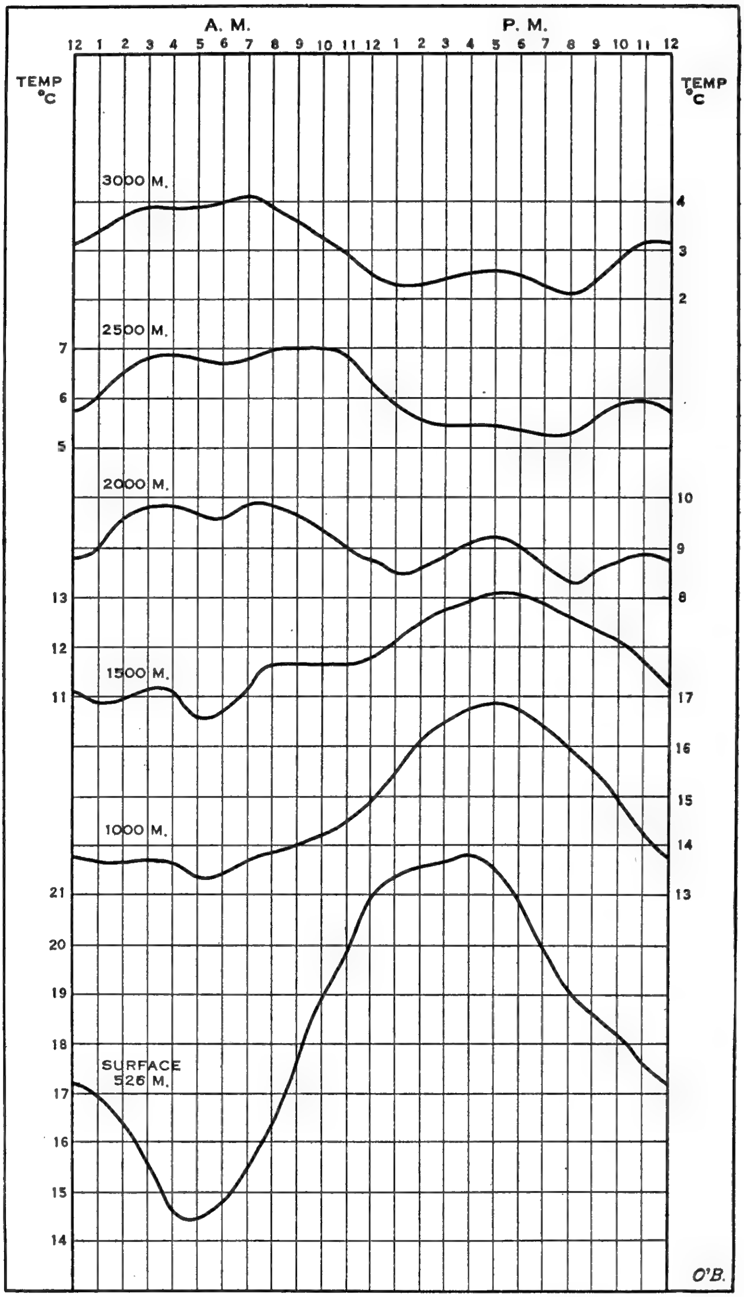

FIG. 19. Diurnal distribution of temperature for the summer half of the year at different levels above Mount Weather.

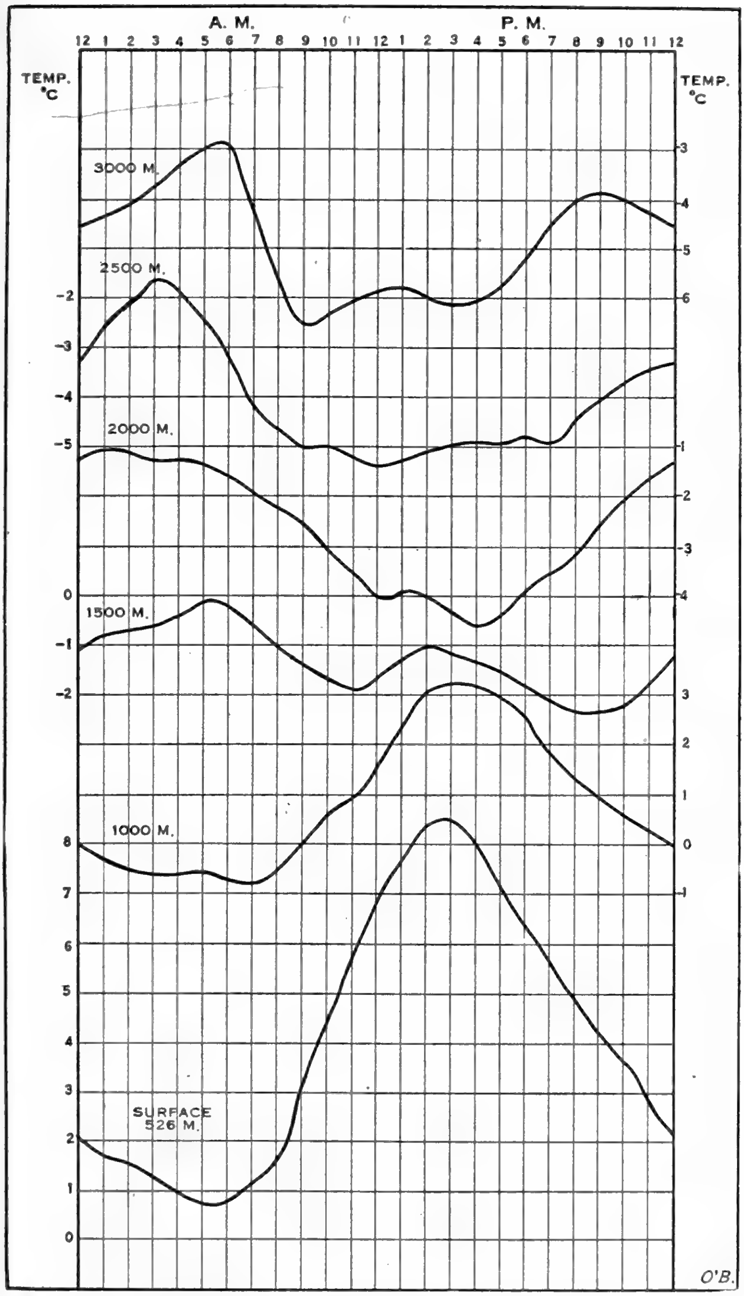

FIG. 20. Diurnal distribution of temperature for the winter half of the year at different levels above Mount Weather.

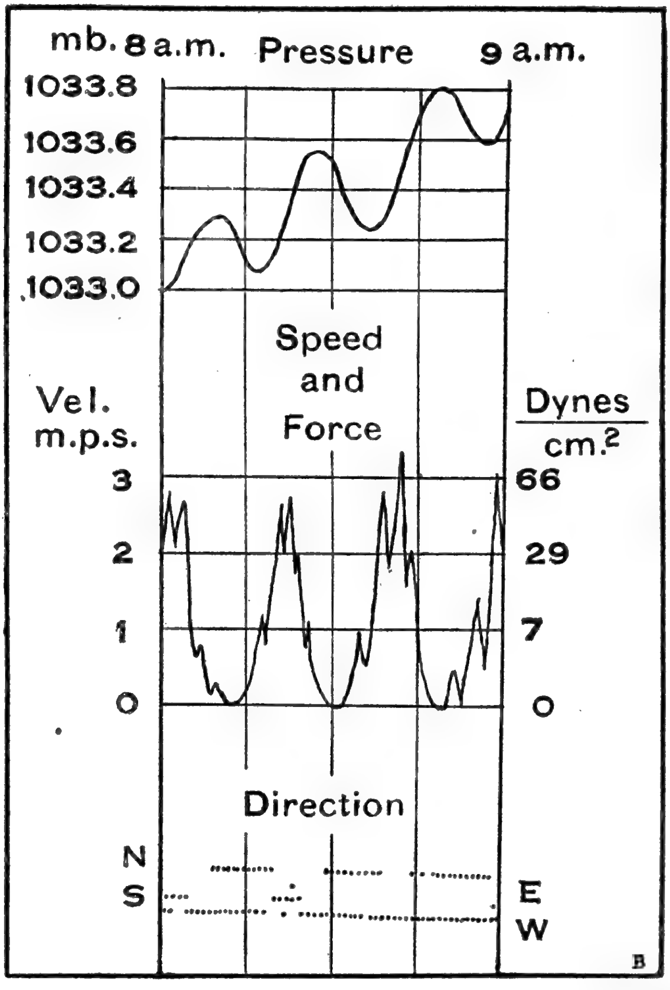

FIG. 21. Relation between speed, force, pressure and direction in wind gusts.

sidered separately is a complete convective unit in which occur appropriate changes in air pressure, temperature and in speed and direction of movement. Fig. 21 illustrates a series of changes in wind speed with accompanying changes in wind direction and air pressure. Fig. 22 (see page 207) is a part of a record made by a pressure tube anemometer showing frequency and amplitude of gusts as they occur in the average westerly wind. The acceleration in the horizontal component of the wind speed shown is about 7.5 centimeters per second. It would require a horizontal acceleration of 17 to 20 times this amount to sustain a bird or a well-constructed glider in soaring flight, but together with the changes in direction in the horizonal plane recorded by our instruments, vertical changes in direction occur in these gusts which are really only a series of expansions and contractions in the moving air.

When the air expands and contracts with sufficient rapidity, the vibrations become audible. The use of these vibrations and possibly of aërial vibrations of still higher frequency in detecting the presence of aircraft or as a means of communication between aircraft or to receiving stations is outside the scope of this paper.

The subject of atmospheric electricity and possibly closely connected with it the loading of aircraft with liquid or solid H_2O are also matters of interest to the aëronaut. So far not much has been done toward the solution of the problems arising from these atmospheric conditions. It is likely that the solid formations, both crystalline and amorphous, occur more readily, if not altogether, on electrically charged surfaces.

U. S. Weather Bureau,
Washington, D. C.

V

THEORY OF AN AËROPLANE ENCOUNTERING GUSTS, II.

By EDWIN BIDWELL WILSON.

1. This discussion is an immediate continuation of my previous treatment of the subject published in the First Annual Report of the National Advisory Committee for Aëronautics, Washington, 1915, pp. 52–75 (Senate Document, 268, 64th Congress, 1st Session, reference to which will be by pages). The notations of that work will be continued without change except as hereafter noted.

Periodic Longitudinal Gusts.

2. That there is a certain degree of periodicity in gusts is obvious from casual observation, from the records of scientific observatories like Blue Hill, and from the familiar fact that all such phenomena in nature reveal a general tendency toward periodicity. Needless to say the periodicity is not mathematically exact in its regularity nor indefinite in continuance.

The object, however, of an investigation of the effect of periodic gusts on an aëroplane can for practical purposes be no other than to reveal any exceptional effects that periodic, as compared with single, gusts may have upon the flight of the machine; and these exceptional effects will probably be indicated with sufficient practical completeness by an analysis built on the assumption of strict periodicity, long continued in operation—the phenomenon most to be feared being resonance.

3. The longitudinal gusts are in, 1°, head-on velocity u_1; 2°, vertical velocity w_1; 3°, rotary velocity q_1. Very little is known as to the nature of rotary gusts (p. 65) and hence 3° may be left aside. It is not easy to see how vertical gusts can have any pronounced periodicity; the disturbance of the aëroplane's motion by vertical

gusts is (p. 64), except for very sharp gusts, essentially a convection of the machine with and by the gust; for both these reasons 2° may be discarded. This leaves only 1°—periodicity in the head-on gustiness—as likely to be of interest.

The gust may be assumed in the form

$$u_1 = J \sin pt \quad \text{or} \quad u_1 = Je^{ipt}. \tag{1}$$

The differential equations are (p. 59)

$$\begin{aligned} f(D)u &= -(0.128D^3 + 1.160D^2 + 3.385D + 0.917)u_1, \\ f(D)w &= -D^2(0.557D + 2.458)u_1, \\ f(D)\theta &= -0.02851Du_1, \end{aligned} \tag{2}$$

$$\begin{aligned} \text{with } f(D) &= D^4 + 8.49D^3 + 24.5D^2 + 3.385D + 0.917 \\ &= (D^2 + 8.359D + 23.37)(D^2 + 0.1308D + 0.03924). \end{aligned}$$

4. In the previous investigation it was found that the short-period heavily damped oscillation was not of much significance except in the case of a sharp up-gust (pp. 62–69), and that its significance in that case was not revealed in the major motion of the machine but in the initial acceleration (or stress) upon it. It may therefore be expected that for periodic head-on gusts the short-period motion will be negligible in its effects. It is consequently desirable to carry out the numerical analysis in such a way as to separate, so far as may be, the short and long natural periods of the machine.

Let us separate into partial fractions the operator

$$\frac{1}{f(D)} = \frac{1}{(D^2 + 8.359D + 23.37)(D^2 + 0.1308D + 0.03924)},$$

or

$$\frac{1}{f(D)} = \frac{0.016D + 0.089}{D^2 + 8.359D + 23.37} + \frac{-0.01601D + 0.04263}{D^2 + 0.1308D + 0.03924}. \tag{3}$$

The first fraction has to do with the short, the second with the long oscillation. The two operators are to be applied to certain expressions derived from (1) by substitution in (2).

5. If $D = ip$, the numerators of (3) have the respective magnitudes

$$(0.089^2 + 0.016^2p^2)^{1/2} \quad \text{and} \quad (0.0426^2 + 0.016^2p^2)^{1/2}.$$

For $p=0$, the second is about half the first; for $p=\infty$, the two are equal; the numerators therefore do not differ greatly in magnitude for any value of p.

The ratio of the denominators is

$$R=\left[\frac{(.03924-p^2)^2+.1308^2p^2}{(23.37-p^2)^2+8.329^2p^2}\right]^{1/2},$$

and is very small when p is less than 1. For larger values of p, we have approximately

$$1/R^2=1+23.2/p^2+545/p^4.$$

Hence the short oscillations may be neglected when $p<1$ without introducing much error; but as p increases beyond the value 1, the importance of the short oscillation grows rapidly.

6. Consider first the case $p<1$, neglecting the short oscillation. The particular solutions for u, w, and θ, that is, I_u, I_w, I_θ, are obtained from the imaginary parts of

$$\begin{aligned}\frac{u}{J}&=\frac{-.01601pi+.04263}{-p^2+.1308pi+.03924}(.128p^3i+1.16p^2-3.385pi\\&\qquad\qquad-.917)e^{ipt},\\ \frac{w}{J}&=\frac{-.01601pi+.04263}{-p^2+.1308pi+.03924}(.557p^3i+2.458p^2)e^{ipt},\qquad(4)\\ \frac{\theta}{J}&=\frac{-.01601pi+.04263}{-p^2+.1308pi+.03924}(-.02851pi)e^{ipt}.\end{aligned}$$

To estimate the value of p corresponding to the maximum disturbance we may examine the amplitude of θ/J, which is

$$\text{amp.}\frac{\theta}{J}=.02851p\left[\frac{(.04263)^2+(.016p)^2}{(.03924p^2)^2+(.1308p)^2}\right]^{1/2}.\qquad(5)$$

The calculation gives $p^2=0.0394$ or $p=0.1985$. The value of the amplitude is then about $0.0095J$ radians or $0.54J$ degrees. If J should be 20 ft./sec., the forced oscillation would have an amplitude of about 10°.

7. As the use of $p=0.1985$ in calculating is somewhat more complicated than the use of $p=0.2$, and as the change from 0.1985 to 0.2 does not materially alter the amplitude of the forced oscillation (and probably does not exceed the error of observations), we

may use $p = 0.2$ in calculating the effect of a periodic gust of maximum resonance on the aëroplane. We shall first note that for $p = 0.2$ the ratio of the amplitudes of the two fractions in (3) is of the order 400 to 1, and the first fraction is therefore entirely negligible in determining the particular integrals.

For the second fraction we have the complex value

$$\frac{4.263 - .32i}{2.616i - .076} = \frac{(4.275, \ -4.3^\circ)}{(2.617, \ 91.6^\circ)} = \left(\frac{4.275}{2.617}, \ -95.9^\circ\right),$$

where the parentheses contain the polar coördinates of the complex numbers. The expressions into which this is multiplied to determine the coefficients of e^{ipt} are for u/J, w/J, θ/J respectively

$$-0.922 - 0.676i = (1.144, \ 216.24^\circ),$$

$$0.0983 + 0.00456i = (.0984, \ 2.67^\circ),$$

$$-0.0057i = (.0057, \ -90^\circ).$$

Hence the values of u/J, w/J, θ/J are

$$u/J = (-.965 + 1.65i)(\cos .2t + i \sin .2t),$$

$$w/J = (-.00918 - .164i)(\cos. .2t + i \sin .2t),$$

$$\theta/J = (-.00948 + .00098i)(\cos .2t + i \sin .2t),$$

and $I_u = J(1.65 \cos .2t - .965 \sin .2t)$,

$$I_w = J(-.164 \cos 2t - .0092 \sin .2t).$$

$$I_\theta = J(.00098 \cos .2t - .00948 \sin .2t),$$

$$I_\theta' = J(-.0019 \cos .2t - .0002 \sin .2t),$$

$$I_{u0} = 1.65J, \quad I_{w0} = -.164J, \quad I_{\theta 0} = .00098J, \quad I'_{\theta 0} = -.0019J.$$

8. On substituting these values to find the constants of integration (p. 61), it is found that A and C, corresponding to the short oscillation in u, are negligible. Also $B = -1.65J$, $D = .726J$. Hence

$$u = Je^{-.0654t}(-1.65 \cos .187t + .726 \sin .187t) + J(1.65 \cos .2t - .965 \sin .2t).$$

In like manner (p. 62), A' and C' are small and $B' = .176J$, $D' = -.051J$.

$$w = Je^{-.0654t}(.176 \cos .187t - .051 \sin .187t)$$
$$- J(.164 \cos .2t + .009 \sin .2t) - .012Je^{-4.18t} \cos 2.43t.$$

(The last term is added as a check on the initial condition $w=0$.) Finally (p. 62), $A''=.00007J$, $B''=.00104J$, $D''=.0109J$, and

$$\theta = Je^{-.0654t}(-.00104 \cos .187t + .0109 \sin .187t)$$
$$+ J(.00098 \cos .2t - .00948 \sin .2t) + .00007Je^{-4.18t} \cos 2.43t.$$

9. Now to find the rise of the machine when the gust strikes it (p. 64).

$$w + 115.5\theta = Je^{-.0654t}(.056 \cos .187t + 1.208 \sin .187t)$$
$$- J(.051 \cos .2t + 1.064 \sin .2t).$$

The cosine terms may be omitted. The integration then gives

$$z = 5.32J \cos .2t + 0.44J - Je^{-.0654t}(2 \sin .187t + 5.76 \cos .187t).$$

A table of values of z may be computed as:

$t=0$,	2,	4,	6,	8,	10,	12,	14,
$z/J=0$,	0,	—.15,	—.54,	—1.16,	—1.90,	—2.60,	—2.97.

This shows the rise or drop, according as J is negative or positive, during the first quarter minute. The values of z now fall off, pass through 0, and only become large as t nears 35. The natural oscillation is then becoming less effective relative to the forced oscillation which has a double amplitude of about $10.6J$, or 202 ft. if $J=20$ ft./sec.

As the existence of a regular periodic gust for any long time is almost unbelievable, the only real interest in the calculation is in showing that during the first 15 seconds the effect of resonance fails to become so far established that the motion differs appreciably from that due to the simple head-on gust previously studied (p. 74).

10. In the case of the machine constrained to remain horizontal during flight (by some automatic steering device), the corresponding equations (p. 69) are for $u_1 = Je^{ipt}$

$$\frac{u}{J} = -\frac{.128pi + .598}{.598 - p^2 + 4.078pi} e^{ipt},$$

$$\frac{w}{J} = -\frac{.557pi}{.598 - p^2 + 4.078pi} e^{ipt}.$$

As the natural motion is no longer periodic, there can hardly be any such thing as resonance, in the usual acceptation of that term. We can, however, ask what value of p will make w/J a maximum and hence induce the maximum oscillation in the vertical motion. To maximize

$$\frac{p^2}{(.598 - p^2)^2 + 4.078^2 p^2} \quad \text{or} \quad \frac{1}{4.078^2 + (p - .598/p)^2}$$

take $p^2 = 0.598$ or $p = 0.774$. The value of w/J is then

$$w/J = -0.136 e^{ipt},$$

and the amplitude of w is $0.136J$. The amplitude of the oscillation corresponding to the particular solution I_w is $0.175J$.

Thus again it is seen that the steering device makes the motion far easier than when the machine is free (p. 70). There seems to be no need of carrying out the details of the integration.

Note on Resonance.

11. In defining, by implication, a state of resonance in the calculations above, I have assumed that it was the angle θ which was to be maximized by the proper choice of the frequency p of the applied periodic force. It may be well to take up the theory of resonance in a little greater detail, for there are complications in the kind of system we have here to consider.

A. G. Webster, in his "Dynamics of Particles, etc.," Teubner, 1904, p. 175, gives general formulas for resonance and shows that if the damping coefficients are small and if the frequency of the impressed force nearly coincides with that of the natural oscillation, the amplitude of the forced vibration will be relatively large.

This is not enough. For in the first place, the damping coefficients in the case of the aëroplane can hardly be regarded as small (they sometimes exceed the frequencies); in the second place, we are not even certain that the motion of the system is wholly oscillatory (some of the roots may be real, and even positive if the machine has a certain amount of dynamical instability); and in the third place, under such conditions, the amplitude of the forced oscillation may be considerably greater when the frequency of the applied force is materially different from that of the system (supposed oscillatory) than when the system and the force are nearly synchronous.

12. The ordinary theory of simple resonance depends on the equation

$$(D^2 + kD + n)x = J \sin pt.$$

The particular solution

$$I_x = \frac{J}{D^2 + kD + n} \sin pt$$

is the imaginary part of the expression

$$x = \frac{Je^{ipt}}{n - p^2 + kpi}.$$

The amplitude of I_x is the same as the modulus of the complex value x. The modulus of e^{ipt} is 1; that of x is

$$\text{amp. } I_x = \frac{J.}{[(n - p^2)^2 + k^2p^2]^{1/2}}.$$

13. To make the denominator a minimum we have merely to minimize

$$(n - q)^2 + k^2q, \quad q = p^2 > 0.$$

We find $q = n - \frac{1}{2}k^2$, necessitating $n > \frac{1}{2}k^2$. If, then, $n > k^2$, the maximum amplitude of I_x is

$$\text{max. amp. } I_x = \frac{J}{\pm k \sqrt{n - \frac{1}{4}k^2}},$$

where the positive or negative sign must be taken according as k is positive or negative. If $n < \frac{1}{2}k^2$, the maximum amplitude for I_x occurs when $p = 0$ and is J/n.

The amplitude is large when k or $(n - \frac{1}{4}k^2)^{\frac{1}{2}}$ is small; it is very large when both conditions are satisfied. The largest possible value occurs when $n = \frac{1}{2}k^2$ and is $\sqrt{2}J/k^2$. In this case the applied force has an indefinitely small frequency where the natural oscillation has the frequency $k/\sqrt{2}$. The theory of the system here considered is given by Webster (op. cit., p. 155).

14. The case which corresponds to that in which we are interested is where the system starts from rest at the position of

equilibrium. The motion is then defined by the equation

$$x = \frac{J\sqrt{n - \frac{1}{2}k^2}}{k(n - \frac{1}{4}k^2)}(e^{-\frac{1}{2}kt}\cos\sqrt{n - \tfrac{1}{4}k^2}t - \cos\sqrt{n - \tfrac{1}{2}k^2}t)$$

$$+ \frac{J}{2(n - \frac{1}{4}k^2)}\left(\frac{\sqrt{n - \frac{1}{2}k^2}}{\sqrt{n - \frac{1}{4}k^2}}e^{-\frac{1}{2}kt}\sin\sqrt{n - \tfrac{1}{4}k^2}t - \sin\sqrt{n - \tfrac{1}{2}k^2}t\right).$$

Under normal conditions this quantity remains tolerably small until the natural motion is nearly damped out or until that motion has time to increase greatly ($k > 0$). Even if $n = \frac{1}{2}k^2 + \epsilon^2 k^2$, the equation becomes

$$x = \frac{2J\epsilon}{k^2}(e^{-\frac{1}{2}kt}\cos\tfrac{1}{2}kt - \cos\epsilon kt) + \frac{2J}{k^2}(\epsilon e^{-\frac{1}{2}kt}\sin\tfrac{1}{2}kt - \sin\epsilon kt),$$

and the conclusion still holds.

For the simple system ordinarily treated for resonance the statement that the motion must be only slightly damped and the frequencies of the natural and forced vibrations must be reasonably near together, is therefore amply justified. The result holds even when $n < \frac{1}{2}k^2$, in which case the maximum amplitude for I_x (resonance) occurs when $p = 0$ and is J/n.

15. The next simplest case is like that which arises in treating the constrained longitudinal motion ($\theta = 0$) of the aëroplane (p. 69):

$$(D + a)u + bw = -au_1 - bw_1, \quad a = .128, \quad b = -.162,$$

$$cu + (D + d)w = -cu_1 - dw_1, \quad c = .557, \quad d = 3.95.$$

The natural motion is given by

$$\Delta' = D^2 + (a + d)D + (ad - bc) = 0,$$

and in this case by $D^2 + 4.078D + .598 = 0$. Here the roots are both real, viz., -3.93 and -0.15. So far as the equation in D is concerned we have the case where k is large and n is small. The equations for the forced motion are

$$\Delta' u = -(aD + n)u_1 - bDw_1,$$

$$\Delta' w = -(dD + n)w_1 - cu_1.$$

The question now arises: What is it that is to be a maximum?

For some purposes it might be the variables u or w—for example, the whole theory of gusts here given depends on the gust being small and producing small effects, and if by an applied force, the values of u or w should become too large, the theory would become worthless. Again, if the question had to do with the strain on the machine, the derivatives du/dt and dw/dt would be the essential objects of interest, and should be maximized. Finally it might be the values $x = \int u dt$ and $z = \int w dt$—the actual displacements of the machine—which we desired to examine. Let us therefore consider several problems seriatim.

16. *Case 1.*—To maximize u with a head-on gust $u_1 = e^{ipt}$.

$$u = -\frac{aip + n}{\Delta'} e^{ipt} = -\frac{.128ip + .598}{.598 - p^2 + 4.098ip} e^{ipt}.$$

The maximum value of

$$\frac{.128^2 p^2 + .598^2}{(.598 - p^2)^2 + 4.098^2 p^2} = \frac{.128^2(p^2 + 21.83)}{p^4 + 15.59p^2 + .3576}$$

occurs when p^2 is 0, that is, "resonance" occurs for $p = 0$, the amplitude of the force and the oscillation being the same.

Case 2.—To maximize w with a head gust.

This was treated above (§ 10). The ratio .136 was found; the required value of p was .776.

Case 3.—To maximize u with an up-gust w_1.

$$u = \frac{.162pi}{.598 - p^2 + 4.098pi} e^{ipt}.$$

The condition is $p = .776$ as is Case 2; the ratio is .04.

Case 4.—To maximize w with an up-gust.

$$w = -\frac{3.95pi + .598}{.598 - p^2 + 4.098pi} e^{ipt}.$$

The maximum value of

$$\frac{3.95^2 p^2 + .598^2}{(.598 - p^2)^2 + 4.098^2 p^2} = \frac{3.95^2(p^2 + .0228)}{p^4 + 15.59p^2 + .3576}$$

occurs when $p^2 = .022$ and $p = .15$, and the amplitude ratio is about 1.

We note the very different values of p thus found, namely, 0, 0.15, 0.776, according to the choice of case. If in Case 1, we had taken $p = .15$, the amplitude ratio would have been about .7 instead of 1; if $p = .776$ had been assumed, the ratio would have been .37 instead of 1.

Case 5.—If we desired to maximize z we should have had to treat

$$-\frac{1}{i}\frac{3.95i + .598/p}{.598 - p^2 + 4.098pi}e^{ipt},$$

which would have given an infinite amplitude ratio for $p = 0$.

17. Now if we turn to the free machine and try to maximize $\int\theta dt$ instead of θ, we have to maximize

$$\frac{.04263^2 + .016^2 p^2}{(.03924^2 - p^2)^2 + .1308^2 p^2}$$

instead of (5, § 6). The value of p^2 is about .0307 and of p about .175 instead of .2 as before. The amplitude ratio is then only slightly in excess (about 4 per cent.) of that previously found—in other words the numerical values are such that resonance for θ and for $\int\theta dt$, which is the preponderating term in the expression for z, occurs for considerably different values of p, but the effect is about the same. This may be regarded as validating our procedure (§ 6) in maximizing θ instead of $\int\theta dt$.

18. To sum up this discussion of resonance as applied to the aëroplane we may say that the frequencies which produce "resonance" depend largely upon the quantity in which the effect of resonance is to be sought and that the frequency which makes for a strong resonant effect in one quantity may make on another an effect much weaker than the maximum—or it may not.

19. There remains to discuss the question whether the effect of resonance is practically serious, *i. e.*, whether as in the case of the motion of the machine, above treated, the effect fails to make itself felt until after so long a time that the pilot would be entirely able to deal with it or the wind would really have in all probability ceased to be periodic with the period required.

Now in order to insure that resonance is effective both of itself and as against the natural motion, we should reasonably expect to require, 1°, that the resonant frequency p be large (for if it be small the pilot will have ample time to take care of it), and that, 2°, it be reasonably different from any natural frequency which is only slightly damped (for in the latter case the initial conditions will probably be such as to cause the natural and forced effects to clash for a considerable interval of time).

This problem in its generality is so complicated that I have as yet been unable to determine whether there may be practically serious effects due to resonance, but from the cases I have here treated, from the general considerations which I have advanced, with due regard to the restrictions on p which appear to be reasonable, and from cases which I have examined without mentioning them here, I should judge that resonance is not a practically serious matter in longitudinal motion, and that we may safely confine our attention to gusts of the form $J(1-e^{-rt})$.

20. One type of resonance which deserves consideration is that of the damped harmonic gust $Je^{-nt} \sin pt$. It would be conjectured that if $-n \pm pi$ were nearly equal to a pair of roots of $\Delta = 0$, there might arise a considerable disturbance. It is not likely that a gust of this type would exist in reality, but the commencement of any gust might resemble very closely the commencement of such a gust and if the effect of this type were very marked as compared to that of the types already considered, it would be necessary, for the sake of foreseeing the worst that could happen, to discuss this type.

I have not time to take the matter up here. Moreover, I imagine that it would be found that the constants of integration turned out to have such values that the gust, though tuned in damping and in frequency to the natural motion of the machine, did not have very large effects except in cases where n and p were small enough to allow the pilot easily to correct for the disturbance.

The damped periodic gust has been treated by Brodetsky,[1] who finds the amplitude of the particular solution is a maximum (for the machine I am dealing with) when $t = 16$ sec. and is then a tolerably large quantity,—but the pilot has a quarter of a minute in which to react to his environment. It is, however, by no means certain that

[1] *Aëronautical Journal,* London, 20, 1916, p. 154.

the pilot would have to react so quickly—the constants of integration might turn out, as I have just suggested, such that the motion during the first quarter minute was not far different from that in the case of the simple gust. This was what was found to happen in the case of the periodic gust above treated (§ 9). The amplitude of the vertical motion so far as the particular solution was concerned turned out to be about $5.3J$, but the constants of integration were such as to postpone the major effect of the particular solution until 30 or 40 seconds had elapsed. If we have a damped harmonic gust and such a postponement were operative, the damping would become effective and the gust might turn out to have at no time an effect much in excess of the maximum effect of a single gust of the form $J(1 - e^{-rt})$.

Infinitely Sharp Gusts.

21. In my previous paper I discussed gusts $J(1 - e^{-rt})$ rising from zero to J with various degrees of sharpness depending on the value of r—the larger r, the sharper the gust. An infinitely sharp gust would be one for which r was indefinitely large. Such a gust would represent an absolute discontinuity in the velocity of the wind. This is impossible, though it represents a state of aërial motion which may be nearly approached. Moreover, the infinitely sharp gust could not strike the machine all over at once, and hence the theoretical effect of such a gust on the assumption that the machine is instantaneously immersed must differ from the actual effect upon a machine running into a discontinuity in the wind velocity.

For this reason one may well limit his considerations to finite gusts with a value of r not greater than 5, say, as I did. Nevertheless if the calculation of the effect of an infinitely sharp gust is simpler than for a finite gust and if the limiting motion derived for such a gust is not appreciably different from that for a sharp gust of reasonable sharpness, the discussion of the limiting case will be justified.

22. Consider first the longitudinal motion and a head-on gust $u_1 = J(1 - e^{-rt})$, r enormously large. According to the symbolic method $D = -r$ must be substituted to find the particular solution for e^{-rt}. As, however, Δ is of the fourth degree in D and all the

polynomials upon the right hand are of degree 3 or less, the result of the substitution is easy to find.

For example, when $u_1 = J(1 - e^{-rt})$,

$$I_u/J = -1 - e^{-rt}(.128/r), \qquad I_{u0} = -J,$$

$$I_w/J = -e^{-rt}(.557/r), \qquad I_{w0} = 0,$$

$$I_\theta/J = -e^{-rt}(.02851/r^3) = 0, \qquad I_{\theta 0} = 0,$$

$$I'_\theta/J = e^{-rt}(.02851/r^2) = 0, \qquad I'_{\theta 0} = 0.$$

The equations of motion are

$$u/J = e^{-4.18t}(.0009 \cos 2.43t + .0032 \sin 2.43t)$$
$$+ e^{-.0654t}(.9991 \cos .187t - .3577 \sin .187t) - 1 - e^{-rt}(.128/r),$$

$$w/J = e^{-4.18t}(.1066 \cos 2.43t - .0435 \sin 2.43t)$$
$$+ e^{-.0654t}(-.1066 \cos .187t + .0352 \sin .187t) - e^{-rt}(.557/r),$$

$$100\theta/J = e^{-4.18t}(-.0402 \cos 2.43t - .0278 \sin 2.43t)$$
$$+ e^{-.0654t}(.0402 \cos .187t - .6683 \sin .187t).$$

The calculation of the constants of integration is much simplified. The terms e^{-rt}/r are retained because the stresses (forces) due to the gust are calculated from du/dt and dw/dt to which these terms make an initial contribution—there is an instantaneous initial stress. When $t = 0$,

$$du/dt = (.128 - .004 - .008 - .085 - .067)J = -.016J,$$

$$dw/dt = (.557 - .446 - .106 + .007 + .006)J = .018J.$$

These are the initial accelerations and should vanish because the gust though infinitely sharp begins at zero. That they do not vanish is due to an accumulation of errors.

23. Immediately after the initial instant, however, the first terms, viz., .128 and .557, being multiplied by e^{-rt} vanish. The other terms, however, being multiplied by comparatively slow changing functions are not altered. Hence immediately after the first instant there are accelerations $-.128J$ and $-.557J$ along the x and z axes respectively.

To put it another way, there is a discontinuity in the stress at the initial instant—as might be expected. The amounts of the discontinuities are also just what might be expected, viz., X_uJ and Z_uJ. In like manner for an up-gust the initial discontinuities in acceleration are X_wJ and Z_wJ along the x and z axes. These results could have been foreseen from the differential equations themselves as well as from "common sense." The path in space is not materially different for an infinitely sharp gust from what it is for a reasonably sharp gust.

It may therefore be said that a tolerably good idea of what happens for sharp gusts may be had from the consideration of infinitely sharp gusts.

24. It has just been stated that the conclusions concerning the initial accelerations may be foreseen from the differential equations. This may be proved as follows: We have

$$\begin{aligned}
&(D-X_u)u-X_ww-X_qq-g\theta=X_uu_1+X_ww_1+X_qq_1,\\
&-Z_uu+(D-Z_w)w-(Z_q+U)q=Z_uu_1+Z_ww_1+Z_qq_1,\\
&-M_uu-M_uw+(k_B{}^2D-M_q)q=M_uu_1+M_ww_1+M_qq_1,\\
&\qquad\qquad D\theta-q=0,
\end{aligned}\tag{6}$$

where the equations have been reduced to four involving only the first derivatives of the four variables u, w, q, θ, with the initial conditions $u=w=q=\theta=0$, by the device of choosing $q=D\theta$ as an independent variable so as to eliminate the second derivatives.

These equations determine the first derivatives at the initial instant or at any instant in terms of the values of the variables at that instant, namely,

$$\begin{aligned}
Du&=X_uu+X_ww+X_qq+g\theta+X_uu_1+X_ww_1+X_qq_1,\\
Dw&=Z_uu+Z_ww+Z_qq+Uq+Z_uu_1+Z_ww_1+Z_qq_1,\\
k_B{}^2Dq&=M_uu+M_ww+M_qq+M_uu_1+M_ww_1+M_qq_1,\\
D\theta&=q.
\end{aligned}\tag{7}$$

At the initial instant u, w, q, θ vanish.

With an infinitely sharp gust u_1, w_1, q_1 may be considered as not vanishing but as starting at finite values, J_u, J_w, J_q. The derivatives are then at the initial instant

$$\begin{aligned} Du &= X_u J_u + X_w J_w + X_q J_q, \\ Dw &= Z_u J_u + Z_w J_w + Z_q J_q, \\ k_B{}^2 Dq &= M_u J_u + M_w J_w + M_q J_q, \\ D\theta &= 0. \end{aligned} \qquad (8)$$

The first two equations give the X and Z accelerations of the machine which determine the stresses as the accelerations times the mass.

We have, for numerical values,

$$\begin{aligned} Du &= -.128 J_u + .162 J_w + 0 J_q, \qquad &\text{if } X_q = 0, \\ Dw &= -.557 J_u - 3.95 J_w + 0 J_q, \qquad &\text{if } Z_q = 0, \\ 34 Dq &= 0 J_u + 1.74 J_w - 150 J_q, \qquad &\text{if } M_u = 0. \end{aligned}$$

The last equation determines the couple tending to break the machine, by bending in the x-z-plane, on multiplication by the mass m.

25. That which I have called an infinitely sharp gust is not an impulsive gust. The implusive gust is both infinitely sharp and infinitely intense, but endures for only an infinitesimal time. The effect of an impulsive gust is to produce instantaneous changes in u, w, q. Such an impulse, like the impulses of ordinary mechanics, puts an infinite strain on the machine for an infinitesimal time, and the only way to tell whether the machine will stand the strain is to take the yielding of the framework into account—it is a problem in elasticity. For the purpose of calculating the *stresses* produced by gusts on the machine I therefore prefer the sharp gust to the impulsive gust.

For the purpose of treating the *motion* of the machine after the gust strikes it—the gust being now a sudden fierce squall in otherwise still air—we have merely to determine the constants of integration from the initial condition u_0, w_0, q_0, and $\theta = 0$, where u_0, w_0, q_0 are the impulsively generated velocities. These equations are (p. 61):

$$
\begin{aligned}
u_0 &= A + B, \\
w_0 &= -4.04A + 34.5C - .1058D + .002587D, \\
0 &= -.132A - .0946C + .002478B + .005799D, \\
q_0 &= .703A + .205C - .001246D + .000084D.
\end{aligned}
\tag{9}
$$

Analytically the effect of the impulsive gust upon the equations for determining the constants of integration is merely to replace the initial values of the particular solutions I_{u0}, I_{w0}, $I_{\theta 0}$, $I'_{\theta 0}$, obtained on the hypothesis of finite gusts, by the respective values $-u_0$, $-w_0$, 0, $-q_0$. The effect of the disturbance may therefore be calculated at once from my equations (23), (24), (25), (26), as soon as the values u_0, w_0, q_0 have been determined.

26. In the calculation of u_0, w_0, q_0 the same doubt arises as in the theory of any very sharp gust, namely, the effect of the partial immersion of the machine. Is the effect of a blow traveling along a mechanism the same as that of the blow applied instantaneously at all points of the mechanism? The possibility of a difference between the instantaneous immersion and the immersion distributed in time would arise only if, 1°, the machine had time enough to change its orientation appreciably or, 2°, the acquired velocities were sufficient to change the relative wind and thus affect considerably the impulsive pressure.

Even if we assume that no material difference in effect is to be expected, it is difficult to make the proper assumptions to lead to reasonably satisfactory values for u_0, w_0, q_0 for any actual machine whose characteristics are expressed in terms of the mechanical coefficients m, k_B^2, U, and the aërodynamical coefficients X_u, X_w, X_q, Z_u, Z_w, Z_q, M_u, M_w, M_q. It is by no means certain that for a considerable aërial disturbance the finite instantaneous changes in u, w, q can be calculated from the equations (8) by replacing D by the sign Δ for the increment and taking J_u, J_w, J_q as the intensities of the impulsive gusts; for the nine coefficients X_u, etc., vary with the intensity of the relative wind.

It is for this reason that I have used finite gusts of various degrees of sharpness instead of impulsive gusts. Moreover, it is not certain but the finite gust represents more nearly actual conditions in the air when flying is at all possible.

An article by Brodetsky, with an introduction by Bryan, has recently reached this country,[2] in which impulsive gusts are considered, relative to Bryan's skeleton aëroplane consisting of a forward main plane and rear tail plane. The discussion is both interesting and important as is everything to which Bryan, the great pioneer in this subject, sets his name, but it does not seem to help me, so far as I have yet been able to examine it, in regard to the effect of an impulsive gust upon a machine whose properties are actually determined in the wind tunnel. I have therefore decided to let stand the brief general considerations above.

The Action of the Air Screw.

27. In the work to this point, I have made for the discussion of gusts the same assumption concerning the action of the propeller that Hunsaker, Bairstow, and others have made for discussions of stability, namely, that under varying conditions the motor speeds up or slows down so as to deliver a constant thrust along the x-axis.

It would be equally reasonable, from some points of view more reasonable, to assume that under changing conditions of relative air velocity a motor speeds up or slows down so as to deliver the same effective horsepower. We should then have the power P equal to the thrust H (taken positive) multiplied by the velocity $-U$:

$$P = -HU = -(H + dH)(U + u),$$

$$UdH + uH = 0,$$

$$dH = -H\frac{u}{U} = -P\frac{u}{U^2}. \tag{10}$$

This is an additional force which is directed along the X-axis if the propeller shaft is horizontal for the velocity of flight $-U$. If in the standard condition the shaft is not horizontal there would be components

$$-P\frac{u}{U^2}\cos\alpha, \quad +P\frac{u}{U^2}\sin\alpha$$

[2] *Aëronautical Journal*, London, 20, 1916, 139–156.

along the x and z axes, α being the angle from the horizontal up to the direction of the shaft. Furthermore if the shaft did not pass through the center of gravity there would be a pitching moment $-Phu/U^2$ if h is the distance of the line of the shaft above the center of gravity.

28. The equations for the natural longitudinal motion would then be

$$\left(D - X_u + \frac{Pg}{mU^2}\right)u - X_w w - (X_q D + g)\theta = 0, \qquad (11)$$

the other two equations remaining unchanged, if we assume for simplicity that $\alpha = h = 0$. The effect of the varying thrust is to change X_u to $X_u - Pg/mU^2$. We have the value $X_u = -.128$ for this machine. If the effective propeller horsepower were 87 for $U = -115.5$, the value Pg/mU^2 is

$$\frac{Pg}{mU^2} = \frac{87 \times 550 \times 32}{1800 \times 13350} = .063.$$

The modification of the equations of motion on replacing $X_u = -.128$ by $X_u = -.191$ would make an appreciable, though not very serious change.

The determinant Δ would become

$$34D^4 + 290.8D^3 + 850.9D^2 + 165.1D + 31.18$$
$$= 34(D^4 + 8.553D^3 + 25.03D^2 + 4.856D + .917)$$

as compared with

$$34(D^4 + 8.490D^3 + 24.50D^2 + 3.385D + .917).$$

The rapidly damped oscillation would, as a first approximation, be

$$-4.276 \pm 2.596i \text{ instead of } -4.245 \pm 2.545i.$$

The first approximation for the small root would be

$$-.097 \pm .177i \text{ instead of } -.069 \pm .181i.$$

The damping would be more pronounced and the oscillation a trifle faster.

29. It may be concluded that whether the screw is supposed to

deliver a constant thrust or a constant power is not very important to the theory either of stability or of gusts. It is not unlikely that the actual behavior of the screw lies within the limits set by these two assumptions or sufficiently near to one of the limits to validate the use of either hypothesis.

The Aëronautical Journal, London, 20, 1916, p. 142, quotes Bairstow and Fage as giving the formula

$$dH = -.011 HdV, \qquad V \text{ in miles per hour,}$$

which is $$dH = -.0073 HdV, \qquad V \text{ in feet per second.}$$

With $U = 115.5$ numerically we would have for constant power

$$dH = -.00866 HdV, \qquad V \text{ in feet per second;}$$

and, if I understand correctly the use of the signs + and — in the quotation, the results are in as good agreement as could be expected in view of the fact that I have no knowledge of the value of U for which the data quoted are given. (If the motor and screw were exactly designed to give a maximum efficiency at a standard speed U, we could not expect the efficiency to be the same at relative air speeds either higher or lower, and this would slightly influence the result.)

Equations for Lateral Motion.

30. The differential equations for the lateral motion of a machine in a gust may be written as (p. 54):

$$dv/dt + g\phi + Ur - Y_v v - Y_p p - Y_r r = Y_v v_1 + Y_p p_1 + Y_r r_1,$$
$$A/m.\ dp/dt - L_v v - L_p p - L_r r = L_v v_1 + L_p p_1 + L_r r_1, \qquad (12)$$
$$C/m.\ dr/dt - N_v v - N_p p - N_r r = N_v v_1 + N_p p_1 + N_r r_1,$$

where the terms involving the small unknown product of inertia E have been neglected and gusts of the type v_1, p_1, r_1 have been allowed.

The gust v_1 corresponds to a side wind. A change in the direction of the wind by a small angle would produce such a gust even in absence of any change in the wind velocity. The gust p_1 is a rotary gust tending to produce a bank; as a disturbance in the air it would correspond to a horizontal roller run into end-on (axially).

The gust r_1 corresponds to a column of air rotating about a vertical line.

This last is a common type of aërial disturbance, easily observed on a warm day, often of very small diameter compared with the spread of the wings of an aëroplane, and accompanied by a strong rising current of air. Such a vertical vortex, if small, might strike one wing of the machine alone, and, due to the rising current, heel it over suddenly. It is, however, not this small local disturbance which we can consider by our methods here, but the larger and more gentle rotation in the air which might immerse the whole machine many times over and which produces a yawing motion in the machine rather than (primarily) a roll or bank.

31. Place $D=d/dt$. Then the equations are

$$\begin{aligned}(D-Y_v)v+(g-Y_pD)\phi+(U-Y_r)r&=Y_vv_1+Y_pp_1+Y_rr_1,\\ -L_vv+(k_A{}^2D-L_p)D\phi-L_rr&=L_vv_1+L_pp_1+L_rr_1,\\ -N_vv-N_pD\phi+(k_C{}^2D-N_r)r&=N_vv_1+N_pp_1+N_rr_1,\end{aligned}\tag{13}$$

where $k_A{}^2=A/m$ and $k_C{}^2=C/m$. The determinant whose vanishing determines the natural motion is

$$\Delta=\begin{vmatrix} D-Y_v & g-Y_pD & U-Y_r\\ -L_v & k_A{}^2D^2-L_pD & -L_r\\ -N_v & -N_pD & k_C{}^2D-N_r\end{vmatrix}.$$

Let the cofactors of Δ be

$$\delta_{11}=\begin{vmatrix} k_A{}^2D^2-L_pD & -L_r\\ -N_pD & k_C{}^2D-N_r\end{vmatrix}=2592D^3+23140D^2+8478D,$$

$$\delta_{12}=\begin{vmatrix} -L_r & -L_v\\ k_C{}^2D-N_r & -N_v\end{vmatrix}=-59.55D-26.55,$$

$$\delta_{13}=\begin{vmatrix} -L_v & k_A{}^2D^2-L_pD\\ -N_v & -N_pD\end{vmatrix}=-32.84D^2-280.7D,$$

$$\delta_{21}=\begin{vmatrix} -N_pD & k_C{}^2D-N_r\\ g-Y_pD & U-Y_r\end{vmatrix}=-2270D-868.8,$$

$$\delta_{22}=\begin{vmatrix} D-Y_v & U-Y_r\\ -N_v & k_C{}^2D-N_r\end{vmatrix}=70.6D^2+44.5D+109.9,$$

$$\delta_{23}=\begin{vmatrix} -N_v & -N_pD\\ D-Y_v & g-Y_pD\end{vmatrix}=28.76,$$

$$\delta_{31} = \begin{vmatrix} g - Y_pD & U - Y_r \\ k_A{}^2D^2 - L_pD & -L_r \end{vmatrix} = 4243D^2 + 36270D - 1776,$$

$$\delta_{32} = \begin{vmatrix} U - Y_r & D - Y_v \\ -L_r & -L_v \end{vmatrix} = 55.2D + 111.2,$$

$$\delta_{33} = \begin{vmatrix} D - Y_v & g - Y_pD \\ -L_v & k_A{}^2D^2 - L_pD \end{vmatrix} = 36.7D^3 + 323.1D^2 + 77.88D + 27.15,$$

where the numerical values are those arising from the data determined for the Curtiss Tractor (which is the machine under investigation) by Dr. J. C. Hunsaker as given on page 78 of his paper, "Dynamical Stability of Aëroplanes," Smithsonian Misc. Collect., Washington, Vol. 62, No. 5, pp. 1–78, 1916, namely,

$Y_v = -0.248$, $\quad Y_p = 0$, $\quad Y_r = 0$,

$L_v = +0.844$, $\quad L_p = -314$, $\quad L_r = +55.2$,

$N_v = -0.894$, $\quad N_p = 0$, $\quad N_r = -27.0$,

$$k_A{}^2 = 36.7+, \quad k_C{}^2 = 70.6-, \quad U = -115.5, \quad g = 32.17.$$

The value of Δ is then $(D - Y_v)\delta_{11} + g\delta_{12} + U\delta_{13}$ or

$$\Delta = 2592D^4 + 23780D^3 + 18000D^2 + 34610D - 854.$$

This result checks with Hunsaker's (loc. cit., p. 78) as well as probable. The equation $\Delta = 0$ may be written as

$$D^4 + 9.172D^3 + 6.943D^2 + 13.35D - 0.3295 = 0.$$

32. From the last two terms, one root is indicated as $D = 0.02468$; and the correction can readily be found, giving

$$D = 0.02436.$$

There is another root near $D = -8.5$, the exact value being

$$D = -8.542.$$

The other factor of the biquadratic equation is

$$D^2 + 0.6537D + 1.583 = 0,$$

of which the roots are

$$D = -0.3268 \pm 1.215i.$$

The complementary functions for v, ϕ, and r are therefore of the form

$$v = C_{11}e^{.02436t} + C_{12}e^{-8.542t} + e^{-.3268t}(C_{13}\cos 1.215t + C_{14}\sin 1.215t),$$

$$\phi = C_{21}e^{.02436t} + C_{22}e^{-8.542t} + e^{-.3268t}(C_{23}\cos 1.215t + C_{24}\sin 1.215t),$$

$$r = C_{31}e^{.02436t} + C_{32}e^{-8.542t} + e^{-.3268t}(C_{33}\cos 1.215t + C_{34}\sin 1.215t).$$

The particular integrals for any gust may be represented as I_v, I_ϕ, I_r, and their initial values as I_{v0}, $I_{\phi 0}$, I_{r0}, the derivative of I_ϕ being I'_ϕ with the corresponding initial values $I'_{\phi 0}$.

33. If as before (p. 59) we restrict the possible gusts to those of which the functional form is different from any of the four functions entering into the complementary functions, the particular solutions must, on substitution, annihilate the right-hand members of the differential equations, and the relations between the constants C_{ij} of integration may be determined from the two equations

$$(D + 0.248)v + 32.17\phi - 115.5r = 0,$$

$$0.894v + 0\phi + (70.6D + 27.0)r = 0.$$

Hence

$$.2724C_{11} + 32.17C_{21} - 115.5C_{31} = 0,$$

$$.894C_{11} + 0C_{21} + 28.72C_{31} = 0,$$

and

$$C_{11} = -8.326C_{21}, \quad C_{31} = .2591C_{21}.$$

Further

$$-8.294C_{12} + 32.17C_{22} - 115.5C_{32} = 0,$$

$$.894C_{12} + 0C_{22} - 575.8C_{32} = 0,$$

and

$$C_{12} = 3.797C_{22}, \quad C_{32} = .005897C_{22}.$$

Finally

$$-.0788C_{13} + 1.215C_{14} + 32.17C_{23} - 115.5C_{33} = 0,$$

$$-1.215C_{13} - .0788C_{14} + 32.17C_{24} - 115.5C_{34} = 0,$$

$$.894C_{13} + 3.92C_{33} + 85.74C_{34} = 0,$$

$$.894C_{14} - 85.74C_{33} + 3.92C_{34} = 0,$$

and

$$C_{13} = 1041C_{23} + 564.8C_{24}, \qquad C_{33} = -6.371C_{23} + 10.56C_{24},$$

$$C_{14} = -564.8C_{23} + 1041C_{24}, \quad C_{34} = -10.56C_{23} - 6.371C_{24}.$$

The solutions therefore, so far as concerns the complementary function, are

$$\phi = C_{21}e^{.02436t} + C_{22}e^{-8.542t} + e^{-.8268t}(C_{23} \cos 1.215t + C_{24} \sin 1.215t),$$

$$v = -8.326C_{21}e^{.02436t} + 3.797C_{22}e^{-8.542t} + e^{-.3268t}[(1041C_{23} + 564.8C_{24}) \cos 1.215t + (-564.8C_{23} + 1041C_{24}) \sin 1.215t],$$

$$r = 0.2571C_{21}e^{.02436t} + 0.005897C_{22}e^{-8.542t} + e^{-.8268t}[(-6.371C_{23} + 10.56C_{24}) \cos 1.215t - (10.56C_{23} + 6.371) \sin 1.215t].$$

34. These equations determine the relative magnitudes of the various sorts of natural motion.

The first term is the slowly amplifying divergence, this machine being slightly unstable laterally. If a side gust is such as to induce a lateral velocity of $-8.326C_{21}$, it induces a bank of C_{21}, an eighth as much in radians or seven times as much in degrees. It is therefore clear that only very small values of C_{21} are admissible for safety. The second term, corresponding to the rapidly damped motion, shows such rapid damping that it can hardly be of importance, except for possible strains on the mechanism, unless C_{22} is so large that the whole work is inapplicable because of the failure of the motions to be small.

The trigonometric terms show that the oscillation in v will be of great amplitude compared with that in ϕ, the factor being about 1200 when ϕ is in radians or 20 when ϕ is in degrees; even the oscillation in r will be over 12 times as great as in ϕ. In other words, the machine may have a large oscillatory side-slip or angular velocity of yaw without much bank, but for the divergent motion the bank is a serious matter for even moderate side-slip.

35. The initial conditions $\phi = p = v = r = 0$ give

$$0 = C_{21} + C_{22} + C_{23} + I_{\phi 0},$$

$$0 = .02436C_{21} - 8.542C_{22} - .3268C_{23} + 1.215C_{24} + I'_{\phi 0},$$

$$0 = -8.326C_{21} + 3.797C_{22} + 1041C_{23} + 564.8C_{24} + I_{v0},$$

$$0 = .2571C_{21} + .005897C_{22} - 6.371C_{23} + 10.56C_{24} + I_{r0}.$$

These equations must be solved for the four constants C.

$$C_{21} = -.9839I_{\phi 0} - .1148I'_{\phi 0} + .000740I_{v0} - .02797I_{r0},$$

$$C_{22} = -.000149I_{\phi 0} + .1170I'_{\phi 0} - .0000342I_{v0} - .01163I_{r0},$$

$$C_{23} = -.01595I_{\phi 0} - .002153I'_{\phi 0} - .000706I_{v0} + .0396I_{r0},$$

$$C_{24} = .01468I_{\phi 0} + .001466I'_{\phi 0} - .0004537I_{v0} - .07201I_{r0}.$$

36. The equations from which the particular solutions are obtained are (since $Y_p = N_p = Y_r = 0$):

$$\begin{aligned} \Delta v &= (D\delta_{11} - \Delta)\, v_1 + L_p\delta_{21}p_1 + (L_r\delta_{21} + N_r\delta_{31})r_1, \\ \Delta\phi &= D\delta_{12}v_1 + L_p\delta_{22}p_1 + (L_r\delta_{22} + N_r\delta_{32})r_1, \\ \Delta r &= D\delta_{13}v_1 + L_p\delta_{23}p_1 + (L_r\delta_{23} + N_r\delta_{33})r_1, \end{aligned} \qquad (14)$$

or

$$\Delta v = (-640D^3 - 9522D^2 - 34610D + 854)v_1 + (7134D + 2732)p_1 - (112560D^2 + 1104700D)r_1,$$

$$\Delta\phi = (-59.55D - 26.55)Dv_1 + (-22150D^2 - 13970D - 34510)p_1 + (3895D^2 + 970D + 3062)r_1,$$

$$\Delta r = (-32.84D - 280.7)D^2v_1 + (-9030)p_1 + (-992D^3 - 8724D^2 - 2103D + 854)r_1,$$

with

$$\Delta = 2592D^4 + 23780D^3 + 18000D^2 + 34610D - 854.$$

Motion in Lateral Gusts.

37. We shall take as before the type $J(1 - e^{-rt})$ for that of a single gust.

Case 1.—Side-gust—sharp. $v_1 = J(1 - e^{-5t})$.

$$I_v = J(-1 + .01473e^{-5t}), \qquad I_{v0} = -.98527J,$$
$$I_\phi = J(-.001028)e^{-5t}, \qquad I_{\phi 0} = -.001028J,$$
$$I'_\phi = J(.00514)e^{-5t}, \qquad I'_{\phi 0} = .00514J,$$
$$I_r = J(.002706)e^{-5t}, \qquad I_{r0} = .002706J,$$
$$C_{21} = -.000384J, \quad C_{22} = .0005364J,$$
$$C_{23} = .000809J, \quad C_{24} = .0002445J.$$

The equations of motion are

$$1000\phi/J = -.384e^{.02436t} + .536e^{-8.542t} - 1.028e^{-5t}$$
$$+ e^{-.3268t}(.809 \cos 1.215t + .2445 \sin 1.215t).$$

This is all negligibly small. For the same reason certain terms may be neglected in v and r.

$$v/J = .003e^{.02436t} + .002e^{-8.542t} - 1 + .01473e^{-5t}$$
$$+ e^{-.3268t}(.98 \cos 1.215t - .2022 \sin 1.215t),$$
$$100r/J = -.01e^{.02436t} + .271e^{-5t} - e^{-.3268t}(.257 \cos 1.215t$$
$$+ 1.009 \sin 1.215t).$$

The effect of the sharp side-gust is to carry the machine sideways with it, but not very powerfully at first—much of the air blows through the machine—the dominating term at first being

$$v = -.2Je^{-.3268t} \sin 1.215t;$$

after a few seconds the dominating term is $v = -J$, with the very slowly growing divergent term effective only after a considerable time. There is a slight yawing oscillation, but the extreme angle of yaw is only about $0.01J$ radians or $J/2$ degrees—the angle being computed as

$$100\psi/J = \int_0^t 100r/J \cdot dt = .4(1 - e^{.02436t}) + .054(1 - e^{-5t}) - .8316$$
$$+ e^{-.3268t}(.8316 \cos 1.215t + .0122 \sin 1.215t).$$

The actual sidewise velocity is compounded of v and the amount -115.5ψ due to the yaw. Hence

$$y = \int_0^t (v - 115.5\psi)dt.$$

For this calculation v and ψ may be simplified to

$$v = -J + Je^{-.3268t}(\cos 1.215t - .2 \sin 1.215t),$$

$$100\psi = -.378J - .4Je^{.02436t} + Je^{-.3268t}(.832 \cos 1.215t);$$

and

$$y = -.56Jt + 18.5J(e^{.02436t} - 1) - .146J$$
$$+ Je^{-.3268t}(.146 \cos 1.215t + .066 \sin 1.215t).$$

From this it will be seen that the oscillatory motion is, so far as concerns the lateral displacement, of very small amplitude. The first two terms which are progressive, are the ones which count. Moreover, the displacement is of the same sign as J although the side-slip v is of the opposite sign. This apparent contradiction is due to the change in orientation ψ— the machine moves away from the gust owing to the lateral excess wind-pressure, but turns into the gust owing to the moment of the pressures, and by virtue of the great forward velocity, this turning more than makes up, in the displacement, for the side-slipping.

38. *Case 2.*—Side-gust—mild. $v_1 = J(1 - e^{-.2t})$.

$$I_v = J(-1 + 1.0205e^{-.2t}), \qquad I_{v0} = .0205J,$$

$$I_\phi = J(.0004043e^{-.2t}), \qquad I_{\phi 0} = .0004043J,$$

$$I'_\phi = J(-.0000809e^{-.2t}), \qquad I'_{\phi 0} = -.0000809J,$$

$$I_r = J(-.001514e^{-.2t}), \qquad I_{r0} = -.001514J,$$

$$C_{21} = -.000331J, \quad C_{22} = .00000738J, \quad C_{23} = -.0000807J,$$
$$C_{24} = .0001055J.$$

It is again seen that there is practically no rolling motion produced by the side-gust. For v and r,

$$v/J = .0027e^{.02436t} - 1 + 1.0205e^{-.2t}$$
$$+ e^{-.3268t}(-.0244 \cos 1.215t + .1554 \sin 1.215t),$$

$$100r/J = -.0085e^{.02436t} - .1514e^{-.2t}$$
$$+ e^{-.3268t}(.1628 \cos 1.215t + .0672 \sin 1.215t).$$

(The check $v = 0$, $r = 0$, when $t = 0$, shows that the accuracy has been reduced so that the third place is not sure.) The effects of the gust are qualitatively as before. The oscillatory motion is not pronounced; the ultimate side-slip velocity is $-J$; the ultimate displacement has the same sign as J because the divergent term in $v - 115.5\psi$ is positive.

39. *Case 3.*—Side-gust—oscillatory. When one examines the records made or making at such an observatory as Blue Hill for gustiness in the air, no phenomenon is perhaps more striking than the reasonably periodic side-switching of a reasonably steady wind. A south wind, for example, may whip back and forth between S.S.E. and S.S.W. for hours at a stretch, as Prof. Alexander McAdie has been kind enough to show me on some of his records. In the absence of rotary motion, concerning which I am unable to find satisfactory data, the simplest way to figure this change in direction is as a periodic side-gust. A machine going south in such a wind would experience an alternating side-gust. (The oscillations in the head-on velocity of the wind would be relatively very small except for actual changes in head-on velocity superimposed upon the changes in direction.) It is therefore especially interesting to discuss a periodic side-gust—this being the only periodic gust of which we can reasonably be said to know anything at all definite.

Let $v_1 = Je^{ipt}$. We may assume, from our work above that the rolling motion will be small and that the side-slip velocity v will not be of as much importance in determining the path as the angle ψ coupled with the large forward velocity. The complex value of r is

$$r = \frac{(280.7 - 32.84pi)p^2Je^{ipt}}{2592p^4 - 18000p^2 - 854 + i(34610p - 23780p^3)}.$$

If at any one place the period of the complete oscillation is $2\pi/n$ with the wind velocity V, the distance traveled by the wind during the time of an oscillation in direction is $2\pi V/n$, and this is the distance between the nodes of the motion. The time required for this machine ($U = -115.5$) to pass over the distance $2\pi V/n$ is $2\pi V/115.5n$. The periodicity of the gust as it appears to the operator of the machine will therefore correspond to the value $p = 115.5n/V$. For instance, if $V = 20$ and the time of an oscillation at one spot were 10 secs. so that $n = 0.63$, the value of p would be about $p = 3.6$, and the oscillations would appear to the pilot as taking place about every $1\frac{3}{4}$ seconds. A slower oscillation, *i. e.*, a longer periodic time, would diminish n and p,—an oscillation at one spot every half minute corresponds to a value $p=1.2$ on the basis of the assumptions made above.

In considering the values of p which make the amplitude of r large, the only hope is to make the term $34610p-23780p^3$ tolerably small. This means p^2 must be about 1.5. For this value, the modulus of r is about $.03J$ and the modulus of the yawing oscillation corresponding will be about $.025J$. If a wind of 20 ft./sec. is whipping through an angle of 45°, the side-gust will be only of about 7 ft./sec. semi-amplitude and the angle of yaw will be in the neighborhood of .175 radians or 10°. There is nothing to indicate that this would be fatal, though it would surely be a nuisance.

Owing to the fact that the coefficients of i in both numerator and denominator are relatively small, the angular velocity I_r would be about in phase with the gust v_1, and hence the angle I_ψ would be about quartered in phase. If there were periodically an angle of 10° or 12° between the direction of flight and the relative wind, we should find that we were getting into a region where considerable rolling and pitching might be induced—for as Hunsaker has shown (loc. cit., p. 62) the lateral and longitudinal motions are not strictly independent; but as the machine makes the major part of the relative wind, the directions of flight and of the relative wind never differ greatly—only some three degrees at most in the case under consideration.

It seems hardly necessary at this time to go into the calculation of the actual motion; enough has perhaps been accomplished in showing that the oscillation of the direction of the wind induces at most a moderate yawing of the machine. The semi-amplitude of 115.5ψ would be, if $J=7$ ft./sec., about 20 ft.; the center of gravity of the machine would sway back and forth across the line of flight with a total amplitude of 40 ft., until the divergent term became effective.

40. *Case 4.*—Rolling gust. $p_1=J(1-e^{-rt})$. If there were no interaction between v, p, r, the effect on rolling of a rolling gust would be figured from the equation

$$36.7Dp + 314p = -314J(1 - e^{-rt}),$$

$$p/J = -8.055e^{-8.055t}\int_0^t e^{8.055t}(1 - e^{-rt})dt,$$

$$p/J = -1 + e^{-8.055t} + \frac{8.055}{8.055 - r}e^{-rt} - \frac{8.055}{8.055 - r}e^{-8.055t}.$$

This means that for any ordinary sharp gust p rapidly acquires the value $-J$, and ϕ the value $-Jt$ (radians). It must therefore be expected that unless J is very small indeed, the motion will be much disturbed. There will be developed a component of the weight inducing side-slipping, and yawing will rapidly develop—the machine apparently goes off on a spiral dive.

We may make the calculations in detail when $r=1$. Here

$$I_v/J = -3.14 - .114e^{-t}, \qquad I_{v0} = -3.25J,$$

$$I_\phi/J = 40.4 - 1.1e^{-t}, \qquad I_{\phi 0} = 39.3J,$$

$$I'_\phi/J = 1.1e^{-t}, \qquad I'_{\phi 0} = 1.1J,$$

$$I_r/J = 10.58 - .234e^{-t}, \qquad I_{r0} = 10.35J.$$

$$C_{21} = -39.1J, \quad C_{22} = .0027J, \quad C_{23} = -.219J, \quad C_{24} = -.163J.$$

The equations of motion become

$$\phi/J = -39.1e^{.02436t} + .003e^{-8.542t} + 40.4 - 1.1e^{-t}$$
$$+ e^{-.3268t}(-.219 \cos 1.215t - .163 \sin 1.215t),$$

$$v/J = 324e^{.02436t} + .0103e^{-8.542t} - 3.14 - .114e^{-t}$$
$$+ e^{-.3268t}(-320 \cos 1.215t + 49.2 \sin 1.215t),$$

$$r/J = -10e^{.02436t} + 10.58 - .234e^{-t}$$
$$+ e^{-.3268t}(-.33 \cos 1.215t + 3.35 \sin 1.215t).$$

In the equation for ϕ the effective terms are

$$\phi/J = -39(e^{.02436t} - 1) = -t(\text{nearly}),$$

and there is a steady divergence in ϕ to the approximate amount $-Jt$ as foreseen. The side-ways velocity v develops more slowly, perhaps, but after one second amounts to something like $300J$. It is clear that J must be very small or the motion becomes disastrous.

It would be of especial interest to know what sorts of magnitudes for J are likely to arise in flight under normal conditions. In so far as experience shows that machines are not liable to roll and side-slip, it is pretty good evidence that aërial rotary motion with axis parallel to the earth is rare and small.

41. *Case 5.*—Yawing gust. $r_1 = J(1 - e^{-t})$.

$$I_v/J = 25.67e^{-t}, \qquad I_{v0} = 25.67J,$$
$$I_\phi/J = -.0792 + .154e^{-t}, \qquad I_{\phi 0} = .075J,$$
$$I'_\phi/J = -.154e^{-t}, \qquad I'_{\phi 0} = -.154J,$$
$$I_r/J = -1 - .1235e^{-t}, \qquad I_{r0} = -.1.12J,$$
$$C_{21} = -.006J, \quad C_{22} = -.006J, \quad C_{23} = -.0634J, \quad C_{24} = .0702J.$$

In this case the motion is

$$\phi/J = -.006e^{.02436t} - .006e^{-8.542t} - .0792 + .154e^{-t} + e^{-.3268t}(-.0634 \cos 1.215t + .0701 \sin 1.215t),$$

$$v/J = +.05e^{.02436t} - .023e^{-8.542t} + 25.67e^{-t} + e^{-.3268t}(-26.35 \cos 1.215t + 108.9 \sin 1.215t),$$

$$r/J = -1 - .1235e^{-t} + e^{-.3268t}(1.145 \cos 1.215t + .222 \sin 1.215t).$$

For moderate values of J, there is nothing serious indicated. The coefficients of the divergent terms are small. There cannot be much roll. The most noteworthy phenomenon is the large amount of side-slip which is fairly rapidly damped out.

42. This leaves the rolling gust as the only dangerous type of lateral gust.

The infinitely sharp side-gust would produce an initial acceleration Y_vJ.

Constrained Aëroplanes.

43. Suppose now that by some automatic steering device the aëroplane were constrained to remain pointing in the same direction, *i. e.*, so that $r = 0$ identically. The equations of motion become

$$\begin{aligned} (D - Y_v)v + (g - Y_pD)\phi &= Y_vv_1 + Y_pp_1 + Y_rr_1, \\ -L_vv + (k_A{}^2D - L_p)D\phi &= L_vv_1 + L_pp_1 + L_rr_1, \qquad (15) \\ -N_vv - N_pD\phi &= N_vv_1 + N_pp_1 + N_rr_1 + F, \end{aligned}$$

where Fm is the moment necessary to maintain the constraint. The last equation may be regarded as determining F.

The natural motion of the constrained machine is found from the determinant

$$\Delta' = \delta_{33} = 36.7D^3 + 323.1D^2 + 77.88D + 27.15 = 0.$$

This is a cubic equation which has no positive root.

The negative root is -8.54. The quadratic factor remaining after division by $D + 8.54$ is

$$36.7D^2 + 8.746D + 3.18 = 0,$$

of which the roots are

$$D = -0.119 \pm 0.269i.$$

The real part is negative and hence the motion is dynamically stable.

The introduction of the automatic device has removed the instability in the lateral motion. As compared with the complex roots in the free motion, these roots indicate a much slower period and a considerably smaller damping.

44. On the other hand suppose that the constraint had been such as to keep the machine level, *i. e.*, $\phi = 0$ identically. The equations would have been

$$\begin{aligned} (D - Y_v)v + (U - Y_r)r &= Y_v v_1 + Y_p p_1 + Y_r r_1, \\ -L_v v - L_r r &= L_v v_1 + L_p p_1 + L_r r_1 + F, \\ -N_v v + (k_C{}^2 D - N_r)r &= N_v v_1 + N_p p_1 + N_r r_1. \end{aligned} \tag{16}$$

The natural motion would have been determined by

$$\Delta'' = \delta_{22} = 70.6D^2 + 44.5D + 109.9 = 0,$$

The roots are

$$D = -0.315 \pm 0.237i.$$

The machine is again stable.

45. It follows that at high speed this Curtiss Tractor, which is laterally unstable when free, becomes quite stable when constrained either to remain on its course or to fly on even keel.

If stabilizers against rolling *and* turning were provided, the motion would reduce to

$$(D - Y_v)v = Y_v v_1 + Y_p p_1 + Y_r r_1, \tag{17}$$

and would be stable, $D = Y_v = -0.248$.

46. It would be a relatively easy matter to discuss the effect of gusts of various types on the aëroplane constrained in various ways; two equations are much easier to handle than three. Until some definite problem is proposed as important, until some particular constraining device is indicated as likely to be adopted, it may be as well not to go into the calculations, which are quite straightforward.

That a constraint against rolling might be worth while, and would indeed be very valuable if rolling gusts were a common thing, is suggested by the work done on the free machine (§ 42) where gustiness was seen not to be very serious except for the rolling gust.

Discussion of Method.

47. I pointed out in my earlier paper that there were several outs about my method of treating gusts. First the gusts must be small. If they are not tolerably small, flying would be too difficult—so that assumption is not wholly unjustifiable. Second, the calculations for determining the individual equations of motion and for determining formulas for the constants of integration are very tedious. Third, the numbers are of such various magnitudes that the arithmetical operations which must be carried out cut down the accuracy of the work a good deal and indeed, unless great care is taken, will lead to illusory or incorrect results. This does not appear to be due to any very rapid variation of the true results calculated from varying data, but to the mode of computing.

To offset these inconveniences we have the satisfactory result that once the preliminary calculations are made, many and varied types of gusts may easily be treated, and the further valuable result that the actual motion for each case is known so that not only the initial motion is determined, but the whole extent of the motion. This last is necessary for any just appreciation of the effects of periodic gusts and resonance, as has been shown.

48. For another method of treating gusts reference may be made to a recent paper by Brodetsky and Bryan, "The Longitudinal Initial Motion and Forced Oscillations of a Disturbed Aëroplane," *Aëronautical Journal,* London, **20,** 1916, 139–156, which has already been cited in the text.

Much may be said for their method of expansion in series—for some problems the work is decidedly simpler than with my method. It has been my experience, however, that the application of series to the motion of any aëroplane has its own difficulties and complicated calculations when the motion is to be followed for any reasonable length of time and especially if the machine is defined, as I have always preferred to regard it as defined, by the actual coefficients determined by wind tunnel experiments rather than as Bryan's skeleton plane consisting of a main front plane plus tail plane,—even though the results obtained from such a skeleton may be extended to more complicated machines by Bryan's invariant method (see his "Stability in Aviation," Chap. VI.).

49. The question therefore arises whether there may not be some way of abridging the calculations leading to the actual motion of the machine. Since finishing my work above, I have received the *Proceedings of the London Mathematical Society*, **15**, 1917, Pt. 6, in which there is an article on "Normal Coördinates in Dynamical Systems," by T. J. I'A. Bromwich in which he develops a method of treating the motions of dynamical systems by means of the theory of functions of a complex variable. I wish, in closing, to describe the application of Bromwich's work to the problem in hand.

We have to solve for the longitudinal motion equations of the type

$$\begin{aligned} (D-X_u)u - X_w w - (X_q D + g)\theta &= P_1 e^{\mu t}, \\ Z_u u + (D - Z_w)w - (Z_q + U)D\theta &= P_2 e^{\mu t} \qquad (18) \\ -M_u u - M_w w + (k_B{}^2 D^2 - M_q D)\theta &= P_3 e^{\mu t}, \end{aligned}$$

where μ is a real or complex number, the values we have used being $0, -r, \pm pi$. We substitute

$$\begin{aligned} u &= \frac{1}{2\pi i}\int_0 e^{\lambda t}\xi d\lambda, \\ w &= \frac{1}{2\pi i}\int_0 e^{\lambda t}\eta d\lambda, \qquad (19) \\ \theta &= \frac{1}{2\pi i}\int_0 e^{\lambda t}\zeta d\lambda, \end{aligned}$$

where the integrals are loop integrals in the complex plane and ξ, η, ζ are any functions of λ. The results are

$$\frac{1}{2\pi i}\int_0 [(\lambda - X_u)\xi - X_w\eta - (X_q\lambda + g)\zeta]e^{\lambda t}d\lambda = P_1e^{\mu t},$$

$$\frac{1}{2\pi i}\int_0 [- Z_u\xi + (\lambda - Z_w)\eta - (Z_q + U)\lambda\zeta]e^{\lambda t}d\lambda = P_2e^{\mu t}, \quad (20)$$

$$\frac{1}{2\pi i}\int_0 [- M_u\xi - M_w\eta + (k_B^2\lambda^2 - M_q\lambda)\zeta]e^{\lambda t}d\lambda = P_3e^{\mu t}.$$

We next set

$$\begin{aligned}(\lambda - X_u)\xi - X_w\eta - (X_q\lambda + g)\zeta &= P_1/(\lambda - \mu),\\ - Z_u\xi + (\lambda - Z_w)\eta - (Z_q + U)\lambda\zeta &= P_2/(\lambda - \mu),\\ - M_u\xi - M_w\eta + (k_B^2\lambda^2 - M_q\lambda)\zeta &= P_3/(\lambda - \mu),\end{aligned} \quad (21)$$

and solve for ξ, η, ζ, finding

$$\begin{aligned}\xi &= \frac{P_1\delta_{11} + P_2\delta_{21} + P_3\delta_{31}}{\Delta(\lambda - \mu)},\\ \eta &= \frac{P_1\delta_{12} + P_2\delta_{22} + P_3\delta_{32}}{\Delta(\lambda - \mu)},\\ \zeta &= \frac{P_1\delta_{12} + P_2\delta_{23} + P_3\delta_{33}}{\Delta(\lambda - \mu)},\end{aligned} \quad (22)$$

$$\Delta = 34(\lambda^4 + 8.49\lambda^3 + 24.5\lambda^2 + 3.385\lambda + .917).$$

Bromwich shows that, if with these values of ξ, η, ζ we take the loop integrals (19) around a very large circle, the results for u, w, θ will be the solutions for the motion disturbed from rest at the position of equilibrium by the impressed forces P. As he points out, this integration is equivalent to the sum of the integrals around infinitesimal circles about $\lambda = \mu$ and about each of the roots λ of $\Delta = 0$, that is, the integral is equal to the sum of the residues of $\xi e^{\lambda t}$, $\eta e^{\lambda t}$, $\zeta e^{\lambda t}$. There is no need to calculate any constants of integration. Moreover any of the quantities u, w, θ can be obtained without the others. The numerators in ξ, η, ζ are already calculated in (20 *a*, *b*, *c*) of p. 59.

We have, for example, for a head gust u_1,

$$\xi = \frac{.128\lambda^3 + 1.16\lambda^2 + 3.385\lambda + .917}{(\lambda - \mu)(\lambda + 4.18 \pm 2.43i)(\lambda + .0654 \pm .187i)} u_1, \qquad (23)$$

where the double sign stands for two factors, and $u_1 = J(1 - e^{-t})$, to take a particular case. The residues at each point are merely the values of the fraction when one of the factors, the one which vanishes at that point, is thrown out of the denominator. In the first case for $1 = e^{0t}$ we have as residue of $\xi e^{\lambda t} = \xi$:
at $\lambda = \mu = 0$,

$$-\frac{.917}{(+4.18 \pm 2.43i)(.0654 \pm .187i)} = 1;$$

at $\lambda = -4.18 - 2.43i$,

$$-\frac{.128\lambda^3 + 1.16\lambda^2 + 3.385\lambda + .917}{(-4.18 + 2.43i)(-4.86i)(-4.12 - 2.43i \pm .187i)};$$

at $\lambda = -4.18 + 2.43i$, the conjugate imaginary expression. And so on. To treat e^{-t} we should have:
at $\lambda = \mu = -1$,

$$-\frac{-.128 + 1.16 - 3.385 + .917}{(3.18 \pm 2.43i)(.9346 \pm .187i)};$$

and so on.

As the calculation with imaginaries involving squares, cubes, products, and quotients is by no means simple, it is clear that to get the solution for u will be reasonably hard work—much harder than to find the particular solutions which for the simple gust involved only real numbers. It may be admitted that to work any one gust the labor will probably be much less than by my method of determining formulas for the constants of integration in terms of the initial values of the particular integrals. But as far as I can see, Bromwich's method is of no particular advantage if we desire to calculate the effects of a large number of gusts $J(1 - e^{-rt})$ of various degrees of sharpness both head-on, up, and rotary. When we came to calculate a periodic gust we found that we were involved in powers and products and quotients of complex numbers, and it is probable that the work we did in finding the particular integrals was comparable with that required for the present analysis.

Summary.

In continuation of my previous work in gusts as affecting the Curtiss Tractor *JN2*, I have discussed:

1. *Periodic Longitudinal Gusts.*—It was found that, even in the case of best resonance with the slow natural oscillation, the motion was not much different from that produced by a simple head-on gust until after a considerable time (over 14 sec.) had elapsed. The amplitude of the forced oscillation (in up and down motion) which ultimately became effective was about 5 times the amplitude of the gust. This was not regarded as serious because true periodicity can rarely be maintained in a head gust and because no pilot would wait to let its effect reach such a magnitude. Periodic up gusts and rotary gusts were considered as not likely to arise.

2. *General Theory of Resonance.*—It was shown that for aëroplane problems resonance meant different things for different problems. It was inferred that resonance was unlikely to be particularly serious because in all probability its effect would either be small or would take so long to become established that the pilot would check it.

3. *Infinitely Sharp Gusts.*—It was seen that the shock to a machine was mX_uJ and mZ_uJ for a head gust, and mX_wJ and mZ_wJ for an up gust. The serious case is mZ_wJ, the vertical shock in an up gust which was about $4J/g$ times the weight, more than twice that found for the sharpest gust previously treated. It would be still more serious in a machine where Z_w was greater than in the *JN2*. The Moral: Keep Z_w small, clashes with Hunsaker's conclusion[3] that lateral stability is incompatible with high wing loading—but such an antithesis is common.[4] Reference was made to impulsive gusts.

4. *The Effect of the Propeller.*—The assumption that a constant power instead of a constant thrust was delivered did not very materially alter conditions of flight.

5. *Lateral Gusts.*—The general equations were set up and integrated.

[3] "Dynamical Stability of Aëroplanes," Washington, Smithsonian Misc. Collect., 62, 1916, p. 77.

[4] "The production of a laterally stable aëroplane is attentant with many compromises," Hunsaker, p. 74.

(*a*) Single side-gusts were shown to produce modern side-slipping, insignificant roll, and moderate yaw. It was seen that the yaw was into the relative wind so that the displacement of the machine in space was toward the gust despite the side-slipping.

(*b*) Oscillatory side-gusts were shown to be a common condition of flight, to produce moderate side-slipping and yawing, but insignificant rolling. The path of the center of gravity proved to be sinusoidal, so far as the forced oscillation was concerned, and of amplitude about 2 or 3 times the amplitude of the gust.

(*c*) Yawing gusts were found to induce a good deal of side-slipping, but did not appear to be serious. The roll was very small.

(*d*) Rolling gusts were seen to put the machine into a spiral dive, and thus to cause a real danger unless the motion were checked promptly by the pilot.

6. *Constrained Machines.*—A device to keep the aëroplane on its course or to prevent rolling made the previously unstable machine stable. Such a device might be important to reduce the liability to the spiral dive in rolling gusts provided such gusts were common phenomena in flying weather.

7. *Other Methods of Treatment.*—The Bryan-Bordetsky method of initial motions and Bromwich's new method of finding the solution for a disturbed state without calculating the constants of integration were briefly compared with my system of analysis.

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VI

ENGINEERING ASPECTS.

By JEROME C. HUNSAKER, Eng.D.

1. It is of especial significance that the American Philosophical Society devotes an afternoon to aëronautics and of especial significance to the Navy that the problems of aëronautics have been so clearly stated to you here today. For these problems are unfortunately not only perplexing but pressing, and engineering progress cannot wait for a satisfactory solution. Just now we are forced to adopt rather daring assumptions and to extrapolate to a truly alarming extent our experimental data.

2. I was sorry to arrive too late to hear Professor Webster's treatment of the dynamical aspects of the subject, but I shall have, of course, the opportunity for a more leisurely study of his paper when it appears in printed form.

3. Professor Durand's estimate of the economical size of aëroplanes is especially timely as we are building all sizes now in search of the most useful, and it is indeed encouraging to have Professor Durand as authority for making haste slowing in expanding the dimensions of the existing types. If I understand him correctly, the weight of the structure of aëroplane wings may be assumed to increase more rapidly than their carrying power so that there must be a limiting size for any given system of construction beyond which it is uneconomical to go. I believe this conclusion to be entirely true provided, as Professor Durand carefully states, the same system of construction be used for a family of similar structures. However, I would consider that it would not be good engineering to use the same material or even the same system of distributing material, for large and for small structures. For example, it is not economical to apply the materials and methods of construction used in small boats to large ships. Where we would use solid spruce beams for small wings, larger wings would have hollow spruce beams, and perhaps

still larger wings, beams of aluminum alloy or steel. In the great aëroplanes of the future, we may have an opportunity to use a lattice construction combining a great moment of inertia with a minimum of material. The smaller the structure the less favorably can we employ the material. In many cases to give sufficient security against local injury and deterioration we make parts several times stronger than would be indicated by a strength calculation alone. For example, no matter how small the aëroplane, we would use no less than a certain minimum rib thickness and cover with a fabric of sufficient weight and strength to stand exposure. Consequently, in the small aëroplanes, we build relatively heavier than necessary.

4. The exploration of the upper air has now become of pressing concern to those who expect to navigate in it and, in a general way, to designers of aircraft. Dr. Blair's soundings are most illuminating and it is especially gratifying to note the progress which our own Weather Bureau is making in this work. For the airship and balloon, especially, a knowledge of the pressure, temperature, and wind at different altitudes is of first importance and it is to be hoped that forecasts can be supplied the aëronant before his ascent, which will acquaint him with the probable conditions he will encounter aloft. Dr. Blair's data, I assume, show typical conditions or rather average conditions. It would be valuable if his explorations of the upper air could be extended to show in addition the possible and typical deviations from average values. The aviator is less concerned with the average velocity of the wind than with its internal structure; the frequency and intensity of its gusts and their nature.

5. The importance of a study of gusts is clearly brought out by Professor Wilson's analysis of the effect of lateral gusts on an aëroplane in flight. Professor Wilson has assumed gusts of given intensity and direction and computed the effect upon a typical aëroplane. There is abundant testimony of a qualitative nature as to the violence of these effects in practice. Aviators speak of "air holes" in explanation of uncontrolled diving and turning experienced. It is of course evident that there are no holes in the air, and Professor Wilson shows that gusts produce effects of the sort observed. Now it is possible in the design of aëroplanes to so arrange surfaces that the effect of particular kinds of gusts is minimized. What we need

to know now is what kinds of gusts are to be expected. For example, if sudden horizontal shifts in the direction of the wind are the usual state of affairs, we should not put a great preponderance of vertical fin surface on the tails of our aëroplanes. An excessive "weather-cock" propensity will make a machine head into the relative wind and if the wind direction shifts constantly it will be difficult to maintain a straight course. The "weather-cock" stability is of course provided to make steering easier.

6. Also Professor Wilson shows that a roller in the air is certain to bring disaster to an aëroplane. We have evidence of rotation in the eddy formed in the lee of a hill or other obstruction, but there is little information as to the extent and intensity of the disturbance. What aviators call "bad air" may be eddies in the wind.

7. I would appreciate the opportunity to outline in a general way some of the problems of lighter-than-air craft, airships and balloons, in order to make the symposium more complete.

8. In the design of airships we are confronted with indeterminate structural features, mysteries of the upper air, atmospheric electrical phenomena, and in addition to these difficulties we must work with fabrics and membranes of unfamiliar and indefinite physical properties.

9. The theory of hydrogen-filled balloons was developed in a very elaborate and complete form by the pioneers of the French Army Engineering Corps. Their theoretical considerations are of the greatest practical utility but depend upon an assumed stable condition of the atmosphere. Unfortunately a balloon and to a less degree a dirigible or airship is extremely sensitive to changes of equilibrium. For example, a balloon floating at its zone of equilibrium has exactly the weight of the air displaced. A wet cloud may condense a little water on its surface, the balloon will sink into regions of more dense air which will compress its volume and cause continued descent until ballast is released or the ground reached.

10. An airship is also handicapped by changes of weight in the air due to picking up loads of condensed water, snow, or sleet. The balloon fabric should be proofed in some manner to prevent such accumulations.

11. At the same time, though weight may not change, tempera-

ture variations cause expansion and contraction of gas and consequent changes in buoyancy. We may expect the air to grow at least 0.5° colder for each 100 meters rise, but this is rather an average than a normal condition.

12. Only at night is the gas at the same temperature as the air, for the sun's heat on the balloon keeps the gas inside 10 to 20 degrees warmer. A cloud which cuts off this radiation will cause a contraction of the gas enough to cause a descent. It is of great importance to check temperature changes in the gas. Airships have been given metallic flake paints, and light colors in an effort to reduce heating. The most effective means would appear to be a double wall with air space as in the Zeppelin type. Aluminum paint was found to reflect fourteen times as much radiant heat as unprotected rubber.

13. Rubberized fabric has been the envelope material for nearly all dirigibles except Zeppelins. Such fabric can be obtained in quantity and of uniform quality. Unfortunately the chemical action of light causes the rubber to deteriorate. Protective coatings of chrome yellow have been used with fair success. More recently carbon black has been found to protect the rubber better. But a dark envelope exaggerates the disturbances of equilibrium due to heating.

14. The hydrogen leakage through good rubberized fabric should be about 9 liters per square meter per day. Goldbeater's skin, which is animal intestine, tanned, shows a leakage of but a quarter of a liter. Such a membrane is immensely superior as a hydrogen container and does not oxidize. However, gold-beater's skin rots if wet, is difficult to work and to obtain in quantity. It is to be hoped that a hydrogen-tight material can be developed equal to goldbeater's skin but without these disadvantages.

15. The envelope of a dirigible is a nonconductor of electricity, but presumably picks up the electro-static potential of the air. Experiments with kites have shown a potential difference of 20,000 volts at 1,000 meters. It is likely that an airship takes up the potential of the air in less than a second and cannot reach the ground even after a rapid descent with any very considerable charge. The potential gradient may be 50 volts per meter and a dirigible of 20

meters height may have different charges above and below which may cause sparks and consequent explosion of the leaking hydrogen. There have been explosions for which no explanation is adequate. Should high metal parts such as valves have a wire to the car as a ground, or should we use a valve cord of non-conducting material?

16. The addition of radio on an airship for signaling introduces another complication. The radio uses the car as a counterpoise and has a trailing wire as antenna. It is possible that sparking between car and envelope may be induced when sending unless precautions are taken. The nature of the necessary precautions is at present not clearly understood.

17. The structural strength of the envelope of a nonrigid dirigible is not yet a definite engineering problem. As you know a torpedo-shaped elongated envelope inflated with hydrogen carries by means of a set of cables a car containing passengers and power plant. The buoyancy of the envelope is distributed from end to end of the envelope, but the weight is largely concentrated in the short car. Hence there are serious bending moments impressed on the envelope which is held stiff only by its pressure of inflation. The well-known theory of an elastic membrane can be used to compute the stress in the envelope at any point due to the inflation pressure. However, the stresses due to these bending moments must also be considered, and at a high velocity the suction of the stream line motion of the external air tends to augment the effective inflation pressure at points near the maximum cross section.

18. In addition to stresses due to inflation pressure, bending moments and external pressures and suctions, we have our problem confused from an engineer's point of view by having to deal with balloon fabric of indefinite elasticity and strength.

19. The strength of the fabric in warp and filler may be measured, but when we use a doubled fabric in which the threads cross at 45° the strength becomes more difficult to estimate. Furthermore, the envelope under load deforms and parts severely stressed may shirk their load. The exact calculation of the stress in an envelope is not attempted.

20. There is, however, a simple experimental method of studying the problem. A model of the envelope filled with water is

suspended below a model of the car by a suspension of cords. The ratio of densities of hydrogen and water in air is about 900 and it can be shown that if the scale of a model be $1/30$ and that if the model is made of the same material, the stresses at corresponding points are equal and the model as it deforms under load remains similar to the full size envelope as it would deform under corresponding loads.

21. Finally we have to consider the dynamical problem of driving the dirigible through the air at high speeds. As is well known to students of hydrodynamics, an elongated body tends to place itself broadside to the stream. Dirigibles of good form are essentially unstable and it is necessary to fit fins at the tail end. It is not practicable or necessary to fit very large horizontal fins since the center of gravity is usually below the center of buoyancy and hence affords a statical righting couple against pitching. This statical righting moment is supposed to overcome the tendency of the envelope to deviate from the trajectory. However, as speed is increased the upsetting moment increases as the square of the speed, while the statical righting moment of weight remains constant. Consequently, there is some critical speed at which the dirigible becomes unstable or even unmanageable.

VII

REMARKS ON THE COMPASS IN AËRONAUTICS.

By LOUIS A. BAUER.

The few remarks which I am able to contribute to the discussion of the papers we have just had the pleasure of listening to, relate to the use of the compass in aërial navigation.

The recent great progress in aëronautical art and in the construction of ships to navigate the air, have called renewed attention to the importance of perfecting the magnetic compass used in steering the craft, and to the need of studying the "vagaries of the fickle needle." Just as in ocean navigation, it has become necessary in aërial navigation, though not yet to the same degree of refinement as in ocean work, to determine the effects on the compass of the magnetic materials used in the construction and in the equipment of the aircraft. The airship-compass must, accordingly, be compensated, and allowance for any outstanding errors must be made in steering a course with it.

The satisfactory solutions of the various problems are especially difficult for the heavier-than-air type of airship. One of the chief points of difference between the aëroplane-compass and the ocean-ship-compass consists in the form of damping device (horse-hair packing, for example) which must be used to overcome, as well as possible, the very excessive vibration caused by the engine driving the aëroplane.

Besides the so-called "magnetic-deviation errors" of the compass, arising from the magnetic materials in the vicinity of the compass, there are other errors which make themselves seriously felt only, however, while the aëroplane is turning. The latter are called "dynamic-deviation errors"; their magnitude depends upon the tilt of the aëroplane, the magnetic dip, and the heading or course of the airship.

When the aëroplane is turning, it is tilted towards the center of the circle described by it, the tilt becoming greater, of course, with the speed of turning or with the decrease of radius of the circle. Everything movable which was at rest in the aëroplane during straight-line uniform flight under the action of gravity alone is still at rest relative to the aëroplane as it tilts on the turn, but now, everything is at rest under the action of the resultant of gravity and centrifugal accelerations. The compass card, which was horizontal during rectilinear flight, is now tilted with the aëroplane and, consequently, partly turned in the terrestrial magnetic field. The vertical component of the earth's magnetic field, which was normal to the card in its level position in rectilinear flight and which, consequently, had then no directive effect, now has a component in the plane of the card and normal to the magnetic axis which tends to produce the "dynamic deviation." The horizontal component of the earth's magnetic field also plays a part in this kind of deviation.

According to some recent investigations in England by S. G. Starling,[1] when the angle of tilt of the aëroplane approaches the complement of the magnetic dip, which for Philadelphia would mean a tilt of about 19°, the dynamic deviations of the compass, if, for example, the course steered be an easterly one, may increase to nearly 90°. And if the tilt of the aëroplane exceeded 19° the direction of the compass on the course stated would even be reversed.

While the dynamic deviations may be large during turns of the aëroplane, yet they disappear, practically, when straight flight is resumed. We, therefore, question the desirability of adopting the movable compensating devices, suggested by Starling, which while effective during aëroplane-turns, might introduce magnetic deviations of a more permanent character during the more usual straight flights. If his devices are used, they will require careful control.

In connection with the use of the compass in aërial navigation, an interesting scientific question comes up as to the change of the earth's magnetic field, or of the magnetic elements with altitude above the surface. Magnetic experiments of this nature were made in balloons by Gay Lussac and Biot in 1804 which were repeated, with more success, a half century later by Glaisher. The available

[1] "The Equilibrium of the Magnetic Compass in Aëroplanes," *Phil. Mag.*, London, Vol. 32, November, 1916 (461–476).

observations to date do not possess, however, the requisite refinement, and it is hoped that some day a non-magnetic airship and the necessary instrumental appliances will be available for conducting a magnetic survey of the aërial regions in the same manner as that employed in the ocean-magnetic survey of the non-magnetic ship, the *Carnegie*.

Referring to the possible scientific work for airships, it will be of interest to recall that the first scientific aërological observations in a balloon were made in 1784 by an American physician, Dr. John Jeffries, a graduate of Harvard College, residing at the time in London. Dr. Jeffries presented a printed copy of the extremely interesting narrative on his two aërial voyages[2] to Benjamin Franklin, as also a manuscript copy; both are now in the possession of the American Philosophical Society. Other aëronautical papers and letters of historical interest will be found among the magnificent collection of "Frankliniana," belonging to the Society.

[2] In the second of these voyages, made on January 7, 1785, the English Channel was successfully crossed for the first time by aërial flight.

SPECTRAL STRUCTURE OF THE PHOSPHORESCENCE OF CERTAIN SULPHIDES.[1]

DISCUSSING MEASUREMENTS BY DRS. H. E. HOWE, H. L. HOWES AND PERCY HODGE.

By EDWARD L. NICHOLS.

(*Read April 13, 1917.*)

Ph. Lenard, to whom we owe extended studies of the class of highly phosphorescent substances known as the Lenard and Klatt[2] sulphides, describes[3] the spectrum of the emitted light as consisting of a single broad band in the visible spectrum. This band which appears single, in most cases, as viewed with the spectroscope does not however conform to the recognized criteria. The marked difference between the color of fluorescence and that of phosphorescence and the changes of color during decay, suggest overlapping bands. E. Becquerel[4] in 1861 showed in his pioneer work on phosphorescence, that the color of the emitted light varies with the wave-length of the exciting light. His observations apply, it is true, to sulphides of barium, calcium and strontium not identical in make-up with the sulphides of Lenard and Klatt but obviously belonging to the same class. In a recent paper[5] the present writer gave more direct evidence of the existence of more than one band in the spectra of these substances. In that investigation which dealt primarily with the phenomena of color as seen in the phosphorescence, it was shown that with the aid of a special form of phosphoroscope[6] which permitted of the observation of phosphorescence during the first few

[1] An investigation carried out in part with apparatus purchased by aid of a grant from the Carnegie Institution of Washington.

[2] Lenard and Klatt, *Ann. der Physik.*, XV., p. 225, 1804.

[3] Lenard, *Ann. der Physik.*, XXXI., p. 641, 1910.

[4] E. Becquerel, *La Lumiere*, Vol. I., 1861.

[5] Nichols, *Proc. Am. Philos. Soc.*, 55, p. 494, 1916.

[6] Nichols, *Proc. Nat. Acad. Sc.*, II., p. 328, 1916; also Nichols and Howes, *Science*, N. S., XLIII., p. 937, 1916.

thousandths of a second after the cessation of excitation as well as later, various marked changes of color during decay not previously noted could be detected. These changes were readily explained by the assumption of overlapping bands, one of which decays with great rapidity and vanishes in a few thousandths of a second, while the other persists. The actual existence of these two components was readily verified:

1. By observing the spectrum of the light as viewed through the openings of the phosphoroscope. One end of the band could be seen to collapse immediately after the cessation of excitation, *i. e.*, the end towards the violet in the case of the luminous barium sulphides and the end towards the red when the sulphides of calcium or strontium were under observation.

2. By exciting the substance at the temperature of liquid air. Under these conditions the persistent band was completely destroyed leaving only the band of short duration visible in the phosphoroscope; with consequent change of color.

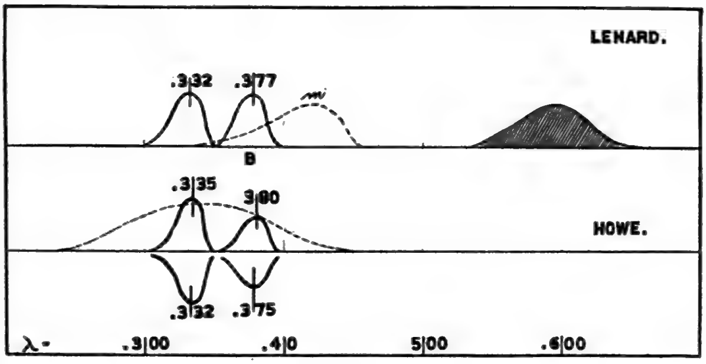


FIG. 1.

It should be noted in this connection that in their original paper[7] Lenard and Klatt depicted these spectra as complex, while in his latest paper, already cited, Lenard prefers to regard them as single. This later view may be most briefly and conveniently indicated by the upper part of Fig. 1, which is a typical diagram reproduced from Lenard's plate. Here the shaded area represents the location of the band of emission, indicated as a single broad band and the two

[7] Lenard and Klatt, *Ann. der Physik*, (4), XV., p. 225, 1904.

enclosed areas *BB* in the ultra-violet show the regions capable of exciting phosphorescence. These two crests or so-called bands of excitation (Erregungsbände) have fixed positions as to wave-length, for each sulphide.

Significance of the Bands of Excitation.

It seemed to the writer probable that these regions of maximum excitation, the positions and appearance of which had long since been beautifully depicted by Becquerel in the work already cited, were due to the presence of absorption bands. Dr. H. E. Howe who was employed during the past summer in the study of the ultra-violet absorption spectra of certain fluorescent solutions, was kind enough to test this hypothesis. Following the method developed by Stokes and by Becquerel and subsequently used by Lenard and Klatt, the phosphorescent substance was exposed to the dispersed rays of a large quartz spectrograph. The source of light was the powerful submerged aluminum spark described by *Henri*[8] and subsequently employed by Howe[9] in his study of absorption spectra. This affords a continuous spectrum of great intensity extending to about .2 μ. A considerable portion of the ultra-violet spectrum was found capable of exciting fluorescence. In the case of a barium sulphide with lead with a flux of sodium sulphate this broad band of excitation, corresponding to Lenard's "Momentanband," extended from .42 μ to about .23 μ. It is indicated by the dotted line in the lower diagram in Fig. 1. Upon this were gradually developed two narrow crests or maxima which glowed for sometime after the close of excitation, the "Dauerbände" of Lenard. The wave-lengths of these crests were estimated as .380 μ and .335 μ, Lenard gives for a sulphide of similar composition .377 μ and .332 μ respectively, as shown in the upper diagram.

To obtain the absorption spectrum of these sulphides by transmission is impracticable on account of their great opacity, but the following procedure was in some instances successful. A thin layer of the substance was pressed between quartz plates, and mounted in front of the slit in such a position that rays from the spark would

[8] V. Henri, *Physikalische Zeitschrift*, 14, p. 516, 1913.
[9] H. E. Howe, *Physical Review*, 2, VIII., December, 1916.

be diffusely reflected into the collimator of the spectrograph. Photographs which exhibited the selective absorption of the substance were thus obtained. The barium sulphide under investigation showed two narrow absorption bands, indicated below the base line in Fig. 1, and a region of general absorption beyond $.3\,\mu$. The two narrow bands whose crests as determined from the photographs were at $.375\,\mu$ and $.332\,\mu$ obviously correspond with the bands of excitation and sufficiently explain the existence of the latter.

Similar coincidences between selective absorption and selective excitation were established in the case of the compound SrPbNaF at $.355\,\mu$ (Lenard's band $.358\,\mu$) and of SrZuF at $.360\,\mu$ and $.297\,\mu$ (Lenard's bands $.360\,\mu$ and $.297\,\mu$). The relation is therefore probably a general one, corresponding to that already demonstrated in the case of the selective action of infra-red rays upon phosphorescence of zinc sulphide, where the maximum effect was found in regions of maximum absorption.[10]

Spectrophotometric Measurements.

A detailed spectrophotometric study reveals widely varying degrees of complexity in the spectra of the different sulphides. Dr. H. L. Howes kindly made for the writer very careful measurements of three characteristic compounds, which may be regarded as preliminary to a more extended investigation.

His method, briefly stated, was as follows: The substance was mounted behind the disk of the synchrono-phosphoroscope and was illuminated by means of the radiation of the zinc spark; the disk being adjusted so as to afford observation of the phosphorescence in its earliest stages, *i. e.,* after a few ten thousandths of a second from the close of excitation. In place of the photometer used in taking curves of decay a spectrophotometer with two collimators, Lummer-Brodhun cube (L) and constant deviation prism was mounted as shown in Fig. 2. One collimator was directed towards the phosphorescent surface P, the other towards the comparison light A. The latter consisted of an acetylene flame properly screened. The two slits S, S of the spectrophotometer were of equal width and

[10] Nichols and Merritt, "Studies in Luminescence," Publications of the Carnegie Institution, No. 152, p. 84.

measurements were made by moving the flame along a photometer bar *B, B* in the prolonged axis of the collimator. Settings were made at intervals of 50 Ångström units throughout the spectrum. On account of the very great range of intensities within the phosphorescence spectrum it was necessary to increase the effective range of the photometer bar by the interposition of screens for which the reduction factors had been carefully determined.

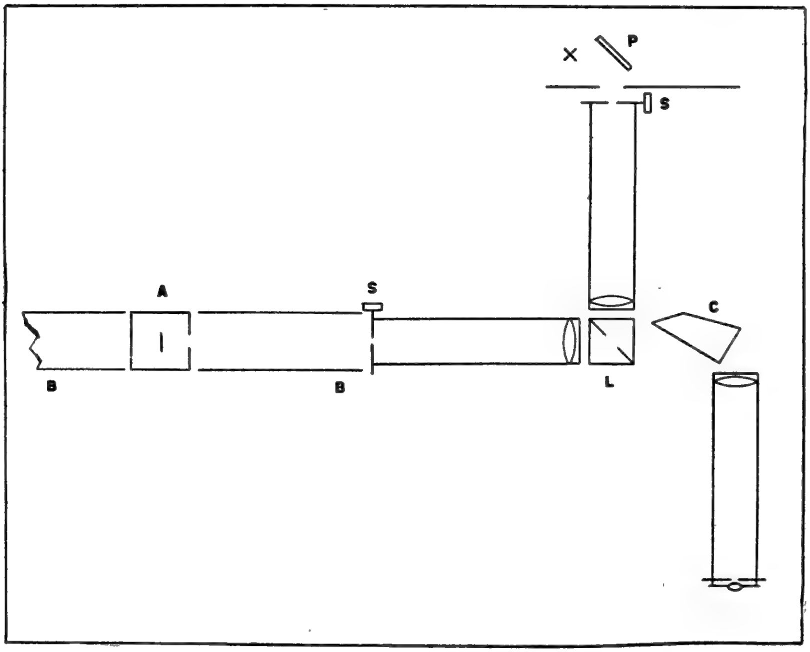


FIG. 2.

The first substance studied in this manner was a strontium sulphide, with bismuth as the active metal, designated as L. and K. No. 13. The spectrum curve obtained by Dr. Howes, using the method described above, is shown in Fig. 3. The complexity of the band is very obvious, there being subordinate crests on either side of the principal maximum.

The curve suggests at once a group of overlapping bands, so nearly merged that to the eye it would appear as a single simple band. There is moreover a distinct suggestion of a systematic relation.

Taking the relative frequencies, *i. e.*, reciprocals of the approximate wave-lengths ($1/\mu \times 10^3$), of the crests as estimated from the curve, it is found that the intervals are either very nearly 58 or twice that number. If a series having 58 as its constant interval be formed with one member located at the principal crest ($\lambda = 4800$)

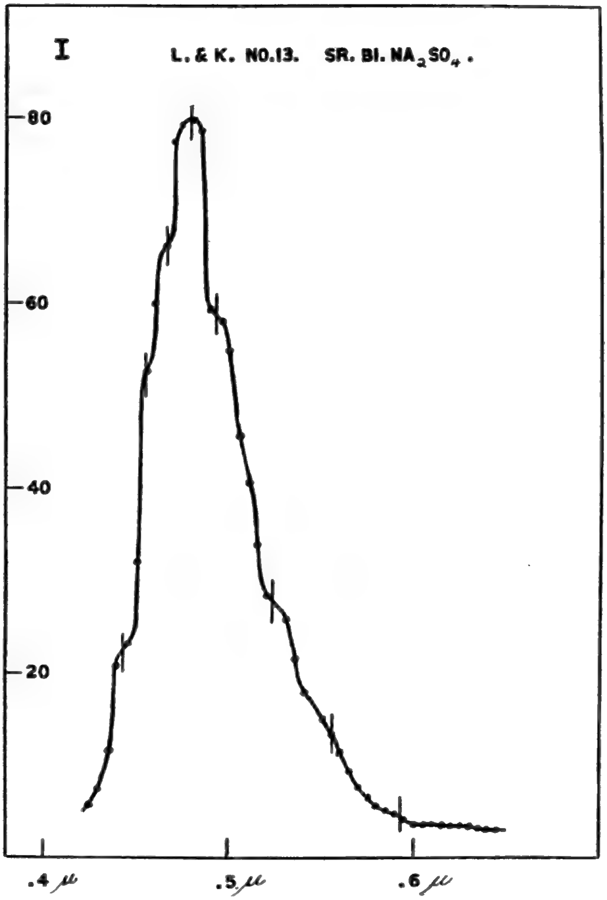


FIG. 3.

other members of this series will coincide with the subordinate crests of the curve. The short vertical lines in Fig. 3 indicate the positions of those members of such a series as coincide with the crests and of two further members which fall on a slight and not very well defined maxima at .5562 μ and .5921 μ.

The agreement is sufficiently good throughout to warrant the statement that:

The band consists of a complex the overlapping components of which, so far as visible, are members of a series having a constant interval.

The following table gives the appproximate frequencies and wave-lengths.

TABLE I.

APPROXIMATE FREQUENCIES AND WAVE-LENGTHS OF VISIBLE CRESTS IN SPECTRUM OF THE PHOSPHORESCENT SULPHIDE L. AND K. No. 13 (Sr. Bi, Na_2SO_4).

Visible Crests. μ	Series. $1/\mu \times 10^3$	Intervals.
.4430	2257	58
.4547	2199	58
.4670	2141	58
.4801	2083	58
.4938	2025	
——	1967	2 × 58
.5238	1909	
——	1851	2 × 58
.5562	1793	
——	1735	2 × 58
.5921	1677	

The three members of the above series not designated in the table as corresponding to visible crests have wave-lengths at .5084 μ, .5402 μ and .5764 μ and these fall upon less definite maxima on the curve than those which have been called *visible crests.*

Another substance investigated with the spectroscope was a calcium sulphide with bismuth as the active metal (L. and K. No. 3) which is notable for its intense blue phosphorescence.

The spectrum, as will be seen from Fig. 4, appears as a single crested band with a well-defined maximum of unusual brightness at about .447 μ. It is of the well-known typical form, steeper towards the violet and shows no visible evidence of complexity; but the phosphorescent light extends throughout the visible spectrum although of relatively very small intensity in the longer wave-lengths. Plotted to this scale no details of this weaker region can be seen but if the ordinates be increased one hundred fold, as in curve *BB,* various maxima and minima appear; indicating a second complex band, or overlapping group of bands which merge into the brilliant blue band at their more refrangible end.

This is in agreement with the fact recorded in a recent paper[11] that when this substance is excited to phosphorescence at the temper-

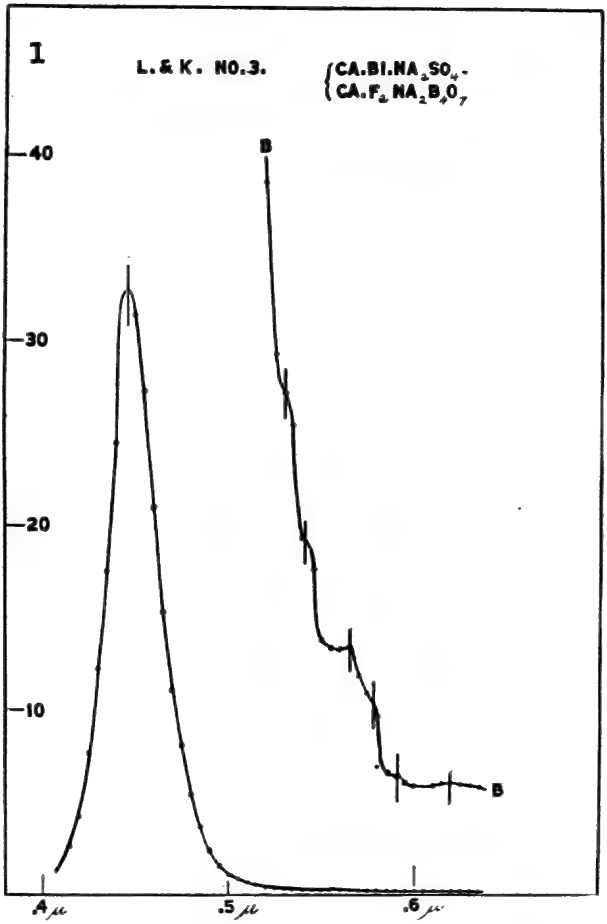


Fig. 4.

ature of liquid air its color is blue-green instead of blue-violet on account of the suppression of the band of shorter wave-length which is dominant at ordinary temperatures.

The crests shown in the curve *BB* also belong to a series of con-

[11] Nichols, Proc. of the American Philos. Society, Vol. LV., p. 496, 1916.

stant frequency interval, the approximate interval being 39. The location of the members of this series which coincide with maxima are indicated by vertical lines. Frequencies ($1/\mu \times 10^3$) and wave-lengths are given in Table II.

TABLE II.

SERIES OF VISIBLE CRESTS IN THE SPECTRUM OF L. AND K. SULPHIDE No. 3 (CaB_2').

Visible Crests. μ	Series. $1/\mu \times 10^3$	Interval from Series.
.5300	1887	39
.5411	1848	39
.5528	1809	39
.5650	1770	39
.5781	1731	39
.5910	1692	39
.6049	1653	39
.6200	1614	

Here every member of the series is represented by a recognizable, although in some cases somewhat indefinite maximum in the curve, as far as .5300 μ. If we extend the series further towards the violet we find that the ninth member beyond .5300 μ lies at .4468 μ (frequency 2238) and this coincides with the main crest well within the errors of observation. There are other barely discernible indications of submerged crests on either side of the principal crest.

The most striking example investigated in this preliminary study is that presented by L. and K. No. 33, a barium sulphide with copper.

Here we have obviously two overlapping complexes of bands (see Fig. 5), at least 14 crests of which are indicated more or less definitely by the irregularities in the spectrum curve.

In this case the bands fall into two groups. From wave-length .5 μ towards the violet the frequency intervals between neighboring crests are all multiples of 70. Towards the red the interval is 26.6 for all but one band. This band at .5376 μ falls however into the series having the constant interval of 70.

To indicate the closeness of the agreement vertical lines have been drawn on the diagram in Fig. 5, as in the previous cases, at wave-lengths corresponding to those members of the two series of constant interval which coincide with observable crests. Solid lines belong to the group with an interval 70, dotted lines to the 26.6 interval. Wave-lengths, reciprocals and intervals are given in Table III.

The designation of these series as of constant interval, upon the basis of the curves in Figs. 3, 4 and 5, can be tentative and approximate only; but no systematic departure large enough to be detected appears to exist. The wave-lengths given in the tables are those of the vertical lines and therefore of the members of the constant interval series which coincide with the various crests. No independent

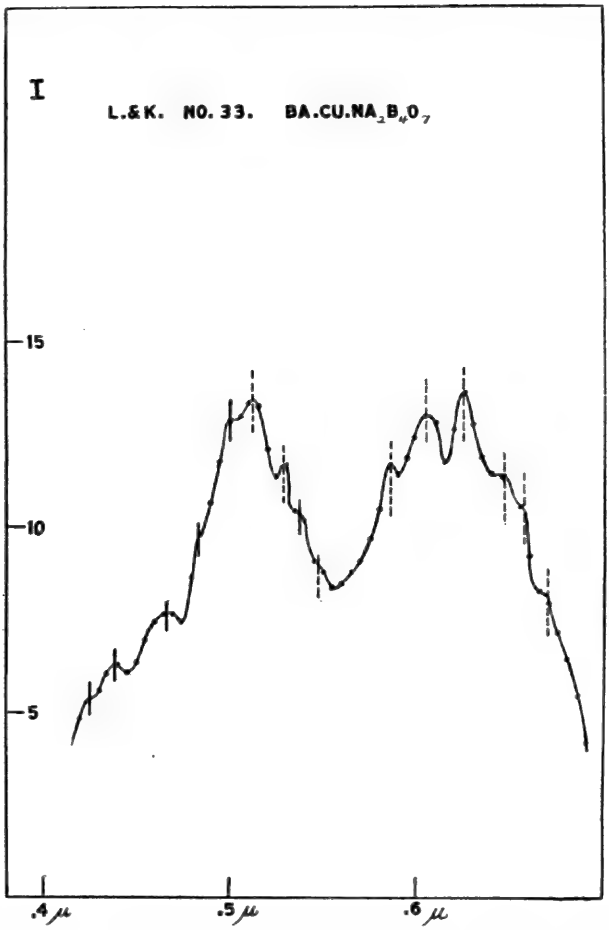


Fig. 5.

estimates of the wave-lengths would seem to be significant. The curves however were plotted directly from the spectrophotometric readings without reference to any possibly symmetrical arrangement of the crests.

TABLE III.

Approximate Frequencies and Wave-Lengths of Visible Crests in the Spectrum of the Phosphorescent Sulphide L. and K. No. 33.

Visible crests with interval = 70.

Wave-Lengths.	Frequencies $1/\lambda \times 10^3$.	Intervals.
4255	2350	70
4386	2280	
——		70 × 2
4673	2140	70
4831	2070	70
5000	2000	
——		70 × 2
5376	1860	

Visible crests with interval = 26.6.

Wave-Lengths.	Frequencies.	Intervals.
5000 μ	2000.0	26.6 × 2
5136	1946.8	26.6 × 2
5283	1892.6	26.6 × 7
5861	1706.4	26.6 × 2
6049	1653.2	26.6 × 2
6250	1600.0	26.6 × 2
6465	1546.8	
6578	1520.2	26.6
6695	1493.6	26.6

Whether the spectra under consideration are to be regarded as consisting of a single band or of more than one band is not a question of complexity of structure. Any system, however complex, which behaves as a unit under varying conditions of temperature, mode of excitation, etc., all the components being affected in like manner, may be considered as a single band in the sense in which that term has been used by Lenard. We have a striking example indeed of such bands or systems of great complexity of structure in the case of the uranyl salts.

The evidence that, in general, the spectra of the phosphorescent sulphides contain more than one band or complex has already been mentioned, *e. g.*, the marked changes of the color of phosphorescence with temperature and during the process of decay, the change of color with the mode of excitation as described by Becquerel, etc.

In the three sulphides the spectra of which have just been discussed it was thought probable that in spite of the overlapping of the components something might be learned by observing the decay of phosphorescence of different regions of the spectra separately and for this purpose Drs. Howes and Hodge made the following determinations.

The Decay of Phosphorescence in Different Portions of the Spectrum.

To obtain the curve of decay for a restricted region of the spectrum the spectrophotometer was used in combination with the synchrono-phosphoroscope and photometer bar as described in a previous paragraph (see Fig. 2). The collimator slits which, to secure the greatest possible detail in the spectrophotometric measurements had been very narrow, were opened to a width of 2.0 mm. so that the brightness of the contrast field would be sufficient to allow the observer to follow the rapidly fading phosphorescence even in the weaker portions of the spectrum.

The spectrophotometer was set for a selected region and the curve of decay was obtained in the usual manner by observing the position of the comparison lamp upon the photometer bar which gave equality in the contrast field for increasing times after the close of excitation. The range of the readings was from .001 sec. to .03 sec. according to the position of the sectored disk upon the shaft of the phosphoroscope.

In this way a set of curves corresponding to several nearly equidistant regions within the phosphorescence spectrum was obtained for each of the three sulphides under consideration.

Three such curves for the Ca, Bi sulphide No. 3, plotted with $I^{-1/2}$ as ordinates, are shown in Fig. 6; four for the Sr, Pb sulphide No. 13 in Fig. 7 and three for the Ba, Cu sulphide No. 33 in Fig. 8. A notable feature of all these curves is the existence of two so-called linear processes the first of steeper slope and therefore indicative of a more rapid decay of phosphorescence than the second. This form

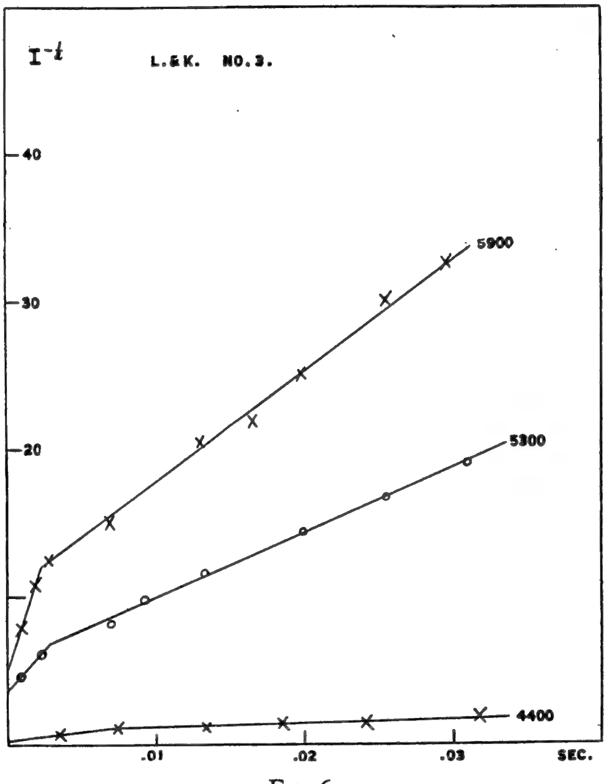


FIG. 6.

of curve, as is well known, is characteristic of phosphorescent substances in general, the only well established exceptions being those occurring in the case of the uranyl salts.[12] As regards the relation of the two processes recorded in these diagrams to what appear as the first and second processes in the usual study of the long time phosphorescence of such sulphides, it is clear that the second process

[12] Nichols, *Proc. Nat. Academy of Sciences*, II., p. 328, 1916.

in our curves is not identical with the first process as observed by the usual long time methods.

Assuming the second process to continue; the intensity after 1 second would be about 1/1,000 of that at .01 sec. or roughly 1/20,000 of its initial brightness; whereas as is well known these substances retain an easily visible phosphorescence after many seconds.

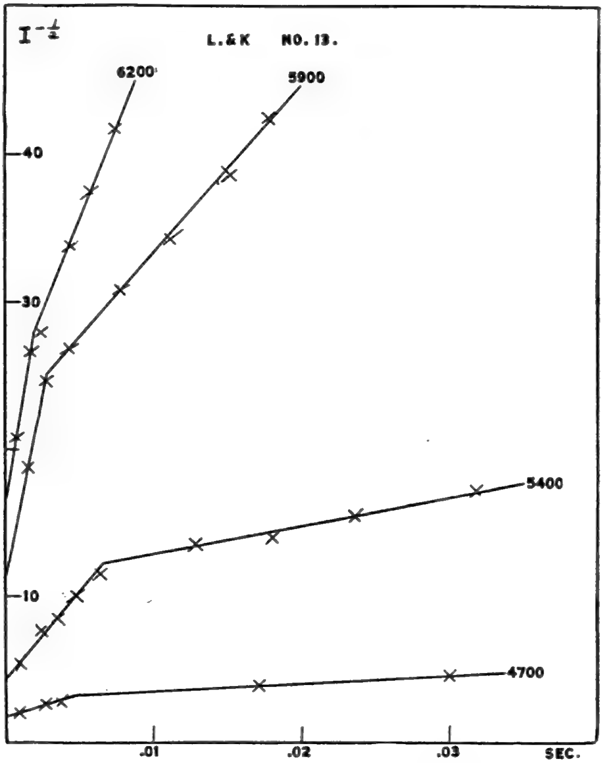


Fig. 7.

This can only be accounted for by supposing that one or more later processes of successively slower decay follow one another; making up a more complicated curve of decay than has generally been assumed. Carl Zeller,[13] the only previous investigator to determine the earlier stage of this type of phosphorescence, has

[13] Zeller, *Physical Review,* (1), 31, p. 367; also Carnegie Publications, No. 152, p. 124.

published a diagram which overlaps the range of the present experiments. Three of his curves are for a Sr, Bi; Ca, Bi and Ba, Cu sulphide respectively; corresponding to and possibly identical with our 13, 3 and 33. These show a linear process which he regards as the first process in the decay and which, as he points out, has,

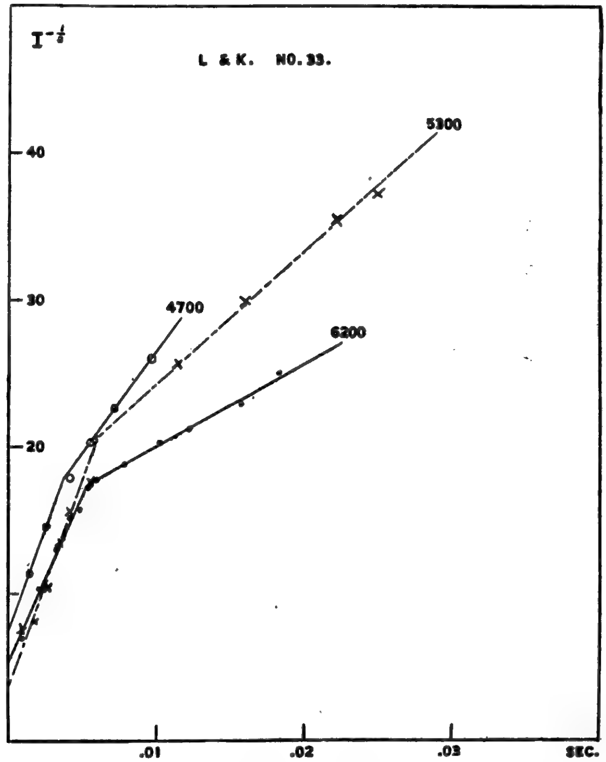


Fig. 8.

in each case, a much steeper slope than the first process, so called, obtained by observations covering the range from a second or more onwards. The slope of his lines considering the range from .01^s to .03^s and remembering that Zeller did not determine the decay for various regions of the spectrum separately are fairly comparable with the second process (beyond the knee) in Figs. 6 and 7 if we select the regions including the principal crest. We may therefore regard Zeller's process which extends as far as .06 second as the same as our second process.

The change of slope between this process and the *first process* so called in the curves of decay for these sulphides as observed during the interval from two seconds onward is very great. In a representative curve obtained by Mr. Carleton E. Power[14] for example his first process extends for nearly 50 seconds. The slope if computed for a time scale such as that used in our measurements where 1/100 sec. may be taken as a convenient unit, is scarcely perceptible. The increase in the ordinate ($I^{-1/2}$) in passing from time .01 sec. to .02 sec. in our second process or in Zeller's process is of the order

$$\frac{I_{02}^{-1/2}}{I_{01}^{-1/2}} = 1.2;$$

Power's first process would give a ratio of the order of 1.008.

In other words during the first few hundredths of a second after the close of excitation the intensity of phosphorescence falls in each 1/100 of a second from unity to about .70 while after several seconds, it falls in 1/100 second only from unity to .99.

It seems probable, assuming continuity in the progress of the decay, that if we had a complete curve of decay for one of these sulphides, the knee between our second process and the first process of the long-time curves would be found to lie somewhere between 0.10 second and 1.0 second. If it occurs much earlier than 0.10 second, Zeller would have discovered it; if much beyond 1.0 second it should appear in the long-time measurements. In fact many curves for the decay of phosphorescence by the latter process do show a downward trend and Lenard, among others, has disputed the linear character of the curve as we approach the origin of time. The existence of at least four linear processes each of longer duration and lesser slope than the preceding may well account for the difference of opinion. An observer determining the law of decay as a whole by a method not taking cognizance of time intervals of less than say 1/10 second, would describe as a curve what under much more detailed study might be revealed as a succession of linear processes.

Owing to the overlapping of the components in the spectra under consideration it is difficult to determine whether the group of equidistant bands are to be regarded as a unit, as in the case of the

[14] Power, C. E., Manuscript Thesis in the Library of Cornell University.

uranyl salts, or indeed whether they constitute the whole of the phosphorescence spectrum. To that end some method permitting of more complete resolution must be devised. The pronounced changes in the color of the phosphorescent light would make it seem probable that we have to do in these observations chiefly with components of the phosphorescence that are of rapid decay and which, after a few hundredths of a second, disappear leaving behind other components which constitute the phosphorescence of long duration. These, which are probably of relatively insignificant initial brightness, doubtless overlap the phosphorescence of short duration but occupy, as a whole, a somewhat different portion of the spectrum.

In that case since one has to do with a different group of bands in observing the initial and the later phases of phosphorescence there would be an actual discontinuity between the processes discussed above and the great change of slope is readily explained.

Summary.

1. The regions of selective excitation (the bands of excitation for the Lenard and Klatt sulphides, are shown to coincide in position and extent with absorption bands in the transmission spectrum.

2. The spectrum of the phosphorescent light, during the first few thousandths of a second after the close of excitation, contains one or more groups of overlapping bands, the crests of each group forming a spectral series having a constant frequency interval.

3. The decay of phosphorescence during the first three hundredths of a second after the close of excitation may be described as consisting of two processes each showing a linear relation between $I^{-1/2}$ and time. The first and more rapid process lasts for less than .01 second for the three sulphides studied under the intensity of excitation employed. The second process probably persists for .06 second or more.

4. The phosphorescence of long duration of the sulphides under consideration is probably due to another group of bands of comparatively feeble initial brightness which come under observation only after the phosphorescence of short duration has vanished.

Cornell University,
Department of Physics,
March, 1917.

A NEW BABYLONIAN ACCOUNT OF THE CREATION OF MAN.

By GEORGE A. BARTON.

The Babylonians were particularly fond of stories of the creation, of the world and the beginnings of civilization. The best known of these is the "Epic of Creation" in seven tablets or cantos, parts of which were discovered by George Smith in the British Museum more than forty years ago. Still another was found in 1882 at Abu Habba by Rassam and brought to the British Museum. It was later published by Dr. Pinches. The same museum contains fragments of a third story of the creation which was written in Assyria.

The University Museum in Philadelphia is particularly rich in texts of this kind. In 1914 Dr. Poebel published one which combined accounts of the creation and the flood,[1] in 1915 Dr. Langdon published one which contains a most interesting account of the beginnings of agriculture,[2] and to these the writer is now able to add another that he came upon among some uncatalogued tablets some months ago.[3] This last text was excavated at Nippur and is one of the many tablets that lay unpacked for years in the basement of the Museum. As the subjoined translation will show, the text deals with the creation of man, the origin of Babylonian pastoral life and the exigencies which led to the construction of cities. Some of its phrases remind us of expressions in the early chapters of the Book of Genesis. The text is as follows:

1. The mountain of heaven and earth
2. The assembly of heaven, the great gods, entered. Afterwards
3. Because Ashnan[4] had not come forth, they conversed together.

[1] A. Poebel, "Historical Texts," Philadelphia, 1914, 9 ff., also G. A. Barton, "Archæology and the Bible," Philadelphia, 1916, 278–282.

[2] S. Langdon, "Sumerian Epic of Paradise, the Flood, and the Fall of Man," Philadelphia, 1915; also Barton, op. cit., 283–289.

[3] The tablet has since been catalogued as No. 14005.

4. The land Tikku[5] had not created;
5. For Tikku a temple platform had not been filled in;
6. A lofty dwelling had not been built.
7. The arable land was without any seed;
8. A well or a canal(?) had not been dug;
9. Horses and cattle had not been brought forth,
10. So that Ashnan could shepherd a corral;
11. The Anunua, the great gods, had made no plan;
12. There was no *šes*-grain of thirty fold;
13. There was no *šes*-grain of fifty fold;
14. Small grain, mountain grain, and great *asal*-grain there was not;
15. A possession and house there was not;
16. Tikku had neither entered a gate nor gone out;
17. Together with Nintu,—the lord had not brought forth men.
18. The god Ug as leader came; as leader he came forth to plan;
19. Mankind he planned; many men were brought forth.
20. Food and sleep he planned for them;
21. Clothing and dwellings he did not plan for them.
22. The people with rushes and rope came,
23. By making a dwelling a kindred was formed.
24. To the gardens . . . they brought irrigation;
25. On that day their [gardens sprouted(?)].
26. Trees . . . mountain and country. . . .

1. *g̊ar-sag-an-ki-bi-da-ge*
2. *erim-an-ni dingir-dingir a-nun-na im-tur-ne-eš a-ba*
3. *mu* [d]*ezinu nu-in-da-ma-da ub-še-da-an-dug-ga*
4. *kalam-mu* [d]*tik-ku nu-in-da-an-dim-ma-aš*
5. [d]*tik-ku-ra temen nu-mu-na-sig-ga-aš*
6. *tuš-up-pi-a ra*[6]*-ub-šar-ra*
7. *ar-nu-me-a-am numun šar-ra*
8. *pu-e-x*[7]*-a-bi nu-in-tu-ud*
9. *anše-ra*[8] *bir-eš-bi nu-in-tu-ud*
10. *mu* [d]*ezinu utul-umuna-bi apin*
11. [d]*a-nun-na dingir gal-gal e-ne nu-mu-un-zu-ta-am*
12. *še-šes erim-ušu-am nu-gál-la-am*
13. *še-šes erim-eninnu-am nu-gál-la-am*
14. *še-tur-tur še-kur-ra še-à-sal-gal-la nu-gál-la-am*
15. *šu-gar tuš-tuš-bi nu-gál-la-am*
16. [d]*tik-ku nu-še-tur ka nu-il*

[4] A god of vegetation; Brunnow's "List," 7484.

[5] Tikku is a river-bank personified.

[6] *ra* = *la*, "not"; cf. "Origin of Babylonian Writing," 287. It is often employed in the Stele of Vultures in this sense; see, *e. g.*, Col. XXI., 2, 3, *na-ru-a-bi ba-ra-ad-du*, "this stele one shall not break."

[7] The sign *x* is 606 in the "Origin of Babylonian Writing." Its values are undetermined.

[8] *anše-ra*, for *anše-kur-ra*. *kur* was omitted by the scribe.

17. *en ^d^nin-tu en kal-kal nu-in-tu-ud*
18. *^d^ug*[9] *maš tum-ma maš dù-da ê*
19. *nam-lu un-zu erim-nun-a ga-e-ne*
20. *gar-kù-šà-bi mu-un-zu-uš-am*
21. *tug-gi-tuš-tuš-bi nu-mu-un-zu-uš-am*
22. *uku giš gi-a-na-dur-bi mu-ê*
23. *tuš-gim-ka ba-ni-in-ib ušbar*
24. *a-šar-šar-ra . . . im-gù-gù-ne*
25. *ud-ba-ki dar- . . . r]a-e-n[e . . .*
26. *giš-bi dul . . . bi-kur-gar . . .*
27. *gub? . . . dul? . . . bi . . .*
28. . . . . . . *nu* . . . .

Reverse.

1. Father Enlil(?) . . . .
2. . . . . . . standing grain(?) . . . .
3. . . . . . . for mankind . . . .
4. . . . . creation of Entu . . . .
5. Father Enlil . . . .
6. Duazagga, the way of the gods . . . .
7. Duazagga, the brilliant, for my god I guard(?) . . . .
8. Entu and Enlil to Duazagga. . . . .
9. A dwelling for Ashnan from out of Duazagga I will [make(?) for thee].
10. Two thirds of the fold perished(?);
11. His plants for food he created for them;
12. Ashnan rained on the field for them;
13. The moist(?) wind and the fiery storm-cloud he created for them.
14. Two thirds of the fold stood;
15. For the shepherd of the fold joy was disturbed.
16. The house of rushes did not stand;
17. From Duazagga joy departed.
18. From his dwelling, a lofty height, his boat
19. Descended; from heaven he came
20. To the dwelling of Ashnan; the scepter he brought forth to them;
21. His brilliant city he raised up, he appointed for them;
22. The reed-country he planted; he appointed for them;
23. The falling rain the hollows caught for them;
24. A dwelling-place was their land; food made men multiply;
25. Prosperity entered the land; it caused them to become a multitude.
26. He brought to the hand of man the scepter of command.
27. The lord caused them to be and they came into existence.
28. Companions calling them, with a man his wife he made them dwell.
29. At night[14] as fitting companions they are together.
30. (Sixty lines).

1. *a-a ^d^en-lil.* . . . .
2. . . . . . *nà-si-a.* . . . .

[9] In Semitic, Shamash, the sun-god.

3. *nam-lù-ge*. . . . .
4. . . . . . . *ba en-tu-ge*. . . . .
5. *a-a* *[d]en-lil*. . . . .
6. ***du-azag-ga šid-da dingir***. . . . .
7. ***du-azag-ga lag̃-ga-a dingir-ma-da-ra ab-u[ru***. . . . . . .
8. *[d]en-tu [d]en-lil-bi du-azag-ga-ra ne*. . . . .
9. *du [d]ezinu-bi du-azag-ta im-ma-da-r[a-rú*. . . .
10. *šanabi-e amaš-a im-ma-ab-gab-*. . . . . .
11. ***u-bi** e-gar-ra-ra **mu-un-a-ba-e-ne***
12. *[d]ezinu gan-e mu-un-imi-am-ne*
13. *lil-ap in uraš-lag-bi mu-un-a-ba-e-ne*
14. *šanabi amaš-a-na gub-ba-ni*
15. *sib-amaš-a g̃i-li dú-dú-a*
16. *gi-li-eš nam-na-gub-ba-ni*
17. ***du-el'-azag-ga*[10] *g̃i-li-il sub-am***
18. *ga-ni-ta sag-gi-il mà-ni*
19. ***ib-găl an-na-ta tum-tum-a-ne***
20. *dù [d]ezinu-bi g̃at-tu ši-še-e-eš*
21. ***uru-azag-na ib-gál mu-da-an-gál-li-eš***
22. *kalam-ma-gi-šag*[11]*-gál mu-gub an-gál-li-eš*
23. *šeq-eš e-ka-sig **im-sá-sạ́-e-ne***
24. *gišgal-ma kalam-ma-ne gar **mu-ni-ab-rug-rug** kal-mê*
25. *x*[12] *kalam-ma ne-gig mu-un-ne-gál meš*
26. *ab-a-tum-ra da-ki uš-ir a-g̃at-mê*
27. *u-mu-un mu-ne-eš-ib-gál mu-da-an-gál-li-eš*
28. *man-na gu-ne za*[13]*-ki dam-ne ne-ba-an-gub-eš-a*
29. *gig-bi-ir*[14] *bar-a-gar dag-me-eš*
30. *lx šu-šú lx*.

The tablet on which this text is written is five inches long and 2 and ⅝ inches wide. The script is of the mixed cursive variety that was often employed in the time of the first dynasty of Babylon (2210–1924 B. C.) and the Cassite dynasty (1775–1150 B. C.). It is impossible from the palæography to date the tablet definitely. It is certainly older than 1200 B. C. and may have been written before the year 2000 B. C.

[10] *du-el-azag-ga* is doubtless a variant spelling of *du-azag-ga*. The sign *el* introduces an additional word for brightness, thus emphasizing *azag*.

[11] *kalam-ma-gi-šag-gal*, literally, "the land reeds are in the midst," a very appropriate name for Babylonia.

[12] The sign transcribed *x* is 241 in the "Origin of Babylonian Writing." It has the meaning "favor." I have rendered it somewhat freely "prosperity."

[13] *za* = *amêlu*, "Origin of Babylonian Writing," 523 and Delitzsch, *Sumerisches Glossar*, p. 218.

[14] *gig-bi-ir*, literally "in their night."

The tablet is rather carelessly written. The scribe made a number of mistakes which he was compelled to correct by erasures. One would infer that the writing was that of a scribal apprentice rather than that of a skilled scribe.

The god Ashnan of this text is a god of vegetation. His name is written with the sign for grain plus the sign for forest. The prominent role which Ashnan plays in the text is proof that the agricultural interest was uppermost in the minds of the writers of the myth. The god Tikku is a personified river-bank. The statement made near the beginning, that he had not created the land, takes the reader back to the beginning of Babylonian civilization before the overflow of the rivers had been circumscribed by dykes.

The myth moves in the same circle of ideas as a portion of the text discovered by Dr. Langdon. According to my understanding of that text, irrigation of the earth was made possible by a marital union of the sun-god with the goddess Nintu.[15] The tablet now discovered represents men generated by the lord and Nintu after they had been planned by Ug, the sun-god. This text presupposes the natural generation of men from a union of gods, as the other text does the natural generation of irrigation.

Our new text recognizes that food and sleep are provided by god but clothing and houses men had to invent. The description of the construction of a reed hut in line 22 of the obverse is true to the form of reed huts that may still be seen in the Babylonian marshes.

The lines on the reverse of the tablet are at the bginning broken. Apparently some god was addressing Enlil, because all had not gone well with men. Duazagga was the celestial abyss, the great abyss of the sky-vault. Here it is described as "the way of the gods," perhaps an allusion to the milky way, along which the gods were supposed to dwell. That men might have more direct help, a dwelling for Ashnan was made on the earth. Thereupon Ashnan created plants for food, and sent over the earth the various kinds of rain-clouds. This mitigated human misfortune only in part. Two thirds of the fold had perished before, but one third still perished. A god, possibly Eulil, accordingly came down and founded cities. These led to the formation of clans or kindreds; misfortune vanished, and

[15] See the writer's "Archæology and the Bible," Philadelphia, 1916, p. 284.

men multiplied. This secure life led to dominion on the part of man, and to settled marriage.

The text discovered by Dr. Langdon described, according to my understanding of it, the beginnings of irrigation, agriculture, and the knowledge of medicinal plants; the new text has to do with the origin of man, the beginnings of agriculture, of city life, and of settled marriage.

Some of the statements in this text remind us, sometimes by their form, sometimes by their substance, of passages in the early chapters of Genesis. Thus: "The lord caused them to be and they came into existence" recalls Gen. 1:3: "And God said, Let there be light and there was light." The statement: "He brought to the hand of man the scepter of command," reminds the reader of the way in Gen. 1:28 God is said to have given man dominion over all other forms of animate life. "Companions calling them, a man with his wife he made them dwell," brings to mind the statement of Gen. 2:18 that it is not good for man to be alone, and of Gen. 2:24: "Therefore shall a man leave his father and his mother and shall cleave unto his wife." The last line of the new tablet: "At night as fitting companions they are together" is the Babylonian equivalent of the last clause of Gen. 2:24: "And they shall be one flesh."

The text will be published with full grammatical commentary in a volume that the writer is preparing for the University Museum. which will be entitled "Miscellaneous Religious Texts."

Bryn Mawr, Pa.,
April, 1917.

THE SOUTH AMERICAN INDIAN IN HIS RELATION TO GEOGRAPHIC ENVIRONMENT.

By WILLIAM CURTIS FARABEE.

(*Read April 14, 1917.*)

Man, of whatever race, as we know him to-day is to such an extent a product of his environment that we can have very little idea of what he was in his primitive state. We sometimes speak of primitive men but we mean men in a low stage of culture without any reference whatever to time or age. There are no primitive men, neither is there primitive culture. Both have been so modified by their environment that they give us very little idea of what the first men and their culture were like. From the beginning both have developed in complete agreement with their environment.

It is said that man differs from the other animals in that he is able to overcome his natural environment. Man has been able to profit by his knowledge of nature's laws, but he has not overcome them. He must depend upon natural products for sustenance and hence is limited in migration and habitat. In the cold climates of high altitudes and high latitudes he is limited by his food supply to the line fixed by nature for the growth of plants and animals. In the hot, moist climate of the tropics he is deprived of energy and ambition and degenerates. He has not yet overcome nature but he has succeeded better than his fellows in adapting himself to nature's requirements. His individual handicap at the beginning of life makes for the greater development of his race. His prolonged period of growth allows the persistent forces of environment to act upon his developing body and fit it for its habitat. If his migrations do not take place too rapidly or do not extend over too wide a range of geographic conditions these body changes become habitual and the race survives. The new characters developed are retained. There is some question as to whether or not the characters acquired by the ancestors are inherited, but it is certain that the habitat with all the geographic factors which have produced those characters is inherited. If the effect of environment is upon the individual and does not become permanently fixed in the race and if it acts only as an inhibitor in the development of characteristics it has the force of an inheritance because it never ceases to operate. Hence the race develops true to the environment. Primitive man must have originated in a tropical but not a jungle country where the environment made little demand upon his growing intellect. The search for food probably took him temporarily outside of his first habitat. After a time the pressure of numbers would prevent his return. His customs and habits would change to meet the new conditions. So, no doubt, he has slowly moved through the long period of his history, from one stage to another, from one environment to another, and from one development to another. These developments were not necessarily from a lower to a higher plane. He had little choice; the quest for food or the pressure from numbers either called or drove him onward from the old to newer fields. He followed the animals and may have learned from them to build his shelter and to store his food against a future need. Necessity developed forethought and made him an inventor. The forces of nature were first feared and then followed. He became as mobile as the wind and the water by whose aid he traveled. After he had thus occupied the habitable globe each section continued to develop a culture, peculiar to its own environment. Every geographical factor had its influence in this development. Sea and bay, lake and river, mountain and valley, forest and desert, temperature and humidity, wind and rain, sunshine and cloud, each and all had their effect in isolating or uniting, separating or deflecting, expanding or confining, the migrating peoples and in determining their physical development, their forms of culture, their economic and political organization. Man has followed no plan, has had no standards. Whatever advancement he has made has been by chance rather than by choice, by accident rather than by conscious direction.

In the migration of man from his original home probably in southern Asia, by way of Behring Strait and North America to the tropics again he completed the cycle of climatic conditions. His long and varied experience had made him wise. Yet he was continually on the march. Crowded into the neck of the Isthmus of Panama he pushed on through and found another continent which, like the one he was leaving, lent itself to a north-south migration with the routes well marked. The Orinoco, the great branches of the Amazon and the La Plata together with the Andes and the coast all offered direct lines of travel, but they all led to hard conditions. The mountains were too high, the forests too dense, the south too cold and the tropics too hot to make a strong appeal. But there was no possibility of retreat until the farthest corner had been reached and turned. By the time of the Discovery he had overrun the whole continent and a return migration was in progress across the isthmus and through the West Indies.

When the first migration entered the continent the people were deflected by the mountains to the two coasts. Those who continued down the west coast, forced to compete with the rank jungle growth for supremacy in a humid debilitating climate, were unable to establish themselves and develop a high culture. So they moved on to the interior plateaus where they found more congenial conditions and where they left evidence of an advanced culture.

Those who made their way to the coast south of the equator must have been surprised to step out of the jungle into an immense desert country, the most arid in the world, stretching away for nearly 2,000 miles as a narrow fringe along the sea. Here they found fertile valleys, watered by the innumerable small rivers and streams which, fed by the melting of the perpetual snows of the mountain tops, made their way to the sea or lost themselves in the desert. These valleys separated by trackless sands offered both food and security. The sea made no call. There were few protected harbors along the great stretch of coast; no outlying islands to be inhabited and no timber for canoes. They became an agricultural people living in villages and using the rivers for irrigating purposes. Irrigation guaranteed regular crops and hence a constant food supply. It also developed inventiveness and coöperation. Their common dependence upon the same water supply developed social organization and a strong government. As these different valleys had the same products there was very little commerce between them and each was allowed to develop its own culture. The archæological remains show the results of this development from independent centers.

Near the southern end of the continent climatic and topographic conditions are reversed. The coast and western slopes of the mountains are forested, while the interior is a semi-desert. The deeply embayed coast has a chain of outlying islands. The steep mountains come down to the sea leaving little arable land. The forests furnish an abundance of suitable timber for canoes. All these elements of environment unite to force the unfortunate tribes who have been pushed along into this region to become a maritime people. The inhospitable snowclad mountains prevent contact with the interior tribes. They were shut off also from the people of the northern coast by rough seas and steep harborless shores. They were thus limited to the islands and the channels between. Their isolation and their hard conditions of life with an uncertain food supply has prevented them from developing a high culture. They have had no leisure. All their energies have been taxed to the uttermost to secure their daily bread.

The nearest neighbors of these canoe people are living under worse conditions even because they were an interior people who have been forced down across the straits into the last point of land on the continent, from which there is no possible escape. With hard conditions and scant food supply they lead a precarious life. They must live in small separate groups in order to make the most of their wild foods. These small units have developed a rugged independence which will permit of no control. There is no necessity nor opportunity for community effort and hence there are no chiefs and no organized government. Left behind and held at bay in a most rigorous climate they have done well to maintain themselves even in their present culture. Their simple life reveals their origin. The absence of the canoe proves them to belong to the mainland east of the mountains where there are no navigable rivers and a harborless cliff coast for a thousand miles. The inhabitants of this plain have always been hunters and not fishermen.

Farther north on the same coast the narrow fringe of lowland is fertile and contains a number of deep bays. Here the people became agriculturists but added to their food supply shellfish from the sea. Many large refuse heaps mark the centers of occupation. The steep coast range of mountains prevented them from passing into the interior where other cultures are found.

Along the north coast from the Amazon to the isthmus representatives of the same people occupy the savannahs and the forested interior. Here the savannah coast tribes with their broader view and easy communication in every instance have developed the higher culture.

While the coast peoples have had every variety of climatic condition due to the change of latitude from the equator to the most southern inhabited point in the world those of the mountains have had much the same variety due to change in elevation from a tropical sea level to the highest habitat of man. The mountains on account of their great height, hard conditions and lack of arable land served at first only as a barrier to deflect and to separate the migrating peoples. After a time the pressure of the populations in the lowland valleys on the west forced the people up the slopes and into the high valleys and plateaus between the Cordilleras. Here they found the Quinua, the oca, and the potato, the hardiest and most useful food plants for cold climates. On the high plateaus they found among other animals the Llama, one of the most useful animals known to man. It offered its flesh for food, its coat for clothing, its hide for harness, and its back for burdens. The high valley dwellers became agriculturists and traders while their neighbors were first hunters, then herdsmen. The cold, raw winds sweeping across the broad open plateaus drove the people to the leeward of the mountains for protection where they formed small communities, each herdsman having his separate corral. These people while living in these remote places were in trade relations with the agriculturists in the valleys. They had a constant food supply in their herds and while conditions of life were somewhat severe they were secure, contented and happy. The broad horizon and invigorating climate stimulated thought. Their occupations gave them leisure for contemplation. So here among the shepherds music and myth reached their highest development.

In the center of this high plateau area is located a very large lake with no outlet to the sea. The valleys all led to the lake. There was no passageway to a more congenial climate. There were no forests whose timber could be used for buildings and canoes but there was abundance of stone in the mountains and turf in the fields for houses and reeds in the swamps about the lake for balsas or rafts. Great towns developed on the shores of the lake which could be reached either by water or by land. The lake exerted a unifying influence for either commerce or war. Magic gave place to a highly developed form of sun worship with a priestly class headed by a great chief who assumed autocratic power. There was soon a desire to extend the functions of this centralized government. Following the command of the spirit they moved their center of dominion northward across the divide to the head of a fertile valley and established a city. With the advantage of organization and location they easily overcame one group after another of the valley peoples who were unable to unite for common defence on account of their natural boundaries. Thus the city became the center of a great empire with a stable government and a state religion. The arts and industries were encouraged, schools and churches established and a high state of civilization secured.

The large number of tribes inhabiting the interior of the continent have had a very different history. The great plains of the southeast have few natural boundaries to confine the people, so from the beginning they have dissipated their energies in spreading far and wide over the whole area without developing one single great center. They have exhausted themselves in the running and have left nothing of importance behind.

In the eastern highlands of Brazil away from all migration routes and cut off from the coast are found a number of tribes belonging to the same stock. As a whole they are the most backward people of the continent. They may be a remnant of the first tribes to inhabit the plateau region who have been pushed aside into the out-of-the-way corners by stronger more advanced tribes who came to the plateau in later times. They occupy the only mountains east of the Andes which are high enough to form a barrier or undesirable enough to serve as place of retreat.

The rivers and valleys north and south and the low divide on the west all lead to the savannah plateau west of these highlands. This became a meeting place for the migrations from all these directions and also a place of dispersion. The routes of forward or backward migration of three great stocks may be traced to this center, by tribes scattered along the way. Representatives of one stock apparently descended the La Plata River to the sea and passed along the coast three thousand miles into the Amazon valley; another followed down the southeastern branches of the Amazon, down the main river and around the coast to the West Indies; while a third occupied the higher branches of the Amazon and crossed the watershed to the north coast.

The Amazon Valley, an area nearly as large as the United States, was occupied by hundreds of tribes belonging to several different linguistic stocks and all in very much the same stage of cultural development. The whole area is well within the tropics and shut off from the high cultures of the west by impassable mountains. It is a humid tropical forest jungle with a most monotonous debilitating climate. Nature here is overpowering, because she makes life so easy there is no necessity for effort. There is no struggle of intelligence against the forces of nature, because she provides the necessities of life ready made. The bounties of nature gratify the enfeebled ambition without labor. The daily needs have daily satisfactions. The climate is so mild that little or no clothing is required nor any habitations except the simplest shelters which may be built in a few hours when needed. There is no necessity for exercise of forethought, invention, or ingenuity. There is leisure but no energy. The law of social gravitation does not operate because there is no necessity for coöperation. The people live in small isolated groups because they require space for hunting and fishing. Hence there can be no central government. The sluggish rivers offered easy transportation. As there were no natural boundaries to confine the people and no central authority the different groups moved about at will coming into contact with other groups of different stocks and mingling cultures. There was no commerce because there was no variety of natural products in any one area not common to every other. There is little relief of land, change of climate, or variety of soil. The culture is as uniform as the environment. A characterless country is producing a characterless people. The Amazon Valley was the last great region to be occupied by man. There is no evidence of great antiquity either in archæological remains or in present cultures. The languages spoken show a close relationship with outside groups. The cultures, always first to reveal the effects of a change of environment, show certain similarities, but are decadent in form.

All the evidence at hand tends to show that the culture of the South American Indian has developed in perfect harmony with his geographic environment.

University of Pennsylvania,
April 14, 1917.

GROWTH AND IMBIBITION.

By D. T. MACDOUGAL, Ph.D., LL.D., and H. A. SPOEHR, Ph.D.

(*Read April 13, 1917.*)

General Considerations.

The chief purpose of the studies described in the present paper has been to correlate some of the more striking features of growth in plants with the action of contributory factors, and to resolve this complex process into its constituent reactions so far as might be possible.

New viewpoints have been sought by the reduction and analyses of continuous series of measurements of the entire course of enlargement of single organs or members. Experimental species were chosen concerning which much was known as to their respiration, transpiration, imbibition capacity and chemical composition. The daily, seasonal and developmental variations in such matters as carbohydrate content, acidity and swelling capacity of some of the plants had already been the subject of various investigations at the Desert Laboratory, and additional determinations were made in the course of the work. The final or actual increase which is measurable as growth, by weight or dimensions is predominantly a hydration or imbibition process as the increment to any growing cell or embryonic region is at least 99 per cent. water. There is immediate necessity therefore for a study of factors influencing imbibition. Whatever theory of colloidal structure may be adopted, there is no reason for supposing that the interpolation or absorption of water in a complex mixture of such substances is different in the plant cell from what it might be in similar material in the laboratory. The protoplast and its envelopes are undoubtedly a complicated mixture of colloids in a state of more or less constant change.

A successful search was instituted for mixtures which would show the same general imbibition phenomena as the living plant.

Gelatine alone has been found to furnish valuable analogies in the study of the action of animal tissues. It is not adequate for the vegetable protoplast however. Mixtures consisting largely of the amorphous condensed carbohydrates such as agar to which is added a small proportion of albumen or amino-acid are found to respond to the action of acids, alkalies and salts in a manner similar to that of the plant.

Some new conceptions of the general nature of respiration and its correlation with growth have been made possible. The origin and fate of the sugars, particularly the pentosans, have been made the object of extended experimentation, and the results obtained are not the least important of those presented herewith. Most of the attempts which have been made to ascertain the essential nature of growth have been made on the assumption that it is a single, simple or unified process. Thus for example, much attention has been concentrated upon fixing the lower and upper limits of growth with regard to temperature, and recently much has been written concerning the temperature coefficient. A number of authors concur in the assertion that within a certain range, generally between 15° C. and 30° C., the rate of acceleration is one which follows the van't Hof law of doubling or tripling for every rise of 10° C., it being agreed that no such conformity is shown in the extreme upper and lower ranges of temperature. This partial or accidental agreement of smoothed curves of growth with those depicting the course of simple reactions has diverted attention more than once from the fundamental fact that growth depends primarily on respiration, imbibition and osmosis. Respiration is essentially a complicated swirl of sugar disintegration processes which may be influenced in any one of its parts by the oxidation potential, by the dearth of material or over-accumulation of products in any part of the complex. The concentration of the various reaction products may exert their own direct effect on imbibition and consequent enlargement. In addition to, and partly dependent upon the imbibition phenomena, elongation may be modified by such factors as water-loss. Thus for instance, growth upon a rising temperature may reach a point where, as a result of temperature, the water-loss would temporarily be greater than the supply, with the result that a cessation, slackening or shortening would ensue until an adequate supply reached the expanding region.

The proposal of Rahn[1] to explain the relation of growth to temperature upon the basis of a direct integration of enzymatic action and enzyme destruction does not seem adequate. It is true that among the reactions upon which the growth of plants depends are syntheses or renewals of thermo-labile material, and upon metabolism possibly including oxidation of carbohydrates. Each of the separate processes or reactions, enzymatic or otherwise, goes on at a rate determined by the temperature, and by the concentration of its products, and to an extent limited by the amount of material brought into its reactions. The extent to which, for example, the sugars are oxidized determines the degree of acidity or alkalinity of the cell thus affecting its water relations in a very serious manner. Also as will be shown later, the swelling of colloids, and presumably the growth capacity of a cell, may be modified by proteins, while its volume or measurable variation in volume is at all times a function of the balance between water-accession and water-loss.

The cell itself may be considered as a mass of colloidal material variously altered from the globular by pressure and contacts. The outermost layer being of greater density or compactness is usually designated as a membrane, and much has been written during the past few years concerning the permeability and the modifiable semipermeability of such structures. The meristematic or embryonic cell with the action of which we are chiefly concerned in growth, is in its earlier stages dense and shows none of the cavities or clear spaces which form such a large part of the volume of a mature cell, while the relatively large nucleus shows even greater density.

The enlargement of this mass consists to an extent as great as 98 or 99 per cent. in swelling by the imbibition of water. The rate, extent and total amount of such swelling will be determined by the character of the colloidal mixture, by salts, acidity or alkalinity of the solutions present, and only to a very slight extent by osmosis as this process takes place in colloids. Hence turgidity may play a very minor part in the earlier stages.

[1] Rahn, O., "Der Einfluss der Temperatur und der Gifte auf Enzymwirkung, Gärung, und Wachstum," *Biochem. Ztschrft.*, *27*: 351, 1916.

With increase in size vacuoles begin to appear. The active cell is usually conceived as a sac with irregular strands of cytoplasm extending from the peripheral layers of protoplasm, the nucleus being variously placed in this irregular mass. The vacuoles or spaces appearing colorless in living cells and clear in preparations are taken to be sacs containing electrolytes or other dissolved material. The capacity of these dissolved substances to absorb water osmotically tends to increase their volume and cause distension resulting in turgidity or swelling of the cell and in rigidity of the organ when whole tracts or layers act in this manner. Turgidity has hitherto been held to account for the entire expansion of growth as noted above. It is now apparent, however, that we are in a position to draw a slightly different picture of the mechanical features of the cell in what may be termed the second stage. In addition to the denser colloids of the wall, the lining layer of protoplasm, and the nuclear structures, it is known that even in the clear regions of the cell there are emulsions and that the entire cell is a mass of gels of different composition and varying degrees of dispersion. The cell may take water into the vacuoles by the osmotic action of the electrolytes, but the entire mass tends to swell as would a mixture of protein, cellulose, agar, gum arabic, starch and other substances, and such masses may be modified by transpiration or direct loss of water.

The first recognition of the differential action of acidity and alkalinity appears to have been expressed by Spoehr and Estill who say:[2]

> It has become evident that the total swelling of plants like *Opuntia blakeana* and *O. discata* in dilute solutions of acids, alkalis, and salts represents the summation of independent reactions of various material to these reagents. Thus, solutions of acids, alkalies and salts influence the swelling and growth of these plants by affecting: (1) the hydratation of the protoplasts; (2) the material that goes to make up the cell-wall and fibro-vascular system; (3) the permeability and osmotic properties of the plasma-membrane. It has been found that these three factors can act independently and even in opposite directions. Great differences were found in these respects in different portions of the same cactus joint and between young and mature ones; the colloidal material of the former showed much greater swelling than the latter in all solutions, and the excess of swelling in acid media above that in

[2] Report Dept. Bot. Res. Carnegie Inst. of Wash. for 1915, p. 66:

alkaline media or distilled water was much greater in the young joints. Of interest is the observation that the colloidal material from mature joints which have been freed as much as possible from the fibro-vascular strands showed a diminution in volume in weak alkaline solution.

Mr. E. R. Long also working at the Desert Laboratory made some tests of this matter and found that the swelling capacity of sections of *Opuntia discata* as determined by weighing, was less in acidified than in neutral solutions and that the swelling was sometimes less in alkaline solutions than in distilled water.[3] These results suggested that it would not longer be profitable to consider the plant as a protein gel and that some comprehensive tests would be necessary to establish the general colloidal character of growing parts.

This mistake had been made by Borowikow[4] who assumed that plant cells would grow in an acid condition like a mass of gelatine, showing the greatest imbibition of water in acids.

The action of plant tissues having been determined, it was attempted to make up mixtures of colloids similar to those occurring in the plant which might show parallel reactions. The technique and results of measurements of the swelling of plant tissues and of plates of colloidal mixtures will be given in a separate section of this paper. It may be said in this place that some highly profitable comparisons are made possible by the data obtained.

The effort to compound colloidal mixtures which might simulate living material was extended to include additions of other proteins beside gelatine, such as egg-albumin, bean-albumin and of amino-acids, together with complex condensed carbohydrates as agar. This was rewarded by results which show that small proportions of soluble proteins or albumens added to gelatine-agar mixtures decrease the water-absorbing capacity of these physical analogues of the protoplasts in the presence of electrolytes, and suggest the highly interesting possibility that the growth-enlargement of the cell might be definitely checked or terminated by the passage of such albuminous emulsions from the nucleus to the cytoplasm. The

[3] "Growth and Colloid Hydratation in Cacti," *Botan. Gazette*, 59: 491, 1914.

[4] *Biochem. Ztschrft.*, 48: 230–246 and 50: 119–128, 1913.

actual quantities necessary to produce the action described in a later section of this paper would be small and in some cases lie beyond detection by ordinary microchemical or cytological methods.

Some of the earlier results obtained by a study of the growth of opuntias have already been described by the senior author.[5]

The comparison of the action of *Opuntia* with that of roots and stems of peas, beans, wheat, corn and oats, etc., led to the inference that many of the accepted conclusions concerning growth rested upon data obtained from material representing a specialized or narrow range of physiological action. An inspection of the records of measurement shows that no distinction is usually made as to whether the elongation is due to the action of one embryonic tract as in the case of roots or hypocotyls, or of many as in the case of stems and leaves. It is also to be noted that even in the simplified action of roots the elongation is a different expression from that of such an organ as a sporangiophore. Measurements of growth of the tip of a root include the imbibitional swelling of younger cells, the combined swelling and turgidity effects of older protoplasts, with all of the modifications due to salinity, acidity, alkalinity, character of the respiration, permeability of the membranes and albumen condition.

The elongation of a stem may include the total action of several internodes representing various stages of the grand period of growth, while it may be assumed that in some cases the records of leaves represent the variations in length of these organs and of one or more internodes.

The experimental material used in the investigation described in the present paper included the conventional subjects, *Zea* and *Triticum,* which were tested for purposes of orientation. Chief attention however was given to succulents which have long been known to present a type of respiration different from that of the leafy and slender-bodied plants. Futhermore, the massive bodies of the succulents presented characteristic body-temperature conditions which could be readily measured.

The flattened shoots of *Opuntia* present a single growing region

[5] See MacDougal, "Mechanism and Conditions of Growth," *Mem. N. Y. Bot. Garden,* 6: 5–26, 1916.

of great volume which is active through a long period. Such plants are amenable to chemical analyses, and have mechanical qualities which make it possible to place the apex in bearing upon an auxograph lever and secure a continuous record of its activity during the entire period of enlargement, as well as of the subsequent variations in length. Detailed studies of the course of transpiration and respiration of these plants have been made at the Desert Laboratory, and the available information on these subjects was of great usefulness in interpreting growth and other changes in volume. A cylindropuntia was also tested in order to ascertain possible differences due to mechanical form. Both kinds have a type of respiration in which a notable accumulation of acids occur at temperatures in the lower part of the tonic range and in darkness. The leaves of *Mesembryanthemum* presented different morphological features, but a similar type of respiration. The massive globose and cylindrical stems of *Echinocactus* and *Carnegiea* were also used as their metabolism is of a character which does not result in any notable accumulation of residual acids in any part of the respiratory mesh. The meristem region in both is entirely terminal, and some detailed studies of the fate of the carbohydrates and of the non-auxetic variations in thickness and length as well as of transpiration had been previously made.

Growth of Opuntia.

These preliminary studies brought out the fact that the flattened joints of the opuntias undergo most rapid growth during the daylight period, coincident with decreasing acidity and lessened transpiration, and that actual shrinkage occurs in maturing joints as the result of reactions which are masked during the period of most active growth. The entire development of about forty flattened joints has been followed from bud to maturity, and the changes in volume of members in an adult condition have been noted for long periods under varying conditions. The swelling of hundreds of specimens from growing and mature joints were measured, and an extended series of records of the action of gelatine, agar, albumen and cactus mucilage in acids, alkalies and salt solutions made.

Unless otherwise stated, all of the growth records included in the present paper were made by an improved form of the auxograph described by the senior author in 1916. The changes in the instrument were for the purpose of securing greater delicacy and accuracy. Twelve of these instruments as described on page 330 of the present paper were available.

The joints of *Opuntia* occupy the better part of a month in developing from a length of 15 mm. with a volume of a few cu. cm. to a length of 200 mm. with a volume of perhaps 150–200 cu. cm. The entire mass of this member remains in an embryonic or elongating condition until nearly mature, the development of woody or permanent tissue being very light during the first 20–25 days. It may be conceived therefore as a thick plate of protoplasts in all stages of development from the earliest when enlargement is a result of imbibition alone, to a state approaching maturity where the osmotic action of the electrolytes in the vacuoles maintains a turgidity indicated by the fact that expressed juice shows a possible pressure of 5 to 8 atmospheres. Temperatures were established or taken by thermometers with thin bulbs thrust into similar members in close proximity, and as has been mentioned elsewhere in this paper, the temperatures cited are those of the plant instead of the air as is the case in many of the papers dealing with growth (Fig. 1).

A feature prominently emphasized by our studies is the interdependence of effects. The influence of any one environic agency is of course affected by the intensity of action of other agencies influencing the plant. This is well illustrated by the behavior of *O. discata* No. 14, with respect to temperature. A young joint in the form of a flattened naked bud of this plant was followed from Feb. 28, 1916, to maturity, about April 30, 1916, and then its further alterations in volume until June 7, 1916, at which time disks were taken and the swelling capacity of the tissues determined. Measurements of growth for every moment of 62 days, of reversible alterations 38 days and of final hydration capacity are available together with body and air-temperatures.

The plant stood on a cement bench near the glass of the southern end of a greenhouse and exposed to normal illumination as modified by the glass. It was kept in bearing with a precision auxograph in such manner as to reduce errors to a minimum. The following entries are cited from the notes accompanying the auxographic tracings:

Elongating at 12° C. and below on March 2, with the air at about

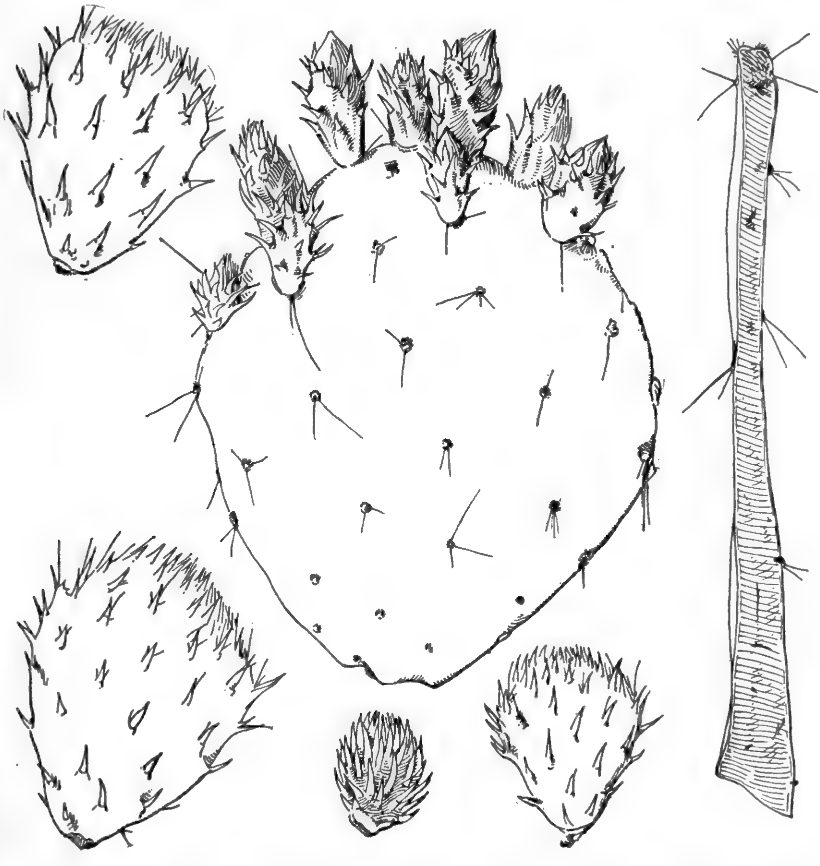


FIG. 1. Joints of *Opuntia Sp.* The youngest stage at which growth measurements were begun is illustrated by the small figure at the bottom. Successive stages are denoted by size. The largest figure is that of a mature joint bearing flower buds. Longitudinal section of joint on the right. Growth throughout the entire joint during its development is denoted by the increasing distances between the nodes denoted by the clusters of spines. About one third actual size.

the same temperature: Elongation began on March 23, after a night of shortening, at a temperature of 18° C., and under similar conditions, but with air temperature falling to 9° C. growth began at 14° or 15° C. on the 24th. Growth began at 14° C. on March 25 and at some point between 15.5° C. and 17.5° C. on the 26th. Growth began at 17° C. after a night of shortening, at 19° C. on the 31st after a night of shortening, at 15° C. on April 1, at 18° C. on the 2d and 3d, at 14° C. on the 4th and 5th, at 18° C. on the 6th, 16° C. on the 7th, at 18° C. on the 9th, 19° C. on the 11th, 18° C. on the 12th, at 13° C. on the 13th, at 17° C. on the 14th, 22° C. on the 18th, 17° C. on the 19th, above 20° C. on the 19th, and 21° C. on the 20th.

Similar experiences with many other growing joints are in our records. Thus we have the entry that on March 31 all growing joints under observation began elongation at temperatures ranging from 15° to 19° C. This single growing member began elongation in temperatures rising from 9° to 10° C. early in its development to 12° to 22° C. in its more advanced stages. Another joint, No. 2, began its daily growth at temperatures as follows:

March 24,	10:00 A.M.	21.5° C.
28,	8:30 "	22° C.
29,	8:40 "	23° C.
31,	9:40 "	19° C.
April 1,	8:40 "	20° C.
2,	9:00 "	21.5° C.
3,	8:40 "	20° C.
4,	8:30 "	21.5° C.
5,	8:40 "	22.5° C.
6,	8:35 "	23° C.
7,	8:30 "	23° C.
9,	8:40 "	24.5° C.
10,	8:30 "	25° C.
11,	8:50 "	17° C.
12,	8:00 "	19° C.
13,	11:30 "	16° C.
14,	10:30 "	16.5° C.

The temperatures of the body at which growth ceased likewise showed great variation as illustrated by the behavior of No. 14. Thus on March 28, 1916, elongation ceased abruptly when it reached 40° C., and the temperature of the air was 26° C. Growth stopped at 35° C. at 1:30 P.M. on the 25th; at 28° C. at 2:30 P.M. on March 30, the temperature having been above that point since 10 A.M.; at

39° C. at 1 P.M. March 29; at 35° C. at 1:30 P.M. April 4; at 32° C. at 3 P.M. April 5; at 36° C. at 1:30 P.M April 6; 37° C. at 2 P.M. April 7. The upper temperature limit is given in other records included in the present paper, the extreme highest recorded being 51.5° C.

A second series of cultures for observation of growth and temperature were arranged at the Coastal Laboratory, Carmel, California, in the summer of 1916. Preparations consisting of an old joint with roots were placed in a dark chamber in which temperature could be controlled. The basal joints from which the buds arose held a supply of reserve material quite adequate for the development of the etiolated shoots. Some of the latter were growing vigorously six months after the close of the tests described.

These tests were made under conditions different from those encountered by the plants in the open in two important essentials, viz.: the temperature did not rise to a daily maximum and fall to a nightly minimum, but was maintained at fixed levels or varied as described and the action of light was excluded except for brief intervals when observations were being made. The effect of such conditions would be to exclude the disintegrating action of light on the acids resulting from respiration, and also to make photosynthesis impossible. Both of these features contribute to the daily variation in growth of plants in the open. Growth of shoots in darkness may be taken to be normal otherwise, so far as respiration and imbibition are concerned.

An etiolated shoot of *Opuntia discata* which had arisen in the dark chamber in which it had been placed in May, 1916, having a length of 65 mm. and a width of 15 mm., was chosen for the first test, which was duplicated by later ones. The container in which the plant stood was fastened firmly in place and an auxograph was brought into contact with it adjusted to record alterations in length magnified twenty times. A small thermometer with thin bulb of the "clinical" type was inserted in the old joint near the base of the young shoot and its readings taken to be those of the growing organ. The difference between the two could be only very slight. The amount of growth displayed by the shoot on five successive days was 1.2, 1, .1, 1 and 1.1 mm. at temperatures of 17°–18° C., July

21–25, 1916. Current was now turned on an electric heater, July 25, 10 A.M., and the *Opuntia* reached 25° C. about 6 P.M.

July 27, 1916: 4:30 P.M.—A growth of nearly 3 mm. had occurred in the previous 24 hours at a temperature of 24° C. and 25° C.

28, 11:00 A.M. Growth during the previous 18.5 hours was at rate of 3.6 mm. per day, 25° C. 3:00 P.M. Growth for previous 4 hours was at rate of 3.9 mm. per day, 25° C.

Current off and plant cooled to 18° C. at midnight—in 9 hours.

29, 8:00 A.M. Growth during previous 8 hours was at rate of 3.3 mm. per day at 18° C. 10:00 A.M. Growth of .2 mm. in 2 hours was at rate of 2.4 mm. per day, 18–17° C., which was double the rate displayed at the same temperature before being heated. 4:00 P.M. Growth at rate of 2 mm. daily during previous 6 hours at 19° C.

30, 7:00 A.M. Growth during previous ten hours was at rate of 2.4 mm. daily at 19° C.

31, 7:00 A.M. Growth of 2.4 mm. during previous 24 hours at 18° C.

Aug. 1, 6:30 A.M. Growth in previous 19 hours was at rate of 2.6 mm. daily, at 18–19° C.

The plant failing to return to the initial rate of about 1 mm. daily, the heater was again put in action and the plant had a temperature of 28° C. at 11 A.M. Growth during this rise of 9° C. in 4.5 hours was 1 mm. or at rate of about 5.4 mm. daily.

The temperature was held constant to within a degree but the rate was 6 mm. daily during the first 6 hours, then 7.2 mm. per day during the next 3.5 hours.

2, 8:00 A.M. Growth at rate of 8.04 mm. per day during previous 11.5 hours at 28° C. 2:00 P.M. Rate during previous 5 hours 10.8 mm. daily at 27–28° C. 4:00 P.M. Rate during previous 2 hours 12 mm. daily at 28° C. 9:00 P.M. Rate 9 mm. daily during previous 5 hours.

Heat was now cut off and the temperature fell to 16° C. in 4 hours.

3, 8:00 A.M. Rate of 2.9 mm. daily during previous 7 hours at

16° C 2:00 P.M. Rate 2.4 mm. daily during previous 6 hours at 18–16° C.

Heat was again turned on, and the control set at 25° C. This point was reached in 2 hours. The rate during this time was 4.8 mm. daily. 9:00 P.M. Rate 2.7 mm. daily during previous 3 hours at 25° C.

4, 8:00 A.M. Rate 6.6. mm. daily during previous 9 hours at 25.5° C. 11:00 A.M. Rate 5.6 mm. daily during previous 3 hours at 25° C.

Control reset and temperatures of 32° C. were reached by 3 P.M., the rate during this period of 4 hours being 6 mm. daily. The temperature rose from 32° C. to 36° C. during the next 3 hours.

5, 12 Noon. Rate 9.6 mm. daily during previous 4.5 hours at 34–35° C. 3:15 P.M. Rate 9.9 mm. during previous 3.25 hours.

Current was now cut to reduce temperature as follows: 3:45 P.M. Temperature 26° C. 5:30 P.M. Rate .5 mm. in 1.25 hours at 29° C. at rate of 9.5 mm. daily. 8:00 P.M. Rate 8.1 mm. daily during previous 2.5 hours at 27° C.

6, 8:00 A.M. Rate 7.2 mm. per day during previous 12 hours at 24° C.

Earthquake disarranged record. Current cut off. 7:15 P.M. Temperature 19° C.

7, 8:00 A.M. Rate of 3.2 mm. per day in previous 12 hours at 18° C., which fell to 2.8 mm. per day during following 2 hours at 18° C.

The shoot was now 12.2 cm. in length. Record was discontinued until August 14, during which time the plant stood at 16–18° C. and gained 18 mm. in length, or about 3 mm. per day.

17. Current on heater at 2 P.M. resulted in a temperature of 23° C. at 9:15 P.M.

18, 8:00 A.M. Rate of 2.1 mm. during previous 10 hours at 23° C.

19, 8:00 A.M. Rate of 3.3 mm. daily during previous 15.5 hours at 25° C.

23, 8:00 A.M. Plant had stood at 25° C. for 4 days. Rate during previous 16 hours was 5.7 mm. per day at 25° C. 12 Noon. Rate 7.8 mm. per day during previous 4 hours at 25° C.

Watered and record disturbed for 2 hours. 5:00 P.M. Rate 7.8 mm. per day at 25° C.

24, 8:00 A.M. Rate 5.7 mm. per day for previous 15 hours at 25° C.

25, 8:00 A.M. Rate 6 mm. daily, 25° C.

Control reset and as temperature of the body rose the rate calculated in 2 hour intervals increased from 8.4 mm. at 27° C. to 9.6 mm. at 29° C. and 10.8 mm. at 29.5° C.

26, 10:00 A.M. Rate was substantially maintained at 29° C., being 9.6 mm. for the forenoon. 2:00 P.M. Rate 11.4 mm. daily, 31.5° C. 4:00 P.M. Rate 11.4 mm. daily, 32° C.

27, 8:00 A.M. Rate 3.9 mm. daily at 17° C. 11:00 A.M. Rate 5.8 mm. daily at 18° C. 10:00 P.M. Rate 3.8 mm. daily at 18° C.

28, 8:00 A.M. Current on for higher temperature. 9:15 A.M. Temperature of 32° C. was reached and 39° C. at 11:30 A.M. One hour later at 12:30 midday, the rate was 7.2 mm. per day at 39° C. 1:30 P.M. Rate 4.8 mm. per day at 40° C. 2:30 P.M. Rate 3.6 mm. per day at 40° C. 3:30 P.M. Rate 4.8 mm. per day at 40° C. 5:30 P.M. Rate 1.8 mm. per day at 41.5° C. 7:30 P.M. No growth had taken place in the previous 2 hours. 9:30 P.M. Rate of 3.6 mm. daily, the temperature having fallen to 36° C.

Another shoot of the plant used in making the preceding record being available, an auxograph was put in bearing with it when a length of about 150 mm. had been reached on August 29, 1916. The rate varied from about 15.6 mm. to 20.4 mm. daily at 35° C. to 37° C. The temperature was raised from 36° C. to 47° C. in an hour and a half on the third day, elongation stopping when this point was reached. During the second hour and a half the temperature was allowed to fall to 43° C., growth being resumed above 43° C. and continued at a rate varying from 10.8 mm. daily in the first hour, 6.6 mm. daily during the following four hours, to 8.4 mm. daily during the sixth hour. The temperature being raised to 46° C. in twenty minutes, growth stopped at that point. Shortening took place during the following hour and a half at temperatures of 46° C. to 48.5° C., but ceased as the temperature was brought back to 44° C. at some point above that temperature. The shoot appeared to be slightly limp, suggesting that elongation and shortening might be a matter of the balance between water accession and loss.

The shoot was now subjected to a temperature above 43° C. continuously for two days, the maximum being 52° C. Its body

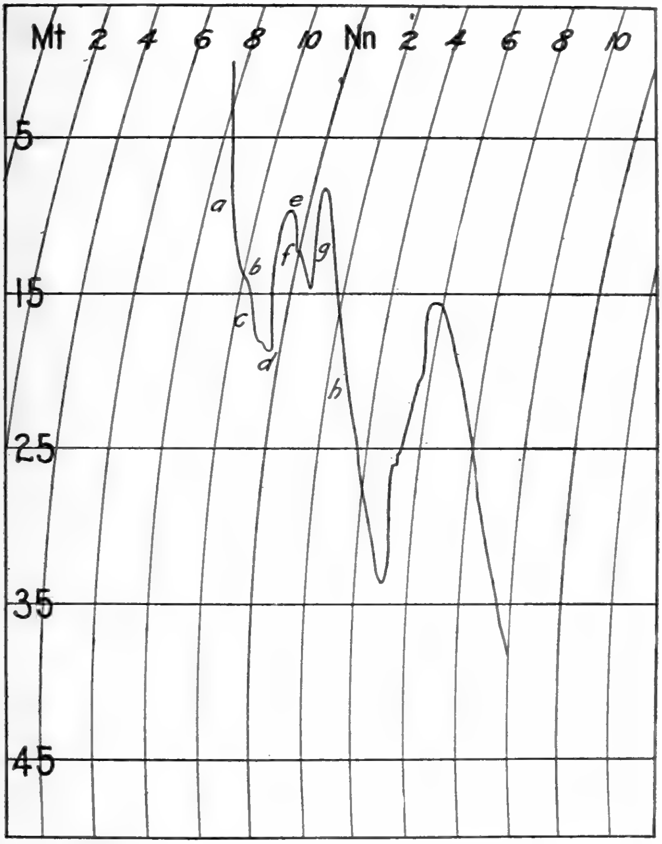


FIG. 2. Auxographic tracing of variations in length of shoots of *Opuntia* at high temperatures in dark room at Carmel, September 1, 1916. The sheet is ruled into two-hour periods by arcs and the 10 mm. horizontal lines of the millimeter sheets are reproduced. The variation in length is magnified 26 times. (*a*) Downward movement of pen 7:30 A.M. to 9:40 A.M. denoting growth at temperatures of the stem of 45° to 49° C. (*b*) Growth checked for 20 minutes at 49° C. (*c*) Growth resumed at temperature of 49° C. (*d*) Shortening at 48.5° to 52° C. (*e*) Stationary at 50.5° C. (*f*) Growing at temperatures of 48° to 49° C. (*g*) Shortening at 49° C. (*h*) Growing at 38° to 41° C. (*i*) Shortening at 49° C.

temperature was then brought down to 25° C. and after twelve hours at this point it showed rates of 5.4 mm., 6.6 mm., 6.6 mm. and 5.4 mm. daily for two days as measured at two hour intervals. The temperature was now raised to 35° C. at which the rate was 16.4 mm. to 16.8 mm. daily for an entire day. This rate was fairly duplicated on a second day, but with a somewhat wider variation, the rate ranging from 15.6 mm. daily to 22.2 mm. daily (Fig. 2).

The etiolated shoot of a second *Opuntia* elongated as follows:

Rate of 1 mm. daily at 19° C.
Rate of 1.3 mm. daily at 19° C.
Rate of .7 mm. daily at 15° C.
Rate of .93 mm. daily at 15–18° C.
Rate of 1.08 mm. daily at 17–18° C.
Rate of 1.44 mm. daily at 18–19.5° C.

Rates of 1, 2, 1.2, 1.15, .85 and 1 mm. per day at 16–18° C.

The preparation was moved into control chamber and the following results were obtained:

Rates of 2.9, 3, 3, and 3 mm. daily at 26° C.
Rates of 3.2 and 3.44 mm. daily at 26° C.
Rate of 4.2 mm. daily at 29° C.
Rates of 3.6, 6.7 and 9.6 mm. daily at 30° C.
Rates of 11.4, 11.4, 8.4, 9.2, and 11.4 mm. daily at 31.5–32° C.
The heat was now cut off and rates of 4 mm. daily at 17° C. were displayed.
Rate of 5.7 mm. daily at 18.5° C.
Rate of 5.3 mm. daily at 19° C.

The temperature being raised again from 18° C. at 8 A.M. to 39° C. at 12:30 midday, a rate of 8.4 mm. daily was displayed during the first hour.

The continuation of similar temperatures during two days was attended by sustained rate of 18.6 to 19.2 mm. daily (37–38° C). After three days at this temperature it was raised from 37° C. to 45° C. in 1.5 hours during which time the elongation was at the rate of 13.2 mm. daily, and growth stopped entirely at 45° C. Some shortening now ensued, but at the end of an hour and a half elongation began again at 46° C., and was maintained at the rate of 25 mm. per day for an hour, and the total for the four succeeding hours at 46° C. was a rate of about 20 mm. daily, which was not exceeded by any rate at lower temperatures. The rate during the sixth hour rose to 20.4 mm. daily at 45° C. The temperature being raised to 49° C. during the next hour, elongation ensued at the rate of 18.7 mm. daily until it was checked at 48.5° C. The period of checking was not measured accurately, but after an hour with the temperature still between 48° C. to 46° C. the rate was 19.2 mm. daily. It is thus to be seen that the maximum is maintained up to very near the point of actual cessation of growth, an experience duplicated scores of times with green plants in the glass house at Tucson. It was noted that the air temperature was 40° C. and 41° C. when the plant was at its maximum of 48° C. and 49° C. Similar differences have probably gone unnoted in the observations made by many workers.

After the experiences described above the plant remained at 45° C. and 46° C. over night without calibration. Measurements begun at 7:30 A.M. at 45° C. Elongation during the hour and a half in which the temperature rose a degree and a half (to 47.5° C.) amounted to .95 mm. at a rate of about 15 mm. daily. Continued rise of temperature was accompanied by lessened growth which did not cease altogether until 49° C. was reached. Elongation was resumed at this temperature however after 20 minutes, but was checked again. The temperature was now raised to 52° C. for a half hour with an air temperature of 43° C. Reducing the temperature to 49° C. with an air temperature of 41° C. resulted in a growth of .4 mm. at a rate of 9.6 mm. daily. Similar changes resulted in starting and checking growth in much the same manner. At the end of the day the chamber was allowed to cool to give the plant a constant temperature of 25° C. and after standing at this temperature for 12 hours measurements were made to determine the rate at this point.

The rate at 25° C. on the following day varied from 9.6 mm. daily in the morning to 12.6 mm. at 26.5° C., then to 8.8 mm. daily at the close of the day at 26° C. No measurements were made at night but during the two hours beginning at 8 A.M. the rate was 13.2 mm. daily at 25° C., after which the temperature was raised to get values for the next ten degree interval. A rate of 17.9 mm. daily was found between 5 P.M. and 10:30 P.M. at temperatures of 34–37° C.

The plant now stood over night at 34–37° C., at a rate of 27 mm.

daily, which decreased to 21.6 mm. daily at a temperature kept within a narrow range at 35° C. This now being gradually raised to 40° C. in a six hour interval the rate at first fell to 19.2 mm. daily, then rose to 29 mm. daily, the maximum when measured at two hour intervals. Almost any rise in temperature up to about 46° C. seemed to be followed by a temporary acceleration in rate.

Two younger shoots had arisen from the second *Opuntia* during these tests and had attained a length of about 30 mm. during the previous ten days. These were designated as "A" and "B."

The temperature of these young shoots was between 25–45° C. during most of this time, and for a few hours rose to 52° C. as described in connection with the tests with other shoots. Separate auxographs were put in bearing with the two shoots and thermometers were arranged to take the temperature of the basal joint from which they arose and of one of the other growing shoots near by.

The interest attached to the detail of the growth of these two shoots warrants the transcription of the complete record.

Sept. 5, 1916, continued: As soon as the instruments were adjusted, the temperatures which were standing at 30° C. were raised by the use of an additional heater giving the following records:

		A *B*	
	8:00 A.M.	Both growing.	30° C.
	9:00 "	Both growing.	32
	10:00 "	Both growing.	37–40
	10:30 "	Both growing.	41–42
	11:00 "	Both growing.	43
	12:30 P.M.	Both growing.	46–47
		Growth stopped in both.	
	12:45 "	Growth starting.	43
	1:30 "	Both growing.	46.5
	2:00 "	Both growing.	47
	2:15 "	Both growing.	50
	4:00 "	Stopped.	
	4:35 "	A little growth in both.	46.5
	5:15 "	Some growth.	49 +
	6:30 "	Some growth.	49 +
	7:30 "	Some growth.	49 +
	9:30 "	Stationary.	48 +
6,	7:30 A.M.	Shortening but had grown until four hours before.	51° C.

	8:00 A.M.	Stationary.		48
	8:30 "	Stationary.		45–46
	9:00 "	Just beginning to grow.		46.5–47
	10:00 "	Shortening.		46–48
	11:00 "	Stationary.		45–46.5
	12:00 M.	Stationary.		47
	1:00 P.M.	Stationary.		48
	1:30 "	Stationary.		47.5
	5:00 "	Shortening.		49–50
	6:00 "	Shortening.		48.5–49
	7:30 "	Shortening.		49
7,	7:30 A.M.	Plants had shortened until pen was above sheet and the temperature now stood at 51° C.		
	8:00 "			45–47 C.
	8:45 "	No action.		43–44
	9:00 "	No action.		42–43
	9:20 "	No action.		41.5–42.5
	9:50 "	No action.		42
	10:30 "	No action.		42
	11:00 "	No action.		40.5–41.5
	12:30 P.M.	No action.		42–43
	2:00 "	No action.		39
	2:30 "	No action.		38
	3:00 "	No action.		37.5
	3:50 "	Growth beginning.		37
	5:00 "	Growth checked.		38
8,	7:30 A.M.	5.8 mm. daily.	6.8 mm. daily.	31
	10:00 "	3.8 mm. daily.	3.3 mm. daily.	31.5
	10:30 "	Shortening.		32
	4:00 P.M.	2.4 mm. daily.	5.2 mm. daily.	32
	9:00 "	3.0 mm. daily.	3.6 mm. daily.	31
9,	7:30 A.M.	4.3 mm. daily.	5.0 mm. daily.	30
	10:00 "	1.9 mm. daily.	5.3 mm. daily.	30
		Reset.		
	1:30 P.M.	1.9 mm. daily.	2.9 mm. daily.	30
		2.4 mm. daily.	4.8 mm. daily.	31
	9:30 "	1.9 mm. daily.	4.0 mm. daily.	31
10,	8:00 A.M.	1.7 mm. daily. (For 10.5 hours.)	4.8 mm. daily. (For 10.5 hours.)	29
		Temperature raised to 39° at noon.		
	12:15 P.M.	Checking.	6.0 mm. daily.	39
	5:00 "	Stopped.	8.0 mm. daily.	39
	9:15 "	Stopped.	7.9 mm. daily.	39
11,	7:30 A.M.	Stopped. (During entire night.)	8.4 mm.	39–37
	10:00 "	Stopped.	7.2 mm. daily.	36
	11:00 "	Stopped.	12.0 mm. daily.	37

	2:00 P.M.	Stopped.	10.8 mm. daily.	41
	3:30 "	Stopped.	8.0 mm. daily.	38
	7:30 "	Stopped.	8.1 mm. daily.	37
12,	8:00 A.M.	Stopped.	8.6 mm. (All night.)	37
	11:00 "	Stopped.	13.6 mm. daily.	36.5
	1:30 P.M.	Stopped.	12.3 mm. daily.	37
	3:30 "	Stopped.	9.0 mm. daily.	39
	5:00 "	Stopped.	12.8 mm. daily.	38
	6:00 "	Stopped.	10.8 mm. daily.	38
	7:30 "	Stopped.	13.6 mm. daily.	38
	9:30 "	Stopped.	15.0 mm. daily.	38

The behavior of green opuntias in daylight was tested in March, 1917, at Tucson. Preparations consisting of a rooted joint from which a flower bud was arising were placed in the south end of a glass house in an equatorial position. The temperature of the body rose to 40° C. and 43° C. by the heat of the sun after 1 P.M. Additional heat was supplied by tungsten incandescent lights so that the temperature was raised to 49° C. in an hour at which point elongation ceased. The temperature following same rising curve reached 51.5° C. a half hour later at which elongation was resumed, and was maintained at temperatures of 51° C. to 51.5° C. for an hour and a half when it ceased. This behavior is in accordance with that of etiolated shoots illustrated in Fig. 2. On the following day the temperature near midday, which was above 40° C. by the sun's heat, was raised to 48° C. and 49° C. for a half hour by additional heat from a tungsten incandescent light bulb. Growth continued at a rate near the maximum. In an additional preparation a bulb for heating not regulated properly raised the temperature of a portion of the joint 75° C. for a few minutes, resulting in the death of a sector within the next two days. The young shoot arising from the margin of the injured area probably reached a temperature of 65° C. or 70° C. as some of the outer leaves were blackened. Growth was checked at once but was resumed eighteen hours later and continued for two days with the customary mid-afternoon shortening.

The gas interchange and variation in the concentration of the residual acids has been worked out in detail in *Opuntia versicolor*. Some available data show that the platyopuntia used so extensively in this work present an identical type of respiration. That the course of growth was similar in its general features was evidenced by the records of the two plants which were under observation for some time. Elongation begins with full daylight and assumes its highest rate near midday and then checks abruptly about 1 P.M. Shrinkage continues from this time until daylight of the following morning. The end of the growing period is marked by a decrease of the midday elongation and by increased shrinkage which equal-

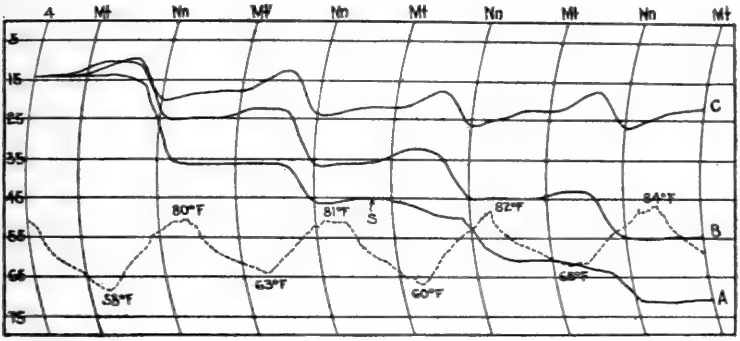


FIG. 3. Auxographic records of growth of joint of *Opuntia versicolor*.

A. Record April 10 to April 15, 1916, rapid midday elongation of joint near the maximum of its grand period. The first occurrence of shortening at *S*.

B. Record from April 18 to April 22, 1916. Slight diminution of daily growth and accentuated contraction at night. The temperature record applies to this period.

C. Record from April 25 to April 29, 1916. Increasing reversible variation in length with cessation of growth.

ize each other while allowing a great total variation in length (see Fig. 3).

The general facts as to alterations in volume of *Opuntia* by growth and other changes, including shrinkage, are in accordance with those previously described.[6] Elongation takes place chiefly in the first half of the day both in mature and growing joints. Shrinkage, slackening or stoppage of growth ensues after midday and continues for a varying period which may extend until the following morning. The type of respiration of these plants is one in

[6] MacDougal, D. T., "Mechanism and Conditions of Growth," *Mem. N. Y. Bot. Garden*, 6: 5–26, 1916.

which residual acids accumulate at low temperatures and in darkness. Acidosis decreases imbibition. Growth beginning with sunrise shows an acceleration parallel to the disintegration of the clogging acids and the rising capacity for imbibition, till midday only. The retardation after this may not be ascribed to lessened power of imbibition or to increased transpiration as water-loss is not greater during this time and the capacity of the plant continues to increase until near the end of the daylight period. The cause of the retardation cannot be identified with the direct action of light, nor does it seem warranted to assume that the "supply of building material" becomes exhausted, as was previously suggested by the senior author. The nature of the stoppage suggests the inhibiting action of respiratory products or the destruction of an enzyme. Respiration in *Opuntia* is profoundly affected by light as has been shown by its effect on acid-accumulation and destruction. Yet no immediate effects were secured by exposure of growing members to the action of mercury vapor quartz lamps with an intensity equivalent to normal sunlight at 2 meters distance, for periods of one to three hours. It is noteworthy that the characteristic retardation or stoppage does not take place in the first few days of the development of the bud, and that the leaves of *Mesembryanthemum* exhibit a similar behavior. The young shoots of *Opuntia* in this stage are not more than 8 to 12 mm. in length, 1 to 2 mm. in thickness and are all but hidden by the slender conical leaves. The joint as well as the leaves are in a state of extreme imbibition. The character of the respiration under such conditions is in all probability such that acids do not accumulate and other by-products are modified with the result that the daily decrease in imbibition capacity is not experienced. A similar behavior attends the development of the flower buds. That retardation and stoppage as observed in hundreds of instances could not be ascribed primarily to temperature seemed to be established by the great variation in the point at which growth might begin or cease.

Growth began on rising temperatures at 9° C. to 25° C. in the same green plants on different days at Tucson and was noted at 50° C. in flower buds. The continued rise of the temperature resulted in a stoppage of elongation at temperatures between 26° C.

and 43° C., in the plant which has been cited, with a final limit of temperatures of the body of 51.5° C. in some other extreme cases.

Growth of etiolated shoots of a nearly related species in a dark room was 1 mm. or less per day in members at body temperatures of 15° C. or 16° C. Rates of 2 to 2.6 mm. daily at 16° C. to 18° C. were followed by 8 to 12 mm. daily at 27° C. and 28° C. yielding values of 3 to 4 mm. for a rise of 10° C. Rates of 5.6 to 7.8 mm. daily at 24° C. and 25° C. being compared with 8.4 to 10.2 mm. daily at 29° C. to 32° C. show a similar coefficient at 29° C. to 31.5° C. The meager records at 35° C. and 36° C. yield rates of 10.2 to 13.2 mm. daily. Observed rates at temperatures above 32° C. or 33° C. in the shoot showing such rates were not readily to be integrated with these results, and growth ceased at 41.5° C. in the shoot yielding them.

The second shoot of the same plant showed rates of .85 to 1.2 mm. daily at 16° C. to 18° C.; 2.9 to 3.4 mm. at 26° C., and 13.2 mm. daily at 35° C.; 20.4 mm. daily at 46° C., and 18.5 mm. daily at 48.5° C.

The highest observed rates, both in green plants and in etiolated shoots, were those immediately preceding cessation of growth; a daily occurrence in plants exposed to normal sunlight.

Accepted conclusions as to growth include an *optimum* at which growth proceeds continuously at a high rate, and above which the rate is higher for a brief period then falls off. Some of the records are conformable to such ideas and others are not. The two shoots of the same plant subjected to the same treatment did not agree in this matter, as may be seen in the preceding pages. It is conceded that our experiments were not arranged to bear critically on this point. It is to be noted that growing shoots in the open may cease to elongate at temperatures as low as 26° C. which would be below any *optimum* hitherto suggested. Hundreds of observations of such cessations under external conditions supposedly favorable to continuous growth are available. The facts in question seem to lessen the importance and the usefulness of the term *optimum temperature*.

The results of measurements of growth of the apical part of the globular *Echinocactus* and of the cylindrical *Carnegiea* afford some interesting comparisons, since both are massive succulents, but present a type of respiration something different from that of *Opuntia*.[7]

The spines of *Echinocactus* arise from special meristem tracts lateral to the growing point, and as the growth is wholly basal the rigid tips afford an excellent bearing for an auxograph arm. A preparation was kept under observation at a point some distance from the walls of a greenhouse late in April, 1916. Temperatures of the body near the surface were taken by a thermometer with a thin bulb left in place during the course of the observation. Growth began at 22° C. to 24° C., about 8 A.M., continuing during the warm daylight period and until nearly 8 P.M. Nothing higher than 37° C. was shown by the body. The daily rate varied from zero to .05 mm. per hour and no retractions were discernible. The length remained fairly constant when growth ceased. The temperature of the body of this plant did not fall below about 14° C. during any part of the period.

The same plant was available for experimental purposes in

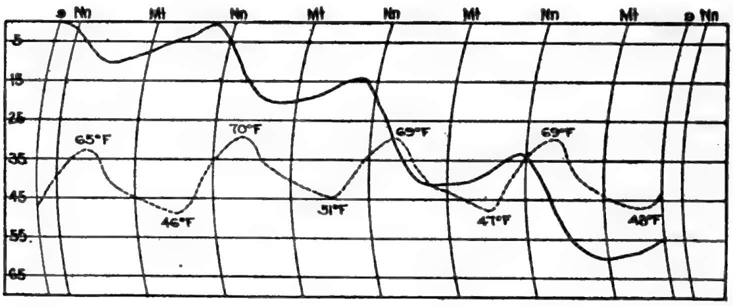


FIG. 4. Auxographic record of variations in length of spine of *Echinocactus*, March 13 to March 17, 1917. Shortening from 8 P.M. to 8 A.M. due to low temperature. × 10.

March, 1916. The cluster of spines, the tips of which had emerged for a length of 4 to 6 mm. in 1916, began to show freshly colored sections at their bases indicative of elongation and one of these was brought into bearing in the cup-shaped end of the vertical arm of

[7] MacDougal, "The End-results of Desiccation and Starvation of Succulent Plants," Physiological Researches, Vol. 1, No. 7, 1915.

an auxograph. The preparation was placed near the south end of an unheated glass house with the result that the temperature of the body fell as low as 4° C. at 7 A.M., and reached a point at which growth ceased at about 8 P.M. The steadily decreasing temperature was accompanied by a shrinkage—due in all probability to lessened imbibition capacity as a result of low temperature. Resumption of growth took place in the forenoon at temperatures about identical with those of the previous year. The total daily growth amounted to as much as 1.25 mm. to 1.5 mm. daily all of which was made between 9 A.M. and 8 P.M. (Fig. 4).

The record of growth of *Carnegiea* included measurements of the variations in the length of the spine as well as of coincident readings of the swelling of the apical region of the stem near the base of the spine.

Elongation of the spine on daily rising temperatures began at temperatures of 24° C., 18° C., 18° C., 15° C., 13° C. and 13° C. on sepa-

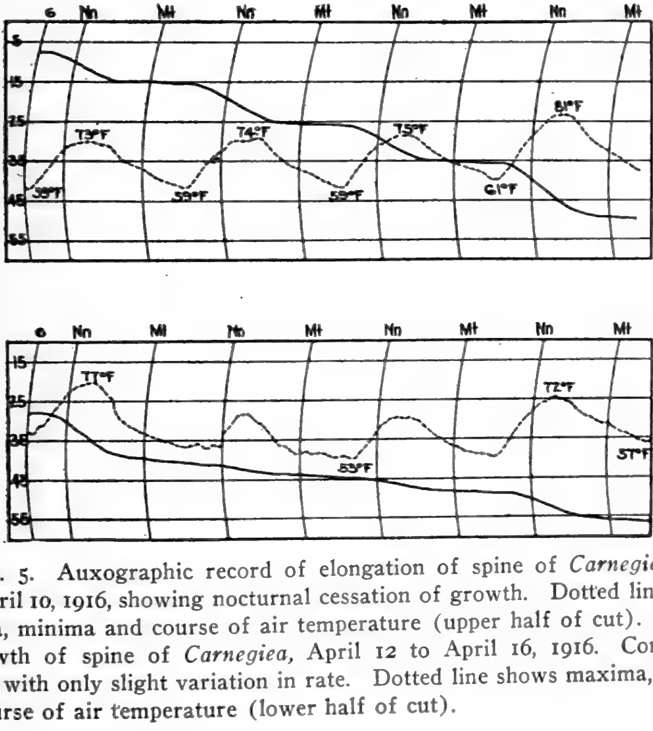


FIG. 5. Auxographic record of elongation of spine of *Carnegiea* April 3 to April 10, 1916, showing nocturnal cessation of growth. Dotted line shows maxima, minima and course of air temperature (upper half of cut). Record of growth of spine of *Carnegiea,* April 12 to April 16, 1916. Continuous growth with only slight variation in rate. Dotted line shows maxima, minima and course of air temperature (lower half of cut).

rate days and was very active at 32° C. A period of continuous elongation of the spine was comprised between April 10 to 17, 1916, during which time the air temperature ranged between 14° C. and 28° C. The temperature of the body coincided with the lower night temperature of the air and did not rise above 32° C. (Fig. 5).

The maximum enlargement of the spine was at rate of .075 mm. per hour, while that of the neighboring apical tract was not more than a third of this rate. After the spine had reached nearly mature length the apical tissue accelerated showing a rate as .088 mm. per hour. Growth began on rising temperatures of 15° C. and above and was observed at 40° C. of the body. The main part of the growth took place in the daytime and no action directly attributable to light effects could be detected.

Echinocactus and *Carnegiea* are active during the period in which the temperature is within the tonic range, as taken from thermometers inserted in the tissues. This implies that such plants grow during the daylight period in the open and as far into the night as the temperature permits, the maximum rate being attained during midday. Numerous tests show but little variation in the acidity of *Echinocactus* and *Carnegiea,* and it is to be inferred that the respiration of the sugars is of a kind in which the disintegration is carried through to its final limits.

A number of records of growth of the succulent leaves of *Mesembryanthemum inequilaterale* were obtained for comparison with *Opuntia, Carnegiea* and *Echinocactus.* Determinations of the acidity of the sap show that while the total range is not as great as that found in *Opuntia versicolor* by Richards,[8] yet the daily course of variation is marked, as may be seen from the following measurements of *Mesembryanthemum.*

Acidity in Cubic Centimeters of N/100 NaOH.

	December 7.			December 8.		
	Pure Juice per C.cm.	Total Acidity per Gm. Dry Material.	Total Acidity per Gm. Fresh Material.	Pure Juice per C.cm.	Total Acidity per Gm. Dry Material.	Total Acidity per Gm. Fresh Material.
8:00 A.M....	.0280	1.584	.0356	.0273	1.072	.029
12:00 M......	.0279	1.509	.0351	.0225	1.091	.0241
4:30 P.M....	.0232	1.191	.0264	.0205	1.056	.0275

[8] "Acidity and Gas Interchange in Cacti," Publ. No. 209, Carnegie Inst. of Washington, 1915.

The leaves are triangular in cross section and as the pairs emerge from the sheathing bases of the antecedent pair the inner or upper faces are appressed. The upright position implied is held until a half or a third of their length is attained. The tips of a pair were harnessed together and being turgid and firm were arranged to press upward on the bearing lever of the auxograph.

The general features of the daily behavior of this plant were quite similar to those of *Opuntia* in that elongation accelerated in mid-forenoon, about 9 to 11 A.M., and continued until 1 to 3 P.M., when it was checked and a shrinkage ensued which generally ended at 5 or 6 P.M. or sunset. After this time temperature being favorable a low rate of growth continued through the night and until the daily acceleration occurred a few hours after sunrise.

The daily course of transpiration has not been determined, but it is allowable to assume that the imbibition capacity of the growing regions is lessened by acidity as it is in *Opuntia*.

Growth of Wheat (*Triticum*) and Corn (*Zea*).

A great amount of data obtained by the measurement of the elongation of *Triticum* is available. The figures have been obtained chiefly by the measurement of numbers of organs for a brief period. The so-called critical temperature points have been obtained by taking averages of the performance of several plants. The facts of importance in connection with the present paper are those which have been obtained by analyses of the march of growth from day to day. Similar methods were used with corn (*Zea*).

Varieties of these two plants cultivated in the region of the Desert Laboratory were selected, and grains were germinated in an unheated glass house. The temperatures given were obtained by shaded mercurial thermometers and are Fahrenheit scale.

The bases of the plantlets were fixed in place by layers of plaster poured on the surface of the soil. The tips of leaves which had emerged to a length of 10 to 15 mm. were brought into the field of a horizontal microscope and the variation in length measured at half hour intervals so far as it was possible to do so. The leaves were maintained in a vertical position by a requisite number of horizontal glass rods with a minimum of shading effect.

The increments measured are of course inclusive of the elongation of the base of the leaf and of the internode from which it arises, as well as of any residual action of internodes below, consequently a figure illustrative of the grand period of growth of a single member could not be plotted from the data given. (Measurements showing a beginning of decreasing rate are given in bold-faced type.)

Variations in Length of Leaf of "Altar Corn" (*Zea*).

1914 Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
April 8	11:30 A.M.	0	85° F.	0 mm.
	12:30 P.M.	2.6	87	2.6
	1:00	3.7	90	**2.2**
	1:30	4.9	90	2.4
	2:00	6.1	91	2.4
	2:30	7.2	91	**2.2**
	3:00	8.1	92	1.8
	3:30	9.0	90	1.8
	4:00	9.8	90	1.6
	4:30	10.5	89	1.4
	5:30	10.7	85	1.2
April 9 (18 hours)	11:30 A.M.	43.3	86.5	1.8
	12:00 Noon	44.9	88	3.2
	12:30 P.M.	46.5	88	3.2
	1:00	48.1	90	3.2
	1:30	49.3	90	**2.4**
	2:00	50.8	89	3.0
	2:30	52.3	87	3.0
	3:00	53.4	86	**2.2**
	3:30	54.7	85	2.6
	4:00	55.7	83	**2.0**
	5:00	57.2	83	1.5
	5:30	58.1	82	1.8
	6:00	59.4	80	2.6
	6:30	60.6	78	**2.4**
	Reset at	2.8		0.0
	7:00	4.0	77	2.4
	7:30	4.9	76	**1.8**
	8:00	5.9	75	2.0
April 10 (13 hours)	9:00 A.M.		74	1.9
	9:30	32.8	76	2.4
	10:00	34.2	79	2.8

VARIATIONS IN LENGTH OF LEAF OF "ALTAR CORN" (*Zea*).—*Continued.*

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
	10:30	35.6	80	2.8
	11:00	37.1	82	3.0
	11:30	38.6	83	3.0
	12:00 Noon	40.3	85	3.4
	12:30 P.M.	41.8	87	3.0
	1:00	43.4	87	3.2
	1:30	44.8	88	2.8
	2:00	46.2	89	2.8
	2:30	47.5	89	2.6
	3:00	48.8	88	2.6
	3:30	50.1	88	2.6
	4:30	52.5	87	2.4
	5:00	53.4	85	1.8
	5:30	54.9	84	3.0
April 11	11:30 A.M.			
	Reset at	0.2	84	—
	12:00 Noon	2.3	84	4.2
	12:30 P.M.	4.3	86	4.0
	1:00	6.3	86	4.0
	1:30	7.9	86	3.2
	2:00	9.6	87.5	3.4
	4:00	16.4	88	3.2
	4:30	17.7	87	2.6
	5:00	18.9	85	2.4
April 12 (15 hours)	8:00 A.M.	53.2	63	2.3
	Reset at	0.2		
	9:00	1.8	74	1.6
	10:30	6.0	83	3.4
	11:00	8.0	85	4.0
	2:30 P.M.	18.5	90	3.5
	3:30	21.0	90	3.5
	5:30	25.3	91.5	2.2
	8:00	32.0	80.0	2.7
April 13 (13.5 hours)	9:30 A.M.	56.0	78.0	1.8
	Reset at	0.8	78	—
	10:00	1.7	81	1.8
	10:30	2.8	84	2.2
	11:00	3.7	86	1.8
	11:30 (watered)	4.9	88	2.4
	12:00 Noon	7.3	90	4.8
	12:30 P.M.	10.8	92	7.0
	1:00	13.5	92	5.4
	1:30	16.2	93	5.4

VARIATIONS IN LENGTH OF LEAF OF "ALTAR CORN" (*Zea*).—*Continued.*

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
	2:00	18.4	94	4.4
	2:30	20.4	95	4.0
	3:00	22.2	95	3.6
	3:30	23.7	94	3.0
	4:00	25.5	94.5	3.6
	4:30	26.9	93.5	2.8
	5:00	28.2	92	2.6
	5:30	29.7	91	3.0
April 14 (16 hours)	9:30 A.M.	74.0	81	2.8
	Reset at	0.0	81	—
	10:00	3.7	83	3.4
	10:30	5.3	85.5	3.2
	11:00	7.4	88	4.2
	11:30	9.6	90	4.4
	12:00 Noon	11.5	91	3.8
	12:30 P.M.	13.6	93	4.2
	1:00	15.5	95.5	3.8
	1:30	17.3	97	3.6
	2:00	19.1	98	3.6
	2:30		98	3.0
	3:00	21.9	98.5	2.6
	3:30	23.6	97	3.4
	4:00	24.7	97	2.2
April 15 (17.5 hours)	9:30 A.M.	63.0	83	2.2
	Reset at	1.4	83	—
	10:00	3.2	86	3.6
	10:30	4.9	89.5	3.4
	11:00	6.7	92	3.6
	11:30	8.5	94	3.6
	12:00 Noon	10.4	95.5	3.8
	12:30 P.M.	12.0	97	3.2
	1:00	13.3	98	2.6
	1:30	14.4	99	2.2
	2:00	15.6	99.5	2.4
	3:00	17.8	99	2.2
	3:30	18.7	97	1.8
	Reset	0.6	97	—
April 16 (19 hours)	10:30 A.M.	37.8	86	1.5
	11:00	39.2	88	2.8
	11:30	40.4	89	2.4
	12:00 Noon	41.4	90	2.0
	12:30 P.M.	42.5	91.5	2.2

VARIATIONS IN LENGTH OF LEAF OF "ALTAR CORN" (*Zea*).—*Continued.*

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
	1:00	43.5	93	2.0
	1:30	44.4	93	1.8
	2:00	45.1	93	1.4
	3:00	46.8	93	1.7
	4:00	48.1	92	1.3
	5:00	49.1	90	1.0
	6:00	50.7	89	1.6
	Reset	15.4	76	—
April 17				
	9:00 A.M.	30.4	72	1.0
	10:00	31.4	76	1.0
	11:00	32.4	79.5	1.0
	(watered)			
	1:00 P.M.	34.6	84	1.1
	2:15	36.0	85	1.1
	3:15	38.8	85	2.0
	4:30	37.6	82	—
	5:30	38.4	80	.8
	Reset	23.1	—	—
April 18				
(16 hours)	9:30 A.M.	30.3	78	.45
	10:30	30.9	81	.6
	11:30	31.6	84.5	.7
	12:30 P.M.	32.5	89	.9
	1:30	32.9	91.5	.4
	2:30	33.4	92	.4
	3:30	34.0	91	.5
	4:30	34.4	90	.4
	5:30	34.9	85	.5
April 19				
(16.5 hours)	10:00 A.M.	41.9	83	.4
	11:00	42.3	88	.4
	12:00 Noon	42.8	90	.4
	3:30 P.M.	43.4	95	.2
	4:45	43.7	95	.2
April 20	9:30 A.M.	48.0	81.5	.25
	11:00	48.0	90	.00
	2:00 P.M.	48.0	98	.00
	5:30	48.0	93	.00
April 21				
(16 hours)	9:30 A.M.	52.6	77	.3 —
	2:00 P.M.	54.1	78	.3 +
April 22				
(19.25 hours)	11:15 A.M.	58.8	74	.24
April 23	1:00 P.M.	69.2	83	.4

GROWTH OF "TURKEY RED" WHEAT (*Triticum*), MARCH, 1914.

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
March 19	11:00 A.M.	0.0	70° F.	— mm.
	11:30	.8	70	1.6
	12:00 Noon	1.3	66	1.0
	12:30 P.M.	1.5	65	.4
	1:00	1.8	64	.6
	1:30	2.1	63	.6
	2:30	2.4	63	.3
	3:00	2.5	62	.2
	3:30	2.6	62	.2
	4:30	2.6	62	.0
	5:30	2.6	60	.0
	Reset at	0.0	—	—
March 20	9:00 A.M.	9.1	54	1.6
(5.5 hours)	9:30	9.6	56.5	1.0
	10:00	10.6	59	2.0
	10:30	11.4	61	1.6
	11:00	12.1	63	1.4
	11:30	12.8	64	1.4
	12:00 Noon	13.6	65	1.6
	12:30 P.M.	14.5	65	1.8
	1:00	15.4	65.5	1.8
	1:30	16.1	69.5	1.4
	2:00	17.2	70	2.2
	2:30	18.2	69	2.0
	3:00	18.9	70	1.4
	3:30	20.0	70	2.2
	4:00	21.1	70.5	2.2
	4:30	22.1	69.5	2.0
	5:00	23.0	68.5	1.8
	5:30	23.9	68.5	1.8
March 21	9:00 A.M.	42.7	62	1.2
(13.5 hours)	(Total length of leaf-blade 49 mm.)			
	9:30	43.3	65	1.2
	10:00	44.1	68	1.6
	10:30	45.4	71	2.6
	11:00	46.6	73.5	2.4
	11:30	48.3	76.5	3.4
	12:00 Noon	49.6	78	2.6
	12:30 P.M.	51.0	80	2.8
	1:00	52.4	82	2.8
	1:30	53.7	82	2.6
	2:00	54.6	81.5	1.8
	2:30	55.7	82	2.2
	3:00	56.9	82.5	2.4
	3:30	58.2	82	2.6

GROWTH OF "TURKEY RED" WHEAT (*Triticum*).—*Continued.*

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
	4:00	59.3	82	2.2
	4:30	60.4	80	2.2
	5:00	70.2	78	1.6
	Reset at	0.0	—	—
March 22	9:15 A.M.	23.2	68	1.4
(16.25 hours)	(Total length 91.5 mm.)			
	9:45	24.5	70	2.6
	10:15	26.2	72	3.4
	10:45	27.5	75	2.6
	11:15	28.6	76.5	2.2
	11:45	29.7	79	2.2
	12:15 P.M.	31.2	81	3.0
	12:45	32.8	82	3.2
	12:45 Reset	35.4	82	—
	1:15	36.8	84	2.8
	1:45	38.4	84.5	3.2
	2:15	39.9	84	3.0
	2:45	42.2	84	4.6
	3:15	43.5	84	2.6
	3:45	45.1	84	3.2
	4:15	46.2	82	2.2
	4:45	47.2	82	2.0
	5:15	48.3	81	2.2
March 23	9:30 A.M.	70.0	72	1.3
(16.25 hours)	(Total length 147 mm.)			
	Reset	0.0	72	—
	10:00	2.2	74	3.2
	10:30	3.9	76	3.4
	11:00	5.2	78	2.6
	11:30	6.3	81	2.2
	12:00 Noon	7.8	82	3.0
	12:30 P.M.	9.3	83.5	3.0
	1:00	10.6	86	2.6
	1:30	12.0	86.5	2.8
	2:00	13.5	87	3.0
	2:30	14.6	83.5	2.2
	3:00	15.8	84	2.4
	3:30	17.2	84	2.8
	4:00	18.6	81.5	2.8
March 24	9:30 A.M.	7.0	70	—
(17 hours)	(Total length 194.5 mm.)			
	10:00	7.8	72	1.6
	10:30	9.4	74	3.2
	11:00	10.6	75	2.4
	11:30	12.2	81	3.2

GROWTH OF "TURKEY RED" WHEAT (*Triticum*).—*Continued.*

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
	12:00 Noon	13.5	82	2.6
	12:30 P.M.	15.0	80	3.0
	1:00	16.4	81.5	2.8
	1:30	18.0	83	3.2
	2:00	19.2	84	2.4
	2:30	20.8	83	3.2
	3:00	22.2	83	2.8
	3:30	23.4	83	2.4
	4:00	24.7	82	2.6
	4:30	26.0	82	2.6
	8:00	34.4	77	2.4
March 25	9:30 A.M.	0.3	72.5	—
	(Total length 244.5 mm.)			
	10:00	1.4	74	2.2
	10:30	2.9	76	3.0
	11:00	4.4	77	2.8
	11:30	5.6	78	2.4
	12:00 Noon	7.3	81	3.4
	12:30 P.M.	8.6	83	2.6
	1:00	10.0	85	2.8
	1:30	11.3	85	2.6
	2:00	12.6	85	2.6
	3:00	16.6	86	4.0
	4:00	17.9	85	1.3
	4:30	19.4	84	3.0
	5:00	20.7	83	2.6
	5:30	21.9	81	2.4
March 26	9:30 A.M.	40.4	74	1.1
(16 hours)	(Total length 295.5 mm.)			
	10:00	41.5	75	2.2
	10:30	42.7	72	2.4
	11:00	44.0	73	2.6
	11:30	45.4	75	2.8
	12:00 Noon	46.7	75	2.6
	12:30 P.M.	48.8	76	2.2
	1:00	49.1	77	.6
	1:30	50.7	78.5	3.2
	2:00	51.8	80	2.2
	2:30	53.3	82	3.0
	3:00	54.4	82	2.2
	3:30	55.7	82	2.6
	4:00	57.1	80	2.8
	4:30	58.1	80	2.0
March 27	9:00 A.M.	0.7	64	
(16 hours)	(Total length 334.5 mm.)			

GROWTH OF "TURKEY RED" WHEAT (*Triticum*).—*Continued.*

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
	9:30	1.6	64	1.8
	10:00	2.2	67	1.2
	3:30 P.M.	13.2	88.5	2.0
	4:00	14.2	87	2.0
	4:30	15.2	81	2.0
	5:00	16.0	80	1.6
	5:30	16.9	79	1.8
March 28 (13.5 hours)	9:00 A.M.	35.2	67	1.2
	(Total length 369 mm.)			
	9:30	36.1	69	1.8
	10:00	37.2	68.5	2.2
	10:30	38.2	68.5	2.0
	11:00	39.1	72	1.8
	11:30	40.3	74	2.4
	12:00 Noon	41.6	74	2.6
	12:30 P.M.	42.7	74	2.2
	1:30	44.7	70	4.0
	2:00	46.0	71	2.6
	2:30	47.1	69	2.2
	3:30	48.7	65	1.6
	5:00	50.9	65	1.5
	5:30	51.6	64.5	.7
	6:00	52.3	63	.7
	6:30	52.9	61	.6
	7:00	53.5	60	.6
	7:30	53.9	59	.4
	9:00	55.5	56	1.0
March 29 (9.5 hours)	6:30 A.M.	0.4	53	—
	(Total length 400 mm.)			
	7:00	0.7	53	.3
	7:30	1.0	53	.3
	8:00	1.8	54	.8
	8:30	2.5	55	.7
	9:00	3.2	56	.7
	9:30	3.9	59	.7
	10:00	4.7	62	.8
	3:00 P.M.	14.4	66	1.9
	3:30	15.2	68	.8
	4:00	16.1	70.5	.9
	4:30	17.1	70	1.0
	5:00	17.7	69.5	.6
	5:30	18.6	69.5	—
March 30 (16 hours)	9:30 A.M.	37.9	65	1.2
	10:00	38.9	65	2.0
	10:30	39.5	64	1.2

Growth of "Turkey Red" Wheat (*Triticum*).—*Concluded.*

Date.	Hour.	Scale Reading.	Air Temperature.	Rate Per Hour.
	11:00	40.2	67.5	1.4
	11:30	41.5	71	2.6
	12:00 Noon	42.4	71	**1.8**
	12:30 P.M.	43.5	72.5	2.2
	1:00	44.4	72	**1.8**
	1:30	45.5	72.5	2.2
	2:00	47.4	76	**1.8**
	2:30	47.4	75	2.0
	3:00	48.3	73	**1.8**
	3:30	48.9	75	**1.2**
	4:00	49.9	76	2.0
	4:30	50.8	76	**1.8**
	5:00	51.6	75	**1.6**
	5:30	52.4	75	1.6
March 31 (16.25 hours)	9:45 A.M.	12.6 (Total length 467 mm.)	70	—
	10:15	13.0	72	**.8**
	10:45	13.5	74	1.0
	11:15	13.9	75.5	**.8**
	11:45	14.3	77	.8
	12:15 P.M.	14.6	80	**.6**
	1:00	15.3	81.5	.9
	2:00	15.7	84	**.4**
	4:00	16.3	83	**.3**
	6:00	16.5	75	**.1**
April 1	9:30 A.M. (15.5 hours—growth .1 mm.; stopped). Total length 470 mm.			

Retardation of growth of *Zea* and *Triticum* occurs at more than one place in the temperature scale and at different times of the day, as may be seen from the inspection of the bold-faced figures on the preceding pages. An uneven rate of elongation was particularly noticeable in *Triticum,* although displayed by *Zea* as well. It was thought that the irregularity might be due to a sagging of the leaf blade which would cause its tip to move with a varying rate across the field. Similar leaves attached to the bearing arm of an auxograph under a stretching tension traced an undulating line indicative of similar irregularities (Fig. 6). Cessation of growth, especially in some of the instances in *Zea,* may be reasonably attributed to a direct temperature effect, especially in the cases in which the thermometer stood at 30° C. to 35° C. for extended periods. In the greater number of instances particularly in *Triticum,* no such explanation could be deemed adequate, and the matter is referred to varying imbibition capacity coincident with alternations of acidity, alkalinity and neutralization (see page 309).

The highest rate that was maintained for some time by *Zea* was found to lie between 27° C. and 30° C. The elongation of the leaf

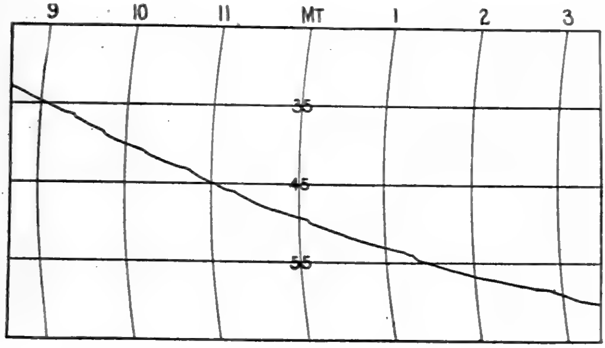


FIG. 6. Auxographic record of growth of leaf of wheat (*Triticum*) for six hours showing sudden alterations in rate of elongation. The pen moves downward with elongation. Actual variation in length. × 15.

of *Triticum* was erratic and retardations were numerous and occurring at all temperatures between 15° C. and 30° C. It is not possible to fix upon any limits of temperature within which growth might be continuous in this plant. It is obvious that "secondary" maxima might readily be derived from data of this character.

No retardations occurred except after 11 A.M. in either *Zea* or *Triticum* and while *Zea* showed an acceleration late in the day after retardation at high temperatures, *Triticum* did not. The tonic range of the two plants is of course not identical. Wheat grows at a lower range than corn and probably reaches its upper limit near the figures given.

There are but three allowable causes in the present state of our knowledge, to which might be attributed the slackening or inhibition of growth or actual shrinkage of growing joints after midday and continuing until the following morning. The retardations in question are relatively least in the earlier stages of development when the joints are not more than one fourth or one fifth adult size and have the effect of a flattening of the curve that is of slowing down growth. The action becomes more pronounced until a stage is reached when more and more of the elongation of the forenoon is retracted in the afternoon (see Fig. 3).

Such negative action might be due to the reduction of an enzyme concerned in the renewal of the constructive material below the effective amount, or to the clogging action of accumulated products, or as has been previously suggested, to transpiration counterbalancing imbibition and accretion of suspended material. Cessation of growth at 26° C. to 30° C. would be difficult to reconcile with the assumption that it might be due to a destruction of an enzyme, since all known bodies of this kind do not begin to show a rapid rate of disintegration until a much higher temperature is reached. An accumulation of the products in some part of the chain of reactions might well take place, however. Similar retardations in photosynthesis are known to occur when translocation of the carbohydrates is prevented.

As to the third suggestion it is to be said that the stoppage or slackened growth of green plants in the open in the hours immediately preceding daylight coincides with a condition of lessened imbibition capacity due to high acidity and accompanied by the most rapid transpiration displayed by the plant. The low temperatures at this time might also cause a decreased absorption. The rate of absorption of green plants would be greatest in the afternoon, and as water-loss at this time has been found to be actually less than in early morning, it is to be seen that the decreased growth characteristic of this part of the day may not be attributed to excessive transpiration. Acidity is near the minimum at this time and the imbibition capacity of the growing joint is greatest. That transpiration may actually check or neutralize growth has been demonstrated in *Eriogonum* by Lloyd:[9]

> The daily march of growth is as follows: During the early daylight hours until about 8, there is usually a slight rise in growth rate. After that hour the rate falls to a low value, or, much more frequently there ensues an actual shrinkage. This is the period during which the loss of water by transpiration is rapidly increasing, reaching its maximum at about noon. Coincidentally with the checking of transpiration, the growth rates rapidly increase in value.

[9] Report Dept. Bot. Research, Carnegie Inst. of Washington for 1916.

the maximum rate being attained by 1 or 2 P.M. and thereafter maintained, with fluctuations, until 6 P.M., when the rates again fall to the night values. The afternoon rates are great enough to more than make up for the negative behavior of the morning, except, as above stated, under unusual conditions.

That light cannot be held to account for the retardation of growth during the morning hours as above indicated has been shown to be an untenable view, since it was found possible experimentally to alter the rates both positively and negatively quite independently of the constancy, increase or decrease of illumination, even when this has been increased with respect to the growing part by insolation from three directions. There seems indeed to be no maximum insolation normally occurring in the field at this locality which can cause any cessation or inhibition of growth when conditions which insure water supply to the growing part obtain. Thus, when a cessation of growth is apparent, it can be checked, and high rates instituted, by the removal of leaves (which divert the water supply), by increasing the vapor tension in the vicinity of the growing part, or by merely increasing the temperature when the volume of the growing part is small (as when the internode under observation is young). These positive changes may occur coincidentally with increase of illumination from the blue or red portions of the spectrum to full insolation.

A similar action may occur in the inactivity of green opuntias in the open, but certainly does not apply to the daylight retardation. On the other hand the checking of growth or shrinkage of etiolated members in darkness and of green shoots at high temperatures may well be due to transpiration or modification of imbibition capacity.

Water-Absorbing Capacity of Plant Tissues.

Growth is essentially the irreversible enlargement of embryonic cells, by the appropriation of material of which 98 or 99 per cent. is water. The process depends upon the availability of the building material which enters into the structure of the protoplast, its inclusions and its envelopes, and upon the continuance of reactions, such as enzymosis and respiration, which maintain an unsatisfied absorptive capacity.

The incorporation of the solutions in the colloids of the protoplast is essentially a hydration process which is usually designated as imbibition. A stable colloid takes up a fixed solution at a rate expressible by a regular curve. The protoplast is a complex mixture of both emulsoids and suspensoids in which there is almost unceasing change. Its structure may be modified by the uneven action of the metabolic plexus which may also result in the accumulation of products such as acids, the presence of which may cause acceleration, retardation or cessation of growth by modifying imbibition or capacity for absorption of water.

It is obvious that a determination of the water-absorbing capacity or swelling coefficient of a growing organ would be an index of its capacity for enlargement at that moment, and by the use of differential solutions the influence of acidity or alkalinity on the process may also be ascertained. The catabolic and synthetic processes which accompany growth are in the main continued in mature organs, especially if these contain tracts of open meristem as do the joints of *Opuntia*. It was thought highly important therefore to make extensive tests of the swelling capacity of *Opuntia* with analyses of the carbohydrate content of the joints. These tests yield some data of great interest when considered in connection with the growth records given in the preceding section of this paper.

The flattened joints of *Opuntia sp.* which formed the principal experimental material are elongated oval in outline, the basal part being usually about 20–24 mm. in thickness and the apical part half or less than half of this diameter. After some extensive comparisons of sections from all parts of the joint it was found that the apical third of the member furnished the best material for comparative purposes. Sections or disks about 12 to 14 mm. across were cut from this region with a cork borer, avoiding the inclusion of nodes bearing the spines and spicules. Such sections consisted of the indurated epidermal layers between which was a cylindrical mass of parenchymatous cells, the outer ones being chlorophyllous and some of the inner ones being mucilaginous. An anastomosed network of thin fibrovascular strands was included in the parenchymatous mass and this mechanical tissue probably checked expansion in some cases, especially those in which disks were taken too close to the nodes. More care was exercised in this matter in 1917 than in the preceding tests, a fact that may be taken to explain in part at least the decreasing number of anomalies as the work progressed. Three of such disks about 12 mm. across the epidermal surfaces and from 6 to 11 mm. in thickness were arranged in a triangle in the bottom of a stender dish and a triangle of thin sheet glass arranged to rest its apices on the three disks. The vertical swinging arm of an auxograph was now adjusted to a shallow socket in the center of the glass triangle while the pen was set at zero on the recording sheet. Water or a solution being poured into the dish, the course of the swelling was traced, the record showing the averaged result of the action of the trio of specimens (see Fig. 7). That the amount of imbibition depended upon the presence of certain recognizable substances was demonstrated by the fact that dried

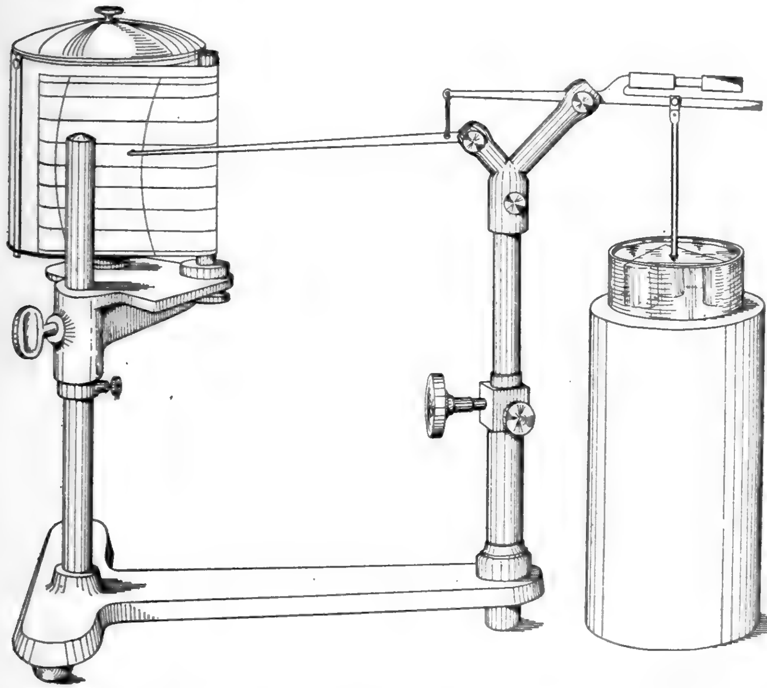


FIG. 7. Auxograph arranged for recording changes in thickness of trio of cylindrical sections of *Opuntia*. The vertical arm, which is set in position on horizontal arm to give a magnification of twenty, rests on a triangle of glass laid on top of the sections. The dish containing the sections rests on an iron cylinder to secure stability and a weight is placed on the T base of the instrument. The record sheet is ruled to millimeters (not shown) with heavier horizontal lines 1 cm. apart. The heavy curved lines shown represent four hour intervals. The space is ruled to fifteen minute intervals (not shown). Height of clock and lever supports adjustable.

and dead disks gave proportionate differences equivalent to those shown by freshly cut and living material.

The auxograph used in making the measurements represents an modified form of an apparatus originally designed by the senior author in 1901. The improved instrument consists of a compound lever, the components of which are suspended in adjustable bearings held in the arms of a metal support of "Y" form with the arms of unequal length. One free arm of the bearing lever is forked, the upper segment carrying a counterpoise which may be moved to give any desired pressure on the bearing contact with an object the swelling of which is to be measured. The lower segment of the free part of the bearing lever has a sleeve with a short socket hinged to its lower side. A thin glass rod set in this socket extends downward to a length of a few centimeters and rests in a concavity in the center of a glass plate laid on the trio of sections in a suitable small glass dish. The sleeve may be moved along the lever to give a magnification between ten and fifty to a pen carried by the other free lever arm. The two small levers are connected by a short length of jewelers' chain in such manner as to minimize friction and other sources of error. The pen is arranged to bear on a slip of paper 8 cm. wide ruled to millimeters and it is carried by a cylindrical clock which gives it a movement of 28 cm. in 24 hours. The compound lever was supported by a rack and pinion column which made it adjustable through a range of 12 cm. in height.

The clock may be moved vertically on its support and fastened at any height by a set screw. The delicacy of this apparatus was such that it could not be operated on a wooden table in an ordinary room. Cement, stone or brick piers with a slab of slate, wood or stone furnished the necessary steadiness. The dishes in which the sections were immersed in swelling solutions were placed on top of iron cylinders 15 cm. high and about 8 cm. in thickness and the dishes were held in place by clay luting. A weight of about 4 or 5 kg. placed on the "T" base of the instrument completed an arrangement by which it was possible to secure undisturbed records of swelling of sections of cactus, of plates of colloids, and also of growth of joints of this and other plants.

The following measurements of the swelling capacity of sections from the terminal joints were secured in 1916 and 1917. One set was made from joints which had been formed during the previous year. Their development as buds began in March and April and was nearly complete by June 1st. Some enlargement may ensue later in the season, or in the following season, as has already been described.[10]

SWELLING—*Opuntia Sp.*

Mature Joints.

(See Fig. 8.)

(Joints of 1915.)

	Water Percentage.	HCl N/100 Percentage.	Na OH N/100 Percentage.
May 19, 1916	50.0	43.3	70.0
" 26, "	40.0	36.6	52.1
June 3, "	72.2	35.3	72.6
" 13, "	23.9	53.6	55.1
" 10, "	51.7	35.7	57.6
Nov. 25, "	65.0	62.0	54.1
(Measured)	47.6	50.0	35.5
Jan. 28–30, 1917	37.6	34.3	36.0
Feb. 20–21, "	12.3	9.1	10.3
" 23–24, "	14.7	19.9	19.1
Mar. 27–28, "	11.0	10.9	11.0

Swelling of Other Joints Three Years Old.

	Water. Per Cent.	HCl N/100. Per Cent.	NaOH N/100. Per Cent.
May 23, 1916	54.4	40.4	58.5
Dried disks of percentage of original diam.	41.3	31.6	42.4

The swelling capacity of sections appears to increase with development and rising temperatures to June at which high values were shown by both young and mature joints. A decrease during midsummer is followed by a maximum reached in November.

The average swelling of young joints was 31.2 per cent. in water, 28.9 per cent. in acid and 29.5 per cent in alkali for the season.

The variations in swelling capacity during the second year are indefinite but an average of the available records (seven tests) shows 50.5 per cent. in distilled water, 45.2 per cent. in hundredth normal hydrochloric acid and 56.7 per cent. in hundredth normal

[10] MacDougal, "Mechanism and Conditions of Growth," *Mem. N. Y. Bot. Garden*, 6: 5, 1916.

Swelling of Joints Formed in 1916.

(See Fig. 8.)

	Water. Per Cent.	HCl N/100. Per Cent.	NaOH N/100. Per Cent.
May 18, 1916	24.3	30.0	40.0
June 2, "	23.6	16.4	22.9
" 13, "	70.1	41.5	49.1
Aug. 3, " (swelled at Carmel)	16.6	14.0	14.3
" 3, " (grown and swelled at Carmel)	18.2	9.3	15.7
Nov. 2, "	20.5	21.0	22.2
" 3, "	14.6	21.3	19.5
" 4, "	28.0	28.0	28.3
" 5, "	27.9	26.0	24.7
" 6, "	20.8	18.4	17.1
" 6, "	27.9	26.0	24.7
" 23, "	44.0	53.5	46.0
" 23, "	34.4	34.9	35.3
" 23, "	49.3	47.9	47.0
" 23, "	48.0	45.4	35.3
Jan. 24–25, 1917 (12 sections)	25.7	27.9	25.0
Feb. 20–21, " (6 ")	10.7	11.7	10.8
Mar. 23–24, " (6 ")	9.4	12.0	10.9
April 24	21.8	20.4	13.9
	20.4	21.8	33.8

sodium hydrate. Inspection of the data obtained by the chemical analyses fails to bring to light any connection between the amount of imbibition and the proportion of any carbohydrate or salt present. The diverging variations suggest combinations of substances to which the swelling may be due. It is to be noted that the proportionate swelling of the sections would be lowered by the thickness of the sections which are fifty to seventy times the diameter of the colloid sections used in other experiments. Furthermore, the amount of swelling is in all probability lessened by the presence of mechanically resistant fibrovascular tissue.

Imbibition and Carbohydrate Metabolism.

In the foregoing pages special attention has been directed to the conditions affecting imbibition and the water-absorbing capacity of the growing plant cell. It is evident that the metabolic activity of the cell itself affects imbibition very greatly; an accumulation of the intermediate or end products of respiration may thus cause an in-

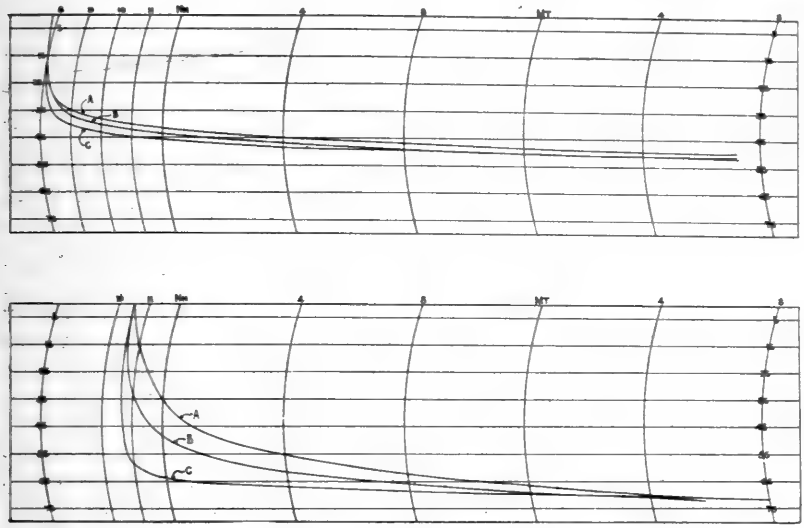


FIG. 8. Auxographic tracings of swelling of cylindrical sections of *Opuntia Sp.*—joints formed in 1915. A compound lever set to magnify swelling 20 times carries a pen downward from the zero line on a sheet 80 millimeters in width, carried past the pen in 24 hours. The right hand or upper line *a* was traced by a trio of sections of an average diameter of 13 mm. which showed a swelling of 50/20 = 2.5 mm. in hundredth-normal sodium hydrate, which was 19.2 per cent. of the original. The lower line *c* was traced by a trio of sections of an average diameter of 13.8 mm. in hundredth-normal hydrochloric acid which showed a swelling of 2.55 mm. or 18.5 per cent. The middle line was traced by a trio of sections of an average diameter of 12 mm. which swelling 2.55 mm. or 21.3 per cent. Feb. 22, 1917. (Upper half of figure.) Reduced ½.

Auxographic tracings of old joint of *Opuntia blakeana.* The upper right hand line *a* was traced by swelling of trio of sections of an average diameter of 10 mm. in hundredth-normal sodium hydrate. The increase was 3.6 mm. or 36 per cent. The middle line *b* was traced by the swelling of a trio of sections of an average diameter of 11 mm. in distilled water. The swelling was 3.6 mm. or 32 per cent. The lower line *c* was traced by the swelling of a trio of sections with an average diameter of 10 mm. in distilled water. The swelling was 3.5 mm. or 35 per cent. of the original. A notable difference between the rates of swelling in the three solutions is exhibited in contrast with those of the series of joints of 1915. (Lower half of figure.) Reduced ½.

crease or decrease in the water-absorbing capacity of the colloidal substratum of the cell. At the same time the degree of imbibition and of swelling plays an exceedingly important part in metabolism and hence in the formation of plastic material necessary for growth and in the liberation of energy. Although these two activities, imbibition and metabolism, are so closely interrelated in the growth processes they are nevertheless of such a widely different nature that it cannot be assumed, as will be shown, that they are equally influenced by external conditions, as for instance, temperature; the conditions under which one affects the other depending, in turn, upon several other factors.

In general, chemical inversion, or the transformation of the highly condensed to the simpler molecules capable of oxidation and translocation, takes place only under conditions of ample water supply. However, these reversible enzymatic reactions never run entirely in one direction. Only differences between the two are observable. We are dealing with a delicate compound dynamic equilibrium, involving probably dozens of steps and many more substances. The very interesting investigations of Lobry de Bruyn and Van Ekenstein[11] and of Nef on the rearrangements of the hexose molecule demonstrate the extreme complexity of such equilibria. Thus Nef[12] has shown that when the relatively simple hexose sugar, dextrose, is dissolved in a weak alkaline solution there are formed no less than 93 different substances which constitute a system in dynamic equilibrium. Any number of these can react selectively and shift the equilibrium, by oxidation, condensation or the like, the course of the reaction depending upon the condition of solution as to concentration, temperature, etc. How much more complex must the condition be in the living cell with the numerous delicate enzymatic equilibria each with its own temperature and concentration coefficient?

The following results (which are a portion of an extensive investigation of the carbohydrate economy of cacti now in progress) throw some light on the relation of carbohydrate metabolism to growth.

The carbohydrates predominate in the general food economy of the cacti. There is no reason for believing that the metabolic processes concerned in the growth of such plants consist chiefly of

[11] Lobry de Bruyn and Van Ekenstein, *Rec. trav. chim. de Pays-Bas, 14,* 158, 203; *15,* 92; *16,* 257.

[12] Nef, J. U., *Annalen der Chemie, Liebig, 403,* 204–383, 1913.

protein synthesis and catabolism as is probably the case in animals. In fact these plants behave largely like masses of gel of carbohydrate nature.

Roughly the fresh material of the growing and mature joints is composed of about:

	Per Cent.	Per Cent.
Water	95	75
Crude protein	0.5	1.0
Carbohydrates hydrolyzable with 1.0 per cent. HCl	5.0	10.0
Cellulose	1.0	3.0
Crude fat	0.25	0.5
Ash	1.0	3.5

The total carbohydrate content and of food supply in general is of little significance or value in studying the various functions of an organism such as the cactus. It is rather the nature of the sugars, or the degree of general chemical inversion, that determines the supply of building material necessary for growth. The records show many instances of large food supply, and all known external conditions favorable for growth, and still no such action taking place. The question of rest period undoubtedly is largely one of adjustment of chemical inversion and reversion, and in general the conditions favoring the awakening of buds are those in which inversion has attained a lead over reversion, permitting a sufficient accumulation of plastic material; while on the other hand, an accumulation in the protoplasmic medium of the products of reversion affects the inhibiting of growth. It seems therefore that in order for growth to occur there must be a sufficient supply of the simpler sugars necessary for respiration as well as for the synthesis of new substances, that synthesis can overbalance the break-down with the accumulation of new material, the latter being the product of an irreversible reaction. In the study of the relation of carbohydrates to growth it is therefore a question of the carbohydrate balance, the ratio of the simple to the condensed sugars that is of prime importance.

The problem of determining the different sugars in a growing organism is one of great difficulty because, as has been indicated, of the large number of sugars belonging to the same group and of the similarity of their chemical properties. It must therefore suffice to determine together groups of sugars of the same general physiological significance. It has been found preferable for the present to make a large number of analyses with as great accuracy as possible, rather than attempt to isolate and determine each of the sugars in a few cases, especially as individual cases show considerable variation. For the present purpose a discussion of the methods of analysis[13] employed does not seem essential.

The following experiment will illustrate the effect of water on the carbohydrate balance of *Opuntia discata*. A number of joints of the same age were taken from one plant and divided into three lots each of six joints. The first (1) was analyzed immediately, the second (2) was suspended in battery jars without water, and the third (3) was placed in the same manner in battery jars so that the base of the joints were immersed as in a water-culture. (2) and (3) were kept in a dark constant temperature room at 28° for thirty days, when they were analyzed. The joints in water had developed roots 5 to 10 cm. in length.

	Immediate (1).		Dry (2).		Water (3).	
	Fresh.	Dry.	Fresh.	Dry.	Fresh.	Dry.
Water	80.34		77.20		82.30	
Total sugars	4.30	20.49	4.29	18.84	3.60	18.58
Total polysaccharides	3.50	17.80	3.60	18.01	2.80	17.54
Hexose-polysaccharides	1.65	8.40	1.81	8.83	1.25	7.85
Disaccharides and hexoses	0.10	0.49	0.13	0.56	0.14	0.83
Disaccharides	0.04	0.20	0.07	0.30	0.06	0.38
Hexoses	0.06	0.29	0.06	0.26	0.08	0.45
Pentosan	1.74	8.86	1.78	9.18	1.25	7.85

The joints without water (2) lost 3.14 per cent. in water content, while those in water (3) gained 1.96 per cent. In total polysaccharides and hexose-polysaccharides (3) is considerably lower than (2), while in hexoses (3) shows a gain over (1) and (2).

The difference in the carbohydrate balance between plants growing in the desert and in Carmel, California, is illustrated in the following analyses of *Opuntia sp.* during September. The values are per cent. of fresh weight:

[13] Full particulars thereof will appear in a later publication on the "Carbohydrate Economy of Cacti."

	Carmel.	Tucson.
Water	91.15	80.34
Total sugars	2.61	4.30
Total polysaccharides	1.94	3.50
Hexose polysaccharides	.09	1.65
Disaccharides	.07	0.04
Hexoses	.52	0.06
Pentoses	.14	0.05
Pentosan	1.70	1.74

Under natural condition similar relations exist. The following table gives typical results of a large number of analyses of *Opuntia sp.* made during each month:

Date.	March 7.	April 3.	April 18.	May 5.	June 9.	July 3.	July 31.	Sept. 20.	Oct. 26.	Nov. 15.	Dec.
Dry weight	15.25	18.20	18.90	21.30	26.74	30.32	16.45	19.66	20.3	23.05	30.1
Total sugars	3.49	4.11	5.58	4.81	6.52	5.07	2.42	4.30	4.24	4.80	5.70
Polysaccharides	2.80	3.13	4.70	4.55	6.31	4.92	2.26	4.24	4.06	4.40	5.25
Monosaccharides	0.69	0.98	0.88	0.26	0.21	0.15	0.16	0.11	0.18	0.40	0.45

Naturally conditions are somewhat more complicated than those in the tests described on p. 336. At the time the new shoots begin to grow, during the end of March and early April, after the winter rains, the parent joints have a high monosaccharide content. As the dry summer advances the amount of these sugars diminishes, although the total sugars increase. With the advent of the summer rains, at the end of July, the decrease in monosaccharides is checked though the high temperatures and resulting high rate of respiration does not permit an accumulation. Another factor entering here is the effect of the temperature on the enzymatic equilibrium. Separate experiments have shown that at the temperatures which prevail in the cacti at this time (during the day as high as 55° C.) there is a distinct shifting in favor of the polysaccharides. During the dry months of September and October the monosaccharides drop to a minimum, in spite of the temperature being considerably lower. With the winter rains there is again an accumulation which is maintained during the winter until spring, when the favorable temperatures again permit growth. The formation of new shoots does not take place in spring when an accumulation of monosaccharides has been prevented, for instance, by means of keeping the joints at a raised temperature in the light during the winter time. However, it need hardly be emphasized that the supply of simple sugars can not be regarded as a single determining factor for growth or the awakening of buds. Such material is essential for the construction of new cells, but as yet no definite conclusions can be drawn as to the exact physiological rôle of the various hexoses and pentoses. When the joints are subjected to starvation, *i. e.*, are placed in the dark for periods of from one to nine months, these simple sugars are used up more rapidly than they are formed from the relatively large store of polysaccharides. With the decrease of the supply of monosaccharides the accumulated organic acids, intermediate products of the normal respiration, are drawn into the process and the total acidity of the organism is thus reduced. Reduced acidity is accompanied by an increased imbibition of the cactus in water. It is also highly probable that other intermediate and end products of metabolism that accumulate in the colloidal substratum of the cell, and affect imbibition as will be shown in the next chapter of this paper, are also removed, resulting in the same effect on the water-absorbing capacity as the removal of the organic acids. Thus cactus joints with a swelling capacity of 20 per cent. in water after being starved four months were neutral to litmus indicator and showed a swelling of 100 per cent. During this period the dry weight of the cactus remained the same.

It is as yet impossible to determine definitely the carbohydrates which make up the colloidal substratum of the cactus cells. Theoretical considerations would require that these be substances of relatively slight physiological reactivity, *i. e.*, substances which are not utilized in the course of metabolism as sources of energy, and are little susceptible to enzymatic disintegration. Of special importance in this connection are the unfermentable sugars which have been found to be present in relatively large amounts, mostly in the condensed form as pentosans.

The Behavior of Carbohydrates and Proteins in Gels Useful in the Interpretation of the Action of Plants.

The amorphous carbohydrates constitute a very important part of the colloids of the protoplast, the remainder of which consists largely of nitrogenous material, in the form of albumen or albumen derivatives with an unknown amount of lipin. The search for material which might simulate the imbibitional behavior of growing tracts in plants begun by the senior author resulted in finding that mixtures of agar with gelatine in which the last-named substance was present in the smaller proportion showed an enhanced capacity for imbibition in distilled water and a reduced swelling in weak acid and alkali as measured in very thin plates by the auxograph.[14]

The swelling of gelatine in percentages of the original thickness of thin dried layers or plates (.1 to .3 mm. in thickness) in water, hydrochloric acid and sodium hydrate, may be illustrated by the following data which represent averages of measurement at the

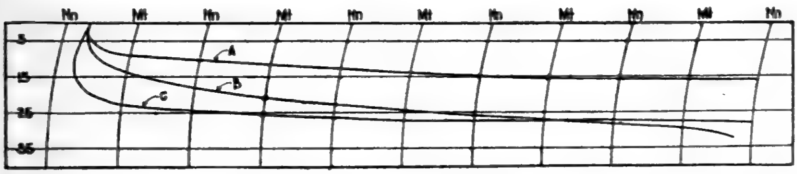


Fig. 9. Auxographic tracing of swelling of agar sections .2 mm. in thickness in NaOH $N/100$, $A = 400$ per cent., in HCl $N/100$, $B = 650$ per cent., and in distilled water, $C = 775$ per cent. $\times$ 10.

end of sixteen hours (see p. 343 for further discussion of swelling determinations by use of thin plates).

Water.	HCl N/100.	NaO N/100.
471.5 per cent.	1012.3 per cent.	587.5 per cent.

Similar plates of agar gave swellings as follows (Fig. 9):

Water.	HCl N/100.	NaO N/100.
462.5 per cent.	725 per cent.	937.5 per cent.

[14] MacDougal, "Imbibitional Swelling of Plants and Colloidal Mixtures," *Science*, N. S., Vol. 44, No. 1136, pp. 502–505, October 6, 1916. See also Ann. Report, Dept. Bot. Res., Carnegie Institution of Washington for 1916, pp. 61–64.

As the plant did not show water relations which might be interpreted as a direct combination of the separate action of gelatine or agar, it was next proposed to test the reactions of a mixture in which these substances would be blended, which was done in July, 1916. The first test mass was one consisting of about equal parts of agar and gelatine, though the quantities were not weighed. Both were soaked and melted separately and the gelatine was poured into the hot agar which was kept at a temperature of about 90° C. for a half hour. The mass was then poured onto a glass slab for cooling. Two days later it was stripped off as a fairly clear and transparent sheet slightly clouded, the average thickness of which was 0.2 mm. Strips about 5 × 7 mm. were placed under the apices of sheet glass triangles in glass dishes after the manner in which plant sections had been tested, and auxographs were arranged to record the action of acids, alkalies, and distilled water. This mixture gave swellings as follows:

Water.	HCl N/100.	NaO N/100.
762.5 per cent.	687.5 per cent.	800 per cent.

The mixture of these two substances having been found to swell more in water and in alkaline solutions than in acid, a series of varying proportions of the two constituents were made up. The mixtures were poured into moulds on glass plates and dried sheets from .1 mm. to .6 mm. in thickness were obtained. The measurements given below include the averages of tests under varied conditions not only of thickness of the samples, but also of temperature, length of period of swelling, tension of instruments, etc. The principal results obtained were as follows:

Water.	HCl N/100.	NaOH N/100.
	Gelatine 100—Agar 1.	
750 per cent.	1100 per cent.	520 per cent.
	Gelatine 100—Agar 5.	
329	850	685.5
	Gelatine 80—Agar 20.	
431.6	789.3	760.7
	Gelatine 50—Agar 50.	
799.0	366.6	580.9

Water.	HCl N/100.	NaOH N/100.
	Gelatine 25—Agar 75.	
378.0	427.3	510.7
	Gelatine 20—Agar 80.	
1144.5	572.1	526.0
	Gelatine 10—Agar 90.	
1000.0	401.0	300.0
	Gelatine 1—Agar 99.	
1825.0	475.0	425.0

The data indicate that as the proportion of agar in the mixture is increased, the relative amplitude of swelling in water may be increased, and the relative amount of imbibition in acid is decreased. This superior imbibition capacity in water as compared to effects of acid and alkali is a fair parallel to the behavior of sections of young, mature and old parts of *Opuntia*.

The second parallel of importance is the one in which the swelling in alkaline solutions is in some cases less and in others greater than in acidified solutions in mixtures containing as much as a third or more of agar.

The mucilaginous material which may be obtained by macerating joints of cacti in distilled water is fairly similar to agar. Some of this was used in mixtures in place of agar. The averages of a series of swellings of a mixture of 90 parts of gelatine and 10 parts of such mucilage, reckoned by dry weight, were as follows:

Water.	HCl N/100.	NaOH N/100.
428.1 per cent.	770.4 per cent.	557.8 per cent.

These data are of interest when compared with the swellings of mixtures of 100 parts gelatine to 5 parts agar, and of mixtures of 80 parts of gelatine to 20 parts of agar (see p. 340). The mucilage from joints of *Opuntia* affects the swelling of gelatine in much the same manner as does agar in equivalent proportions. The watery extract of course contains the soluble salines of the plant, and some of the effect might be attributed to their presence.

A few simple tests were arranged to show the effects of a salt on the colloids used, the results of which are as follows:

GELATINE.

Swelling.

	Water.	HCl N/100.	HCl + NaCl / N/200.
	450.0 per cent.	1200.0 per cent.	1116.7 per cent.
	516.7	1066.7	1400.0
	——	——	1250.0
Averages:	483.4	1133.4	1255.6

Gelatine.

	Water.	HCl N/100.	HCl N/100 + NaCl N/100.
	616.7 per cent.	1016.7 per cent.	833.3 per cent.
	466.7	1083.3	1083.3
	——	1133.3	883.3
	——	——	866.7
	——	——	833.3
Averages:	483.3	1077.8	899.9

The superior swelling of gelatine in acidified solutions is illustrated and a lower average of swelling in hundredth normal hydrochloric acid in the presence of a salt solution of the same concentration was demonstrated. The admixture of hundredth normal acid and of hundredth normal salt solution gives a solution of two hundredths normal concentration. Gelatine shows a lesser swelling in this weaker acid, and furthermore the presence of the salt appears to increase imbibition.

Sugars are an important constituent of living tissues and it is highly probable that in addition to pentose, sucrose and dextrose are also in the colloidal suspensions of the protoplast. It was important to determine whether or not they exerted any direct effect in the concentrations in which they might occur in the cell. A series of tests of the effects of these substances was carried out by Mr. E. E. Free at the Coastal Laboratory in September, 1916. Gelatine and agar were mixed in various proportions, dried to thin sheets and then swelled at temperatures of 16 to 21° C.

Sugar solutions of a concentration less than 25 per cent. did not differ appreciably in its effects from distilled water. Sucrose concentrations of a 50 per cent. concentration produced a markedly lessened concentration of all gels. Dextrose of the same strength had a similar effect on the mixtures low in gelatine in which it was tried. Its effect on mixtures containing a large proportion of gelatine was not determined. The appreciable effects are probably due to the tying up of molecules of water analogous to the osmotic action of such solutions.

Sugar solutions of a concentration of 25 per cent. or higher are not characteristic of growing regions and probably occur only in storage tracts, seeds or cotyledons. While the effect would be to lessen imbibition by the colloidal mass of the protoplast it is to be recalled that a vacuolar fluid of such concentrations would have high osmotic properties and the expansion by turgidity might mask or exceed that due to imbibitional swelling. If sugars contribute directly to the growth expansion of the cell it would therefore be in the later stages of development and by osmotic action.

A duplicate series of tests of the behavior of an admixture of starch with agar gave the following results:

SWELLING.

Agar 90—Starch 10.

Water.	HCl N/100.	NaOH N/100.
1275 per cent.	541.6 per cent.	496.6 per cent.

The complication of the carbohydrate gel by the addition of starch made no essential departure from the behavior of agar alone in water, acidified and alkaline solutions.

The combination of agar and gelatine gave a gel in which two of the three main groups of constituents of living matter were represented.

It is not certain, however, that the combination of amino-acids in gelatine is duplicated in the plant and it was deemed important to test the effects of simpler amino-acid compounds and of the more complex albumens on the swelling of agar, as representing the basically important carbohydrates. Solutions of the various mixtures were poured on glass plates in layers about a centimeter thick and 3 by 5 cm. in area. Desiccation resulted in a reduction of the length and width to about half of the original. The thickness however was reduced to one-tenth or even as much as to one-thirtieth of the original, and having a thickness of .1 mm. to .3 mm. in most cases. The principal axis of deposition of material was in the vertical and the swelling in this direction would of course be correspondingly in excess of that in the plane of the sections. It is extremely unlikely that any of the colloidal masses of the cell are iso-radial as to deposition or structure and the use of thin plates seemed a feature which might increase the similarity of behavior with that of the plant. The strands, sheets or masses of material in the cell are of course mostly thinner than the plates used in the experiments, which however would affect speed of imbibition more than final proportion.

Trios of sections of sheets of the dried colloids 2 to 4 mm. by 3 to 6 mm. were placed in the bottom of stender dishes or of heavy watch glasses securely seated on iron cylinders. Triangles of glass were placed on the sections, and the vertical arms of auxographs were rested in a socket in the center of the triangles. Any change in thickness of the sections would be registered immediately. The use of six instruments gave duplicate results of the effects of water, acid and alkali, and each record was an integration or average of the swelling of three sections.

The only albumen available when this plan was put into operation was a commercial egg-albumen, and this was first tested in mixtures with large proportions of gelatine. The results of the swellings are as follows:

Water.	HCl N/100.	NaOH N/100.
	Gelatine. (Average of 3 tests.)	
313.8 per cent.	825.5 per cent.	558.3 per cent.
	Gelatine 100—Albumen 5. (Average of 5 tests.)	
283.4	611.7	482.2
	Gelatine 85—Albumen 15. (Average of 5 tests.)	
408.6	827.8	673.0
	Gelatine 75—Albumen 25. (Average of 3 tests.)	
378.3	569.7	508.7

The albumen did not exert any important influence on the swelling of the mixture until it was present in proportions as great as 25 per cent. The action is not marked even in this high proportion. Neither this nor any other combination in which gelatine formed the greater part displayed water relations at all similar to those of the plant.

Next egg-albumen was added to agar and agar-gelatine mixtures with results as below, a further illustrative test being made of agar-gelatine:

Water.	HCl N/100.	NaOH N/100.
	Agar 75—Gelatine 25. (Average of 4 tests.)	
378.5 per cent.	427.3 per cent.	515.7 per cent.
	Agar 90—Albumen 10. (Average of 3 tests.)	
1516.6	270.0	333.3
	(Average of 6 tests.)	
1477.1	309.8	297.9
	Agar 70—Gelatine 20—Albumen 10.	
595.0	216.6	298.6

The addition of ten per cent. of albumen to agar notably reduced the capacity of agar for swelling in acid and alkali, and appeared to increase the amplitude of swelling in distilled water, although the last matter is not entirely clear. The albumen reduced the swelling of a mixture containing twenty-five per cent. of gelatine slightly in acid and in alkali, but the swelling in water was not markedly greater. This preliminary test yielded results which made their extension highly desirable. Chemical analyses of the egg-albumen were not available, and as nothing was known as to the salts or other substances which might be included, it was desirable to secure material of known origin and composition. Arrangements were made with Dr. Isaac F. Harris, of Squibb and Sons Laboratory, New Brunswick, New Jersey, to prepare some albumen from beans (*Phaseolus*) and from oats (*Avena*) to be used in the mixtures. The preparations from *Phaseolus* were available in February, 1917, and the first tests were made with the "protein" extract which contained the water soluble salts of the bean and the proteins which were soluble in water containing these salts.

Agar and gelatine were dissolved in the usual way and the temperature of the suspension allowed to fall to a point below 40° C. before the protein was stirred into it. In the course of the cooling and drying, cloudy masses became visible which were taken to be the globulin component of the protein. The dried sheets came down to a thickness of .3 to .4 mm. Calibrated samples were tested in trios under the auxograph in the usual manner. Two complete series of

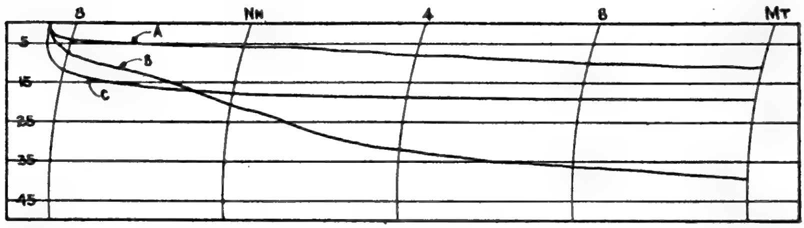


FIG. 10. Auxographic record of swelling of agar 90—protein 10, sections .25 mm. in thickness, in NaOH $N/100$, $A = 220$ per cent., in HCl $N/100$, $B = 360$ per cent., and in distilled water, $C = 800$ per cent. $\times$ 10.

all mixtures were made and an additional measurement of the action of water and alkali was obtained. The swellings were as follows (Fig. 10):

	Water.	HCl N/100.	NaOH N/100.
	Gelatine 90—Protein 10 (Phaseolus).		
	585.7 per cent.	1401.0 per cent.	942.8 per cent.
	486.0	1200.0	704.3
	386.0	——	800.0
Averages:	485.9	1300.5	817.7
	Gelatine 75—Protein 25 (Phaseolus).		
	696.9	818.1	621.2
	500.0	1060.6	848.4
Averages:	598.5	939.4	734.8
	Agar 90—Protein 10 (Phaseolus).		
	800.0	50.0	150.0
	800.0	75.0	150.0
Averages:	800.0	62.5	150.0
	Agar 99—Protein 1 (Phaseolus).		
	1080.0	300.0	220.0
	800.0	360.0	240.0
Averages:	940.0	330.0	230.0

The protein extract from the bean was thus shown to exert an influence on the swelling of agar similar to that of egg-albumen in reducing the amount of swelling in acid and alkali, and increasing it in distilled water.

The next step of importance was to ascertain the effect of some of the simpler amino-acids which might be derived from the albumens in the plant. Tyrosin and cystin were available. As an example of the method the first preparation of tyrosin was one in which one part of this substance in solution was stirred to a liquefied mass of ten parts of agar at a temperature of 32° C. This was poured on a glass slab, and as desiccation was carried out the tyrosin began to collect as a flour-like efflorescence on the surface, and apparently a large part of the substance came out in this way, so that the actual

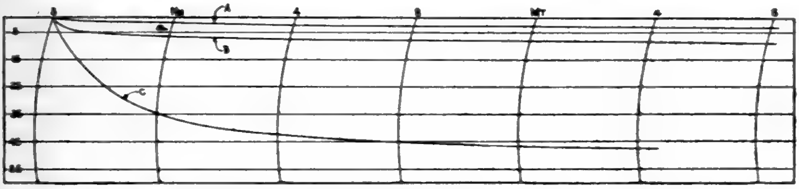


FIG. 11. Auxographic record of swelling of sections of agar 90—tyrosin 10, .15 mm. in thickness, in NaOH $N/100$, $A = 133$ per cent., in HCl $N/100$, $B = 233$ per cent., and in distilled water, $C = 1600$ per cent. × 6.

proportion of the amino-acid in the dried plate was probably not more than a fourth of the amount originally used.

The dried plate of material came down to a thickness of .15 mm. and gave the following results (Fig. 11):

SWELLING.

Agar 90—Tyrosin 10 (less by efflorescence).

	Water.	HCl N/100.	NaOH N/100.
	1600.0 per cent.	133.3 per cent.	133.3 per cent.
	1200.0	233.3	100.0
Averages:	1400.0	183.3	116.6

A similar preparation of agar and cystin gave the following as an average of three tests:

Agar 90—Cystin 10.

Water.	HCl N/100.	NaOH N/100.
2333.3 per cent.	583.1 per cent.	328.6 per cent.

A similar mixture of agar and urea (agar 90 parts, urea 10 parts) gave the following:

SWELLING.

Water.	HCl N/100.	NaOH N/100.
2173.0 per cent.	716.6 per cent.	560.2 per cent.

Urea, the amino-acids, gelatine, albumen, and the saline soluble proteins of the bean dissolved with agar and dried into thin plates produced a greatly enhanced imbibition in water, an imbibition in hundredth normal hydrochloric acid not more than a third of that in water, while it was invariably less in alkaline than in acidified solutions. The interest in swelling which begins with a neutral desiccated section is however much less than that which attaches to the behavior of such material under changing conditions of alkalinity and acidity which are taken to occur in the living plant.

Dried plates of agar-protein, agar-tyrosin and agar-cystin .12 to .25 mm. in thickness and 3 by 4 or 5 mm. were placed in trios on the bottoms of stender dishes. Triangular pieces of glass were placed to cover the sections of colloid in each dish and an auxograph was arranged to give a bearing contact of the swinging arm on a socket in the center of the triangular plate. So long as the preparation remained in this condition the pen of the instrument traced a horizontal line on the sheet carried by the drum. Dried sections of the colloids have a very limited capacity for imbibition of acid and alkaline solutions, and hence it was desirable to start swelling or "growth" by an initial immersion of an hour in distilled water, which was poured in the dishes. After enlargement had begun hundredth-normal acid or alkaline solutions were used in alternation at intervals of one to three hours, as many as four changes being made in some cases before the total swelling capacity was reached. The results met all expectations based on theoretical considerations and the auxographic tracings might easily be mistaken for records of the variations of the length of a joint of *Opuntia,* for example.

Sections of plates 90 parts agar to "10" of tyrosin gave a tracing traversing 12 mm. vertically on the record paper during the first hour immersed in distilled water, remained stationary making a horizontal line during the second hour, the water having been replaced with hundredth-normal hydrochloric acid, traversed 11 mm. of the scale in the third hour during which it was immersed in hundredth-normal sodium hydrate, then shrank 5 mm. in an hour in acid, then enlarged 9 mm. in three and a half hours in alkali, after which it shrank 3 mm. between 8:30 P.M. and 7 A.M. in acid. A change to alkali gave an enlargement of 6 mm. in two hours (Fig. 12). The auxograph was set to multiply so that the actual

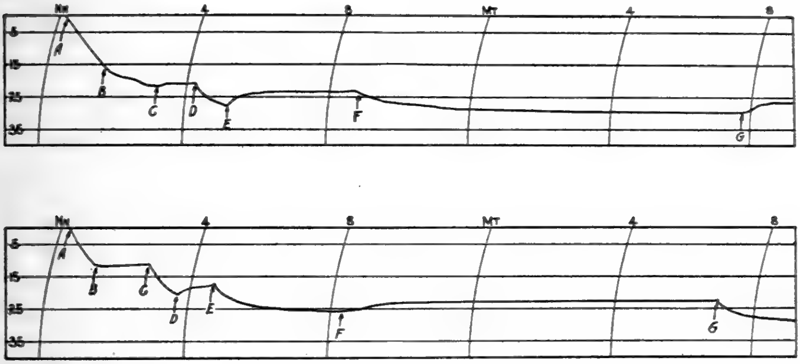


FIG. 12. Auxographic record of changes in section of agar 90—tyrosin 10, .14 mm. in thickness. Immersed in water at *A*, alkali at *B*, acid at *C*, alkali at *D*, acid at *E*, alkali at *F*, and acid at *G*. (Upper half of figure.) × 10.

Auxographic record of changes in section of agar 90—tyrosin 10, .14 mm. in thickness. *A* in distilled water, *B* acid, *C* alkali, *D* acid, *E* alkali, *F* acid, and *G* alkali. (Lower half of figure.) × 10.

enlargement in the periods noted was one twentieth of the distance traversed by the pen. The change from acidity to alkalinity is followed by the most marked effects when the colloid has taken up a fourth or a third of the possible total amount of water. Perhaps the most striking feature is the response of the colloid to acidification under the alternating conditions. Desiccated sections give a greater total swelling in acid than in alkali, but when a certain amount of swelling has already taken place under neutral or alkaline conditions no further increase in acid solutions and actual shrinkage ensues. A change to alkalinity is always followed by increased imbibition. Sections of plates containing 90 parts agar and 10 parts of gelatine gave results similar to those of the tyrosin mixture. No determinations of the minimum proportion of nitrogenous matter necessary to cause an agar mixture to behave in this manner were made. Ordinary agar contains some nitrogen and salts,[16] and it is possible that the varying amounts might cause some disagreement of results obtained by the use of different lots of this substance.

The series of experimental trials with colloids which might display some of the fundamental physical properties of protoplasm of plants has resulted in finding that a mixture of substances of two of the three more important groups of constituents, carbohydrates and proteins, shows the imbibitional behavior of tissues and tracts of protoplasts of the plant. The differential action of such colloidal masses in distilled water, acid and alkaline solutions yields many striking parallels with growth. The changes from acidity to alkalinity have, so far as this type of experiment has been repeated, been made abruptly to avoid instrumental errors. Some acid or some alkali remained in the dishes when the change was made, and a certain amount of acid or alkali fixed or absorbed in the colloidal sec-

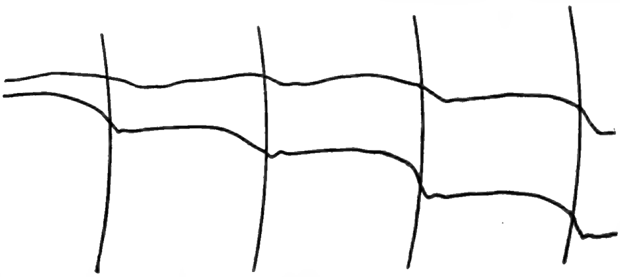


FIG. 13. Auxographic tracing of changes in length of shoot of *Opuntia* showing elongation and shortening (for comparison with Fig. 12).

tion, and neutralization, acidification or the reverse took place slowly with some formation of salts as might likewise occur in the plant (see Fig. 13).

It is through the relations indicated that metabolism or respiration may affect growth by the modification of imbibition capacity. Thus the accumulating surplus of acid in *Opuntia* begins to lessen by disintegration at daybreak and the decrease continues until about

[16] See Noyes, H. A., "Agar for Bacteriological Use," *Science*, Vol. 44, No. 1144, p. 797, 196.

4 P.M. Whether complete neutralization or alkaline conditions ever occur naturally in this plant is doubtful.

The notable augmentation of imbibition which accompanies complete destruction of the balance of acid in the shoot of *Opuntia* under experimental conditions has already been described on p. 295. It has also been found that the mid-afternoon checking of growth characteristic of shoots of *Opuntia* which have accomplished a fourth or a third of their development, did not appear in the single bud, the development of which from a starved joint has been followed since the section of this paper dealing with growth was written.

The almost rhythmic undulations of the auxographic tracing of the elongation of a wheat leaf corroborated by measurements with the horizontal microscope suggest that growth in this organ may be accompanied by metabolic processes by which the balance of acidity and alkalinity falls now on this and then on that side, there being of course periods in which the growing protoplasts or some of them were in a neutralized state. During this time of course imbibition might be four to eight times as great as in either acid or alkaline conditions.

The change from any one of these conditions is of course accompanied by variations in imbibition. The character of the change is readily recognizable in the swelling of colloids, and it is believed that similar interpretations of the auxographic record of growing organs will be possible. The colloidal sections used for experimentation have a general identity with cell-masses except as to the lipin constituents. The part which these substances might play in the mechanics of growth can not as yet be made the subject of profitable conjecture. The analogies as to the action of the salts to be found in plants are also yet to be determined, and probably involve some of the phenomena studied as "antagonisms."

The striking similarities in behavior between the pseudo-protoplastic material and cell-masses makes possible some new correlations in metabolism, imbibition and growth. It is hardly necessary to add in conclusion that whatever measure be given the contributions embodied in the present paper, the results presented do not lead to any simplification of the major processes under discussion.

The advance is in a diametrically opposite direction. Newly determined features of carbohydrate metabolism included in respiration and necessary for growth and functionation have been found to be extremely complex. Imbibition in the plant is not that of a single colloid, and swelling is not the simple resultant of the action of two or more substances. The interaction between two emulsoids presents many possibilities. The proteins viewed physiologically appear to act as "sensitizers" to the carbohydrate gels which make up the greater part of the bulk of the protoplast, and to produce in them highly specialized effects with acids, alkalies and neutral solutions. The general character of respiration, and the nature and amount of its by-products acting upon a "sensitized" protoplastic gel may be taken to determine the general aspect, rate, course and amount of growth in plants.

SPONTANEOUS GENERATION OF HEAT IN RECENTLY HARDENED STEEL. III.

By CHARLES F. BRUSH.

(*Read April 13, 1917.*)

The present paper is the third of a series under this title. In the first paper[1] it was shown that a specimen of carbon tool steel, and also a specimen of "high-speed" tungsten-chromium steel after hardening by water quenching at a high temperature, spontaneously generated heat in appreciable quantity for at least several weeks, the rate of generation steadily diminishing. It was also shown that the carbon steel, after hardening, shrank progressively when tempered to "straw" color, to "light blue" and finally annealed. It was further shown that another specimen of high-carbon steel, after hardening, spontaneously shrank in measurable amount for many days, the rate of shrinking steadily diminishing. The plotted curve of spontaneous shrinkage was strikingly similar to a curve (not plotted) of total heat spontaneously generated in the other specimen of carbon steel, showing an apparent relationship between the two phenomena. But it was pointed out that spontaneous shrinking could not possibly be the prime cause of the spontaneous generation of heat observed because it was wholly inadequate in amount. This conclusion was afterward confirmed (second paper) in the cases of two specimens of nickel-chromium steel which, after quenching just above the temperature of decalescence, spontaneously generated heat freely but did not shrink at all.

The second paper,[2] after reviewing the first, treated principally of two specimens of nickel-chromium steel furnished for this investigation by Sir Robert Hadfield. Each specimen consisted of twelve

[1] *Proc. Am. Phil. Soc.*, Vol. LIV., No. 217, May–July, 1915.

[2] *Physical Review*, N. S., Vol. IX., No. 3, March, 1917. *Proc. Royal Soc.*, Series A, Vol. 93, No. A649, April 2, 1917. Joint paper with Sir R. A. Hadfield.

half-inch round bars five inches long, like in size and number those of each of the steels of the first paper, so that results obtained were quantitatively comparable with the earlier ones. Each specimen was first hardened by quenching at a temperature just above that of decalescence as indicated by almost complete loss of magnetic susceptibility.

For observing the magnetic behavior of the steel while being heated or cooled in the gas furnace employed, the bundle of bars was surrounded by a single turn of asbestos-insulated platinum wire, the ends of which were connected with a ballistic galvanometer having the usual mirror and scale. The furnace was surrounded by a large coil of heavy copper wire through which a direct electric current could be established and broken at will by means of a switch and storage battery. Before the steel bars were placed within the platinum loop inside the furnace, closure of the outer copper coil circuit caused a brief electric pulse in the loop and a "kick" in the galvanometer, giving a definite minimum deflection easily observed with considerable precision. With the steel bars inside the platinum loop the galvanometer deflection was, of course, many times greater until, with rising temperature, the decalescent point was approached; then the deflection fell rapidly to the minimum value as above, or very near it. This simple induction apparatus was found entirely reliable and satisfactory.

Each of the nickel-chromium steels exhibited good generation of heat after hardening as above.

They were again heated, to a temperature considerably above decalescence, and quenched as before. This second hardening induced a greater generation of heat than the first hardening, especially in the case of specimen B.

Specimen B was slowly heated a third time, somewhat above the temperature of complete loss of magnetic susceptibility, and allowed to cool very slowly in the furnace until complete recovery of magnetic susceptibility was attained; then it was immediately quenched. A very fair generation of heat followed this treatment. This was quite unexpected because it was thought that true hardening of the steel could not have taken place. In the absence of suitable apparatus no test of hardness was at that time made. The twelve bars (specimen B) were next annealed by slowly heating to full decalescence and then allowing to cool very slowly in the furnace. As expected, no trace of heat generation followed this treatment which was made for checking purposes.

Before commencing the experiments with specimens A and B, a test bar of each lot was prepared for accurate length measurements which followed each treatment. The very interesting results of these measurements, differing materially in the two specimens, were tabulated and compared.

The present (third) paper deals with some later experiments prompted by the anomalous behavior of specimen B of the Hadfield nickel-chromium steel after its third quenching described above.

In conducting these experiments an electric furnace was employed for heating, instead of the less convenient gas furnace formerly used, and the latest form of "sclerescope" for testing hardness was installed; also, a most modern industrial thermo-electric pyrometer. The latter was used as it came from the maker, without further calibration; hence the temperatures recorded in this paper may be several degrees in error, though they are thought to be relatively consistent.

The apparatus employed in detecting, measuring and following the progress of heat generation in the steels under treatment was fully described and illustrated in each of the former papers, and it is thought best to omit another description here.

It will be recalled that "specimen B" was left in the annealed condition. In this condition it was subsequently found to have a scleroscope hardness of 31. This is the mean of many consistent measurements. Each scleroscope hardness cited in this paper is the mean of at least ten consistent measurements, each measurement made on a fresh spot of surface carefully made smooth and flat.

In order to ascertain the critical temperatures of decalescence and recalescence of "specimen B," three of the twelve bars were very gradually heated until almost complete loss of magnetic susceptibility was reached. This occurred rather abruptly at about

777° C. One of the bars was quenched at this temperature, and its scleroscope hardness was found to be 74. This may be taken as the hardness of "specimen B" after the first quenching described in connection with the second paper.

The remaining two bars were allowed to cool very slowly in the furnace until complete recovery of magnetic susceptibility took place at about 660°. Recovery was abrupt in temperature. One of these bars was quenched at this temperature, and its hardness was found to be only 37, which is not much above annealed hardness (31). This seems to me conclusive evidence that true hardening did not take place in "specimen B" on its third quenching already described

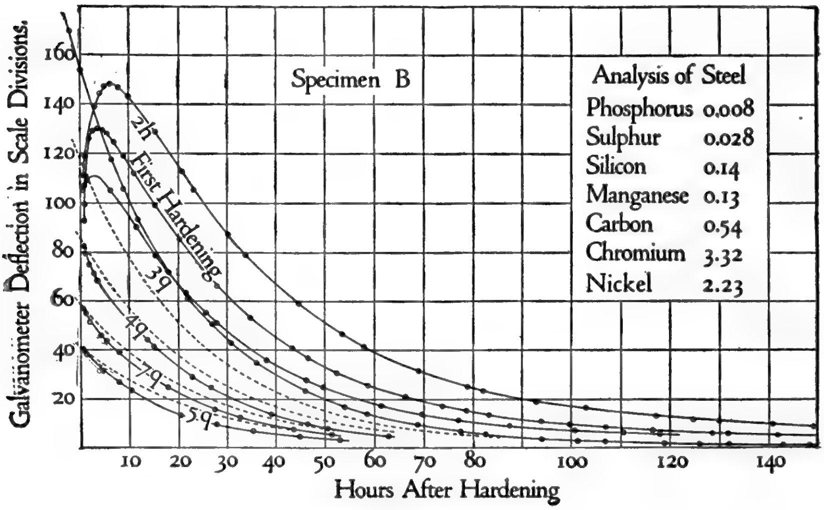


FIG. 1.

above, although good spontaneous generation of heat followed the quenching.

The three bars were again heated to complete decalescence and annealed in the furnace so as to leave all twelve bars of "specimen B" in annealed condition.

Fig. 1 is the curve sheet of "specimen B." "Galvanometer deflection" measures temperature difference, indicated thermo-electrically, between the steel under examination and a thermally equivalent quantity of water, contained separately in silvered Dewar vacuum jars. Both the steel and the water were usually brought to the same room temperature before being placed in the calorimeter. Fifty-five scale divisions indicate a temperature difference of 1° C.

The curve of normal cooling runs out of the figure at the upper left hand corner, and is easily distinguished from the others. This curve was obtained from a quantity of untreated steel equal in weight to "specimen B," and warmed a few degrees above room temperature before being placed in the calorimeter. It shows the normal loss of heat due to imperfect thermal insulation alone, and is the basis of comparison for all the other curves. Obviously this curve may be plotted further to the right or left without impairing its validity; and it may be plotted to intersect any of the other curves at any desired point, to facilitate study of the other curve at and near the intersection. For my own convenience I have constructed a metal template of the normal cooling curve, and find it most useful. Of course it is necessary that the base of the template be always kept coincident with the base line of the curve sheet.

The curve of "first hardening" shows the spontaneous generation of heat which followed the first quenching at about 777°, the temperature of complete loss of magnetic susceptibility, after which the scleroscope hardness must have been about 74.

The curve of second hardening, indicated by "*2h*," shows considerably greater generation of heat. Quenching temperature and hardness were not observed; but it is known that the quenching temperature was much higher than 777°.

The three curves thus far discussed were shown in the "second paper" already referred to, and the other curves here shown were subsequently plotted on the original curve sheet.

The third curve showing spontaneous generation of heat is indicated by "*3q*," meaning third quenching (not hardening). To make it clear that heat was generated in this case I have drawn the curve of normal cooling in a position for easy comparison (the upper dotted line). The "*3q*" curve was described in the second paper, but not plotted. The quenching temperature in this case must have been slightly below 660°, and hardness only about 37.

"Specimen B," left in the annealed condition at the close of former experiments, with a hardness of 31, was next gradually heated to 554°, allowed to cool slowly to 532° and quenched. It was then purposely brought to a temperature slightly above room temperature and placed in the calorimeter. The progress of cooling is plotted in the curve "4*q*" (fourth quenching). For easy comparison the normal cooling curve is drawn as a dotted line through the first station of the 4*q* curve. Beyond this point the 4*q* curve lies everywhere *below* the normal cooling curve, showing conclusively that the steel cooled abnormally fast. In other words, there was spontaneous disappearance or *absorption* of heat in the steel, most notable during the first few hours after quenching. Hardness was 35.5.

The result of this experiment is remarkable, and was quite unlooked for. I had expected to find a small generation of heat, if anything.

The steel was next heated to 562° and quenched. The result of this treatment is shown in the curve "5*q*," with its own dotted normal cooling curve. Absorption of heat is again indicated, even greater than in 4*q* but somewhat differently distributed. Hardness was now 34.5.

Again the steel was heated, this time to 594°, and quenched. Again there was marked absorption of heat. The curve, 6*q*, was almost identical with 4*q*, and is not plotted, to avoid confusion of lines. Hardness was again 34.5.

The seventh heating was carried to 667° for quenching. This was a much larger temperature advance than in either of the preceding experiments, and was *above the temperature of the third quenching,* which was followed by very considerable *generation* of heat. But now there was very considerable *absorption* of heat, as shown in curve "7*q*." Hardness was now 34.

It should be noted that the quenchings which were followed by absorption of heat were made at *rising* temperatures which had not been exceeded (except slightly in the case of 4*q*) since the steel was annealed. But in the case of third quenching the quenching temperature was a falling one, reached by cooling from the much higher temperature of decalescence. I can think of no other cause than this for the radically different results of the third and seventh quenchings, which were made at substantially the same temperature. The temperature difference between complete loss and complete recovery of magnetic susceptibility, 117°, was unusually large; but while this temperature drop brought about almost annealed softness, and full restoration of magnetic qualities, it did not very greatly affect that quality of the steel, whatever it is, which is responsible for the spontaneous generation of heat. Seemingly, one or more of the several unstable compounds or mixtures of the constituents of the steel which were formed at the upper critical temperature did not have time to wholly revert to normal annealed condition while the metal was cooling to and passing through recalescence. The time of this cooling was about half an hour.

To confirm the curious result of the third quenching, *i. e.*, generation of heat without hardening, the bars were quenched the eighth time as follows: Slowly heated (nearly two hours) to 819°, slowly cooled (nearly one hour) to 680° and quenched. During the heating complete loss of magnetic susceptibility occurred at 779°, which was an excellent confirmation of the former finding (777°). But in cooling, full recovery of magnetic susceptibility came at 680°, which is 20° higher than before. The five intermediate treatments

RÉSUMÉ OF SPECIMEN B.

Temperature of complete loss of magnetic susceptibility, 777° C.
Temperature of complete recovery of magnetic susceptibility, 660/680.

	Quenching Temp.	Hardness.	Remarks.
First hardening....	About 777° C.	74	Good generation of heat
Second "	Much higher temp.	—	Much larger generation of heat
Third quenching ...	About 780°/660°	37	Fairly good " " "
Annealing.........		31	
Fourth quenching..	554°/532°	35.5	Good absorption of heat
Fifth " ..	562	34.5	" " " "
Sixth " ..	594	34.5	" " " "
Seventh " ..	667	34	" " " "
Eighth " ..	819°/680°	47	" generation " "

may, perhaps, account for this. And this higher quenching temperature may account for the somewhat greater hardness produced, which was later found to be 47, as against 37 for the third quenching (74 for true hardening above decalescent temperature).

Following the eighth quenching there was *good generation of heat,* better than after third quenching, but differently distributed in time—not so rapid at first, but much better sustained (curve not plotted). This appears to confirm the third experiment.

I cannot, thus far, offer any promising explanation of the absorption of heat in the fourth, fifth, sixth and seventh experiments.

It may be seen that absorption was rapid during the first few hours, and nearly (not quite) ceased at the end of 50 or 60 hours; while generation was well marked up to 150 hours. In earlier experiments generation of heat was easily detected at the end of a month.

As it seemed desirable to learn whether plain carbon steel would show, like the nickel-chromium steel, generation of heat without hardening, or absorption of heat when quenched at rising tempera-

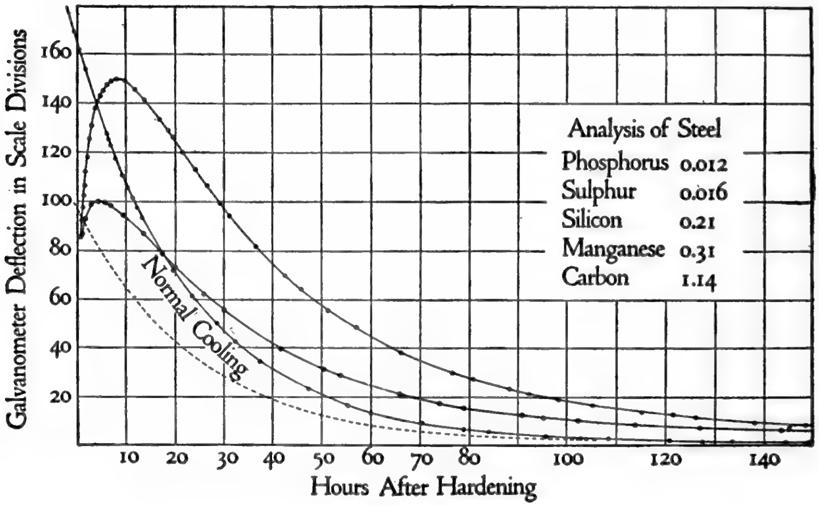


FIG. 2.

tures below the lower critical temperature, after annealing, the following experiments were made with the carbon steel used for the first experiment described in the first paper of the series. The normal cooling curve and upper curve of heat generation shown in Fig. 2 are taken from that paper.

Following is a résumé of the early and recent experiments with the carbon steel:

First (Original) Hardening.—Quenched at very high temperature. Temperature and hardness not then observed. Large generation of heat, as shown in upper curve of Fig. 2. Scleroscope hardness, recently observed, 79.

Second (Recent) Hardening.—Quenched at 802°, considerably above decalescence, but much lower than in first hardening. Complete loss of magnetic susceptibility occurred at 765°. Good generation of heat, but very much less than in first, as shown by the lower curve of Fig. 2. For convenient comparison with this curve the normal cooling curve is shown as a dotted line appropriately located. Hardness was now 73.

Third Quenching.—Heated to 815°, somewhat above preceding quenching temperature, allowed to cool slowly to 720° and quenched. This was a *little below* the temperature of complete recovery of magnetic susceptibility, which had occurred at 729°. Hardness was now only 28.5, and there was *no generation of heat.* (The nickel-chromium steel had shown good generation of heat under similar circumstances.) Note the small temperature difference, 36°, between complete loss and complete recovery of magnetic susceptibility. Annealed by heating to 822°, to obliterate previous quenching effects, and cooling slowly in furnace. Hardness was now 25.5.

Fourth Quenching.—Heated slowly, from annealed condition, to 633° (considerably below the lower critical temperature) and quenched. Hardness was again 28.5, and there was *no trace of absorption of heat.* (The nickel-chromium steel had shown good absorption of heat under similar circumstances.)

Fifth Quenching.—Heated slowly to 732°, just above the temperature of complete recovery of magnetic susceptibility, and quenched. No generation or absorption of heat, nor change in hardness (28.5).

Clearly, the carbon steel showed none of the excentricities of the nickel-chromium steel when quenched below the hardening temperature. But when quenched a little above, as well as far beyond this temperature, they behaved very much alike.

While considering plain carbon steel, I thought it worth while to observe heat generation in some steel (or white cast iron) very high in combined carbon, and very pure otherwise, which I happened to have in my laboratory. Fig. 3 shows the composition of this metal, which is hard and very brittle. The carbon is all combined, and remains so after heating and quenching.

An induction experiment with a large lump of the metal showed: Temperature of complete loss of magnetic susceptibility 757°.

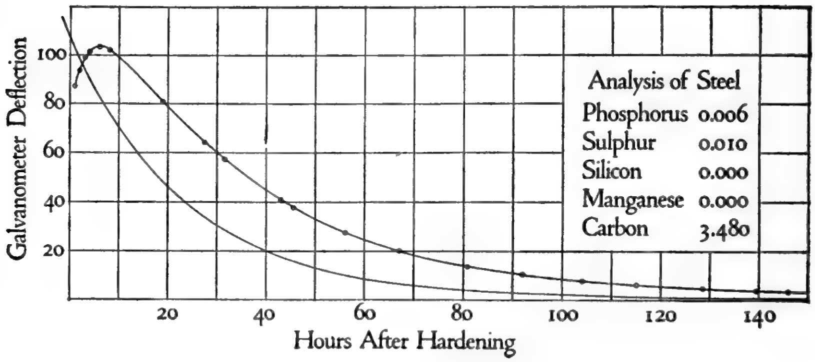


Fig. 3.

Temperature of complete recovery of magnetic susceptibility 704°.

Slowly heated many fragments, aggregating in weight that of the usual twelve bars of steel, to 906° and quenched.

Very moderate generation of heat followed the quenching, as shown in Fig. 3, and it was much less persistent than usual, as indicated by its small value at the end of 150 hours. Hardness was 76.

The behavior of this specimen of steel, or white cast iron, was not thought sufficiently encouraging to warrant further experiments with it.

For a general check on the performance of the apparatus, twelve half inch round bars of Swedish charcoal iron, of the aggregate weight of the steel usually employed, were slowly heated to 960° and quenched. Complete loss of magnetic susceptibility had occurred at 801°. The bars were warmed about three degrees just before being placed in the calorimeter.

There was no trace of heat generation following the quenching. Indeed, the curve of cooling followed the normal cooling curve with such fidelity that nowhere did they differ as much as the width of the curve line. This was very gratifying in view of the fact that observations for the normal cooling curve were made more than two years ago, and checked only once since that time.

Hardness was 18.5.

Again heated above decalescence and annealed by cooling in the furnace.

Hardness remained 18.5, showing that the previous heating and quenching had no effect whatever on the hardness of this, presumably, very pure iron.

Spontaneous generation and absorption of heat in recently quenched nickel-chromium steel, would be a better descriptive title for the present paper; but the subject matter is so intimately related to that of the former papers, that it is thought best to retain the former title for the sake of continuity.

In conclusion, I can only express the hope that contemplated experiments, on somewhat different lines, may throw more light on these interesting phenomena.

CLEVELAND, O.,
April, 1917.

THE EFFECTS OF RACE INTERMINGLING.

By C. B. DAVENPORT.

(*Read April 13, 1917.*)

The problem of the effects of race intermingling may well interest us of America, when a single state, like New York, of 9,000,000 inhabitants contains 840,000 Russians and Finns, 720,000 Italians, 1,000,000 Germans, 880,000 Irish, 470,000 Austro-Hungarians, 310,000 of Great Britain, 125,000 Canadians (largely French), and 90,000 Scandinavians. All figures include those born abroad or born of two foreign-born parents. Nearly two thirds of the population of New York State is foreign-born or of foreign or mixed parentage. Even in a state like Connecticut it is doubtful if 2 per cent. of the population are of pure Anglo-Saxon stock for six generations of ancestors in all lines. Clearly a mixture of European races is going on in America on a colossal scale.

Before proceeding further let us inquire into the meaning of "race." The modern geneticists' definition differs from that of the systematist or old fashioned breeder. A race is a more or less pure bred "group" of individuals that differs from other groups by at least one character, or, strictly, a genetically connected group whose germ plasm is characterized by a difference, in one or more genes, from other groups. Thus a blue-eyed Scotchman belongs to a different race from some of the dark Scotch. Strictly, as the term is employed by geneticists they may be said to belong to different elementary species.

Defining race in this sense of elementary species we have to consider our problem: What are the results of race intermingling, or miscegenation? To this question no general answer can be given. A specific answer can, however, be given to questions involving specific characters. For example, if the question be framed: what are the results of hybridization between a blue-eyed race (say

Swede) and a brown-eyed race (say South Italian)? The answer is that, since brown eye is dominant over blue eye, all the children will have brown eyes; and if two such children inter-marry brown and blue eyes will appear among their children in the ratio of 3 to 1.

Again, if one parent be white and the other a full-blooded negro then the skin color of the children will be about half as dark as that of the darker parent; and the progeny of two such mulattoes will be white, ¼, ½, ¾ and full black in the ratio of 1:4:6:4:1.

Again, if one parent belong to a tall race—like the Scotch or some Irish—and the other to a short race, like the South Italians, then all the progeny will tend to be intermediate in stature. If two such intermediates intermarry then very short, short, medium, tall and very tall offspring may result in proportions that can not be precisely given, but about which one can say that the mediums are the commonest and the more extreme classes are less frequented, the more they depart from mediocrity. In this case of stature we do not have to do with merely one factor as in eye color, or two as in negro skin color, but probably many. That is why all statures seem to form a continuous curve of frequency with only one modal point, that of the median class.

What is true of physical traits is no less true of mental. The offspring of an intellectually well developed man of good stock and a mentally somewhat inferior woman will tend to show a fair to good mentality; but the progeny of the intermarriage of two such will be normal and feeble-minded in the proportion of about 3 to 1. If one parent be of a strain that is highly excitable and liable to outbursts of temper while the other is calm then probably all the children will be excitable, or half of them, if the excitable parent is not of pure excitable stock. Thus, in the intellectual and emotional spheres the traits are no less "inherited" than in the physical sphere.

But I am aware that I have not yet considered the main problem of the consequence of race intermixture, considering races as differing by a number of characters. First, I have to say that this subject has not been sufficiently investigated; but we may, by inference from studies that have been made, draw certain conclusions. Any well-established abundant race is probably well adjusted to its conditions and its parts and functions are harmoniously adjusted.

Take the case of the Leghorn hen. Its function is to lay eggs all the year through and never to waste time in becoming broody. The brooding instinct is, indeed, absent; and for egg farms and those in which incubators are used such birds are the best type. The Brahma fowl, on the other hand, is only a fair layer; it becomes broody two or three times a year and makes an excellent mother. It is well adapted for farms which have no incubators or artificial brooders. Now I have crossed these two races; the progeny were intermediate in size. The hens laid fairly well for a time and then became broody and in time hatched some chicks. For a day or two they mothered the chicks, and then began to roost at night in the trees and in a few days began to lay again, while the chicks perished at night of cold and neglect. The hybrid was a failure both as egg layer and as a brooder of chicks. The instincts and functions of the hybrids were not harmoniously adjusted to each other.

Turning to man, we have races of large tall men, like the Scotch, which are long-lived and whose internal organs are well adapted to care for the large frames. In the South Italians, on the other hand, we have small short bodies, but these, too, have well adjusted viscera. But the hybrids of these or similar two races may be expected to yield, in the second generation, besides the parental types also children with large frame and inadequate viscera—children of whom it is said every inch over 5′ 10″ is an inch of danger; children of insufficient circulation. On the other hand, there may appear children of short stature with too large circulatory apparatus. Despite the great capacity that the body has for self adjustment it fails to overcome the bad hereditary combinations.

Again it seems probable, as dentists with whom I have spoken on the subject agree, that many cases of overcrowding or wide separation of teeth are due to a lack of harmony between size of jaw and size of teeth—probably due to a union of a large-jawed, large-toothed race and a small-jawed, small-toothed race. Nothing is more striking than the regular dental arcades commonly seen in the skulls of inbred native races and the irregular dentations of many children of the tremendously hybridized American.

Not only physical but also mental and temperamental incompatibilities may be a consequence of hybridization. For example, one often sees in mulattoes an ambition and push combined with intellectual inadequacy which makes the unhappy hybrid dissatisfied with his lot and a nuisance to others.

To sum up, then, miscegenation commonly spells disharmony—disharmony of physical, mental and temperamental qualities and this means also disharmony with environment. A hybridized people are a badly put together people and a dissatisfied, restless, ineffective people. One wonders how much of the exceptionally high death rate in middle life in this country is due to such bodily maladjustments; and how much of our crime and insanity is due to mental and temperamental friction.

This country is in for hybridization on the greatest scale that the world has ever seen.

May we predict its consequences? At least we may hazard a prediction and suggest a way of diminishing the evil. Professor Flinders-Petrie in his essay on "Revolutions of Civilization" suggests that the rise and fall of nations is to be accounted for in this fashion. He observes that the countries that developed the highest type of civilization occur on peninsulas—Egypt surrounded on two sides by water and on two sides by the desert and by tropical heat, Greece, and Rome on the Italian peninsula. It is conceded that such peninsulas are centers of inbreeding. Flinders-Petrie concluded that a period of prolonged inbreeding leads to social stratification. In such a period a social harmony is developed, the arts and sciences flourish but certain consequences of inbreeding follow, particularly, the spread of feeble-mindedness, epilepsy, melancholia and sterility. These weaken the nation, which then succumbs to the pressure of stronger, but less civilized, neighbors. Foreign hordes sweep in; miscegenation takes place, disharmonies appear, the arts and sciences languish, physical and mental vigor are increased in one part of the population and diminished in another part and finally after selection has done its beneficent work a hardier, more vigorous people results. In them social stratification in time follows and a high culture reappears; and so on in cycles. The suggestion is an interesting one and there is no evident biological objection to it. Indeed the result of hybridization after two or three generations is great variability. This means that some new combinations will be formed that are better than the old ones; also others that are worse. If selective annihilation is permitted to do its beneficent work, then the worse combinations will tend to die off early. If now new intermixing is stopped and eugenical mating ensues, consciously or unconsciously, especially in the presence of inbreeding, strains may arise that are superior to any that existed in the unhybridized races. This, then, is the hope for our country; if immigration is restricted, if selective elimination is permitted, if the principle of the inequality of generating strains be accepted and if eugenical ideals prevail in mating, then strains with new and better combinations of traits may arise and our nation take front rank in culture among the nations of ancient and modern times.

Cold Spring Harbor, N. Y.,
April 13, 1917.

MEDIÆVAL SERMON-BOOKS AND STORIES AND THEIR STUDY SINCE 1883.

By T. F. CRANE.

(*Read April 12, 1917.*)

Just thirty-four years ago (March 16, 1883) I had the honor of presenting to the American Philosophical Society a paper on "Mediæval Sermon-Books and Stories." The hospitable reception of this paper determined the subsequent scholarly career of the writer, and opened up a new field of investigation to the student of mediæval culture. It has seemed to me not inappropriate at this time to express to the Society my grateful appreciation of its encouragement, and to trace as briefly as possible the progress of studies in this field since the presentation of the paper in question. That the influence of this paper was so much greater in Europe than in this country may be explained by the difficulty of obtaining materials for such studies in American libraries. The incunabula used by me in the preparation of my paper were collected in an unusually short time, and I did not make use of European libraries until after 1883.[1]

[1] The paper was reviewed at length in the following scientific journals: *Literarisches Centralblatt*, 1883, No. 12 (E. Stengel); *Zeitschrift für deutsches Alterthum*, N. F. (1884), XVI., 286 (P. Strauch); *Giornale storico della litteratura italiana*, IV. (1884), p. 269; *Romania*, XII. (1883), p. 416; *Mélusine*, II. (1885), No. 23 (H. Gaidoz). I mentioned my predecessors in the field, Thomas Wright and Karl Goedeke, and should have given greater credit to Hermann Oesterley, who in his editions of Pauli's "Schimpf und Ernst," 1866, Kirchhof's "Wendunmuth," 1869, and "Gesta Romanorum," 1872, showed himself a master of this field of study. But, unfortunately, his erudition is confined to the comparative notes and not displayed in any general work. His innumerable references to mediæval sermon-books and stories were of great use to me in all my studies. The impetus to my work was given by Goedeke's article, "Asinus vulgi" in Benfey's "Orient und Occident," 1861, and Thomas Wright's mention of the subject in the introduction to "A Selection of Latin Stories," Percy Society, Vol. VIII., 1842. I do not know how I overlooked this writer's essay "On the History and Transmission

The history of the study of this field is an interesting one and goes back a little over a century. In 1812, Jacob and Wilhelm Grimm, then obscure officials of the royal library at Cassel, published the first volume of their immortal "Kinder- und Hausmärchen," which was completed three years later. Fairy tales had been collected much earlier in Italy and France, but the Grimms' collection was the first one made by scholars for a scientific purpose. The editors were especially interested in finding that their stories contained features in common with the Northern mythology. As their investigations broadened, however, they discovered that

of Popular Stories" in the second volume, pp. 51–81, of "Essays on Subjects connected with the Literature, Popular Superstitions, and History of England in the Middle Ages," London, 1846. The use of illustrative stories in sermons, and collections of these stories for the use of preachers, are mentioned at some length. The "Promptuarium Exemplorum," and John of Bromyard are named among others. It was not until recently that my attention was called to what is probably the earliest mention of Jacques de Vitry and the use of *exempla.* It occurs in F. W. V. Schmidt's edition of the "Disciplina clericalis," Berlin, 1827. In speaking of the story of Aristotle and Alexander's wife, Schmidt says, p. 106, "Zuerst aber brachte ihn Jacobus de Vitriaco zu Anfange des dreizehnten Jahrhunderts aus dem Morgenlande. Als Bischof von Ptolemais war er besonders geeignet zum Vermittler des Orients und Occidents, indem er seine letzten Tage in Rome verlebte." The story in question Schmidt quotes from Discipulus (Herolt), "Promptuarium Exemplorum," "ut dicit magister Jacobus de Vitriaco." This story is not in the "Sermones vulgares," but is in the "Sermones communes" recently edited by Frenken and Greven. Schmidt cites the "Speculum Exemplorum" several times and frequently mentions Herolt, saying of his "Promptuarium," "Eine unerschöpfliche Schatzkammer von geistlichen und moralischen Historien und Märchen. Wahrscheinlich bestimmt als Anweisung für Kindererzieher zu einer belehrenden Unterhaltung." After Wright and Goedeke there was no general reference to the subject until the histories of French and German preaching by Lecoy de la Marche, 1868, and Cruel (1879). The latter was especially useful on account of its detailed description of the materials employed by German preachers. No conspectus of the entire field appeared until 1890, when the writer's "Jacques de Vitry" was published at London for the Folk-Lore Society. The introduction to this work may be considered an enlargement of the paper presented to the American Philosophical Society. My own library had grown extensively in the seven years which had elapsed between 1883 and 1890, and I had been able to consult European libraries on several occasions. Subsequent works in this field have modified slightly some of my statements in the introduction to "Jacques de Vitry," but I am not aware that I overlooked any important materials accessible before 1890, with the exception of a few works which I shall examine in the course of this supplementary paper.

these features were contained in the popular tales of the other nations of Europe. The Grimms were essentially philologists and applied to their *märchen* the methods of comparative philology which had grown out of the revival of Sanscrit studies by Sir William Jones, Franz Bopp and Theodor Benfey.

The theory that the popular tales of Europe were related as were the languages in which they were narrated, both going back to a period in which the Aryan peoples were supposed to have had a common language and mythology, broke down, so far as the popular tales were concerned, when they were found to be essentially the same as those of non-Aryan peoples, and the favorite theory of diffusion from India in historic times was weakened by the discovery of popular tales in the tombs of ancient Egypt.

The question of the origin of popular tales has from the first been connected with that of mythology, and the further question of their diffusion has depended largely upon the view of their origin. If the popular tales were part of the mythology of the Aryan nations, then their diffusion could be explained by the dispersion of those nations into the different parts of Europe.

If, on the other hand, popular tales were merely a branch of entertaining literature, largely of Oriental origin, then in order to explain their extraordinary diffusion in Europe and elsewhere, it was necessary to discover the channels of transmission, literary or oral, which conveyed these tales over such an amazing expanse of territory.

The theory of the origin of popular tales in India and their transmission, largely through literary works, in historic times, has always been a favorite one in Germany, owing chiefly to the epoch-making translation of the "Pantschatantra" by Theodor Benfey, the introduction to which connected the tales of India with those of Europe.

In England, at a later date, the theory of the origin of popular tales has been connected with the anthropological studies of Tylor, Frazer and Lang, and again become a part of the mythology of primitive races. Before, however, this latter explanation came into vogue, the interest in the subject was almost wholly confined to the question of the means of transmission. These means, it was claimed, were largely literary and consisted of collections of Indian stories translated into the various languages of Europe where they enjoyed extraordinary popularity during the middle ages. It was admitted that these tales were also introduced into Europe by oral transmission on the part of travellers, and later by those engaged in the Crusades.

The earliest mention of a peculiar means of oral transmission, that of preachers in their sermons, was made by Thomas Wright (1810–1877), the distinguished English antiquarian, in the introduction to his "Selection of Latin Stories from Manuscripts of the Thirteenth and Fourteenth Centuries," Percy Society, Vol. VIII., London, 1842. The collection contains 149 tales from various MSS. in the British Museum. Of these the editor says in his Introduction, p. vi, "No manuscripts are of more frequent occurrence than collections of tales like those printed in the present volume; and we owe their preservation in this form to a custom which drew upon the monks the ridicule of the early reformers. The preachers of the thirteenth, fourteenth, and fifteenth centuries attempted to illustrate their texts, and to inculcate their docrines, by fables and stories, which they moralized generally by attaching to them mystical significations. These illustrations they collected from every source which presented itself, the more popular the better, because they more easily attracted the attention of people accustomed to hear them. Sometimes they moralized the jests and satirical anecdotes current among the people —sometimes they adopted the fabliaux and metrical pieces of the jongleurs, or minstrels—and not infrequently they abridged the plots of more extensive romances. Each preacher made collections for his own use—he set down in Latin the stories which he gathered from the mouths of his acquaintance, selected from the collections which had already been made by others, or turned into Latin, tales which he found in a different dress. . . . I am inclined to think that the period at which these collections began to be made was the earlier part of the thirteenth century, and that to that century we owe the compilation in Latin of most of these tales, though the greater number of manuscripts may be ascribed to the fourteenth."

Wright mentions John of Bromyard and the "Promptuarium Exemplorum" and dwells on the importance of these tales for the light they throw on the private life and domestic manners of "our forefathers." Thirty-six of Wright's stories are from the Harley MS. 463 (fourteenth century), the source of which is not indicated, but which really is an extensive collection of the *exempla* of Jacques de Vitry. Wright was unaware of the source of these stories and mentions the name of the famous preacher but once, in a note to story lxxxiii, "Promptuarium Exemplorum (quoted from Jacobus de Vitriaco)."

A few years later Wright returned to the subject in an essay "On the History and Transmission of Popular Stories" in "Essays on Subjects Connected with the Literature, Popular Superstitions, and History of England in the Middle Ages," London, 1846, Vol. II., pp. 51–81, Essay xii. The writer dwells on the introduction into Europe of eastern stories by the jongleurs (citing as illustrations the stories of the "Hunchback," "Weeping Dog," etc.). He mentions the great Oriental story-books and says, p. 61, "Their popularity was increased by another circumstance which has tended, more than anything else, to preserve a class of the mediæval stories, which were less popular as fabliaux, down to the present time. In the twelfth century there arose in the church a school of theologians, who discovered in everything a meaning symbolical of the moral duties of man, or of the deeper mysteries of religion. . . . In the thirteenth century these stories with moralizations were already used extensively by the monks in their sermons, and each preacher made collections in writing for his own private use. . . . The mass of these stories are of the kind we have described above, and are evidently of Eastern origin; but there are also some which are mere mediæval applications of classic stories and abridged romances, while others are anecdotes taken from history, and stories founded on the superstitions and manners of the people of western Europe. Not only were these private collections of tales with moralizations, as we have just observed, very common in the fourteenth century, but several industrious writers undertook to compile and publish larger and more carefully arranged works for the use of preachers, who might not be so capable of making selections for themselves. Among these the most remarkable are the 'Promptuarium Exemplorum,' the 'Summa Predecantium' of John of Bromyard, the 'Repertorium Morale' of Peter Berchorius, and some others."

The subject received no further attention until 1861, when an important article by Karl Goedeke (1814–1887), the famous historian of German literature, was published in Benfey's periodical, *Orient und Occident,* Vol. I. (Göttingen, 1861), pp. 531–560. The article in question, "Asinus vulgi," is a study of the origin and diffusion of the well-known fable of the father and son who ride their ass alternately without satisfying the critical public (La Fontaine, III. 1, "Le meunier, son fils et l'âne"). This fable is found in the "Scala Celi" of Johannes Junior (Gobius), Ulm, 1480, fol. 135, where it is introduced by the words: "Refert Jacobus de Vitriaco." It is a curious fact that this particular fable, which led Goedeke to speak of Jacques de Vitry, is not found in the two collections of sermons belonging to that prelate, but is one of the many stories in circulation attributed to him on what authority we do not know. In the article in question Goedeke emphasizes the importance of Bromyard's work: "Kaum irgend ein andres Werk des Mittelalters ist so reich an Fabeln und Geschichten als das seinige, und kaum ein anderes von dieser Bedeutung so wenig gekannt." A little later he says: "Die Exempla, auf die sich Bromyard beruft, sind kein aufs geratewohl gebrauchter Ausdruck, sondern ein wirklich vorhandenes für die Verbreitung der orientalischen Fabeln und Geschichten ins Abendland sehr wichtiges Werk, das Speculum Exemplorum des Jacobus de Vitriaco." He calls Jacques de Vitry: "einen der Hauptcanäle, durch welche orientalische Sagen nach Europa kamen." Goedeke then gives some twenty-five *exempla* from the Harley MS. 463, used by Wright in his "Latin Stories," which by comparison with the stories in the "Scala Celi" is shown to contain many *exempla* by Jacques de Vitry. He thus shows the importance of the mysterious "Speculum Exemplorum" of Jacques de Vitry, a veritable "Verlorene Handschrift," for which he had sought in vain. It is strange that it did not occur to Goedeke to examine the sermons of Jacques de Vitry, the existence of which at Paris and elsewhere he knew.

In his later book, "Every-Man, Homulus und Hekastus," Hannover, 1865, he returns to the subject and says: "Einen der Hauptkanäle, durch welche die Sagen des Orients nach Europa flossen, hat die Forschung bisher fast unbeachtet gelassen. Es sind die kirchlichen Schriftsteller des Mittelalters, zum Theil auch die älteren Patres, die für die Kirchen- und Dogmengeschichte nicht vorzugsweise von Wichtigkeit erschienen." He does not have occasion to mention Jacques de Vitry, but cites a large number of mediæval writers containing *exempla,* and displays a wide knowledge of individual authors, but nowhere gives any general view of the subject.

In 1868 appeared A. Lecoy de la Marche's "La chaire française au moyen âge" (second edition corrected and enlarged, Paris, 1886), in which was given for the first time an adequate account of the use of *exempla* in French sermons of the thirteenth century, and of the importance of Jacques de Vitry's "Sermones vulgares" for this field of study. A similar work dealing with the twelfth century, "La chaire française au XIIe siècle d'après les manuscrits," was published by the Abbé L. Bourgoin in 1879. This period is not so interesting for the study of *exempla* as the succeeding century, when the systematic use of *exempla* in sermons began to prevail. In the same year appeared R. Cruel's "Geschichte der deutschen Predigt im Mittelalter," Detmold, 1879. This admirable work, to which I was greatly indebted in my paper on "Mediæval Sermon-Books and Stories," is especially full in its treatment of homiletic treatises.[2]

Although the use of illustrative stories in sermons was treated at some length in the three works just mentioned, the first collection of such stories to be published was not taken from sermons, but from a homiletic treatise for the use of preachers, the "Tractatus de diversis materiis predicabilibus ordinatis et distinctis in septem partes, secundum septem dona Spiritus sancti," by Étienne de Bourbon, a Dominican who died at Lyons about 1261.[3] The extracts

[2] A few years earlier than Cruel's work appeared Wilhelm Wackernagel's "Altdeutsche Predigten und Gebete aus Handschriften," Basel, 1876. He mentions Honorius of Autun's "Speculum Ecclesiæ," but not the *exempla* contained in it. He alludes also to symbolism and "Predigtmärlein," although very briefly, and names Herolt and Bromyard alone in their class of writings. Another German work in this field appeared in the same year as my paper: "Kulturgeschichtliches aus deutschen Predigten des Mittelalters," by Dr. H. Rinn, Hamburg, 1883. He mentions "Predigtmärlein" very briefly.

[3] This statement that Lecoy de la Marche's edition of Étienne de Bourbon

from this work published by A. Lecoy de la Marche in 1877 for the Sociètè de l'Histoire de France under the title: "Anecdotes historiques, légendes et apologues, tirés du recueil inédit d'Étienne de Bourbon, dominicain du XIIIe siècle," gave a great impulse to the study of *exempla*. The connection of the author with Jacques de Vitry, many of whose *exempla* he has preserved in his treatise, and the interesting character of the stories themselves, combined to make the book attractive and to increase the interest in the subject.[4]

The only other collection of *exempla* published before 1890 was the "Recull de eximplis. Biblioteca catalana," Barcelona, 1881–88. I was able to use the first volume only for my paper on "Mediæval Sermon-Books and Stories," but in my introduction to Jacques de Vitry I had the second volume also and was fortunate enough to discover the original of the collection, which was the "Alphabetum narrationum," formerly ascribed to Étienne de Besançon, but probably by Arnold of Liège.[5]

Such was the condition of studies in this field when my edition of the *exempla* of Jacques de Vitry was published for the Folk-Lore Society at London in 1890. It is the purpose of this paper to

is the first collection of *exempla* to be published in modern times should be modified somewhat in view of Thomas Wright's "Latin Stories," 1842, which were taken from "Jacques de Vitry" (although Wright did not know this), and from the homiletic treatises and collections of Bromyard, Herolt, etc. The collection of "Predigtmärlein," by Pfeiffer, published in 1858 in the *Germania*, III., 407–436, and the extracts, one hundred in number, from the German "Seelentrost," published by K. Frommann in "Die deutschen Mundarten," Nurnberg, 1854, and, finally, the complete Old-Swedish translation of this work, edited by G. E. Klemming, Stockholm, 1871–73, are all anterior to Lecoy de la Marche's "Étienne de Bourbon." These works, however, with the exception of Wright's were little known, and were overlooked by me in my paper of 1883, and even in my later introduction to "Jacques de Vitry."

[4] In 1889 Lecoy de la Marche published a popular work, "L'Esprit de nos aïeux. Anecdotes et bons mots tirés des manuscrits du XIII[e] siècle," containing one hundred and fifty stories translated from the *exempla* of "Jacques de Vitry" (41), "Étienne de Bourbon" (73), and others.

[5] See Herbert, "Catalogue of Romances," p. 423, and an article by the same writer, "The Authorship of the Alphabetum Narrationum" in *The Library*, N. S., VI. (1905), pp. 94–101. An early English translation of this famous collection was published by Mrs. M. M. Banks for the Early English Text Society, Original Series, 126–7, 1904–5, "An Alphabet of Tales." The third volume of notes, etc., has not yet appeared.

consider briefly the works produced since that date and to estimate the results of study in this field.[6] I shall divide my materials into treatises on *exempla* in particular localities, collections of *exempla*, and works containing selections of *exempla* (anthologies). All these I shall consider so far as possible in chronological order.[7]

The unity of the Church and its official language produced throughout the Middle Ages a cosmopolitanism which has never prevailed again since the Reformation. The preachers in all the countries of Europe used the same homiletic treatises and drew their illustrative stories from the same sources. It is true that the systematic use of *exempla* arose in France and that the influence of Jacques de Vitry and Étienne de Bourbon was very great; but

[6] I have already indicated some of the material which I overlooked in my paper of 1883 and my introduction to "Jacques de Vitry's" *exempla*, 1890. It may be well to recapitulate here these omissions and to correct some errors. Of collections of *exempla* accessible before 1883, I overlooked the German "Selentrost" (in "Die deutschen Mundarten," 1854, and Geffcken's "Bildercatechismus des funfzehnten Jahrhunderts," 1855), as well as the Old-Swedish version edited by G. E. Klemming and printed at Stockholm, 1871–73. I was wrong in supposing that the work of Arnoldus cited by Herolt referred to the "Gnotosolitos sive Speculum conscientiæ" by Arnoldus Geilhoven of Rotterdam. Mr. Herbert in his "Catalogue of Romances," p. 437, points out my mistake and shows that the work in question was a treatise on canon law, and that the Arnoldus cited by Herolt was probably the author of the "Alphabetum narrationum," long ascribed to Étienne de Besançon.

Frenken in his "Jacques de Vitry," to be mentioned further on, mentions my omission of two famous German preachers, Geiler von Kaisersberg and Abraham a Sancta Clara, who by their extensive use of *exempla* contributed greatly to the diffusion of these stories. Some of the statements in my introduction require modification in view of materials discovered and printed subsequently, and I shall consider these in the course of this paper.

[7] As I must necessarily be brief in this paper, I would refer for more lengthy reviews of certain of the works about to be mentioned to articles by me in the following journals: *Modern Philology*, Vol. IX., No. 2, 1911, pp. 225–237, "Mediæval Story-Books," review of Herbert's "Catalogue of Romances," ibid., Vol. X., No. 3, 1913, pp. 301–316, "New Analogues of Old Tales," review of J. Klapper's "Exempla aus Handschriften des Mittelalters," *Romanic Review*, Vol. VI., No. 2, 1915, pp. 219–236, "Recent Collections of Exempla," review of A. Hilka's "Neue Beiträge zur Erzählungsliteratur des Mittelalters," J. Th. Welter's "Speculum Laicorum," and J. Greven's and G. Frenken's "Die Exempla des Jakob von Vitry"; and Vol. XXXII., No. 1, 1917, pp. 26–40, review of J. Klapper's "Erzählungen des Mittelalters," ibid., *Modern Language Notes*, Vol. XXVII., No. 7, 1912, pp. 213–216, "The Exemplum in England," review of J. A. Mosher's book.

Caesarius of Heisterbach belongs to Germany and Odo of Cheriton was an Englishman. The use of *exempla* by French and German preachers has been fully treated by Lecoy de la Marche and R. Cruel in the works mentioned above. The history of *exempla* in the Netherlands during the Middle Ages is the subject of a book by Dr. C. G. N. De Vooys: "Middelnederlandsche Legenden en Exempelen. Bijdrage tot de Kennis van de Prozalitteratoor en het Volksgeloof der Middeleeuwen," S-Gravenhage, 1900, 8vo, pp. xi, 362. The plan of Dr. De Vooys's book is as follows: The first chapter is devoted to the principal sources of *exempla:* the "Vitæ Patrum," Gregory's "Dialogues," the "Exordiuum magnum ordinis Cisterciensis," Cæsarius's "Dialogus miraculorum," Thomas Cantimpratensis's "Bonum universale de apibus," Vincent of Beauvais's "Speculum historiale," and Voragine's "Legenda aurea." The second chapter treats of the rise, development and spread of *exempla,* and discusses briefly the use of *exempla* in sermons and their collection in homiletic treatises. The following nine chapters treat of *exempla* classified according to personages, etc.: the Virgin, Jesus, the Devil, the Jews, the Sacrament, Prayer and Confession, and the "Quotuor novissima" (Death, the Judgment, Hell, and Heaven). The last three chapters are devoted to the allegorical element in *exempla,* the influence of mysticism in *exempla,* and moralizing *exempla.*

Dr. De Vooys's book is a convenient résumé of the whole subject, indeed, almost the only one thus far, and he cites a large number of Dutch works, printed and manuscript. The most important of these are certain fifteenth-century treatises containing *exempla* sporadically. They are interesting only as showing the persistence of the *genre* and its wide diffusion.

To trace the history of "The Exemplum in the Early Religious and Didactic Literature of England" (New York: The Columbia University Press, 1911, 8vo, pp. xi, 150) is the task which Mr. J. H. Mosher has undertaken. The *exemplum* began its course in England in the early translations of Gregory's "Dialogues" and the influence of his "Homilies." Later, some of the most important collections of *exempla* were made by Englishmen, such as Odo of Cheriton, Holkot, Bromyard, the uncertain author of the "Speculum Laicorum," etc. The other classes of *exempla* literature are equally well represented, and Nicole de Bozon's "Contes moralizés," William of Wadington's "Manuel des Pechiez" and its translation by Robert of Brunne, "Handlyng Synne," are among the most important works of their kind. Two of the works treated rather inadequately by Mr. Mosher have been published since my "Jacques de Vitry," and I may consider them here very briefly out of their chronological order. They are: "Jacob's Well" (ed. Brandeis, Early English Text Society, No. 115, 1900) and John Mirk's "Festial" (ed. Erbe, E. E. T. Soc. Extra Series, No. 96, 1905). The latter, which is earlier in date, was written by a member of the Augustinian canonry of Lilleshul in Shropshire before 1415.[8] The work consists of seventy-four sermons for the festivals of the ecclesiastical year, with copious use of illustrative stories, many of which (26) are, as would be expected, from the "Legenda Aurea," three only are from the "Vitæ Patrum," usually more freely drawn upon. "The sermons," as Professor Wells says, op. cit., p. 302, "are all intended to provide material for delivery by ill-equipped priests, of whom, says the Præfatio, 'mony excuson ham by defaute of bokus and sympulnys of lettrure.' . . . But especially notable is the extensive use of narrative, not merely in the main line of the discourse, but in the hundred or more illustrative *narrationes*. Clearly, unlike Wycliffe and his followers, Mirk approved heartily of employment of tales in preaching, indeed, he directly defends the practice. But he shows control and judgment in use of them. The *narrationes,* sometimes, as many as five in a sermon, are always closely connected with the theme; they are introduced with the declared purpose of enforcing the issue through conviction or stimulation; and, the story ended, the hearers are usually brought back to the point illustrated. The tales vary much in kind; some are over-marvelous, some have local flavor. It is not at all wonderful that these simple pieces of prose full of narrative, caught the popular taste, and that, when the other native collections and cycles were on the wane, these were copied into many MSS., and (unlike any of the other groups), as soon as the press was available, were printed in edition after edition."

[8] See G. H. Gerould's "Saints' Legends," Boston and New York, 1916, pp. 184, 363, and J. E. Wells's "A Manual of the Writings in Middle English, 1050–1400," New Haven, 1916, pp. 301, 807.

The other work mentioned above, "Jacob's Well," written by an unknown author in the first quarter of the fifteenth century, according to the editor, belongs to the class of allegorical treatises, although it is really a collection of sermons, which seem to have been delivered day by day within the short space of "þis hool tweyne monythys and more," as the author says in the beginning of his last chapter. Mr. Mosher thus describes the work: "A Biblical figure (John iv, 6, Erat autem ibi fons Jacob) is expanded into a truly marvellous allegory of the elaborate penitential scheme. A pit of oozy water and mire, representing man's body beset with sins, is to be made into a wholesome well wherein may flow the clear water of Divine Grace. The dirty water, or Great Curse, must first be removed; then the mire, *i. e.*, the seven deadly sins. Next the five water gates, the five senses, must be stopped up. After this the digging must continue until the seven pure springs, the gifts of the Holy Ghost, are reached. Then follows the walling process in which stones, sand, mortar, even the windlass, rope and bucket, are, needless to say, the customary virtues.

"At regular and frequent intervals 'Jacob's Well' has a pair of *exempla* taken mainly from the 'Vitæ Patrum,' 'Jacques de Vitry,' 'Cæsarius,' 'Legenda Aurea,' and legends of the Virgin. The tales are therefore hackneyed, but they are frequently forged into a new glow by the striking diction of the zealous redactor. . . . Of course the stories are uneven; some vivid, others dull; some brief, others elaborate. Though not so numerous, they are generally slightly longer than those in Mirk's 'Festial.' . . . With 'Jacob's Well' the *exemplum* appears to have reached its maximum employment in the religious treatise, just as it did in sermon literature with the contemporary 'Festial' of Mirk."[9]

[9] Of the eighty-two stories in the fifty chapters published twenty-two are from "Caesarius," four from the "Legenda aurea," five from "Étienne de Bourbon," ten from the "Vitæ Patrum," and twelve from "Jacques de Vitry." The statement on p. 138, "Local color then became occasionally noticeable, though distinctive English characteristics were here, as elsewhere among the floating body of universal tales, sparse," would have been modified if the author had been able to consult the collections analyzed in Herbert's "Catalogue," which will be mentioned in a moment. He would have seen that there are many specifically English stories in the "Speculum Laicorum," etc. A certain number are in the "Liber Exemplorum," edited by Little (see later in this paper), with which Mr. Mosher was acquainted.

One of the most important, certainly the most useful, of the works published in the field of mediæval tales since 1883 is Mr. J. A. Herbert's "Catalogue of Romances in the Department of Manuscripts in the British Museum," Vol. III., London, 1910, crown 8vo, pp. xii, 720.[10] How extensive the field is with which this volume deals may be judged by the fact that it contains an analysis of one hundred and nine manuscripts and refers to over eight thousand stories, many of which are, of course, frequently repeated. Too much praise cannot be given to the analyses in this and the preceding volumes of the "Catalogue." "In general," as I have said in my review of Mr. Herbert's work in *Modern Philology,* "the stories are without literary form, often they seem mere memoranda for the preacher to expand as he wishes. The scholar who is comparing collections or tracing a particular *exemplum* wishes to know the substance of the story in a concise form, if possible, with references to other manuscripts or printed works. The analyses by the late Mr. Ward and Mr. Herbert are beyond all praise. Especially in the volume before us Mr. Herbert has shown himself profoundly acquainted with the vast and intricate subject of mediæval tales. His references are exact and copious and will save the student an enormous amount of labor." A considerable number of the manuscripts described in this volume have already been printed, wholly or in part (one of the most important, to be mentioned presently, since the "Catalogue" was issued), and are thus fairly well known and accessible to students. A great number of collections, however, were quite unknown, and their contents are now for the first time revealed to scholars, and have widely extended the already

[10] The first and second volumes, edited by the late H. L. D. Ward, were published in 1883 and 1893, and deal, Vol. I., with Classical Romances (Cycle of Troy, Cycle of Alexander, etc.); British and English Traditions (Cycle of Arthur, etc.); French Traditions (Cycle of Charlemagne, etc.); Miscellaneous Romances, and Allegorical and Didactic Romances; Vol. II., with Northern Legends and Tales; Eastern Legends and Tales; Æsopic Fables; Reynard the Fox; Visions of Heaven and Hell; Les Trois Pèlerinages; and Miracles of the Virgin. The last division, filling pp. 586–691, is of particular value for the study of *exempla* and is intimately associated with the subjects treated by Mr. Herbert in Vol. III. The same may be said to a lesser degree in regard to the class of Visions of Heaven and Hell, some of which, the Theophilus legend, for instance, recur so constantly in collections of *exempla.*

enormous field. I shall have occasion to refer frequently to this invaluable work in the remainder of this paper.

The use of *exempla* or illustrative stories is as old as religious instruction itself; but the systematic use of such stories in sermons (to which their great vogue is due) is of comparatively recent date. The influence of Gregory the Great was profound in this direction. In his homilies (before 604), and especially in his dialogues, he employed a large number of legends, and the popularity of the latter work, translated into the various languages of Europe, exercised a powerful influence on later collectors of legends. It was not, however, until the end of the twelfth or the beginning of the thirteenth century that the use of *exempla* in sermons became common, owing to the rise of the preaching orders. In my paper of 1883 and in my introduction to "Jacques de Vitry" I ascribed to that distinguished prelate the first systematic use of *exempla* in sermons. I should have modified somewhat this statement if I had seen some works which appeared after my articles, still, even in the light of recent researches I was not far from the truth.[11] In giving the priority to

[11] My statement, p. xix of my introduction to "Jacques de Vitry," that it was not until the end of the twelfth or the beginning of the thirteenth century that the practice of using *exempla* became common, owing to the rise of the preaching orders, was questioned by the late Anton Schönbach in his "Studien zur Erzählungsliteratur des Mittelalters," Erster Theil, p. 2. He contents himself by stating that my conclusion so far as French preaching in the twelfth century is concerned is in contradiction with the facts, and refers to Bourgain's "La chaire française au XII^{e} siècle," pp. 258 et seq. Bourgain nowhere mentions the systematic use of *exempla*; indeed, he never, I believe, uses the word in its technical meaning. He does cite Guibert de Nogent, without place, as to the use of illustrative material. I said in my introduction, p. xix, note, that I could find no reference to *exempla* in Guibert de Nogent's "Liber quo ordine sermo fieri debeat"; here is the passage quoted by Bourgain; and another I may add. The first is Migne, CLVI., col. 25: "Placere etiam nonnullis comperimus simplices historias, et veterum gesta sermoni inducere, et his omnibus quasi ex diversis picturam coloribus adornare." The second passage is in col. 29: "et per considerationem naturæ illius rei de qua agitur, aliquid allegoriæ vel moralitati conveniens invenitur, sicut de lapidibus gemmariis, de avibus, de bestiis, de quibus quidquid figurate dicitur, non nisi propter significantiam profertur."

Schönbach also cites Honorius of Autun, Werner von Ellerbach, and the collections of German sermons edited by himself and Hoffmann. In Schönbach's collection, Graz, 1886–1891, there are sixteen stories in the first volume, most of them from the "Vitæ Patrum" and Gregory's "Homilies"; in the

Jacques de Vitry I did not take into consideration, however, two other contemporary writers with whose works I subsequently became acquainted. I refer to the sermons of Odo of Cheriton and the homilies of Cæsarius of Heisterbach.

The fables of the former had long been known, but the author to whom they were attributed was, until recently, a mysterious personage, confused with another Kentish ecclesiastical writer, Odo of Canterbury. It is now definitely settled that the Odo of the fables and sermons with which I am now concerned was from Cheriton and died in 1247, seven years after Jacques de Vitry. Some of Odo's fables were published as early as 1834 by Jacob Grimm in his edition of "Reinhart Fuchs," and thirteen were printed by Mone in the following year, while Wright used seventeen in his "Latin Stories." Other German scholars published a considerable number, but the fables were first adequately edited by L. Hervieux in the first edition (1884) of his monumental work, "Les fabulistes latins." In the second edition (1896), both fables and *parabolæ* from the sermons (of which there is only one edition printed at Paris in 1520) were published in a separate, fourth, volume, with an exhaustive examination of the birthplace and life of the author. I am interested at present only in the *exempla* contained in the sermons.[12]

second volume there is one story from Gregory's "Dialogues," and in the third volume there are no stories. In Hoffmann's "Fundgruben," Vol. I., there are only half a dozen stories. In Werner's "Libri Deflorationum," Migne, Vol. CLVII., I do not find *exempla* of any kind, unless the occasional references to animals, birds, fishes and plants moralized in the usual way may be considered *exempla*. On the other hand there are many *exempla* in the "Speculum Ecclesiæ" of Honorius of Autun (who died, it is supposed, shortly after 1152), and I should not have overlooked Cruel's reference on p. 137 of his "Geschichte der deutschen Predigt": "Ausserdem treten die nach Gregor's Beispiel einzeln auch in deutschen Predigten vorkommenden Exempel bei Honorius massenhaft als stehender Schlusstheil auf." Still it is evident that Honorius was an exception; and the statement that the use of *exempla* systematically in sermons was not common until the end of the twelfth or the beginning of the thirteenth century is, I still think, correct. There are, of course, many *exempla* to be found sporadically in homiletic treatises and similar works of the second half of the twelfth century, such as Petrus Cantor's "Verbum abbreviatum" (Migne, CCV.), etc.

[12] Hervieux's edition, printed from MS. 16506 of the National Library of Paris, contains 195 *exempla*; the manuscript (Arundel 231) analyzed by Herbert in his "Catalogue," pp. 58–78, contains 201, of which 43 are not in

Their sources are infrequently mentioned: "Vitæ Patrum," four times, Gregory's "Dialogue" three, the "Book of Kings" and "Saint Bernard" once each. As a matter of fact, however, a very large number of the *exempla* are taken from the "Vitæ Patrum." The name of Jacques de Vitry is not mentioned; but many of Odo's *parabolæ* occur in the sermons of the former, and Frenken is inclined to think that Odo borrowed them directly or indirectly from him. The value of Odo's *parabolæ* consists largely in the fact that they are a popular channel through which many stories have entered into circulation, for although there is only one printed edition of the sermons and that of the sixteenth century, there are many manuscripts left to attest their popularity.

In my introduction to "Jacques de Vitry" I did not include among the preachers using *exempla* Cæsarius of Heisterbach, the most delightful perhaps of all the mediæval story-tellers. I was not at that time acquainted with his homilies, of which there is only one edition, a very rare book, by J. A. Coppenstein, printed at Cologne in 1615.[13] As the "Homilies" were composed between 1222 and

Hervieux. In the sermon for Sexagesima Odo defines the word he uses as follows: "Parabola dicitur a para, quod est juxta, et bole, quod est sententia, quasi juxta sententiam. Parabola enim est similitudo quae ponitur ad sententiam rei comprobandam." Hervieux, p. 111, endeavors to establish a difference between apologues, paraboles and exemples; he says: "En effet, il ne faut pas dans les sermons d'Eudes confondre les apologues ou paraboles avec les exemples; ou, si l'on veut qualifier d'exemples les paraboles, il faut admettre deux sortes d'exemples: ceux qui, contenant le récit d'un fait imaginaire, offrent les caractères de la fable et sont appelés paraboles, et ceux qui se bornent, sans application à aucun cas spécial, à faire mention des habitudes d'une catégorie d'êtres quelconques." He finally ends, p. 112, by confessing that it is safer to consider the exemples as true paraboles and print them all. Frenken in his edition of the *exempla* in the "Sermones communes" of "Jacques de Vitry," to be mentioned later at length, has a chapter on "Die Geschichte des Begriffes 'exemplum,'" in which he connects the word with its use in classical rhetoric, and remarks, p. 14, "Dass man zunächst nach anderen Ausdrücken wie *parabola, narratio, historia,* suchte, lag wohl nur daran, dass man nicht recht wusste, dass das, was man so in der Predigt erzählte, auch das war, was die Grammatiker exemplum nannten. Die kurzen Erklärungen der Tropen in den Grammatiken wurden mit denselben Beispielen Jahrhunderte lang auswendig gelernt, aber man dachte sich nicht viel dabei."

[13] I still know this work only through A. Schönbach's masterly "Studien zur Erzählungsliteratur des Mittelalters," V., VII., VIII., Vienna, 1902, 1908,

1225, as Schönbach thinks, and Jacques de Vitry's sermons after his residence in Palestine until his death, that is 1227 to 1240, Cæsarius is contemporaneous with Odo of Cheriton and a little earlier than Jacques de Vitry.

I used the "Dialogus Miraculorum" of Cæsarius frequently in my notes, but I did not give any space to this interesting personage in my Introduction, although I might have considered the "Dialogus" as a homiletic treatise, so constantly are they quoted in subsequent sermons and collections of *exempla* made for the use of preachers. The author was born probably a few years before 1180 and educated at St. Andrew's School at Cologne. He entered the Cistercian abbey of Heisterbach, where he became master of the novices and prior, dying about 1240.[14] Besides the "Homilies" mentioned above, Cæsarius was the author of many theological works, some of which have perished and all have been forgotten except the "Dialogus Miraculorum." This popular and interesting work was composed about 1222 (Schönbach dates it 1223–1224, Herbert says it was completed in or very soon after 1222). It is fortunately accessible in a good modern edition by J. Strange, two volumes, Cologne, 1851, and consists of twelve books or *distinc-*

1909, originally published in the *Sitzungsberichte der kais. Akad. der Wissenschaften in Wien, Philosophisch-historisch Classe,* Bd. CXLIV., CLIX., CLXIII. Of the 746 stories in the "Dialogus Miraculorum," 84 are found in the "Homilies," and there are 58 in the "Homilies" not found in the "Dialogus," see Schönbach, I., pp. 69–92; III., pp. 4 et seq. Consequently there are now 142 stories contained in the "Homilies" accessible to students. Cæsarius says in regard to his use of *exempla* (Schönbach, I., p. 20): "Quædam (exempla) inserui aliquantulum subtilius ad exercitium legentium, quædam de Vitis Patrum propter utilitatem simplicium. Nonnulla etiam, quæ nostris temporibus sunt gesta et a viris religiosis mihi recitata. Hoc pene in omnibus homiliis observare studui, et, quod probare poteram ex divinæ scripturæ sententiis, hoc etiam firmarem exemplis." This use of *exempla* displeased some even at that early date and he omitted them in his later homilies, saying (Schönbach, op. cit., p. 33): "Secrete quidam ea scripsi et secrete legi volui, ipsam expositionem ita ordinans, ut conversis, quibus singulis diebus dominicis aliquid de divinis scripturis, et maxime de evangeliis, exponi solet, congrueret. Illa enim necessitas occasio præcipua fuit scribendi. Propter quod miracula et visiones ipsis expositionibus inserere studui. Et quia hoc quibusdam minus placuit, in homiliis de solemnitatibus sanctorum hoc ipsum cavi."

[14] See Schönbach, op. cit.; A. Kaufmann, "Caesarius von Heisterbach," Cologne, 1862; and Herbert, "Catalogue," p. 348.

tiones, the subjects of which are: Conversion, Contrition, Confession, Temptation, Demons, Simple-mindedness, the Virgin Mary, the Body of Christ, Divers Visions, Miracles, the Dying, and Rewards of the Dead. The large number of stories, 746, purport to have been told, and probably were, by the master ("monachus") to the novice. The stories are connected by a thread of dialogue between the master and pupil. The name of the author is not mentioned, but the reader is told it can be learned from the first letters of the *distinctiones* ("Cesarii Munus"). "Many things," he says, "have I introduced which happened outside of the order, because they were edifying and told me, like the rest, by religious men (*i. e.,* members of an order). God is my witness that I have not invented (*finxisse*) a single chapter in this Dialogue. If perchance things have happened differently from what I have written, this should be imputed to those who related them to me."

As Herbert remarks, p. 349, "Cæsarius professes to have learnt most of the miracles at first or second hand, and a large proportion of them are connected with Heisterbach, Himmerode, and Cologne, and places in the neighborhood. But in many cases he has merely drawn on the common stock; *e. g.,* in Dist. VIII., Cap. 21 he tells the story of the merciful knight to whom the crucifix bowed, as a miracle which occurred "temporibus nostris in provincia nostra, sicut audivi"; but it has been pointed out in this "Catalogue" (Vol. II., p. 665) that the story occurs, as early as the eleventh century, in the Life of the Italian St. John Gualbertus."[15]

[15] The sources of the stories in the "Dialogus" have never been systematically investigated, but a brief enumeration of the principal ones may be found in Meister's work, to be mentioned presently. "We know," he says, p. xxxii, "that he was acquainted with the 'Life of Bernard of Clairvaux,' Bernard's 'Life of St. Malachiæ,' the 'Book of Visions of St. Aczelina,' Herbert's 'Exordium miraculorum' and 'Liber miraculorum,' and that he used the 'Life of St. David'—all these writings of the Cistercian order. He also drew on the 'Historia Damiatina' and 'Historia regum terræ sanctæ' of Oliver Scholasticus, the 'Dialogues' of Gregory the Great were his model and the 'Vitæ Patrum' were known to him. Most of his stories, however, he owed to oral communication, but all are not new on that account; an old germ lies oftener at bottom. Many of his stories have wandered far before they reached the half hidden cloister of Heisterbach. On this long journey they have worn out their garments and must be clothed anew, so that in their changed exterior it is hard to recognize their weather-beaten figure. Some-

The popularity of the "Dialogus miraculorum," as I have remarked above, was enormous. Its stories were used with or without credit in all subsequent treatises and collections. In the "Alphabet of Tales," which I shall mention again presently, 151 of the 801 stories are from Cæsarius, and some of his tales have found curious enough resting places, one (VIII., 59, see also X., 2) has been shown by P. Rajna in *Romania,* VI., 359, to be the probable source of Boccaccio's fine story of Messer Torello and Saladin ("Decameron," X., 9).

In the list of his writings made by Cæsarius himself (Schönbach, I., pp. 4–69; Meister, pp. xx–xxviii), he mentions under No. 27, "Item scripsi volumen diversarum visionum seu miraculorum libros 8." This work was supposed to have been lost until Professor Marx published in 1856 a fragment of the work containing twenty-three miracles, afterwards reprinted by A. Kaufmann in an appendix to his book on Cæsarius. Later Dr. Aloys Meister discovered two other fragments and published all three under the title "Die Fragmente der Libri VIII Miraculorum des Cæsarius von Heisterbach" (in *Römische Quartalschrift für christliche Alterthums-Kunde und für Kirchen-Geschichte. Dreizehntes Supplementheft.* Rom, 1901). The fragments contain 191 miracles or stories relating to the Sacrament and to the Virgin. They are of

time the paths that Cæsarius's stories have trodden will have to be pointed out. Of course one will not go so far as to confine the substance of a story in the straight-jacket of a genealogy and try to trace the exact pedigree of derivation and relation. A story grows and changes mostly through oral tradition, the fixed written forms are often only chance resting stages in the development; many connecting links of oral transformation have frequently been lost between one fixed form and another. For these changes are not logically necessary, but depend upon chances, it may be, that a locality or a half forgotten historical fact caused assimilation, it may be, that a particular object was connected with the transformation or merely the poetic impulse to remolding brought about the change." This is also the conclusion of Schönbach in his paper, "Die Legende vom Engel und Waldbruder" in *Sitzungsberichte der kais. Akad.,* CXLIII., p. 62. The same writer in his "Studien zur Erzählungsliteratur, Achter Theil, Über Caesarius von Heisterbach," III., undertakes an interesting investigation of the changes which stories undergo in passing from one author to another. He compares the stories which are similar in Caesarius's "Dialogus" and "Homilies" and the stories common to "Jacques de Vitry" and "Étienne de Bourbon," and endeavors to formulate some general principles of transmission.

the same nature as those already published in the "Dialogus," a few are found in both works. There is the same tendency to localize well-known stories, and the same absence of mention of literary sources. The "Vitæ Patrum, Historia ecclesiastica," etc., are occasionally cited, generally the name of the narrator is carefully stated and the locality is exactly described.

Of all the mediæval story-tellers Cæsarius is perhaps the most interesting, partly from his gift of narration, and partly from the diversified character of his stories. In most of the great *exempla*-collections which I shall soon examine, the stories are told in a dry, condensed form, and seem more like memoranda to be expanded at the preacher's will than like independent tales. Cæsarius is a happy exception and his book is one of the most valuable sources for the history of mediæval culture.

While engaged in the study of Jacques de Vitry I learned of the existence in Belgian libraries of a collection of *sermones communes vel quotidiani* by him, but made no effort to trace these, for the author had said in the *procœmium* to the *sermones dominicales* (Antwerp, 1575) that his work was to consist of six divisions, the first four being represented by the *sermones dominicales,* the fifth by the *sermones de sanctis,* and the sixth by the *sermones vulgares.* As it was supposed that all the existing collections of sermons by Jacques de Vitry were written late in life, I did not think that after the *sermones vulgares* which, in his own words, were to complete his work, he would have added anything. It now seems that I was mistaken and that the *sermones communes vel quotidiani* also contain a considerable number of *exempla,* two editions of which, by a strange coincidence, appeared simultaneously three years ago.[16]

[16] Greven, Joseph, "Die Exempla aus den Sermones feriales et communes des Jakob von Vitry," Heidelberg, 1914, 8vo, pp. xviii, 68 (Sammlung mittellateinischer Texte herausgegeben," von Alfons Hilka, 9); Frenken, Goswin, "Die Exempla des Jakob von Vitry," Munich, 1914, Lex. 8vo, pp. iv, 152 ("Quellen und Untersuchungen zur mittellateinischen Philologie des Mittelalters," V. 1). As I have reviewed these two editions recently at length in the *Romanic Review,* Vol. VI. (1915), pp. 223 et seq., I shall not enter into details here. I may, however, remark that Greven's edition is part of Hilka's "Sammlung" and is, like the other texts in that collection, edited in the most concise form, with brief introduction, and briefer annotation. Frenken's edition, on the other hand, contains not only a biography of "Jacques de Vitry,"

The new *exempla* (three only are found in the *sermones vulgares,* Crane, Nos. 30, 31, 160) are 107 in number (Frenken has 104, classifying two as anecdotes, and omitting one as not properly an *exemplum*). Three are from the "Vitæ Patrum" and two from Petrus Alfonsus. The great majority are apparently original with Jacques de Vitry, and did not subsequently enter into wide circulation. The new collection is, therefore, of little interest for the question of the diffusion of popular tales, and its value depends on the light it throws on the manners and customs of the times. Among the *exempla* which are found in subsequent collections are some of the most famous of mediæval stories, *e. g.,* Frenken, No. 15, "Aristotle and Alexander's wife;" No. 195, "Monk in Paradise;" No. 68, man unhappily married wants shoot of tree on which another man's two wives have hanged themselves; No. 99, ape on shipboard throws into the sea the ill-gotten gains of a passenger who had cheated pilgrims with false measures and frothy wine; etc. A certain number of stories are taken from natural history, and a few are fables, the best known of the latter being the one of the treaty between the wolf and the sheep, by which the sheep give up their dogs as hostages (also in the *sermones vulgares,* Crane, No. 45).

Of the stories peculiar to Jacques de Vitry some are connected with his experiences in the East, as Frenken, No. 71, a certain Count Josselin married the daughter of an Armenian on condition of letting his beard grow in accordance with the custom of the country. The Count contracts debts which he does not know how to pay. At last he tells his father-in-law that he has pledged his beard for a thousand marks, and if the debt is not paid his beard will have to be cut off. His father-in-law gives him the money rather than have the Count incur the shame of losing his beard; No. 72, Jacques de Vitry knew a certain knight in Acre that had offended a minstrel, who took his revenge by passing off on the knight an ointment which removes the beard instead of preserving the face in good condition; No. 75, Jacques de Vitry heard that a certain Saracen, over sixty years of age, had never been outside of Damascus. The Sul-

but most valuable dissertations on the history of *exempla,* the sources of "Jacques de Vitry's" *exempla,* and their penetration into later secular literature. I cannot praise too highly Frenken's admirable editorial work.

tan summoned him and commanded him to remain in the city in the future. As soon as he was forbidden to leave it he longed to go, and gave the Sultan money to permit him to do so; No. 96, a woman of Acre knew excellent remedies for the eyes, so that even Saracens came to her. One day she was in a hurry to hear mass and left the case of a Saracen to her maid, telling her to put such and such medicine in his eyes. The Christian maid determined to blind the Saracen, so she put quicklime in his eye and told him not to open it in three days. A week later, after great pain and copious tears, he was cured, and returned with fee and gifts, greatly to the maid's wonder.

There is another group of stories, the scene of which is laid in Paris in the time of Jacques de Vitry. Some of the most interesting are these: Frenken, No. 80, while Jacques de Vitry was at Paris three youths from Flanders came there and on their way told their purposes: one wanted to be a Parisian theologian (magister), the second a Cistercian, the third an "organizator, hystrio et joculator." J. de V. saw later with his own eyes the realization of their desires; No. 82, I remember, he says, while at Paris that a certain scholar, religious and abstinent, went on a Friday to visit friends near Paris and ate wherever he stopped. His famulus at last whispers to him that it is Friday and that he has eaten twice already. His master replies that he had forgotten it. J. de V. remarks that some eat so much that they cannot forget it, but have to say: "Ventrem meum doleo." There are several stories of an ignorant Parisian priest named Maugrinus. In one, Frenken, No. 101, he is called to hear the confession of a certain scholar who speaks in Latin. Maugrinus does not understand him, and calls the servants and tells them that their master is in a frenzy and must be bound. When the scholar recovers he complains to the bishop, who pretends to be ill and sends for Maugrinus to confess him. He, too, speaks Latin, and at every word he utters Maugrinus says, "May the Lord forgive you." At last the bishop cannot restrain his laughter and says, "May the Lord never forgive me, nor will I forgive you," and made him pay a hundred livres or lose his parish. In another story, No. 103, Maugrinus's bishop is in pecuniary straits and feigning to have sore eyes, asks Maugrinus to read certain letters. Maugrinus, who cannot read, opens the letters and looking them over says that they contain news that the bishop is in need and that Maugrinus will lend him ten marks.

Among the usual monastic diatribes on the other sex is the following story, Frenken, No. 61: J. de V. once passed through a certain city in France, where a ham was hung up in the public square to be given to the one who swore that after a year of married life he did not repent of his bargain. The ham had hung there unclaimed for ten years.

It is now time to pass to the collections of *exempla* which have been published since 1883. Before that date the only collections of *exempla* accessible in modern editions were, as we have seen above, the selections from Étienne de Bourbon made by Lecoy de la Marche, and the Catalan translation of the "Alphabetum narrationum." It was not until ten years later, in 1893, that there appeared a collection of Latin stories composed in Bologna in 1326, and contained in a manuscript in the library of Wolfenbüttel.[17] The sixty-nine stories are accompanied in some cases by moralizations, and contain many classical anecdotes. In these two respects the collection resembles the "Gesta Romanorum," and Oesterley in his edition of that work, p. 257, was inclined to regard the "Tractatus" as a peculiar version of the "Gesta," or at least as an offshoot. This opinion is hardly correct in view of the great differences between the "Tractatus" and the many versions of the "Gesta." It is likely that the former is an independent collection made in Italy in the fourteenth century, and shows the growing fondness for secular elements in works of this kind. Valerius Maximus is the source most frequently cited, but other historians of classical and Christian times are also quoted, as well as Seneca, Augustine, "Vitæ Patrum," Petrus Alfonsus, etc. The compilation has no independent value, and but little interest for the question of the diffusion of popular tales.

I must now, in conclusion, consider as briefly as possible the

[17] "Tractatus de diversis historiis romanorum et quibusdam aliis. Verfasst in Bologna i. J. 1326. Nach einer Handschrift in Wolfenbüttel," herausgegeben von Salomon Herzstein. Erlangen, 1893. In "Erlanger Beiträge zur Englischen Philologie und vergleichenden Litteraturgeschichte," herausgegeben von Hermann Varnhagen. XIV. Heft.

recent editions of collections of *exempla,* beginning with A. G. Little's "Liber Exemplorum ad usum Prædicantium," Aberdeen, 1908 (*British Society of Franciscan Studies,* Vol. I.). The manuscript, in the Library of Durham Cathedral, contains two hundred and thirteen chapters or stories, and belongs to the class of treatises for the use of preachers. It is divided into two parts: the first treats "of things above," and the subjects are arranged in the order of precedence—Christ, the Blessed Virgin, Angels and St. James. The second part treats "of things below," and here the subjects are in alphabetical order: *De accidia, de advocatis, de avaritia,* and so on to *de mortis memoria,* where the MS. breaks off. The author does not mention his name in the part of the MS. which has been preserved, although he gives us considerable information about himself, from which we infer that he was an Englishman by birth, probably of Warwickshire; he probably entered the order of the Friars Minor, and, after study in Paris, spent many years of his life in Ireland. Mr. Little, whom I follow in these details, concludes that the work was written probably between 1275 and 1279. The compiler, who nearly always mentions his sources, draws largely from Giraldus Cambrensis, "Gemma Ecclesiastica" (29 times); "Vitæ Patrum" (38); Gregory's "Dialogues" (15); "Miracles of the Virgin" (4); Peraldus, "Summa Virtutum ac Vitiorum" (10); "Life of Johannes Eleemosynarius" (9); "Barlaam and Josaphat" (2); etc. Many of the stories are familiar to us from other collections. "Some are," as the editor says, "of a more individual character and are the result of the writer's experience in Ireland." Among these (I use the editor's analyses) are: No. 95, the story of the bailiff of Turvey, who while going along a lonely road one night saw a horrible beast coming towards him. Knowing that it was the devil, he made with his axe a circle of crosses, and at once hastened to confess his sins to God. Forthwith there began to rise around him a wall which grew with every sin confessed. Against this wall the devil threw himself in vain, and could only terrify the poor sinner by showing his face over the top.

The duty of paying tithes is enforced by the story (No. 105) of the woman of Balrothery, "in our times," who had twenty lambs. To avoid giving two to the Church, she hid ten under a covering and gave the Church only one. "But behold the delightful (*iucundissimum*) judgment of Him who seeth all things!" On removing the covering the woman found nine of the lambs dead and only the Church's tenth still alive. Another story (No. 166) shows the efficacy of indulgences. A man follows two friars on a preaching tour in Ulster and buys all the indulgences he can afford. He afterwards sells these to the host with whom he has passed the night, for what he paid and a pot of beer in addition. The purchaser applies the indulgences to the relief of his dead son, who appears in a vision to his father and tells him that he has freed him from punishment. The foolish seller hearing of this tries in vain to get back his efficacious indulgences by refunding the money he had received for them. A very interesting story (No. 142) of superstition in times of epidemics is told by the Bishop of Clonmacnois. "When I was a preacher in the order (O. M.), I once came on a preaching tour to Connaught, and found a dreadful pestilence raging in the bishopric of Clonfort. For when men went ploughing or otherwise in the fields, or walking in the woods, they used to see armies of devils passing by, and sometimes fighting among themselves. All who saw these devils fell sick and most of them died. So I got together a great meeting, and said to the people: 'Do you know why these devils have this power over you? Simply because you are afraid of them. If you had faith in God and were convinced that He would protect you, they would have no power over you at all. You know that we —we friars—do more against the devils, and say more things about them than any one else in the world. Here am I standing here and abusing them as much as I know how. Do they harm me? Let the devils come, let them all come! Where are they? Why don't they come?' From that hour the devils disappeared and the pestilence with them."

Two other stories from this collection must receive brief notice. One (No. 112) tells the story of a rich widow with many suitors. She preferred a certain one but tells him frankly that his poverty stands in the way of his acceptance. He goes out into the highway and robs and murders a rich merchant. When he again claims the lady's hand she demands an account of his wealth, and after hearing his confession of its source, commands him to pass a night at the spot where the murdered man lies. There he beholds the dead man stretch his hands to heaven and implore justice. A voice declares that he shall be revenged in thirty years. The lady thinking that the murderer will certainly repent before that time marries him. He and his family flourish and penance is postponed. The fated day comes at last and a great feast is given to which are invited all whom he has no cause to fear. A minstrel is admitted, but a wag rubs the strings of his fiddle with grease and the minstrel withdraws in confusion. When he has gone some distance he finds that he has left his glove. He returns and discovers that the castle has disappeared, and where it once stood is a fountain and near it his glove. This story was told by Friar Hugo de Succone in a sermon preached in foreign parts. He said he told it as he had heard it, without vouching for it. One of his hearers said: "Brother, you can tell this story with assurance, for I know the place where it happened." Mr. Little cites two curious Welsh parallels in Rhys, "Celtic Folklore," pp. 73, and 403.

The second story (No. 192) occurs in the chapter "De ludis inordinatis," and refers to a curious custom in Dacia, related by a certain friar Peter, who was from that country. When women are in childbed their neighbors come to assist them with dancing and singing. Sometimes in carrying out their jokes they make a straw man and put on it a hood and girdle, calling it "bovi" and dragging it between two women. At times they cry out to it, "gestu lascivo," "Canta bovi, canta bovi, quid faceret?" (sic, l. facis? or taces?). Once the devil answered from the image with such a terrible voice, "I shall sing," that some of the women fell down dead. Mr. Little remarks that "there is no reason to doubt the English friar's report. The story agrees with the 'Konebarsel' or 'Kvindegilde' custom: a party of women gathering in a house after a birth. The women drink themselves merry, then they dance, then they go in a rout and break into houses and revel along the street, and make every man dance with them, and take the breeches off him, or in more recent times more frequently the hat." The various elements of our story are well known in Danish folklore, but the straw man at the lying-in-revels is elsewhere unknown.

In many respects the most important of recent publications of *exempla*-collections is another work also of English origin, which I shall mention slightly out of its chronological order because, like the one just described above, it is a treatise for the use of preachers, arranged in an alphabetical order. In 1886 while collecting material for the history of the use of *exempla* in mediæval sermons which serves as an introduction to my "Jacques de Vitry," Mr. Ward of the British Museum called my attention to MS. Additional 11284, formerly in the possession of the well-known antiquary Mr. W. J. Thoms, containing an extensive collection of stories arranged alphabetically according to topics. I later ("Jacques de Vitry," p. lxxii) called attention to the importance of this collection in the hope that it might soon find an editor. It was not, however, until the publication in 1910 of the third volume of the "Catalogue of Romances in the Department of Manuscripts in the British Museum," by Mr. Herbert, that the rich contents of the MS. were made adequately known to students of mediæval literature, and it was reserved for a French scholar, Mr. J. Th. Welter, to publish the MS. *in extenso*.[18]

The attribution of the "Speculum Laicorum" to John of Hoveden, the chaplain of Queen Eleanor and the author of "Philomela," first made by Bale in his "Catalogus," 1548, rests on no adequate ground, while the denial of his authorship, because the work contains mention of the reign of Henry IV. (Hoveden having

[18] It is true that in my edition of "Jacques de Vitry" I cited several MSS. in the British Museum containing the "Speculum Laicorum" without suspecting its true title. My excuse must be that the principal MS. (Additional 11284), which formerly belonged to Mr. Thoms, contains no indication of the true title (nor does it appear in the official catalogue), and the same is true of the other MSS. which I used. Neither Mr. Thoms nor Mr. Thomas Wright, who printed stories from this MS., was aware of the true title of the collection from which they were taken. The title of Mr. Welter's edition is: "Thesaurus Exemplorum. Fascicule V: Le Speculum Laicorum. Édition d'une collection d'exempla composée en Angleterre à la fin du XIII[e] siècle," Paris, 1914. The first four fascicules have not yet appeared, but the author has informed me that they are composed as follows: Fasc. I., Inventory of the three thousand anecdotes of "Étienne de Bourbon" from the MS. Lat. 15970 of the Bib. Nat., with indication of sources (Complement to A. Lecoy de la Marche, "Anecdotes historiques, légendes et apologues, tirés du recueil inédit d'Étienne de Bourbon," Paris, 1877); Fasc. II., Inventory of the "Liber de dono timoris" of Humbert de Romans, and of the "Promptuarium exemplorum" of Martinus Polonus; Fasc. III., "Liber exemplorum secundum ordinem Alphabeti"; Fasc. IV., MS. Royal 7 D. i, of the British Museum.

died in 1272 or 1275), is based on the mistake of a scribe who wrote Henry IV. for Henry III. Mr. Welter shows conclusively that the work must have been written between 1279 and 1292. The author purposely conceals his identity, "nomina siquidem nostra subticere me compulit malorum ipsa mater invidia," a statement that would hardly apply to so well-known a writer as John of Hoveden. From the character of his compilation the anonymous author may with reason be supposed to have been a member of the Mendicant Orders, probably an English Franciscan.

The "Speculum Laicorum" is, in reality, a theological treatise for the use of preachers, arranged alphabetically according to topics and containing a great number of illustrative stories. In Welter's edition there are ninety topics or chapters, and five hundred and seventy-nine stories, besides thirty others found in various MSS. of the work in the British Museum and elsewhere. The composition of the collection does not differ from that of the host of similar works, both manuscript and printed, found in European libraries. Two hundred and fifteen stories are taken from: Gregory's "Dialogues" (25), "Vitæ Patrum" (101), "Cassiodorus," "Hist. Tripart." (24), Bede (6), Petrus Alfonsus (5), William of Malmsbury (5), Petrus Cluniacensis (11), Cæsarius Heisterbacensis (5), "Physiologus" (8), "Miracles de N. D." (24), while the various tales are found seven hundred and fifty-eight times in: Jacques de Vitry (47), Odo of Cheriton (75), Arundel MS. 3244 (59), Étienne de Bourbon (273), "Liber de Dono Timoris" (72), "Liber Exemplorum secundum ordinem Alphabeti" (42), MS. Royal 7 D. i (85), and "Legenda Aurea" (58). In addition to these a great number of lives of the saints have been used, as well as many mediæval works of an historical character.

If the collection contained merely stories taken from well-known popular sources, it would be interesting as affording evidence of the extensive diffusion of stories through the medium of preachers; but the collector has added, as he says in the Prologue, "temporumque preteritorum ac modernorum quibusdam eventis." It is true, as the editor remarks, that the compiler, contrary to the custom of Jacques de Vitry or Étienne de Bourbon, has drawn few stories from his personal experience. He introduces the *exemplum,* sometimes by "fertur" or "legitur," sometimes without any preamble, localizing it in time and space, *i. e.*, in the thirteenth century and in the east of England, exceptionally in a foreign land. Still, as the editor says, the compiler has transmitted to us certain new features relating to great personages and others, and permits us to form a condensed sketch of the manners of the day, "qui se reflètent plus ou moins fidèlement dans ce miroir des laics."

The enormous extent of *exempla*-literature may be estimated from the hundred and nine manuscript collections in the British Museum alone (so admirably analyzed by Mr. Herbert in his "Catalogue"), which contain something like eight thousand stories. A few of the typical collections, as, for example, the "Alphabetum Narrationum," were frequently copied, and are found in many of the continental libraries. But, in the main, no two collections are alike, and each represents the individual fancy of the compiler. Very few of these collections have been published, but some have long attracted the attention of scholars. Among these the most interesting is a collection contained in a MS. in the Library of Tours, of which an incomplete version is in the University Library of Bonn. Both MSS. are of the fifteenth century, but the collection itself goes back to the second half of the thirteenth century, and was probably made by a Dominican monk well acquainted with the French provinces of Touraine, Maine and Anjou. Dr. Hilka, the able editor of the "Sammlung mittellateinischer Texte," communicated a considerable number of the *exempla* in the Tours MS. to the Schlesische Gesellschaft für vaterländische Cultur, in whose ninetieth annual report they were printed (1912). The *exempla* collections are in a comparatively few instances arranged alphabetically; sometimes they assume the character of treatises of theology and are disposed according to subjects. In the Tours MS. alone, I believe, the stories are arranged in nine groups, under the heads of classes and professions. The number of *exempla* is very large; there are four hundred and ten in the eighth group, which deals with secular and civil society. The *exempla* themselves are of great value for the question of the diffusion of popular tales as they contain a large number of stories which belong to the most widely circulated class. The stories are sometimes told at great length, contrary to the usual abbreviated form of the *exemplum,* and some deal with themes not hitherto represented in sermon-book literature; one, No. XI., p. 13, belongs to the cycle of the "Maiden with her hands cut off," of which a version is found in the "Scala Celi," fol. 27 vo., "Castitas," and another has been published by Klapper in a work to be mentioned presently; another, No. XII., *a.b.,* pp. 14, 15, contains versions of the theme of the "False Bride"; in the first version the wife substitutes in her place a maiden, whose finger the faithless bailiff cuts off; in the second, the wife kills the seneschal to whose care she has been entrusted, substitutes for herself a maidservant whom she subsequently kills, and is miraculously saved from the denunciation of wicked confessor.

The last collections of *exempla* recently published which I shall mention are two works containing extensive selections from manuscripts in German libraries, more particularly those in the Royal and University Library of Breslau. Both are edited by Dr. Joseph Klapper of the city just mentioned, and were published, the first in Hilka's "Sammlung mittellateinischer Texte," No. 2 ("Exempla aus Handschriften des Mittelalters"), Heidelberg, 1911; the second in "*Wort und Brauch.* Volkskundliche Arbeiten namens der Schlesischen Gesellschaft für Volkskunde," in zwanglosen Heften herausgegeben von Prof. Dr. Theodor Siebs und Prof. Dr. Max Hippe, 12 Heft ("Erzählungen des Mittelalters in deutscher Übersetzung und lateinischen Urtext"), Breslau, 1914.

These works contain respectively 115 and 211 *exempla,* in all 326 stories, the largest contribution to the subject yet made by any one editor, and one of the most interesting. The many manuscripts from which the editor has drawn range from the end of the twelfth to the end of the fifteenth century. The editor thus states the principle of selection in his first work: "Only those stories were admitted which are found in the manuscripts without any mention of their sources, or the sources of which are no longer known to us." There are exceptions, however, as p. 76, No. 76, "Legitur exemplum in libro de dono timoris." The editor concedes that the investigator can easily discover the sources of some of the *exempla,* and analogues for others. He gives a few himself, but in general limits his remarks to the age and origin of the MSS. in which the *exempla* are contained. Finally, he admits that certain stories, properly speaking, are not *exempla,* as they are taken from *chronicles,* but claims that they belong to this selection since they contain materials encountered in *exempla, e.g.,* No. 7, "Amicus et Amelius."

Dr. Klapper's second collection is taken largely (164 stories) from a single manuscript and may be dated about the end of the thirteenth century. The group of stories just mentioned was evidently made for the use of preachers, but are not arranged in any systematic manner, alphabetical or topical. The editor thinks that traces of the use of such systematic collections may be found in the manuscript from which the majority of stories are taken. There are small groups of stories devoted to the miracles of the Virgin, penance, confession, temptation, liberality, justice, avarice, and drunkenness. What collections were used it is impossible to say, but the miracles of the Virgin resemble closely those in a MS. of the British Museum, Additional 18929 (Ward's "Catalogue," Vol. II., p. 656), which came from the monastery of St. Peter at Erfurt. Dr. Klapper thinks we must assume the existence at that spot, at the end of the thirteenth century, of a collection of miracles of the Virgin used by Middle German Dominicans and probably put together by them, from which the London collection and most of the miracles in the collection before us are derived.

As I have already said the literary form of the *exemplum* differs considerably in the various collections. Sometimes the story is an independent tale of some length, sometimes it is (notably in the systematic treatises for the use of preachers) the merest sketch, to be expanded and adorned at the will of the preacher. Both of Klapper's collections (although the *exempla* were undoubtedly intended originally for use in sermons) contain almost exclusively stories of the former class. It is only necessary to compare these *exempla* with those in the "Speculum Laicorum" to see the great difference between the two classes. Dr. Klapper's first collection as we have just seen contained only such stories as were quoted without specification of source, or the source of which is no longer known to us at the present time. The second collection, now under consideration, is taken, as has been said, largely from one manuscript, and the stories are given just as they occur in it. Curiously enough, they are generally without indication of source. About twenty-seven stories contain mention of source, not always correctly. The "Vitæ Patrum" is cited seven times (once incorrectly), but in fact twenty-two *exempla* are from that famous work. There are fifty-one stories or miracles of the Virgin, with one citation of source: "Legitur in miraculis beate Marie." St. Gregory's "Dialogues" are mentioned once, and a few "chronicles" and "histories" have been used. It is easy to find sources and analogues for many of the stories, and I have done so in my review of the work in *Modern Language Notes,* January, 1917. I need not repeat here what I have said at length there, but I cannot refrain from again calling attention to the unusually interesting character of this collection. It contains many of the best-known mediæval tales, such as: Longfellow's "King Robert of Sicily," "Beatrice the Nun who saw the World," "Theophilus," "The Angel and Hermit," "Amis and Amiles," "Fridolin," Chaucer's "Pardoner's Tale," etc. Among the stories rarely found in *exempla* literature is a version of the "Don Juan" legend, in which a drunkard passing through a cemetery invites a skull to sup with him. It comes with its body in terrible shape, and in turn invites the host to sup with him in a week in the place where he was found. The guest goes there and is carried by a whirlwind to a deserted castle, and given a seat in a gloomy corner at a wretchedly served table. The host tells his story, how he was a judge neglectful of his office and bibulous. He urges his guest to return home and do good works. One of the most beautiful of the stories is that of the daughter of a heathen king who saw a fair flower in the garden and began to reflect how much more beautiful must be the creator of all flowers. She is betrothed to a youth and on her wedding day asks permission to go into the garden and worship the god of flowers. An angel appears to her and carries her away to a convent in a Christian land, where she spends the rest of her life as a nun. I do not know of any parallel among mediæval *exempla,* although the theme "Marienbräutigam" is widely spread and was used by Mérimée in his story "La Vénus d'Ille." The story was early known in Germany, and a *Volkslied* on the subject was in circulation as early as 1658.

I have kept for the conclusion of my paper two works of popularization. The first is by the late Dr. Jacob Ulrich, professor in the university of Zurich, "Proben der lateinischen Novellistik des Mittelalters," Leipzig, 1906. The editor's object is to give the student a selection from mediæval fiction, embracing fables, translations of the Oriental story-books, and a considerable number of *exempla* from the "Gesta Romanorum," Jacques de Vitry, Étienne de Bourbon and the collection of Tours as cited by Lecoy de la Marche in his "Étienne de Bourbon." Ulrich has given brief references to the individual stories, and furnished a work of value to the student beginning his researches in this fascinating field. I am surprised that the book is not better known.

The second work to which I have referred is by Albert Wesselski, "Mönchslatein, Erzählungen aus geistlichen Schriften des XIII. Jahrhunderts," Leipzig, 1909. The unfortunate title gives no idea of the contents of this handsome volume. It really contains a German translation of one hundred and fifty-four *exempla,* of which ten are from Wright's "Latin Stories," eight from Bromyard's "Summa Prædicantium," twenty-six from Cæsarius, eighteen from Étienne de Bourbon, seven from the "Gesta Romanorum," six from Herolt's "Sermones" and "Promptuarium," thirty-six from "Jacques de Vitry," twenty-two from the "Mensa Philosophica," and the rest from Odo of Cheriton, Vincent of Beauvais, Nicolaus Pergamenus, Thomas Cantipratensis, etc. There is an introduction of no original value, and the individual *exempla* are accompanied by extensive notes, which constitute the most important feature of the work. The contents are more varied than is the case with Klapper's second collection, and greater stress is laid on anecdotes and jests.

I have not space to refer in detail to the extensive use of *exempla* during the last thirty-four years in tracing the diffusion of popular tales. The articles in which *exempla* are so employed must be sought in the periodicals devoted to popular literature or in the collected writings of Benfey, Köhler, W. Hertz, and others.

It is perhaps too soon to be able to speak with authority upon the value of *exempla* for "Kulturgeschichte" (history, superstitions, etc.), and comparative storyology. Much yet remains to be edited, and what is accessible has not yet been closely examined from the above points of view. Many important questions have not yet been settled, such as, why references to fairy tales are so infrequent, etc. Enough has been said, however, to show the general interest and importance of the subject, and it is to be hoped that American scholars may find in it an additional field for their labor.[19]

ITHACA, N. Y.,
March, 1917.

[19] A good illustration of the value of the Sermon-Books for general mediæval history may be found in the admirable article by Professor Charles H. Haskins of Harvard University on "The University of Paris in the Sermons of the Thirteenth Century" in *The American Historical Review*, vol. X (1905), pp. 1–27. In the course of his paper Professor Haskins calls attention to the interesting fact that Harvard University Library possesses a manuscript of Jacques de Vitry's *Sermones vulgares* which was once the property of the monastery of St. Jacques at Liège (MS. Riant 35).

NEBULÆ.

By V. M. SLIPHER, Ph.D.

(Read April 13, 1917.)

In addition to the planets and comets of our solar system and the countless stars of our stellar system there appear on the sky many cloud-like masses—the nebulæ. These for a long time have been generally regarded as presenting an early stage in the evolution of the stars and of our solar system, and they have been carefully studied and something like 10,000 of them catalogued.

Keeler's classical investigation of the nebulæ with the Crossley reflector by photographic means revealed unknown nebulæ in great numbers. He estimated that such plates as his if they were made to cover the whole sky would contain at least 120,000 nebulæ, an estimate which later observations show to be considerably too small. He made also the surprising discovery that more than half of all nebulæ are spiral in form; and he expressed the opinion that the spiral nebulæ might prove to be of particular interest in questions concerning cosmogony.

I wish to give at this time a brief account of a spectrographic investigation of the spiral nebulæ which I have been conducting at the Lowell Observatory since 1912. Observations had been previously made, notably by Fath at the Lick and Mount Wilson Observatories, which yielded valuable information on the character of the spectra of the spiral nebulæ. These objects have since been found to be possessed of extraordinary motions and it is the observation of these that will be discussed here.

In their general features nebular spectra may for convenience be placed under two types characterized as (I.) bright-line and (II.) dark-line. The gaseous nebulæ, which include the planetary and some of the irregular nebulæ, are of the first type; while the much more numerous family of spiral nebulæ are, in the main, of the second type. But the two are not mutually exclusive and in the spirals are sometimes found both types of spectra. This is true of the nebulæ numbered 598, 1068 and 5236 of the "New General Catalogue" of nebulæ.

Some of the gaseous nebulæ are relatively bright and their spectra are especially so since their light is all concentrated in a few bright spectral lines. These have been successfully observed for a long time. Keeler in his well-known determination of the velocities of thirteen gaseous nebulæ was able to employ visually more than twenty times the dispersion usable on the spiral nebulæ.

Spiral nebulæ are intrinsically very faint. The amount of their light admitted by the narrow slit of the spectrograph is only a small fraction of the whole and when it is dispersed by the prism it forms a continuous spectrum of extreme weakness. The faintness of these spectra has discouraged their investigation until recent years. It will be only emphasizing the fact that their faintness still imposes a very serious obstacle to their spectrographic study when it is pointed out, for example, that an excellent spectrogram of the Virgo spiral N.G.C. 4594 secured with the great Mount Wilson reflector by Pease was exposed eighty hours.

A large telescope has some advantages in this work, but unfortunately no choice of telescope either of aperture or focal-length will increase the brightness of the nebular surface. It is chiefly influenced by the spectrograph whose camera alone practically determines the efficiency of the whole equipment. The camera of the Lowell spectrograph has a lens working at a speed ratio of about 1:2.5. The dispersion piece of the spectrograph has generally been a 64° prism of dense glass, but for two of the nebulæ a dispersion of two 64° prisms was used. The spectrograph was attached to the 24-inch refractor.

With this equipment I have secured between forty and fifty spectrograms of 25 spiral nebulæ. The exposures are long—generally from twenty to forty hours. It is usual to continue the exposure through several nights but occasionally it may run into weeks owing to unfavorable weather or the telescope's use in other work. Besides the exposures cannot be continued in the presence of bright moonlight and this seriously retards the accumulation of observations.

The iron-vanadium spark comparison spectrum is exposed a number of times during the nebular exposure in order to insure that the comparison lines are subjected to the same influences as the nebular lines. The spectrograph is electrically maintained at a constant temperature which avoids the ill effects of the usual fall of the night temperature.

The equivalent slit-width is usually about .06 mm.

The linear dispersion of the spectra is about 140 tenth-meters per millimeter in the violet of the spectrum which is sufficient to detect and measure the velocities of the spiral nebulæ. As the objects yet to be observed are fainter than those already observed the prospects of increasing the accuracy by employing greater dispersion are not now promising.

The plates are measured under the Hartmann spectrocomparator in which one optically superposes the nebular plate of unknown velocity upon one of a like dark-line spectrum of known velocity, used as standard. A micrometer screw, which shifts one plate relatively to the other, is read when the dark lines of the nebula and the standard spectrum coincide; and again when the comparison lines of the two plates coincide. The difference of the two screw readings with the known dispersion of the spectrum gives the velocity of the nebula. By this method weak lines and groups of lines can be utilized that otherwise would not be available because of faintness or uncertainty of wave-length.

TABLE I.

Radial Velocities of Twenty-five Spiral Nebulæ.

Nebula.	Vel.	Nebula.	Vel.
N.G.C. 221	− 300 km.	N.G.C. 4526	+ 580 km.
224	− 300	4565	+1100
598	− 260	4594	+1100
1023	+ 300	4649	+1090
1068	+1100	4736	+ 290
2683	+ 400	4826	+ 150
3031	− 30	5005	+ 900
3115	+ 600	5055	+ 450
3379	+ 780	5194	+ 270
3521	+ 730	5236	+ 500
3623	+ 800	5866	+ 650
3627	+ 650	7331	+ 500
4258	+ 500		

In Table I. are given the velocities for the twenty-five spiral nebulæ thus far observed. In the first column is the New General Catalogue number of the nebula and in the second the velocity. The plus sign denotes the nebula is receding, the minus sign that it is approaching.

Generally the value of the velocity depends upon a single plate which, in many instances, was underexposed and some of the values for these reasons may be in error by as much as 100 kilometers. This however is not so discreditable as at first it might seem to be. The arithmetic mean of the velocities is 570 km. and 100 km. is hence scarcely 20 per cent. of the quantity observed. With stars the average velocity is about 20 km. and two observers with different instruments and a single observation each of an average star might differ in its velocity by 20 per cent. of the quantity measured. Thus owing to the very high magnitude of the velocity of the spiral nebulæ the percentage error in its observation is comparable with that of star velocity measures.

Since the earlier publication of my preliminary velocities for a part of this list of spiral nebulæ, observations have been made elsewhere of four objects with results in fair agreement with mine, as shown in Table II.

TABLE II.

Velocities of Nebulæ by Different Observers.

Nebulæ.	Velocity.	Observers.
N.G.C. 224	— 300 km.	Slipher, mean from several plates.
Great Andromeda	— 304	Wright, Lick Observatory, one plate.
Nebula.	— 329	Pease, Mt. Wilson Observatory, one plate.
	— 300 to 400 km.	Wolf, Heidelberg, one plate approx.
N.G.C. 598	— 278	Pease, Mt. Wilson, from bright lines.
Great Spiral of Triangulum.	— 263	Slipher, from bright lines.
N.G.C. 1068	+ 1100	Slipher, from dark and bright lines.
	+ 765	Pease, from two bright lines.
	+ 910	Moore, Lick Observatory, from three bright lines.
N.G.C. 4594	+ 1100	Slipher.
	+ 1180 km.	Pease, Mt. Wilson Observatory.

Referring to the table of velocities again: the average velocity 570 km. is about thirty times the average velocity of the stars. And it is so much greater than that known of any other class of celestial bodies as to set the spiral nebulæ aside in a class to themselves. Their distribution over the sky likewise shows them to be unique—they shun the Milky Way and cluster about its poles.

The mean of the velocities with regard to sign is positive, implying the nebulæ are receding with a velocity of nearly 500 km. This might suggest that the spiral nebulæ are scattering but their distribution on the sky is not in accord with this since they are inclined to cluster. A little later a tentative explanation of the preponderance of positive velocities will be suggested.

Grouping the nebulæ as in Table III., there appears to be some evidence that spiral nebulæ move edge forward.

TABLE III.

Velocities of Spiral Nebulæ Grouped.

Face View Spirals.		Inclined Spirals.		Edge View Spirals.	
N.G.C.	Vel.	N.G.C.	Vel.	N.G.C.	Vel.
598	− 260 km.	224	− 300 km.	2683	+ 400 km.
4736	+ 290	3623	+ 800	3115	+ 600
5194	+ 270	3627	+ 650	4565	+ 1100
5236	+ 500	4826	+ 300	4594	+ 1100
		5005	+ 920	5866	+ 600
		5055	+ 450		
		7331	+ 500		
Mean.....	330 km.	....	560 km.	....	760 km.

The form of the spiral nebulæ strongly suggests rotational motion. In the spring of 1913 I obtained spectrograms of the spiral nebulæ N.G.C. 4594 the lines of which were inclined after the manner of those in the spectrum of Jupiter, and, later, spectrograms which showed rotation or internal motion in the Great Andromeda Nebula and in the two in Leo N.G.C. 3623 and 3627 and in nebulæ N.G.C. 5005 and 2683—less well in the last three. The motion in the Andromeda nebula and in 3623 is possibly more like that in the system of Saturn. It is greatest in nebula N.G.C. 4594. The rotation in this nebula has been verified at the Mt. Wilson Observatory.

Because of its bearing on the evolution of spiral nebulæ it is desirable to know the direction of rotation relative to the arms of the spirals. But this requires us to know which edge of the nebula is the nearer us, and we have not as yet by direct means succeeded in determining even the distance of the spiral nebulæ. However, indirect means, I believe, may here help us. It is well known that spiral nebulæ presenting their edge to us are commonly crossed by a dark band. This coincides with the equatorial plane and must belong to the nebula itself. It doubtless has its origin in dark or deficiently illuminated matter on our edge of the nebula, which absorbs (or occults) the light of the more brightly illumined inner part of the nebula. If now we imagine we view such a nebula from a point somewhat outside its plane the dark band would shift to the side and render the nebula unsymmetrical—the deficient edge being of course the one nearer us. This appears to be borne out by the nebulæ themselves for the inclined ones commonly show this typical dissymmetry. Thus we may infer their deficient side to be the one toward us.

When the result of this reasoning was applied to the above cases of rotation it turned out that the direction of rotation relative to the spiral arms was the same for all. (The nebula N.G.C. 4594 is unfortunately not useful in this as it is not inclined enough to show clearly the arms.) The central part—which is all of the nebulæ the spectrograms record—turns into the spiral arms as a spring turns in winding up. This agreement in direction of rotation furnishes a favorable check on the conclusion as to the nearer edge of the nebulæ, for of course we should expect that dynamically all spiral nebulæ rotate in the same direction with reference to the spiral arms. The character and rapidity of the rotation of the Virgo nebula N.G.C. 4594 suggests the possibility that it is expanding instead of contracting under the influence of gravitation, as we have been wont to think.

As noted before the majority of the nebulæ here discussed have positive velocities, and they are located in the region of sky near right ascension twelve hours which is rich in spiral nebulæ. In the opposite point of the sky some of the spiral nebulæ have negative velocities, *i. e.*, are approaching us; and it is to be expected that when more are observed there, still others will be found to have approaching motion. It is unfortunate that the twenty-five observed objects are not more uniformly distributed over the sky as then the case could be better dealt with. It calls to mind the radial velocities of the stars which, in the sky about Orion, are receding and in the opposite part of the sky are approaching. This arrangement of the star velocities is due to the motion of the solar system relative to the stars. Professor Campbell at the Lick Observatory has accumulated a vast store of star velocities and has determined the motion of our sun with reference to those stars.

We may in like manner determine our motion relative to the spiral nebulæ, when sufficient material becomes available. A preliminary solution of the material at present available indicates that we are moving in the direction of right-ascension 22 hours and declination $-22°$ with a velocity of about 700 km. While the number of nebulæ is small and their distribution poor this result may still be considered as indicating that we have some such drift through space. For us to have such motion and the stars not show it means that our whole stellar system moves and carries us with it. It has for a long time been suggested that the spiral nebulæ are stellar systems seen at great distances. This is the so-called "island universe" theory, which regards our stellar system and the Milky Way as a great spiral nebula which we see from within. This theory, it seems to me, gains favor in the present observations.

It is beyond the scope of this paper to discuss the different theories of the spiral nebulæ in the face of these and other observed facts. However, it seems that, if our solar system evolved from a nebula as we have long believed, that nebula was probably not one of the class of spirals here dealt with.

Our lamented Dr. Lowell was deeply interested in this investigation as he was in all matters touching upon the evolution of our solar system and I am indebted to him for his constant encouragement.

Lowell Observatory,
April, 1917.

THE TRIAL OF ANIMALS AND INSECTS.

A Little Known Chapter of Mediæval Jurisprudence.

By HAMPTON L. CARSON.

(Read April 12, 1917.)

In the open square of the old Norman city of Falaise, in the year 1386, a vast and motley crowd had gathered to witness the execution of a criminal convicted of the crime of murder. Noblemen in armour, proud dames in velvet and feathers, priests in cassock and cowl, falconers with hawks upon their wrists, huntsmen with hounds in leash, aged men with their staves, withered hags with their baskets or reticules, children of all ages and even babes in arms were among the spectators. The prisoner was dressed in a new suit of man's clothes, and was attended by armed men on horseback, while the hangman before mounting the scaffold had provided himself with new gloves and a new rope. As the prisoner had caused the death of a child by mutilating the face and arms to such an extent as to cause a fatal hemorrhage, the town tribunal, or local court, had decreed that the head and legs of the prisoner should be mangled with a knife before the hanging. This was a mediæval application of the *lex talionis,* or "an eye for an eye and a tooth for a tooth." To impress a recollection of the scene upon the memories of the bystanders an artist was employed to paint a frescoe on the west wall of the transept of the Church of the Holy Trinity in Falaise, and for more than four hundred years that picture could be seen and studied until destroyed in 1820 by the carelessness of a white washer. The criminal was not a human being, but a sow, which had indulged in the evil propensity of eating infants on the street.

Within the first ten years of the sixteenth century, Bartholomew

Chassenée, then a young French *avocat,* who became a distinguished jurist, and president of the Parlement de Provence, a position corresponding to chief justice, won his spurs at the bar by his ingenuity in defending the Rats of the province of Autun, who were charged with the crime of having eaten the barley crop. He urged that his clients, like other defendants, were entitled to notice before condemnation. When they failed to appear in court in obedience to the proclamation published from the pulpits of all the parishes, he argued that their non appearance was due to the vigilance of their mortal enemies, the cats, and that if a person be cited to appear at a place to which he could not come in safety the law would excuse his apparent contumacy. Years later, at the height of his fame, in 1540, he insisted upon the same principle, in defending the persecuted Waldenses who were prosecuted for heresy, contending that as it had been established in the Rat case that even animals should not be adjudged and sentenced without a hearing, all of the safeguards of justice should be thrown around the accused.

I have cited these cases of the Sow and the Rats, not as isolated and extraordinary instances of mediæval trials, such as the celebrated Cock at Basel in 1474, but as fair examples of what was common to Continental jurisprudence from the ninth to the eighteenth century. Indeed as late as 1864 in Pleternica in Slavonia, a pig was tried and executed for having maliciously bitten off the ears of an infant one year old, and we are told by Professor Karl von Amira, who reports the case, that while the flesh of the animal was thrown to the dogs, the owner of the pig was put under a bond to provide a dowry for the mutilated girl, so that the loss of her ears might not prove an obstacle to her marriage.[1] Of the extent to which the Trial of Animals formed a substantial part of Mediæval Jurisprudence, the most convincing proof is found in the Report and Researches of Barriat-Saint-Prix,[2] who gives numerous extracts from the original records of such proceedings, and also a list of the kinds of animals tried and condemned. He gives ninety-three cases from the beginning of the twelfth to the middle of the eigh-

[1] "Thierstrafen and Thierprocesse," p. 578, Innsbruck, 1891.

[2] *Memoires of the Royal Society of Antiquaries of France* (Paris, 1829, Tome VIII., pp. 403–50).

teenth century. Carlo D'Addosio,[3] a Neapolitan writer of recent times, enlarges the list to one hundred and forty-four prosecutions, resulting in the execution or excommunication of the accused, and extends the time from the year 824 to 1845; while our fellow countryman, Mr. E. P. Evans, in an exhaustive "Chronological List of the Prosecution of Animals from the Ninth to the Twentieth Century," begins with the case of moles in the valley of Aosta in 824, and closes with that of a fierce dog who aided murderers in their crime in Switzerland and was tried as an accomplice as late as 1906.[4]

An analysis of Mr. Evans' list gives these results. Out of one hundred and ninety-six cases he assigns, 3 to the ninth, 3 to the twelfth, 2 to the thirteenth, 12 to the fourteenth, 36 to the fifteenth, 57 to the sixteenth, 56 to the seventeenth, 12 to the eighteenth, 9 to the nineteenth and 1 to the twentieth centuries. The scenes were laid in Belgium, Denmark, France, Germany, Italy, Portugal, Russia, Spain, Switzerland, Turkey, England, Scotland, Canada and Connecticut, the last named being in the days of Cotton Mather. This wide distribution of time and territory shows how persistent and prevalent the practice was, and corrects any notion of its being due to local passion or territorial superstition. The most numerous cases were in France, but this is due to a more careful study of ancient records by French antiquarians than by those of other nations. The two English cases were those of a dog and a cock, the Scotch case, that of a dog, the Canadian case, that of turtle-doves, and the Connecticut cases those of a cow, two heifers, three sheep and two sows.

As early as 1486, in a curious book, printed by Anthony Neyret, there is a classification of beasts or animals into those which are sweet beasts (bestes doulces) such as the hart and hind, and stenchy beasts (bestes puantes) such as pigs, foxes, wolves and goats, to which in time were added of domestic animals, such as asses, bulls, cows, dogs, horses and sheep, those of a ferocious and vicious disposition. These all fell under the jurisdiction of the civil and crim-

[3] "Bestie Delinquenti," Napoli, 1892.

[4] "The Criminal Prosecution and Capital Punishment of Animals," N. Y., 1906.

inal courts, and after trial and condemnation were executed either by hanging, or burning at the stake. Vermin such as field mice, rats, moles and weasels and pestiferous creatures, such as bugs, beetles, blooksuckers, caterpillars, cockchafers, eels, leeches, flies, grasshoppers, frogs, locusts, serpents, slugs, snails, termites, weevils and worms were disciplined by the ecclesiastical tribunals and in due time excommunicated.

This sharp distinction between the jurisdiction of the secular and ecclesiastical tribunals is explained by Professor von Amira, who says that animals, such as pigs, cows, horses and dogs, which were in the service of man and who committed crimes against mankind, could be arrested, tried, convicted and executed like any other members of his household, but rodents and insects were not the subject of human control, and could not be seized and imprisoned by the civil authorities. Hence, it was necessary to appeal to the intervention of the Church, and implore her to exercise her supernatural functions for the purpose of compelling them to desist from devastation of those fields and places devoted to the production of human food.

The explanation of the mental and moral attitude of the tribunals in those days in relation to the subject is to be traced to the belief of the ancient Greeks, who held that a murder, whether committed by a man, a beast, or an inanimate object, such as a deadly weapon, a spear, a knife, or a hammer, unless properly expiated, would arouse the furies and bring pestilence upon the land. The mediæval Church taught the same doctrine, but substituted the demons of Christian theology for the furies of classical mythology. Eminent authorities, as Mr. Evans has shown, maintained that all beasts and birds, as well as creeping things were devils in disguise, and that homicide committed by them, if it were permitted to go unpunished, would furnish an opportunity for the intervention of devils to take possession of persons and places. The cock at Basel, suspected of laying an egg in violation of his sex, was feared as an abnormal, inauspicious and therefore diabolic creature: the fatal cockatrice might thus be hatched. While as to swine, they were peculiarly attractive to devils, and hence peculiarly liable to diabolical possession as proved by the legend by which devils left the lunatic and entered the herd of swine which pitched itself into the sea. Beelzebub was incarnate in all night beasts, especially if they happened to be black. If Pythagoras was right in teaching, "that souls of animals infuse themselves into the trunks of men," what wonder was it that Gratiano exclaimed to Shylock:

> "Thy currish spirit
> Govern'd a wolf, who, hanged for human slaughter,
> Even from the gallows did his fell soul fleet,
> And, whilst thou lay'st in thy unhallowed dam,
> Infused itself in thee; for thy desires
> Are wolfish, bloody, sterved and ravenous."

In explanation of the judicial proceedings so solemnly resorted to in the trial, conviction and punishment of animals, a Swiss jurist, Edward Osenbrüggen, in 1868, advanced and maintained the thesis, that they can only be understood on the theory of the personification of animals: that as only a human being can commit crime and thus render himself liable to punishment, it is only by an act of personification that the brute can be placed in the same category as man and become subject to the same penalties; and he regarded the Basel cock as a personified heretic, and therefore properly burned at the stake.

Mr. Evans regards this as purely fanciful, and concludes that "the judicial prosecution of animals, resulting in their excommunication by the Church or their execution by the hangman, had its origin in the common superstition of the age, which has left such a tragical record of itself in the incredibly absurd and atrocious annals of witchcraft. The same ancient code that condemned a homicidal ox to be stoned, declared that a witch should not be suffered to live, and although the Jewish law giver may have regarded the former enactment chiefly as a police regulation designed to protect persons against unruly cattle, it was, like the decree of death against witches, genetically connected with the Hebrew cult and had therefore an essentially religious character. It was these two paragraphs of the Mosaic law that Christian tribunals in the Middle Ages were wont to advance as their authority for prosecuting and punishing both classes of delinquents."

In conclusion, may we not exclaim, in the words of the poet Rogers in his Ode to Superstition,

> "Hence to the realms of Night
> Dire Demon hence!
> Thy chain of adamant can bind
> That little world, the human mind,
> And sink its noblest powers
> To impotence."

THE SEX RATIO IN THE DOMESTIC FOWL.[1]

By RAYMOND PEARL.

(Read April 13, 1917.)

I. Introduction.

One of the most notable biological discoveries of recent years is that which has demonstrated the cytological mechanism of sex determination. As a result of the work of McClung, Wilson, Stevens, Montgomery, Morgan, and many other investigators, we have a tolerably clear understanding of the cellular mechanism by which it is determined, in a wide variety of forms, that particular individuals are males while others are females. At first sight it would appear that the discoveries referred to had made superfluous further studies of sex ratios. The whole history of the statistical investigation of sex ratios, viewed from the standpoint of present knowledge of the mechanism of sex determination, seems a rather futile and blind groping after something which very successfully eluded that form of pursuit.

But there are still reasons, as it seems to the writer, why it is desirable to carry on certain sorts of statistical investigations of sex ratios. The most important of these is that there is a considerable body of evidence in the literature, which would seem to show, if

[1] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station. No. 119. This paper constitutes No. VIII. of a series of "Sex Studies" by the present writer.

It was originally intended that this should be a much more extended paper than it now is. When it was presented before the Society a number of matters were discussed which do not appear here at all. This condition of affairs arises from the fact that in the midst of the preparation of the final manuscript for the printer the writer was called to war work which made impossible the completion of the paper in the form originally contemplated. In view of the impossibility of foretelling when the writing could be completed it seemed desirable to publish the portion already done rather than to leave the whole till the somewhat uncertain time of the end of the war.

taken at its face value, that sex ratios may, in some cases at least, be experimentally modified and in some degree controlled. The critical value of all of this evidence is not equal. In some instances it appears certain, and in more cases probable, that the data presented do not warrant the conclusion that the sex ratio has been either modified or controlled. There is, of course, no theoretical impossibility in modifying the sex ratio in an organism where the chromosomal mechanism of sex determination is a definite and constant one. We know of no hereditary character which may not, upon occasion, be modified; and in the case of sex the brilliant researches of Goldschmidt[2] make it clear that not only the somatic manifestation of the chromosomal sex mechanism may vary and be experimentally modified, but presumably also the mechanism itself. But just because of the usual and normal stability of germinal mechanisms it becomes the more important to be sure, on the one hand, that evidence alleged to demonstrate that sex ratios may be modified or controlled is sound and adequate when subjected to the scrutiny of modern statistical science, and, on the other hand, to learn more than we now know about the normal variability of sex ratios. As a contribution in this direction it seems important where possible to present and critically analyze statistical data, of adequate amount, regarding the normal sex ratio of forms frequently used in experimental work.

It is the purpose of this paper to present and analyze such data for the domestic fowl. The statistics here used cover eight years in point of time, and represent over 22,000 individual chicks.

The specific topics which will be discussed are these:

1. The normal, average sex ratio in the domestic fowl.
2. The variation in the sex ratio.
3. The influence of prenatal mortality on the sex ratio.

II. Material and Methods.

Before undertaking the presentation and discussion of the statistics it is desirable to say a word in regard to their collection and analysis. The data are those which have arisen in the writer's ex-

[2] Goldschmidt, R., *Amer. Nat.*, 1916, and other papers.

perimental breeding operations with poultry at the Maine Agricultural Experiment Station during the breeding seasons of 1908 to 1915 inclusive. The 1916 matings are not included except for the discussion of certain special problems because the original record-taking on that year's birds is not completed at the time of writing. During the period covered by the statistics the sex of every chick which hatched was determined if it was physically possible to make such determination. Failure to determine the sex in individual cases resulted from one or another of the following kinds of causes: (*a*) The loss of the bird from predaceous enemies, thieves, or straying; (*b*) the bird's total destruction by fire; (*c*) the loss of its identifying leg band, which rendered its assignment to the proper mating impossible. In the case of birds which died before reaching an age where the development of secondary sex characters made it possible to distinguish the sexes externally, dissection and examination of the gonads was resorted to for the determination.

The number of cases of birds not sexed at all, for the reasons above stated, was not proportionately large. I have elsewhere[3] given detailed figures on the point for one year. Other years presented much the same sort of facts. The important feature is that these irremediable losses, so far as all the evidence indicates, have been random samples of the population in respect of sex. Further on in the paper detailed evidence in support of this statement will be presented.

In the statistical treatment of the data the mating or family has been made the unit, wherever such treatment is possible. While not novel, this method of dealing with sex ratio statistics is unusual. It has certain marked advantages, from a methodological viewpoint, over the more usual procedure of considering a whole population as the unit in studying the sex ratio. These advantages will be apparent as we proceed.

Throughout this paper the sex ratio is presented as the percentage of the males in the total of the group or population. Or, in other words, we express the sex ratio as

[3] Pearl, R., *Amer. Nat.*, Vol. XLV., pp. 107–117. 1911.

$$R_{♂} = \frac{100 ♂♂}{♂♂ + ♀♀}$$

for any mating, group or population. To convert any such sex ratio into the form where the proportion of the sexes is expressed as number of males per 100 females one has only to divide the given R by $100 - R$, and the answer, multiplied by 100, will be the result sought.

III. The Normal Sex Ratio in the Fowl.

In dealing with sex ratios with the single mating or family as the unit it is evident that the absolute size of the family from each mating is a factor which must be considered. In a family of 2 the only possible values for $R_{♂}$ are 0, 50, and 100 per cent. Again, a single family of 2 is a very small sample of the gametic population of the parents. The larger the family, obviously, the better the sampling. Now in the usual method of dealing statistically with sex ratios, where one simply counts all the males and all the females in the population, no account whatever is taken nor can be, of the badness of the gametic sampling in case of very small families. A male in a family of 1 counts as significantly toward the final result as a male in a family of 30. Yet it is quite sure that if we determined the sex ratio of the population on the basis of families of 1 only, the result would be less worthy of confidence (*i. e.*, of a larger "probable" error) than if it were based on large families only.

Tables I. to III. inclusive give the distribution to the sex ratios for all fertile matings of the domestic fowl made by the writer in the eight years from 1908 to 1915 inclusive. Sterile matings are, of course, not included. The data are divided between the three tables on the basis of size of family. Table I. includes only families in which 10 or more chicks were produced. Table II. includes families of from 4 to 9 chicks, and Table III. covers the very small families of 1, 2, or 3 chicks only. In order that there may be no misunderstanding it will be well to state clearly just the significance of these tables. To take an example: The entry 2 in the first row of Table I. means that in the year 1908 there were produced 2 families, each containing 10 or more chicks, in each of which families

TABLE I.

Frequency Distribution of the Sex Ratio in the Fowl. Various Breeds. Families of 10 and Over.

Year.	Sex Ratio $R_♂$.									
	0–9.9.	10.0–19.9.	20.0–29.9.	30.0–39.9.	40.0–49.9.	50.0–59.9.	60.0–69.9.	70.0–79.9.	80.0–89.9.	90.0–100.0.
1908	0	2	10	22	22	18	11	7	0	1
1909	0	4	9	17	38	46	29	2	0	0
1910	0	3	14	17	36	52	24	11	3	1
1911	1	3	12	34	43	37	18	11	2	1
1912	0	3	6	19	36	41	22	8	2	0
1913	0	1	6	16	23	33	17	6	0	0
1914	0	2	2	17	35	48	27	1	0	0
1915	0	1	4	16	27	19	12	1	0	0
Totals..	1	19	60	158	260	294	160	47	7	3

TABLE II.

Frequency Distribution of the Sex Ratio in the Fowl. Various Breeds. Families of 4 to 9 Inclusive.

Year.	Sex Ratio. $R_♂$.									
	0–9.9.	10.0–19.9.	20.0–29.9.	30.0–39.9.	40.0–49.9.	50.0–59.9.	60.0–69.9.	70.0–79.9.	80.0–89.9.	90.0–100.0.
1908	5	4	12	7	9	17	13	6	1	3
1909	0	2	9	6	3	14	7	2	2	2
1910	3	2	7	2	1	6	4	2	0	7
1911	9	1	3	8	5	12	8	5	3	4
1912	1	1	3	5	5	8	5	8	3	2
1913	0	2	4	3	6	12	10	5	1	2
1914	2	0	6	6	3	5	4	3	4	2
1915	2	1	2	2	7	13	5	4	3	1
Totals..	22	13	46	39	39	87	56	35	17	23

TABLE III.

Frequency Distribution of the Sex Ratio in the Fowl. Various Breeds. Families of 1 to 3 Inclusive.

Year.	Sex Ratio. $R_♂$.									
	0–9.9.	10.0–19.9.	20.0–29.9	30.0–39.9.	40.0–49.9.	50.0–59.9.	60.0–69.9.	70.0–79.9.	80.0–89.9.	90.0–100.0.
1908	8	0	0	1	0	6	4	0	0	11
1909	6	0	0	2	0	3	4	0	0	4
1910	5	0	0	0	0	2	2	0	0	2
1911	10	0	0	0	0	6	1	0	0	11
1912	2	0	0	2	0	5	2	0	0	8
1913	2	0	0	2	0	6	4	0	0	9
1914	6	0	0	1	0	2	0	0	0	9
1015	4	0	0	3	0	2	1	0	0	3
Totals..	43	0	0	11	0	32	18	0	0	57

the percentage of ♂♂ to total number of chicks was somewhere between 10 per cent. and 19.9 per cent. Other entries are to be correspondingly read.

The first thing which strikes one's attention in examining these tables is that extreme values of the sex ratio (below 20 and above 80 say) occur relatively frequently only in small families. If the families are very small (Table III.) extreme values of the sex ratio become actually *more* frequent than medium values. The greater frequency of extreme sex ratios in small families is obviously what would be expected on merely arithmetic grounds. Thus to take the data of Table III. We find from the original records that there were 54 families of 1, 53 of 2, and 54 of 3 each contributing to this table. Suppose males and females were equally likely to occur (*i. e.*, $R_{♂} = 50$); then according to the laws of chance, the totals of Table III. would be expected to be as shown in Table IV. These are compared with the actually observed totals.

TABLE IV.

COMPARING TOTALS OF TABLE III., WITH CHANCE DISTRIBUTION OF SAME NUMBER OF FAMILIES, ON THE ASSUMPTION THAT $R_{♂} = 50$.

Distribution.	Sex Ratio.									
	0–9.9.	10.0–19.9.	20.0–29.9.	30.0–39.9.	40.0–49.9.	50.0–59.9.	60.0–69.9.	70.0–79.9.	80.0–89.9.	90.0–100.0.
Actual....	43	0	0	11	0	32	18	0	0	57
Chance....	*47*	*0*	*0*	*20.25*	*0*	*26.50*	*20.25*	*0*	*0*	*47*

While this is by no means a perfect fit of the observations by the chance distribution, the latter is close enough to the former to indicate clearly the essentially chance determined character of the observed distribution. The resemblance would be still closer if we took a value of $R_{♂}$ for the computation more nearly in accord with the actual fact than is 50, the value actually used.

There is no need to pursue this point further, as it will be evident to anyone who will examine Tables I., II. and III., in the light of the points just made, that we cannot draw any conclusions of critical value regarding the normal *variation* of the sex ratio in the fowl, at least, except on the basis of families containing at least 10 individuals each.

We may next consider the mean sex ratio, dealing separately with each of the three groups. In calculating these means, and the other variation constants, it was not assumed, as is ordinarily done, that each class centered at the mid-point of the strip of base on which its frequency stands. To have done so would have involved a considerable error. Instead the actual centering point for each class was determined from the individual records. The results are shown in Table V., and from this table one can see how large the error involved in the usual statistical assumption would have been. The reason for the error is, of course, purely arithmetical, and arises from the fact that in small groups, such as the families here dealt with, only certain percentage values are possible.

Using the values of Table V., we get, by ordinary methods, the

TABLE V.

Showing the Actual Centering Points of the Several Classes in Tables I., II., and III.

Class.	Centering Point.		
	Families 10 and Over.	Families 4–9 Inclusive.	Families 1–3 Inclusive.
0 – 9.9	0	0	0
10.0– 19.9	15.46	15.68	—
20.0– 29.9	24.87	24.15	—
30.0– 39.9	35.01	33.70	33.33
40.0– 49.9	43.97	41.73	—
50.0– 59.9	53.57	51.76	50.00
60.0– 69.9	63.65	63.51	66.67
70.0– 79.9	73.09	74.58	—
80.0– 89.9	84.64	81.92	—
90.0–100.0	100.00	100.00	100.00

mean sex ratios exhibited in Table VI. We shall deal at this point only with the total distribution of Tables I., II., and III.

TABLE VI.

Mean Sex Ratio of the Domestic Fowl. Various Breeds.

Group.	$R_{♂}$.	♂♂ per 1,000 ♂♂
Families of 10 and over (Total Table I.)	48.57 ± 0.28	944
Families of 4 to 9 inclusive (Total Table II.)	49.39 ± .84	976
Families of 1 to 3 inclusive (Total Table III.)	55.07 ± 2.11	1226
Families of 4 and over (Tables I. and II. combined)	48.80 ± .33	953
Families of all sizes (Tables I., II., and III. combined)	49.45	978

These figures show that if we take all of the 22,791 chicks, on which this table is based, into account together we get a mean sex ratio of 49.45, or approximately one half of one per cent. fewer males than females. This, however, cannot be regarded as the normal sex ratio for the strains of poultry and the environmental complex here dealt with, because (*a*) the table shows an obvious influence of size of family on the sex ratio, a point to which we shall return for detailed discussion later in the paper, and (*b*) families under 10 cannot be considered as representative of the normal fertility of the *domestic* fowl. The value for families of 10 and over, namely $R_{♂} = 48.58 \pm .28$ (944), is certainly to be regarded as much nearer the true biological norm for the sex ratio of this group of poultry under the environmental conditions prevailing at the Maine Station.

Taking this value as the normal one, how does it compare with other values for other strains of poultry, and for other birds domestic and wild? Unfortunately there are very few data available for comparison. Curiously enough, this lack is most pronounced where it would be least expected,—namely in the case of poultry. Table VII. contains all the data, involving numbers large enough to be statistically of any significance, with which the writer is ac-

TABLE VII.

Sex Ratio Statistics for Various Birds.

Bird.	Total No.	$R_{♂}$.	♂♂ per 1,000 ♀♀.	Authority.
Pigeon	136	53.68	1,159	Cuénot[4]
Pigeon	1,648	51.27	1,052	Cole and Kirkpatrick[5]
Canary	200	43.52	770	Heape[6]
Canary	68	77.94	3,533	Heape[6]
Fowl	1,001	48.64	947	Darwin[7]
Fowl	2,105	44.63	806	Field[8]
Fowl	20,037	48.57	944	Pearl, this paper. Families of 10 and over.

[4] Cuénot, L., *Bulletin Sci. France et Belg.*, T. 32 (5th Ser., T. 1), pp. 462–535, 1899.

[5] Cole, L. J., and Kirkpatrick, W. F., *Rhode Island Agric. Expt. Stat. Bulletin*, 162, pp. 463–512. 1915.

[6] Heape, W., *Proc. Cambridge Phil. Soc.*, Vol. XIV., pp. 201–205, 1907.

[7] Darwin, C., "The Descent of Man," Vol. I.

[8] Field, G. W., *Biol. Bulletin*, Vol. II., pp. 360–361, 1901.

quainted. If, as may well be the case, he has overlooked some extensive tabulations of sex ratios in birds, he will be very grateful for the pertinent references.

It is evident enough from these figures that the sex ratio varies in domestic birds quite as extensively as it does among domestic mammals. In general there would appear to be a tendency toward the production of a slight excess of males among two of the sorts of birds here dealt with. This seems certainly true for pigeons. The canary results are not very clear either way. Heape gives data on the sexes from two canary breeders. The results are widely different. This difference in sex ratios Heape attributes to differences in the mode of managing the breeding birds. Here it suffices merely to point out that in any case, the numbers on which the canary ratios are based are statistically very small. It may well be doubted whether the deviations exhibited in Heape's material are in reality significant.

In the fowl the case appears to be different, all available statistics agreeing in showing a normal excess of females. It is, however, the opinion of many poultrymen of long experience, that the usual condition is practical equality of the sexes, with a small but steady preponderance of males—a sort of sex ratio similar to that which man exhibits. The practical equality of the production of the sexes in poultry has been noted by various writers.[9]

But all of the actual statistics which I have been able to find show the slight preponderance to be of females and not of males. The agreement between Darwin's figures and those of the present investigation is nearly perfect. General experience of poultrymen would indicate that the very low sex ratio got by Field could not be considered as normally representative of fowls in general. The close agreement of my figures with Darwin's, collected rather more than a decade later than Field's, would seem definitely to negative the suggestion of the latter that the normal proportion of the sexes in poultry has actually changed since Darwin's time "as a result of the breeders' desire to produce a larger proportion of females."

[9] E. g., Beeck, A., "Die Federviehzucht," Bd. I., Berlin, 1908, p. 563. Lewis, H. R., "Productive Poultry Husbandry," Philadelphia, 1913, p. 250.

It is to be regretted that more of those who have used poultry as experimental material have not kept and published accurate and complete figures of sex production.

In any case the immediate problem before us is clearly to attempt by analysis of the figures to learn what influence various factors may have in the production of the excess of females plainly shown in the extensive statistics of the present paper. The chromosomal mechanism of sex determination in the individual case would lead us to expect an equality of the sexes in statistically large numbers. But it is plain that, even with very large numbers, no such equality is attained. There must be reasons, scientifically ascertainable, for this deviation. It is our problem to find what these reasons are.

In undertaking such analysis let us first see whether the excess production of females is a secularly regular phenomenon in this stock and under our conditions.

The mean sex ratios for each year for families of 10 and over are set forth in Table VIII.

TABLE VIII.

Showing the Yearly Changes in Mean Sex Ratio. Families of 10 and Over.

Year.	Mean $R_{♂}$.
1908	46.16 ± 1.07
1909	48.33 ± .69
1910	49.96 ± .78
1911	47.08 ± .79
1912	49.59 ± .77
1913	49.999 ± .81
1914	49.83 ± .62
1915	46.46 ± .86

The data of this table are shown graphically in Fig. 1.

From the table and diagram it is evident that the excess of females is not a sporadic, but rather a regular phenomenon in our stock and conditions. While at times the ratio comes very close to 50 (*e. g.*, in 1913) it never quite reaches that value. The fluctuations of the ratio in successive years appear to be entirely random.

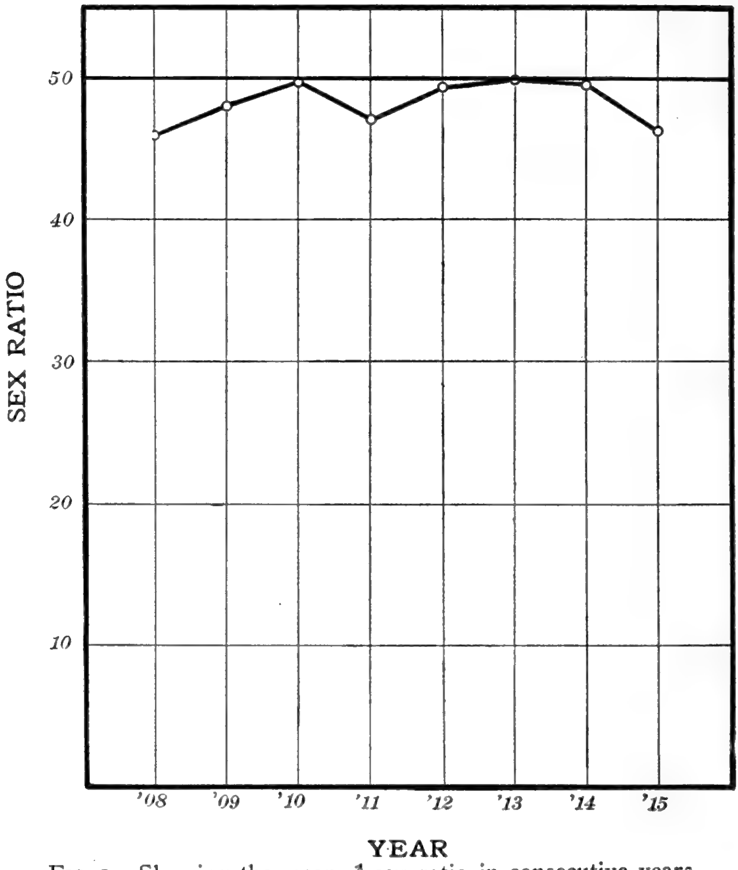


FIG. 1. Showing the mean ♂ sex ratio in consecutive years.

III. The Normal Variation of the Sex Ratio.

So far we have considered only mean values. Let us now examine the dispersion or variation constants. From the totals of Tables I., II., and III. we deduce the standard deviations set forth in Table IX, by the ordinary method.

TABLE IX.

Standard Deviation of the Sex Ratio of the Domestic Fowl. Various Breeds.

Group.	$\sigma_{R_{♂}}$.
Families of 10 and over	13.37 ± .20
Families of 4 to 9 inclusive	24.18 ± .59
Families of 1 to 3 inclusive	39.72 ± 1.49
Families of 4 and over	18.30 ± .23

The striking fact which this table brings out is the great reduction in the variation of the sex ratio from mating to mating as the progeny from the individual mating becomes more numerous.

Even with the large families, however, the amount of variation in the sex ratio is large, absolutely and relatively. Taking families of 10 the percentage of the standard deviation in the mean is 27.53.

This is of roughly the same order of magnitude as the coefficients of variation of such physiological characters as fecundity,[10] etc. There can be no question that the sex ratio is relatively a much more variable character than stature, skull form, and most other morphological characters of animals. In view of this fact, there would seem to be need of vastly more caution than is commonly exercised by writers on the sex ratio in drawing far-reaching conclusions from very small numbers.

The values for the standard deviation of the sex-ratio here obtained for poultry are of the same general order of magnitude as those of Heron[11] for man and horse, and of Weldon[12] for mice.

The form of the normal sex-ratio variation curve is of interest. In order to deal with this adequately, we must resort to the analytical methods of Pearson.[13]

The case presents some difficulties from the standpoint of graphical representation, because of the fact pointed out above, that we have dealt with the actual centers of gravity of each piece of area standing over a unit on the abscissal axis, and have not assumed as is usually done, that the center of gravity of each strip was at its mid-point. The conventional histogram does not give any representation of this distorted concentration, and hence the correct fitted curve does not *seem* to give so true a representation of the facts as an incorrect one, as will presently appear.

[10] Cf. Pearl, R., *Science,* Vol. 37, p. 228, 1913.

[11] Heron, D., *Biometrika,* Vol. V., pp. 79–85, 1906.

[12] "On Heredity in Mice from the Records of the Late W. F. R. Weldon. Part I. On the Inheritance of the Sex-ratio and of the Size of Litter," *Biometrika,* Vol. V., pp. 437–449, 1907.

[13] Pearson, K., *Phil. Trans.,* Vol. 86 *A,* pp. 343–414, 10 pls.,, 1895, *ibid.,* Vol. 197 *A,* pp. 443–459, 1901.

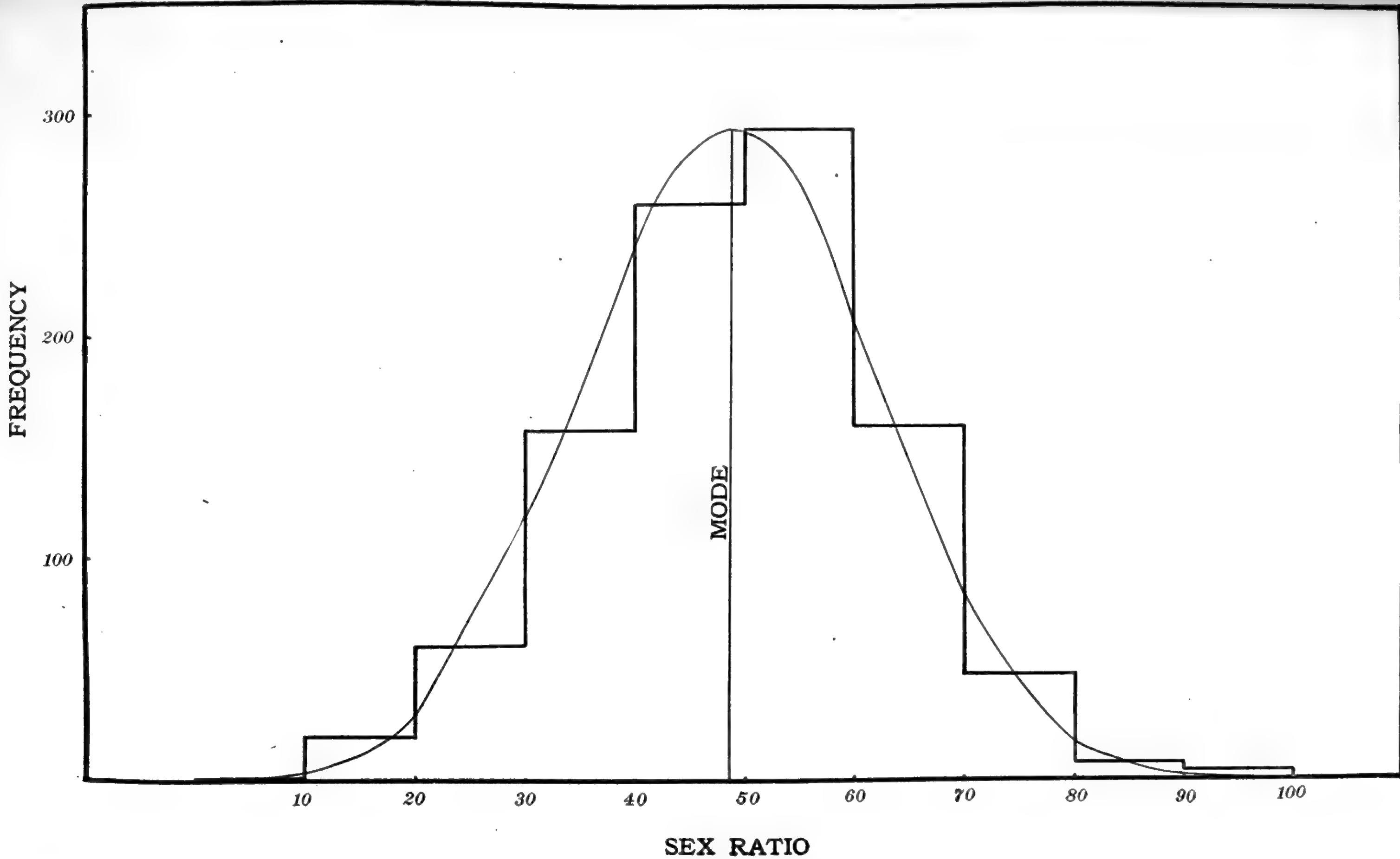


FIG. 2. Histogram and fitted curves for variation in the sex ratio ($R_{\frac{♀}{♂}}$). Frequencies supposed concentrated at centers of gravity of class areas.

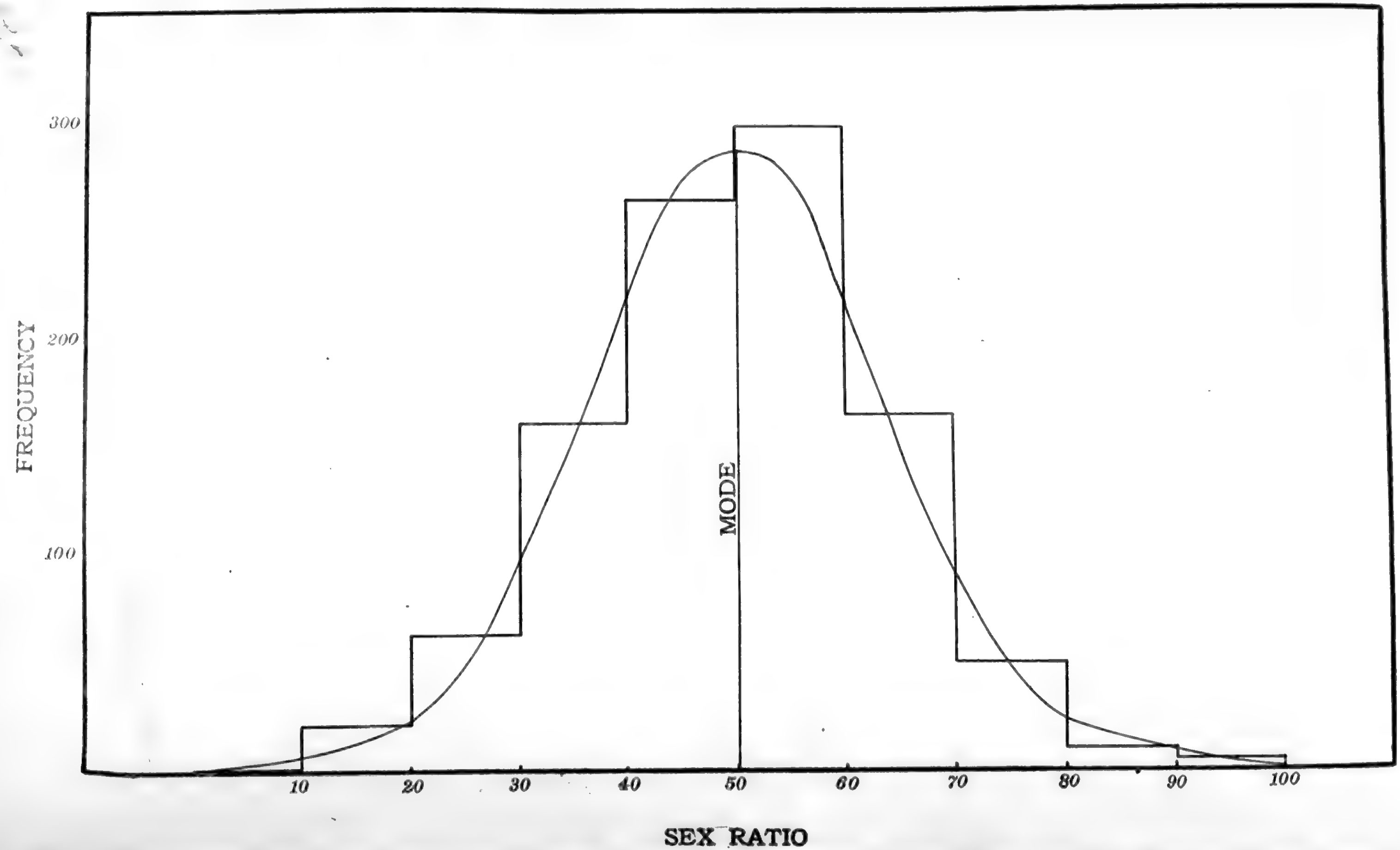


Fig. 3. Histogram and fitted curve for variation in the sex ratio ($R_{♂}$). Frequencies supposed concentrated at mid-points of class areas.

In Table X. are given the true analytical constants of the curve, and, in another column, the analytical constants on the assumption of concentration of the frequencies at the mid-points of the classes.

TABLE X.

ANALYTICAL CONSTANTS FOR VARIATION IN THE SEX RATE IN POULTRY, VARIOUS BREEDS. FAMILIES OF 10 AND OVER.

Constant.	Frequencies Supposed Concentrated at Centers of Gravity of Class Areas.	Frequencies Supposed Concentrated at Mid-points of Class Areas.
N	1009	1009
Mean	48.574	49.549
μ_2	1.7887	1.8197
μ_3	—.0093	—.2622
μ_4	11.0082	10.2718
β_1	.000015	.0114
β_2	3.4407	3.1019
κ_1	+.8814	+.1696
κ_2	+.000013	+.0506
Type	VII.	IV.
Mode	48.574	50.231
Skewness	—.0015 ± .0264	—.0506 ± .0027
y_0	315.25	42.740

The equations to these curves are as follows:

True curve:

$$y = 315.25\left(1 + \frac{x^2}{27.9292}\right)^{-9.3072},$$

Mid-point curve:

$$y = 42.740\frac{e^{-17.0718 \tan^{-1}(x/11.2271)}}{\left(1 + \frac{x^2}{126.0478}\right)^{37.9784}}.$$

The fitted curves and the histograms are shown in Figs. 2 and 3.

From the data and the diagrams, the following points are to be noted:

1. The distribution of the sex ratio about the mean value is approximately symmetrical, and, if sufficiently large families are used, leads to high contact of the curves at both ends of the range.

2. The distribution is *apparently* more skew than it actually is because of the fact that this graphical representation makes no ac-

count of the concentration of the frequency at other than the mid-points of the class areas.

3. The fitted curve makes it possible to make some rather definite statements as to the probability of the occurrence, as a result of chance merely, of distinctly aberrant sex ratios. Poultry papers very frequently, and scientific journals rather more often than would seem compatible with any clear grasp of the theory of chance, contain statements about marvelous deviations from the normal sex ratio in particular families or small groups of families. Usually such widely divergent sex ratios are most uncritically taken to prove either the inheritance of a special sex tendency in a particular line of breeding, or the influence of some external environmental agent upon sex determination. If, for example, a poultry breeder finds that out of twenty chickens from one pair of parents, fifteen are pullets, he is distinctly apt to regard this as a wonderful phenomenon, worthy of his best exegetic powers. But our present statistics show that, if we deal with families of twenty chickens for example, it is to be expected on the basis of chance alone, the following relations will hold.

15 or more chicks will be pullets in 56 out of every 1,000 families of 20
16 or more chicks will be pullets in 26 out of every 1,000 families of 20
17 or more chicks will be pullets in 12 out of every 1,000 families of 20
18 or more chicks will be pullets in 5 out of every 1,000 families of 20
19 or more chicks will be pullets in 2 out of every 1,000 families of 20
20 or more chicks will be pullets in 1 out of every 1,000 families of 20

It needs no particular emphasis on these figures to indicate that before aberrant sex ratios can be considered indicative either of environmental or hereditary effects, it will be necessary to show that they occur with such frequency as to exceed considerably that expected on the basis of chance alone.

IV. Prenatal Mortality and the Sex Ratio.

The first suggestion which comes into one's mind in attempting any analysis of the causes of a deviation of the sex ratio from equality, is that the prenatal mortality has been differential in respect to sex. It is commonly held by statistical writers that this is true of some portion, at least, of the prenatal mortality in man. In still births there is a greater excess of males over females than in living births. The reviews which prevail among statistical writers regarding this matter are well put by Nichols[14] (p. 269) in the following passage:

"Obviously the main cause of the great preponderance of male stillbirths resolves itself into the question of the comparative mortality or death rate of the male and female sexes during the intrauterine period of existence. Vital statistics have shown clearly that there are material differences in the mortality of the two sexes, the death rates among males being, in general, higher than among females throughout nearly the entire period of life, and the average duration of life of females being greater than of males. During the adult and later periods of life this difference is largely or partly explainable on the ground of the greater stress and strain and liability to injury imposed by the greater responsibilities, more laborious occupations, and greater exposure of men, and their greater indulgence in vicious and morbific habits; these factors scarcely being offset by the perils incurred by women during the child-bearing period. But the same greater mortality of males occurs, and in the most marked degree, even in the intrauterine period of existence and in the early years of life before the factors mentioned begin to be operative; it is therefore obvious that the male constitution is intrinsically weaker, less hardy, and more susceptible to morbific and mortific influences, and has less vitality and resisting power against disease, than the female. The cause of this innate disparity of vitality between the two sexes we do not know; but the fact it exists, that the antenatal mortality and death rate of males much exceeds that of female fetuses, accounts for the great excess of male over female still-births."

The demographic objects, in the study of sex ratios, are somewhat different than the purely biological. In the present instance, and generally in purely biological studies on the proportion of the sexes, what we really wish to know is the true proportions in which *zygotes* of the two sexes are *initially* produced. This can not be directly observed in higher vertebrates, owing to the occurrence of prenatal mortality at all stages between the fertilization of the egg and the birth of the young. The earliest easily observable datum plane which one has upon which to base a conclusion as to the sex proportions in the zygotes at the moment of their production, is the sex ratio at birth. Obviously the prenatal mortality may have influenced

[14] Nichols, J. B., *Mem. Amer. Anthropol. Assoc.*, Vol. I., Part 4, pp. 249–300, 1907.

this ratio, and caused a deviation from the initial zygotic ratio. But it is equally obvious that the post-natal mortality, whether differential in respect of sex or not, can give us no direct aid in estimating the initial zygotic ratio from the observed ratio at birth. Hence the post-natal mortality has no special interest in connection with sex studies to the biologist, though it does have to the demographer, who is concerned, among other things, with the sex distribution of populations throughout life.

In poultry, the hatched chicks show a certain fairly definite ratio of males to females as we have seen. Does this observed ratio at birth differ from the initial zygotic sex ratio? To answer this question, it is only necessary to determine whether the sex ratio of the zygotes which die before hatching is, or is not, different from the sex ratio of those which hatch. Theoretically this should be simple. Practically it is not wholly so. The difficulty is that the sex of the zygote is not distinguishable by any practical means until the embryo reaches a certain more or less advanced stage of development. If zygotes die before that stage of development is reached, as some do, then it becomes impossible practically to determine whether that particular moiety of the mortality was or was not differential in respect to sex. Theoretically, of course, one should be able to sex every zygote by means of a cytological examination of its chromosomes. Practically, however, this is not to be seriously considered.

The result is that in the chick it is practically impossible to say absolutely whether the mortality between the fertilization of the egg and about the tenth day of development of the embryo is or is not differential. We can, however, determine, with great precision, the facts regarding the mortality from the tenth day to the end of incubation. This has been done by the writer, during the past two years. Every egg in which the embryo developed to the tenth day or beyond, and died before hatching, has been opened, the embryo removed and dissected, and its sex and certain other characteristics recorded. This is distinctly tedious and unpleasant work, but there appears to be no alternative method of getting certain sorts of information very essential in the analysis of many problems.

The figures for the sex ratio of the dead embryos for the years 1916 and 1917, the only ones for which complete records are at hand, are given in Table XI.

TABLE XI.

Sex Ratio of Embryos Dying Between the Tenth Day of Incubation and Hatching. Various Breeds.

Year.	♂♂.	♀♀.	$R_{♂}$.
1916	325	343	48.7 ± 1.30
1917	602	651	48.0 ± .95
Totals	927	994	48.3 ± .77

These numbers are large enough so that the results are clearly reliable. And it is equally clear that this portion of the prenatal mortality is not differential in respect to sex. For the season of 1916 the sex ratio of the living chicks at hatching was

$$R_{♂} = 48.3 \pm 0.89,$$

a value not significantly different from that for the prenatal mortality given in Table XI. The sex-ratio figures for the living hatched in 1917 are not available at the time of writing, but it is evident enough, if we compare the figures of Table XI. with those of Table VI. (p. 422), that there is no differentiation in respect of sex of the mortality of the last eleven days of the prenatal life of the zygote.

Cole and Kirkpatrick's[5] data for pigeons appear to indicate that probably the prenatal mortality in that form is not differential. It must be said, however, that they take account of only a small amount of the total prenatal mortality, those dying at the very end of incubation, then group this with the *post*-natal mortality of the first five days after hatching. The general impression given by this data, however, is that the prenatal mortality is probably not differential in the pigeon.

It is evident from the data of Table XI., that the explanation for the preponderance of females in poultry is not to be found in the greater frequency of deaths of males during the last eleven days of incubation. But there remains a certain mortality during the first ten days. We are in position to say, on the basis of evidence already given, that in the Maine Station flock male and female zygotes are present in the proportion indicated by $R_♂ = 48.5$ at the time when the zygotes are 10 days old. Were they initially present in equal numbers and did enough more males than females die during the period to the tenth day of incubation to produce the $R_♂ = 48.5$ status? Here we would call attention only to two points. The first is that in the flocks which have furnished the statistics here dealt with, the rate of prenatal mortality before the tenth day of incubation has always been low—so low that if differential mortality within this period is to be adduced as the explanation of the observed sex ratio, it would be necessary to assume that practically *every* embryo which died within these first ten days was male. A theory can only be regarded as highly improbable which demands that during any period of life all naturally occurring deaths are of individuals of the same sex, when it is known to be the fact that in all other periods of life the individuals of the two sexes die in numbers roughly proportional to the numbers living of each sex.

In the second place, it is in the highest degree improbable that there is an abrupt change in the mode of incidence of the mortality with respect to sex at exactly the tenth day of incubation. Yet such an abrupt change would be demanded by any theory which makes differential mortality the explanation of the observed sex ratio in the fowl. From the time when the embryo has developed sufficiently to make it possible certainly to distinguish the sexes in poultry by macroscopic examination of the gonods, we know that the mortality is either not differential at all with respect to sex (prenatal mortality), or is at most only slightly so (possibly so in postnatal mortality though the point has not been fully investigated yet). In the absence of any evidence favorable to such a view, it could only be regarded as a highly improbable speculation to say that in the very earliest stages of embryonic development all deaths are males.

We are justified, I think, in concluding that in the flocks of poultry here dealt with, and probably in the fowl generally, that *prenatal mortality is not differential in respect to sex, and that in consequence the observed sex ratio at birth is substantially the same as the initial zygotic sex ratio.*

V. Conclusion.

The purpose of this paper is to present data regarding the normal sex ratio in the domestic fowl. The data involves something over 22,000 chicks. The normal variability in sex ratio is discussed. It is hoped in a later paper to present a further analysis of the subject dealing with the influence of various internal and external factors upon the sex ratio. It was expected to include such discussion in the present paper but for reasons explained at the beginning of the paper this is not now possible.

MECHANISM OF OVERGROWTH IN PLANTS.

By ERWIN F. SMITH.

(*Read April 13, 1917.*)

I. Introductory.

For 12 years I have been an eager student of overgrowths in plants, partly on account of agricultural phases of the problem which are of economic importance but chiefly because they have seemed to me to offer a clue which might lead to the solution of the greater and very obscure problem of the origin of malignant human and animal tumors.

For a long time I have believed that the direct cause of these plant tumors (of all malignant tumors for that matter) must be chemical substances liberated in the tissues by parasites. It is not a far cry to such a view, especially where parasites are known to cause the overgrowth, and no doubt many other persons have held the same view and have stated it more or less definitely. I expressed it clearly in 1911 in our first crown gall bulletin (U. S. Dept. of Agric., B. P. I., Bul. 213, p. 175).

The difficulty has been to determine the nature of these chemical substances. This is still unsolved so far as relates to the products of gall-forming larvæ of all kinds, and apparently must so remain until they can be grown in quantity in pure culture so as to give to the chemist an abundance of material for his studies. The chemist is very greedy of material and without a great abundance he can seldom accomplish much. Various gall-forming fungi and bacteria offer easier problems because they can be cultivated in flasks on simple culture media in any desired quantity and their products determined with a minimum of labor.

This, rather than the analysis of tumors, is, I am satisfied, the proper method of procedure, because the cells of a tumor are only the cells of a plant or animal grown under an abnormal stimulus, which stimulus, it is very likely, is not only very minute in quantity but also used up during the growth of the tumor cells, that is, converted into something quite different and entirely inoffensive. For this reason analyses of tumor tissue should give only about the same kind and quantity of products as normal tissues in which there is an equally rapid movement of food-stuffs, and in which there is an equally rapid growth, and this is about what tumor analyses thus far have shown. In flask cultures, on the contrary, the products of parasitic growth accumulate and can be locked up for future study.

What I have done, in addition to speculating, is to grow various strains of *Bacterium tumefaciens,* the crown-gall organism, in pure culture in quantity in cotton-plugged Jena glass flasks for chemical examination. Being a member of the United States Department of Agriculture, the greatest coöperative research institution in the world, it has been easy to come into touch with expert organic chemists and through them to have determined for me the various substances produced by the crown-gall organism out of river water, peptone and grape sugar, *i. e.,* substances corresponding to or approximating those which occur naturally in the cells of the plant. These flasks were inoculated with great care and watched as to their behavior. Before turning them over to the chemist, Petri-dish agar plates were poured from each one to determine whether they were still pure cultures. The analyses were then made *pari passu* with inoculations into susceptible plants to determine whether the cultures were still pathogenic. In this way various flasks were tested and worked up separately, with, in the main, concordant results. The inoculated flasks behaved properly, the agar-poured plates yielded uniform normal-looking colonies, and subcultures from colonies derived from each flask were subsequently inoculated into plants with the production of crown galls in every case except that of the isolation from poplar, which was known to be no longer pathogenic when the experiment was begun. All of the flasks had remained pure cultures and were in good condition for the chemist, who worked them over quickly. These cultures originated from single colonies selected from agar-poured plates made from tumors on hop, Paris daisy, rose and poplar, and represent at least two strains of the crown-gall organism.

II. Chemical Findings.

Slide No. 1 (Table I.) shows the chemical findings. On this slide I have starred the substances with which I have now produced overgrowths in plants and have italicized those which Dr. Jacques had previously found in his experiments on animal eggs to be most effective in causing unfertilized eggs to begin to grow.[1] That there should be so many of these egg-starting substances excreted by a tumor-producing parasite is not only astonishing but extremely suggestive. All of them are substances which pass readily through protoplasmic membranes.

TABLE I.

Showing Products of *Bacterium tumefaciens*.

* *Ammonia*	Acetone
* *Amines*	* *Acetic Acid*
* Aldehyd	* *Formic Acid*
Alcohol	*Carbonic Acid* (?)

I have added carbonic acid of my own accord, since I did not ask the chemists to search for it: (1) because the crown-gall schizomycete must be very unlike other organisms if it does not produce some carbonic acid as the result of its growth, although certainly not enough is developed to appear in fermentation tubes as the gas CO_2; (2) because the excess of leaf-green (chlorophyll bodies, which assimilate CO_2) in the deeper tissue of galls on Paris daisy suggests presence of carbonic acid in excess of these tissues; and (3) because carbonic acid also is one of those substances found by Loeb to stimulate the development of unfertilized eggs. My experiments are still under way, none of them are really completed, and today I will only call your attention to a few of my results, some of which have already been published,[2] while others are here mentioned for the first time. I would call attention especially to the substances the names of which I have starred as compounds with which to experiment singly and combined, and in a great variety of dilutions. With each one of these substances, in the absence of bacteria, I have obtained on suitable plants decided overgrowths,

[1] Loeb, "Artificial Parthenogenesis and Fertilization," 1913.

[2] *Jour. Agric. Research,* January 29, 1917.

growths which I think I am warranted in designating as incipient crown galls. The overgrowths I have obtained are small, as was to be expected from the application of a single slight stimulus. They do not continue to grow because they are the response to an abnormal outside influence of very limited duration, or to put it in another way, because there is no parasitic organism back of the growth, as in the case of the natural crown gall, to continually stimulate it by means of its excretions. In this particular, that is in the continuous slow introduction of these substances into the tissues after the manner of the parasite, I have not yet found it possible to imitate nature, but in view of the overgrowths I have obtained by a single slight stimulus it can no longer be doubted that even in the absence of the bacteria the slow continual oozing into growing tissues of the dilute acids, alkalies and other substances named would produce a crown gall of any size desired. So long as the stimulus is applied, and in nature it will be applied as long as the bacteria are present in the tissues and continue to grow, so long the growing tissues must respond.

Before passing I wish once more to call attention to the italicized names, and to urge all students of overgrowths to read Dr. Loeb's book, since these tumor-producing substances, as I have said, are those Dr. Loeb has found most active in starting the development of animals out of unfertilized eggs.

We will now pass to slides showing results obtained with ammonia, dimethylamine, formaldehyde, acetic acid, and formic acid (slides exhibited).

III. The Mechanism of Overgrowths.

We now come to the inquiry embodied in the title of this paper —what is the mechanism of these overgrowths? Is it a chemical or physical action? It is plain that the response is due to soluble substances poured out, as a result of their metabolism, by parasites present in the tissues, but given off in such small quantities that they act not as a poison but as a growth-stimulus. That many poisons when applied in minute doses do act as stimulants of one kind or another is already well known, both in medicine and in agriculture. That suspension colloids would be precipitated, proteins split, and very marked osmotic disturbances set up within the mechanism of the delicately balanced colloids of the cell upon introduction of these dilute, non-plasmolyzing bacterial acids, alkalis and other products, must be apparent to anyone who is at all familiar with the colloidal chemistry of the cell; and later, by means of physical chemistry, we ought to be able to determine at least some of the physical-chemical steps in the process of the abnormal cell division brought about by these disturbing substances.

For the present I interpret the growth in crown gall as due primarily to a physical cause, viz., to an increase in the osmotic pressure due to the heaping up locally of various soluble substances excreted by the bacteria as a result of their metabolism. This would lead to a movement of equalization. Water containing dissolved food stuffs would move toward the tumor and the stimulating acids and alkalies would move outward so that theoretically the strongest tendency to overgrowth should occur in the periphery of the tumor where, as a matter of fact, it does occur. Also in malignant human tumors the growth is peripheral. *Why is it peripheral?* If this hypothesis is correct we ought to be able to detect at least a slight difference between the concentration of salts in fluids on the periphery of a tumor and in the normal tissues just beyond it. This, I believe, could be determined best electrically, although, if the difference is considerable, the coarser method of extraction of the juice of tumors and of adjacent sound tissues and determination whether there is any depression of the freezing point in the former might yield interesting results. One test made for me by Mr. Rodney B. Harvey indicated that there is a concentration of substances in the juice of daisy tumors, *i. e.,* there was a lowering of the freezing point, but no thorough study has been made. This I contemplate taking up in conjunction with physicists of the Department of Agriculture.

The reason I have for thinking the phenomena of plant overgrowth is primarily physical is the fact that it can be obtained by a great variety of substances not the products of parasites, anything in fact, which disturbs tissue equilibriums without destroying cells, seems to be capable of causing overgrowths, which cease, of course, as soon as the stimulus is exhausted. (See Mechanism of Tumor Growth in Crown Gall, *in* Jour. Agric. Research, Jan. 29, 1917.)

I have been asked in what way these overgrowths differ from the ordinary healing of wounds. The growth while excessive is probably not fundamentally different from a wound reaction, but then, for that matter, we may regard all tumors as so many efforts at healing which come to naught because they are continually modified and frustrated by the presence of a parasite, or in animal cancers, let us say, since we do not know their cause, by an abnormal and oft repeated stimulus of some sort, most easily explained in the absence of exact data by the hypothesis of a parasite, especially since the same phenomenon in plants can now be referred to a definite microörganism.

IV. The Kind of Tumor Depends on the Type of Cells Stimulated.

The first crown galls I studied seemed to me to be overgrowths of the conjunctive tissues and most of our many inoculations up to the end of 1915 produced that type of tumor which corresponds, I believe, to overgrowths of the connective tissue of animals and which I have called plant sarcomas.

We had found indeed, as early as 1908–9, and had produced by bacterial inoculation, plant tumors bearing roots, but the full meaning of this discovery, as related to cancer, did not occur to me until early in 1916, when I found crown-gall tumors bearing leafy shoots on some of our inoculated hothouse geraniums. Beginning with this discovery I made numerous inoculations in the leaf axils of various plants which resulted in the production of leafy tumors, and subsequently I produced them freely on leaves and on cut internodes where no buds occur normally. Tumors bearing roots have also been produced by us on the top of plants, and in one cut internode of tobacco I succeeded in producing a tumor which bore flower buds. These perishable root-bearing and shoot-bearing tumors I regard as plant embryomas and have so described them.[3]

These experiments render it probable that every growing organ

[3] *Journ. Cancer Research,* April, 1916, p. 241.

normally contains multipotent or totipotent cells which usually remain dormant, but which under a strong stimulus are capable of developing into either the whole organism or into some considerable part of it, what is developed out of them depending on the degree of differentiation of the cells at the time they are stimulated. We may regard these leafy shoots (produced sometimes in great numbers where no buds occur normally) either as going to show that potentially there is no difference between germ-cells and young somatic cells, or else that dormant "germ-cells" are widely and abundantly distributed among the somatic cells, ready to develop into the whole or a considerable part of the organism whenever a sufficient stimulus is applied. Those who wish further details respecting these recently produced and peculiar crown galls containing fragments of the embryo plant are referred to a special paper on the subject in the "Bulletin of the Johns Hopkins Hospital" for September, 1917.

V. Bearings of These Discoveries.

That these discoveries have many interesting bearings goes without argument. Some of these bearings may be mentioned:

(*a*) On the origin of insect, nematode and fungous galls;

(*b*) On the formation of thyloses in vessels;

(*c*) On the origin, through absorbed poisons, of certain plant diseases whose etiology is very obscure, such as peach yellows, peach rosette, and the various mosaic diseases;

(*d*) On the origin, in the same way, of various plant and animal monstrosities;

(*e*) On various problems of modification by slight changes in environment;

(*f*) On possibility of normal wide distribution of dormant germ-cells among somatic cells;

(*g*) And, finally, on the etiology of various human and animal tumors.

VI. Earlier Work and Reasons Why it Remained Sterile.

I must here refer to some earlier work which remained sterile so far as any influence on tumor etiology is concerned (*a*) because done under the idea that tumors are due to the existence of specific overgrowth stimuli; (*b*) because done with substances which could by no possibility be conceived to be the product of parasites; and still more (*c*) because the experiments fell on stony ground, that is into the unreceptive minds of a generation of pathologists preoccupied with quite other ideas and generalizations respecting tumor growth.

I refer more particularly to Dr. Hermann von Schrenk's papers (1903 and 1905) on intumescences in cauliflower plants due to copper salts,[4] and to Dr. Bernhard Fischer's paper on overgrowths of epithelium due to the injection of scarlet red and indophenol into rabbit's ears.[5]

Fischer's paper in particular pointed the way clearly toward the solution of the cancer problem, but it was received very coldly and he became discouraged, and no one else took up the suggested clue.

What Fischer obtained was downgrowths of epithelium into the connective tissue, strikingly suggestive of epithelioma, but, because these invading epithelial cells subsequently ceased to grow, with disappearance of the stimulus, and were finally absorbed, as one might reasonably have predicted would be the case, they were held to throw no light on the cancer problem; but if specialists had then assumed that quite other substances than scarlet red and indophenol can cause overgrowths, as we now know, and that some of the substances may be the products of the tumor-producing parasites, as also we now know, how suddenly luminous the whole subject would have become and what an incentive it would have given, and *still gives,* to further research!

[4] See especially Report of Missouri Botanical Garden, 1905, p. 125.

[5] Muenchner med. Wochenschrift, 1906, p. 2041.

RECURRENT TETRAHEDRAL DEFORMATIONS AND INTERCONTINENTAL TORSIONS.

By B. K. EMERSON.

(Received May 5, 1917.)

Starting a long time ago to write a review of a very interesting and remarkable book I have woven so much of my own musings with the text that I may not well put upon the author the responsibility therefor.

The book in question is "Die Entwickelung der Kontinente und Ihere Lebewelt. Ein Beitrag zur Vergleichenden Erdgeschichte; von Dr. Theodor Arldt, Oberlehrer an der Realschule in Radeberg, mit 17 Figuren und 23 Karten." Leipzig. Wilhelm Engelmann. 1907. 729 pp., large 8°. It is a ponderous volume comparable to Walther's "Einleitung" or Suess' "Antlitz der Erde," but more systematized, and condensed to the limit; so that an exceedingly great amount of painstaking and acute research, covering many diverse fields, is brought into remarkably small compass.

Just two thirds of the book is devoted to a biogeography of the past and the present. After chapters on method comes a general survey of the distribution of plants and animals in the present and Cenozoic, in the Mesozoic and in the Paleozoic, with discussions of their evolution and many "Stammbäume" to summarize this evolution.

The principal purpose of the study is to get all the light which the distribution and probable migrations of the different classes of animals and plants can throw upon the evolution of the continents. A first chapter takes a position adverse to the so-called "permanence of the continents." Only certain large portions of the great ocean seem to have been permanent.

This section is illustrated by a full and clear chart of the biological provinces and regions and five charts which show the migrations of the families of the vertebrates, and ends with two valuable paleontological chapters which give the first appearance and duration of each of the large groups of plants and animals. In these tables the part of the earth's history before the beginning of life is assumed to be to the part since as 5 to 3.

The second or geological section of the book begins with a condensed systematic discussion of the geological data for the determination of the outlines of the former continents and a comparison of these data with those derived from the distribution of animals.

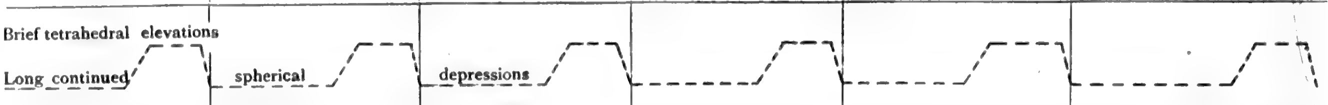
These sections take up the larger part of the volume and then four short chapters on Ice periods; times of volcanic activity; mountain formation, and transgressions prepare for the central idea of the book, viz.: the statement in tabular form of the cycles of the evolution of the earth as given below and the explanation of the same as due to a succession of tetrahedral deformations, producing broad elevated continents and small oceans; and spherical recoveries, causing broad transgressions of the ocean with low lands.

To his table of the geological cycles here presented I have added the statements regarding the changing carbonic acid content in the air, and the changes in climate and evolution, drawn largely from the papers of Chamberlin which are cited below.

The author accepts the tetrahedral deformation of the earth as the basis of the explanation of these cycles.

The law of least action, he explains, demands that the somewhat rigid crustal portion of the earth keep in contact with the lessening interior with the least possible readjustment of its surface. As a tube collapses into a triangular prism a shrinking sphere tends by the law of least action to collapse into a tetrahedron, or a tetrahedroid, a sphere marked by four equal and equidistant triangular projections; and the earth with its three about equal and equidistant double continental masses triangular southward with three intervening depressed oceans triangular northward, its northern ocean and southern continent, with land everywhere antipodal to water, realizes the tetrahedroid status remarkably. When repeatedly in former geological ages ocean waters separated Europe and Asia, the agreement with hypothesis was still more marked. Gravity observations and geodetic measurements agree therewith, even giving for Asia a larger tetrahedroid surface than for Europe, and many other geological homologies point in the same direction.

Table of Geological Cycles.

Archæan Cycle.		Algonkian Cycle		Early Paleozoic Cycle.		Middle Paleozoic Cycle.		Late Paleozoic Cycle.		Mesozoic-Cenozoic Cycle.	
Archæan		Algonkian		Cambrian to Ordovician		Silurian to Middle Devonian		Middle Devonian to Early Permian		Triassic to present	
 Brief tetrahedral elevations Long continued		spherical		depressions							
	Archæan Mountain System	Lower Algonkian Transgression with peneplanation	Hebridian and Laurentian Mountain Systems (Algonkian)	Cambrian Transgression	Brazilian and Green Mountain Systems	Silurian Transgression	Caledonian Mountain System	Devonian and Carboniferous Transgression	Hertzinian and Appalachian Mountain Systems	Mesozoic Transgression, broken by Laramide Revolution with mountain making and many volcanoes but without extensive glaciation	Cordilleran and Alpine Mountain Systems
Absorption of CO_2 Greenville Limestone	Emission of Granite and CO_2	Absorption of CO_2 Huronian Limestone	Emission of Diabase and CO_2	Absorption of CO_2 Cambro-Silurian Limestone	Emission of Diabase and CO_2	Absorption of CO_2 Wenlock and Niagara Limestone	Emission of Diabase and CO_2	Absorption of CO_2 Onondaga and Mountain Limestone Coal Beds	Emission of Porphyry Porphyrite Melaphyr CO_2 Volcanic Dust	Absorption of CO_2 Chalk and Nummulitic Limestone Coal Beds	Emission of Basalt Trachyte Phonolite, CO_2 Volcanic Dust
	Archæan Glaciation		Precambrian Glaciation		Ordovician Glaciation		Devonian Glaciation		Permian Glaciation		Glacial period
			Arid variable climate	Warm equable climate	Arid and variable climate	Warm equable climate	Arid and variable climate	Warm equable climate	Arid and variable climate	Warm equable climate	Arid and variable climate
			Depleted Marine Life	Expansion of Marine Life	Depleted Marine Life	Expanded Marine Life	Depleted Marine Life	Expanded Marine Life	Depleted Marine Life	Expanded Marine Life	Depleted Marine Life
	Great revolution in high latitudes		Great revolution in low latitudes						Great revolution in high latitudes		Great revolution in low latitudes

The axis of figure of the forming tetrahedroid chanced not to coincide with the axis of rotation and the latter gradually shifted from near Behring Straits to its present position, which is one of stable rotational equilibrium. This happened in pre-cambrian time.

At this point comes the interesting novelty in the tetrahedral theory. The development of the tetrahedral form from shrinkage would proceed but a little way when rotation would tend to reproduce the spheroidal form. The tetrahedroid shape would be pushed beyond the strength of the material and collapse would ensue, with reassumption of a more spherical form. In a long period of rest the crust would be recemented and strengthened and the continued escape of heat would then tend to develop the tetrahedroid again and rotation would again restore the spheroid.

This is brought into connection with the six great geologic cycles as follows: The solidified crust becomes by interior shrinking slightly tetrahedral. This involves elevation with glacial conditions, large continents, inner crustal tensions, foldings, fissuring, mountain-making and outpouring of lava. Through this fissuring the crust becomes weakened, the tangential force of rotation becomes predominant, restoring the spheroid; great transgressions of the oceans then intervene while mountain-making and volcanic activity approach a minimum. In the relatively long time of submergence and quiet the faults and fissures are sealed up by the circulating waters and the earth becomes again rigid enough to permit the oncoming of a second period of tetrahedral deformation. The oceans are deepened and contracted, the continents elevated and enlarged with mountain-making and this becomes again the cause of a glacial period and volcanic activity. This cycle is several times repeated.

We are now in a period of deformation, as is shown by the marked tetrahedral features of the earth, the sinking of the Pacific coral region, the abundant volcanic and earthquake activity and the just passed glacial period.

The author assumes the nebular hypothesis and Arrhenius's theory of the condensed-gaseous condition of the earth's interior, and noting the unimportance of the present equator for the structure of the earth, and the great importance of the band going through the three Mediterraneans; that is, THE Mediterranean and the East and West Indian Seas, he assumes that the equator once went parallel with this band and about 10° south of it, with the north pole at Behring's Straits and the axis at right angles to the ecliptic. Then a band on either side of this equator including "the zone of the intercontinental seas" or of the above three Mediterraneans, because of the powerful tidal influence in the early ages, would be a zone of distortion and rupturing during the crust-forming period and of weakness since. This is Lowthian Green's twinning plane.[1] The author follows Green also in assuming that in addition to this equatorial flood-tidal fracture zone and at right angles to it would run a meridional ebb-tidal fracture zone, which would pass through the two points where the old and new equators bisect each other and would be the meridian bordering the Pacific and including Australia and Antarctica.

This equatorial fracture zone he takes to explain the Mediterranean zone and the transverse fracture zone to explain the permanence of the Pacific.

For the establishment of this position he cites that part of the reviewer's article on the tetrahedral earth[2] where Green's theory is explained at length but not accepted. The later postulate of the author that the earth has many times taken the tetrahedral form, collapsed, and become again so rigid that it could again suffer tetrahedral deformation would seem to militate against a continuous inheritance of weakness in this region.

The zone of fissuring remained a plane of weakness and the greater elevation of the northward parts of the three triangular land masses or coigns, or "shields" bringing them to move in a longer circle and so to lag behind, caused a westward torsional motion of these three portions of the coigns as compared with the parts south of the aforesaid zone.

The author accepts the suggestion first made by the reviewer[3] that the depressed ocean bottoms brought by sinking to move along shorter radii must exert pressure against the west sides of the con-

[1] T. Lothian Green, "Vestiges of a Molten Globe," Honolulu, 1875, Pt. II, 1887.

[2] "The Tetrahedral Earth and the Zone on the Intercontinental Seas." Pres. Add., *Bul. Geo. Soc. of Am.*, Vol. II., 1900.

[3] Loc. cit., p. 65.

tinents, and makes it the basis of his classification of mountains and of his explanation of the chains around the Pacific.

He follows Reyer and Suess in explaining the chains of southern Asia as "Abflussbogen," outflow chains due to flowage down a slope from the elevated coign or shield of "Angara land" or Manchuria. The festoon chains along the east of Asia are "Zerrungsbogen," dragged chains due to the separation of ocean bottom and land because of the eastward drag caused by the depression of the ocean bottom and its differential eastward motion. These terms are discussed later in this paper.

Andes and Cordillera are "Stauungsbogen," heaped up chains" caused by eastward pressure of the sunken Pacific ocean bottom and this pressure is transferred eastward to cause the eastward curving Antilles and the submerged South Georgean eastward curve south of South America.

The sinking of the Caribbean is an accessory cause of the Antilles and the sinking of the Mediterranean the sole cause of the chains from Alps to Caucasus.

It is very interesting that the hypothesis of a tetrahedral earth can be thus utilized in the fundamental explanations of the past conditions of the earth and this may be said to add to the arguments in favor of the hypothesis.

Wholly novel is the suggestion that tetrahedroid may have alternated repeatedly with the spheroid. The earth is thus a composite photograph of several tetrahedra, as indicated in the title of this paper.

In the following the reviewer presents (1) a different explanation of the chains in the Mediterranean zone as due to northward flow (rather than to thrust from the sinking of the Mediterranean), an explanation which was advanced in his presidential address, and (2) a new exposition of the torsional movements which differs from the book here reviewed as well as from the above-cited article of the reviewer.

The Torsional Movements.

The very lucid map of the book showing the tetrahedral deformation is here reproduced (Fig. 1) and the reviewer has added arrows at equidistant points on the map, in order to make clear the following explanation.

Under the first arrow, Europe-Africa has not suffered torsion and remains, as Green's map shows, closely occupying the place of the original tetrahedral elevation. There has been no torsional motion between Europe and Africa, because of the small size of the former and the large size of the latter and the parallel relations of the

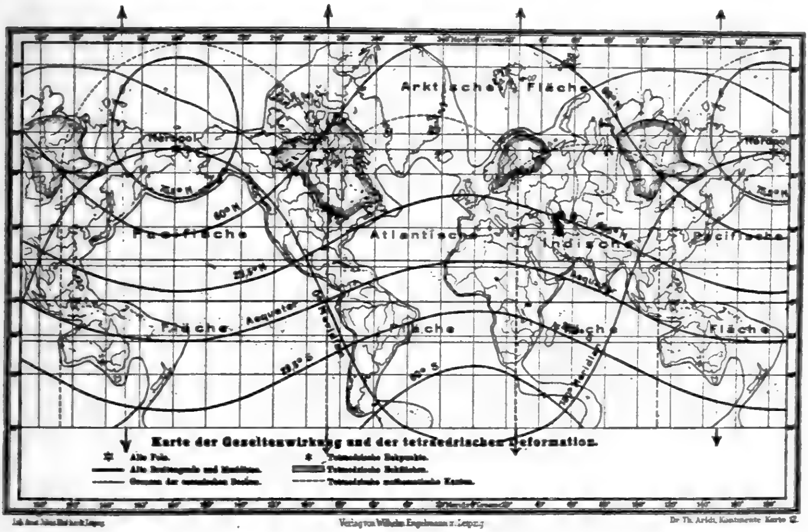


FIG. 1. Map showing the tetrahedral deformation.

old and new equators. Underneath the second arrow is Australia and since the whole of western Australia is unfolded Archæan this meridian may represent the original and symmetrical position of the second tetrahedral elevation, and its north part (Asia) being abnormally large has lagged westwardly, until in its last position it coalesces with Europe. The map shows by a dotted line the depressed area north of the Caspian—the former northward extension of the Indian Ocean.

The next arrow shows that North America is in or near its true tetrahedral position, while South America has drifted eastward, due to its lesser elevation and the excessive eastward thrust of the exceptionally broad South Pacific sea bottom, which was an abnormally large depression from the beginning. Thus the largest elevated land mass has made the only lag, the antipodal largest depressed area has made the only advance. This lessens by one third the amount of torsional movement heretofore assumed in the hypothesis and locates it differently.

Africa is thus the torpid center of the earth in this sense and not in the more adventurous dream of Sacco,[4] that it is the inert center from which the continents have drifted away in great floes as a recoil when the Moon was torn from the bed of the Pacific, an event probably never seen by any "glimpse through the corridors of time."

I will not suppress the fanciful suggestion that if Angara land—the Asian nucleus, or Manchurian shield—was formed (with Australia as its southern apex) and then drifted westward, in a later deformation Angara land in its new position may have grown southward, producing the triangular peninsula of India, which is a dwarf Africa, in shape a true south apex of a tetrahedral coign.

The reviewer has elsewhere suggested that the westward movement of these old lands, to wit, Asia, and in lesser degree North America, may have been not wholly a slipping on some deep plastic layer but rather in part an advance by the crumbling down of eastern parts of these shields and upfolding of western parts.

This may explain why Angara land lies on the eastern part of Asia and the Canadian shield on the eastern part of America and connect with the disappearance of an old land east of our Atlantic coast-line. This westward advance of the Asiatic mass may explain the great westward faulting around Angara land, especially along its western border.

An inspection of the map shows broad bands of land submerged slightly, which extend on curved lines southeasterly from the three south apices to the Antarctic continent. This suggests a westward torsion of the three coigns as wholes on the Antarctic continent independent of the differential movements of the parts among themselves, but dependent on their varying size and distance from the space. As favored by Reyer and Suess the abnormal elevation of Angara Land might furnish a low slope down which a superficial layer could slide, the shear being lessened by internal heat or the moisture of strata newly risen from the sea, and aided by tidal

[4] "Les Lois fondamentales de l'orogenie de la Terre."

strains and earthquakes, thus forming the festoon of outward-curving chains along the east coast of Asia. Their curved out-spreading fronts greatly resemble the curving frontal lobes of a continental glacier. In several of these curves the rearland sunken blocks are wanting and this rearland sinking can best be explained, when it occurs, as a subsequent result of the stretching and not as a cause of the mountain building.

Angara Land by its great and elevated mass developed these eastward-curving chains along its east border, aided by the deep sinking and the eastward tendency of the Pacific bottom, and by its westward lagging motion it brought its south border opposite the deep Indian ocean bottom and made this the slope for the south-ward-curving south Asian chains, and left the north border of Australia facing the deep Pacific, thus making the northward slope for the great northward curves of Oceanica. At the junction of these three bands is the great virgation of southern Asia emphasized by the three strange four-toed fault-bordered[5] islands, Borneo, Celebes, and Gilolo.

It is the home of the tornado, the earthquake and of the great lines of volcanoes like Krakatoa and Tomboro. It is the "Knoten Punkt" of the earth for all natural phenomena, where plant and animal life reach their most remarkable culmination and face each other in the most remarkable contrasts across Wallace's line.

In the same way the eastward movement of South America enabled it to present its north shore to the deepest Atlantic and formed the slope for the northward movement of the northward curving Antilles while the compression of the great Pacific and the small size of North America was sufficient to prevent the formation of southward-moving curves in North America like the Himalayas in Asia.

The Northward Flow of the South European Chains

The south Asian chains flow south as long as the Indian Ocean depression is before them and Angara Land behind them, but long before they come near the influence of the Mediterranean all the great chains between the Caucasus and the Pyrenees turn and flow

[5] Hans v. Staff, *Zeit. Deutsch. Ger. Gesell.*, 1911, p. 180.

north away from the great mass of Arabia-Africa. Later sinking has occurred in part of the rearland and that these sinkings were later is shown because they have often included parts of the chains themselves as in the Crimea. These sinkings could not then be the cause of the chains. Indeed, in the Ægean also they are known to be much more recent than the chains. The land moved northward in many divaricating folds, with enormous overthrusts far beyond the competency of the sinking Mediterranean even in the most favorable sections. The abnormally small size of the European nucleus aided in this formation of the slope on which these wrinkles could form and move northwardly in great overlaps which have been the special study of Swiss and French geologists for many years.

While the depression of the Pacific by combining extensive wedge action and eastward momentum from the sinking seems to be a vera causa for the Andes and Cordillera, this is not possible for the sinking of the Mediterranean where the force acting northwardly, the rotational effect of the earth is wanting, and so there is no momentum, and being much smaller the wedge effect would be insufficient to make the enormous overthrusting of the Alps. Moreover the chains go west across Spain and east across Asia Minor, extending in great loops northward far beyond the influence of the sunken blocks of the Mediterranean and Black Sea. The great virgation of the Alps and the sigmoid curves of Spain, the Carpathians and Balkans suggest a movement far north into narrowing latitudes which crumpled the curves, while the Asian chains moving in the opposite direction in an expanding area deploy flow-like, as does a glacier moving out on a plain. These chains from Spain to the Caucasus lie along the crest and northern slope of the old equatorial protuberance and when the equator was transferred south to its present position this projection was unsupported and sunk, flowing down northwardly in great convex loops. The slow southward transfer of the equatorial protuberance dependent on the movement of the pole prevented corresponding southward-moving chains, except perhaps in the case of the Atlas range, or perhaps here the sinking of the Mediterranean may have been effective. If the transfer of the equator be found indefensible the mass of Africa itself may have been raised abnormally like Angara Land to form the similar slope down which the northward sliding occurred.

The three intercontinental seas are not all alike, but the true Mediterranean is contrasted with the Caribbean and East Indian areas.

The two latter are placed on the borders of the Pacific at the points where the old and new equators intersect near the Galapagos Islands and Sumatra (see the map), and the former where the equators are most widely separated. In the two the east-west torsions have moved the continental segments most apart, so that mountain curves could flow north toward the equatorial depths to form their curved mountain boundaries, and their three deep depressions.

The classical Mediterranean has mountain chains which have moved not toward oceanic depths but toward the continental center, and it is placed directly opposite to the center of the Pacific, while the other two are where both equators intersect the volcanic border of the Pacific. By an unexplained coincidence it has three deeps like the others.

The Mediterranean has been the center of civilization. The other two have been rather the opposite, more centers of seismic and of cyclone activity and the United States has unfortunately acquired foothold in both.

The Mediterranean zone has always been a more continuous ocean (the Tethys of Suess) in transgression periods than in tetrahedral periods, therefore it has been many times built up and destroyed. Therefore its being maintained as equator till the Tertiary has made these cycles possible.

The Migration of the Poles

This transfer of the pole and equator to the new position, in whole or in part, in the late Tertiary agrees with the independent suggestions of many botanists and zoologists in explanation of the Tertiary and modern distribution of plants and animals.

Arldt rejects this Tertiary deformation and places the transfer of the pole in the Archæan, because it would, he believes, have been attended by more enormous mass movements even than those of the Tertiary. He is discussing the matter from the standpoint of the

Kant-Laplace hypothesis; and the hypothesis of Arrhenius (which was independently deduced by Arldt) of an interior of highly comprimated and heated gas essentially a solid of great density and elasticity, and yet the stupendous movements of the Mediterranean zone and of the Pacific zone of fire in the Miocene seem sufficiently great to meet the demand even of this radical hypothesis.

With the evidence at hand interpreted in accord with the planitesimal hypothesis it is hard to estimate the relative importance of the three great revolutions, the pre-Cambrian, the Permian, and the Pleistocene. It seems probable that they increased in intensity. Would not the tetrahedroid be realized in larger and larger degree as the mass increased and solidified, and be antagonized less quickly and efficiently by the spheroidal tendency as rotation became slower? Are we not now passing slowly out of an intense glacial period?

Again would the present equator be so unimportant geologically if it had been with all its tidal strain where it is now, since the early Archæan?

The geological map of the earth shows many contrasts and harmonies dependent on this mode of origin.

Africa is the torpid continent with *no* border folded mountain chains because it met the average tetrahedral conditions with the minimum of resistance.

South America and Australia are balanced in relation to the two similar Mediterraneans, each with a large unfolded Archæan area facing Africa and *one* folded mountain chain farthest from Africa. These chains are, however, of unlike origin and character, the Australian an outflow chain of the Asian festoon type; the South American a compression chain of the Cordilleran type. This is because the broad abnormally depressed Pacific is the predominant factor acting with compression against South America and with tension from Australia.

North America is the normal continent, with two bordering mountain chains. In the Permian upfolding the Appalachians flowed west from an elevation east of the present coast, of which there is evidence in the strata, as the beds mainly grow coarser toward the east. The beds flowed west down a virtual slope crumpling and curving (stauend) where they met an old land in the

Adirondacks, and dying out in faint waves against the flat unfolded forelands to the southwest. The Atlantic is specially bordered by Rias Coasts, indicating sinking. The Cordillera on the west were caused by the tangential thrust of the sunken broad Pacific.

Europe is a dwarf continent. It began with the formation of the Urals in the east like the Appalachian, but stands in relation to the unique Mediterranean, and is abnormally overthrust from the south with a minimum addition to its area.

Asia is a giant continent in size and shows a maximum of motion and of outflowing mountain chains.

India is a dwarf counterpart of Africa. They both have the continental notch on the west, and a big island off to the southeast, but the volcanic area is on the west in India, while it is on the east in Africa.

Attention is called to the consideration that the tetrahedral hypothesis does not stand or fall with the hypothesis of the suggested movement of the poles. The flattening at the poles and bulging in the lower latitudes is favorable to such movement, and if this tetrahedral configuration has been repeated the movement of the pole may be cumulative. It is recognized that the amount 22° is beyond the maximum motion of 15° suggested by G. H. Darwin as possible, and yet the argument of Green does not seem to me to have been completely met and the "zone of the intercontinental seas" seems to plead strongly for such a movement.

Darwin's paper has been quoted recently as proving mathematically that migrations of the pole sufficiently great to be of geological importance have not occurred. What Darwin really said is this: "We have thus clearly a state of things in which the pole may wander indefinitely from its original position." By a succession of considerable changes it might migrate in a devious way some 10° or 15° from its geographical position at consolidation. He then goes on to make the supposition by way of illustration and as if it were a possible case that in the glacial period the north pole stood where Greenland now stands. He goes on to say: "This would require extensive and numerous deformations and if the continents are assumed to be permanent would it not be almost necessary to give up any hypothesis which involved a *very wide* excursion of the poles?" This would rule out pendulations of the north pole into the present southern hemisphere and back again, but need not be called a mathematical proof that the pole may not have moved in several stages 15°–20° from a point north of Behring's Straits to its present position. But even this is not absolutely necessary because we may make the assumption that the Pleistocene tetrahedral deformation was so irregular that the southern half of one lobe (Africa) was so abnormally raised that the Alpine chains flowed north to partly submerge Europe and when the collapse came the sinkings caused the three-lobed Mediterranean and the Black Sea, as the China seas were formed.

In accordance with the idea of multiple working hypotheses we may examine and compare the other current theories concerning the genesis of continents, and see if any reason exists why the tetrahedral tendency may not coëxist with all other agencies of deformation and sometimes partially control the result.

See postulates a thrust from the suboceanic area against or beneath the continental areas, getting the force from oceanic leakage by which abundant sea water penetrating the subcrusted lava froths it so that, expanding, it is thrust beneath the coastal border and raises it in mountain chains. It is difficult to understand why, if the sea bottom cracks, and water penetrates to the deep-seated lavas, the expansive force should not relieve itself through the fissured area whence the waters come, rather than propagate itself many hundred miles beneath coastal areas and form inland mountain chains.

From the deflection of the pendulum at the various stations of observation in the United States Heyford concludes that "isostatic compensation" exists in a superficial earth shell about seventy-one miles thick, so that a short suboceanic vertical section is of equal weight with a long continental one of the same base. If unloading by erosion takes place, the unloaded area will expand because decrease of pressure favors those chemical and solution changes which increase bulk, and vice versa the loaded area will contract because increase of pressure will tend to favor those chemical and solution changes which decrease bulk and increase density. Thus equilibrium will be destroyed without producing a common level, and a slow surface creep of the lighter and higher land areas toward the sea will ensue, and as a result beneath this surface creep a great slow undertow from the ocean areas toward the continents. The undertow being attached continuously to the surface strata, and the two moving in opposite directions, there must be shearing between them or crumpling of the surface layers, which are free to relieve part of the tension by folding. Therefore the mountain chains are a short distance inside the continental borders and parallel to them.

Willis accepts essentially the conclusions of Heyford, but utilizes exclusively the lower layer underthrust from the oceanic areas. He speaks of a "suboceanic spread," *i. e.*, "the expansion of suboceanic masses within the upper hundred miles of the crust in consequence of the efficiency of stresses due to greater density to direct movements occasioned primarily by molecular or mass changes under varying temperature and pressure."

Much is made of the idea of great areas of habitual elevation and depression. These must be subordinate to the great persistent continental elevations and oceanic depressions.

The rhythmicality is explained by the unproved consensus in the rhythm of several causes none of which are shown to be rhythmical.[6]

The special tendency to collapse when the centers of the coigns rise too high would explain the central seas on the three shields, as the Baltic and Hudson's Bay. It is interesting in this connection that Heyford declares[7] the earth to be a failing body. He reconciles this inward thrust with Suess's idea that the Asian chains flowed seaward by saying that the thrust of the ocean bed beneath the coastal parts of the continents would produce the same effect as an outward superficial motion of the land.

"Gondwana land," he says, "has been carried north with the deep underflow"[8] which passed beneath and wrinkled up the Himalaya. But Gondwana land is a rising and thus a lighter area against which the flow should have impinged and formed mountains on its

[6] "Asia," II., 130.

[7] Heyford, "Geodetic Evidence of Isostacy," *Proc. Wash. Acad.*, VIII., 36–39, 1906.

[8] Loc. cit., p. 133.

south, or if Gondwana land is carried north with the deep underflow Angara land should be carried forward also by the larger Pacific flow.

This underthrust would hardly produce the glacier-like lobing of the Asian chains so characteristic of the outflow of ice, and would not explain the northward overthrust of the mountains across Europe from the Pamir to the Pyrenees, where the oceanic area is wanting and the thrust must have come from Arabia and Africa. It does not explain the contrast between the festooned Asian chains and the straight American coasts, nor all the complexity of the zone of the intercontinental seas.

Such a band thrust far under the continental mass must have had behind it an enormous force to overcome the resistance to shear (which may have approached the breaking strength of the rocks) over all its broad upper and under surfaces and have surplus force to upfold the many festooned mountain chains of Asia. Indeed this suboceanic spread occupying the greater portion of the hundred miles in depth would have caused vertical elevation of the sea bottom, instead of being transmitted so far inland beneath so small a load. We may contrast with this the superficial movement down a slope having shear only on an under surface softened by an internal heat. This sliding might be carried down a very low slope, solicited as it were, by the constant stresses of the earth tides and occasional earthquake vibrations, especially in soft and water-soaked strata recently emerged from the sea.

The hypothesis as presented by Heyford can, however, coëxist with the tetrahedral hypothesis, since an elevation of the central continental mass would favor the superficial flow and hinder the deep-seated one.

It would seem, however, that for the formation of the earth's largest features much deeper portions of the earth would be concerned than are involved in the compensations of isostacy.[9]

Heyward bases his theory upon the observed fact of isostacy but this fact itself is still sub judice.

Because of the heatgradient we may assume the centrosphere to now consist of gas above the critical point, by compression made

[9] See Chamberlin and Salisbury, "Geology," p. 556, 1904.

heavier than iron, and from its way of conducting earthquake waves, more rigid than steel, and with rigidity increasing centerward.

We may accept it as highly probable that a condition of approximate isostacy exists over the area of the United States, with compensation of the lighter land and deeper adjacent sea areas within perhaps one hundred miles of the surface.[10] It, however, remains to be proved whether this is true of other continents or a constant condition of any continent. This must be reconciled with the existence of long periods of peneplanation when the base-leveled surface is not raised as the load is removed but often submerged beneath the waters of a transgressing sea.

The theory of isostacy must also meet the fact that the lavas of midoceanic regions are nowhere ultrabasic, but rather intermediate between basic and subacid. They range from rare nepheline basalts (SiO_2 39, sp. gr. 2.9) to rhyolite (SiO_2 76, sp. gr. 2.4). The average is basalt and andesite (SiO_2 53, $FeO = 20$, su. gr. 27–2.95). While all the masses of terrestrial metallic iron, the diamontiferous olivine rocks (sp. gr. 3.2–3.5), the greatest accumulations of magnetite, the greatest areas of heavy "norites with titanic iron borders" are found in the old highlands.

The diamond-bearing rocks would seem to have come from great depths which could furnish great pressures, unless the Ovifak irons and the diamond-bearing Vaalite are planetesimals.

The postulates of the planetesimal hypothesis are distinctly favorable to the tetrahedral hypothesis. The possible considerable irregularity in the accumulation of the matter would supply a needed condition for any such deformation and especially for a deformation into a somewhat irregular and one-sided tetrahedroid.

The storage of outgoing heat in an outer shell which should promote the formation of a plastic stratum along which flow could take place would be an additional favorable condition.[11]

It is quite possible that the planetesimal hypothesis may be found to supplement rather than supplant the nebular hypothesis.

The impact hypothesis, suggested by the great multitude of

[10] J. F. Heyford, "Figure of Earth and Isostacy," Coast Survey, 1909.

[11] Chamberlin, "Geology," p. 539.

spiral nebulæ comes as a welcome antecedent to either hypothesis, and permits a great latitude in the amount of heat and volatilization which may be assumed as the result of a given collision.

At one extreme the conditions postulated by the usual planetesimal hypothesis may prevail; at the other with a maximum of volatilization conditions approaching the older theory may be present, a momentum derived from nebular contraction adding itself to and modifying that caused by impact, so that in most favorable cases even rings either temporary or permanent might be formed. We can perhaps follow a satellite formed by the condensation of such incandescent matter mixed with solid fragments in greater or less quantity through to the present probable condition of the earth or other planets, more easily than one made up of a cold and heterogeneous mass of discrete planetesimals; and equally well or better imagine it to assume in some degree the tetrahedral form.

Chamberlin presents the calculation that shrinkage stresses of the whole globe would support domed elevations on the earth only eight miles high, but this is on the assumption that the earth material is "firm crystalline rock."[12] But the crushing strength of the deep-seated earth material should be taken as that of the steel dies of the crushing machine rather than that of brittle rock (or indeed twice that of steel as deduced from the rapidity of earthquake transmission), which would give a value for this elevation of the proper order for even more than the continental protuberances. Indeed Chamberlin in the same page seems almost to have contemplated the very rhythmical mechanism we have assumed when he says: "It is as if the shrinkage stresses accumulated to the full strength of the stress-resisting power of the whole sphere and then collapsed."

There are good grounds to believe with Chamberlin[13] that the greater earth movements affect all quarters of the globe together, that they are periodic and that the "ocean basins become progressively deeper and more capacious, while the protuberances become more protuberant," that "in the process of periodic adjustment of the earth to its internal stresses, portions of the crust are thrust

[12] "Geology," I., 556.

[13] "Diastrophism as the Ultimate Law of Correlation," *Jour. Geo.*, XVII., 685, 1909.

up to heights notably above the plane of isostatic equilibrium, and that these portions gradually settle back toward equilibrium."[14] That "the conditions prerequisite to baselevelling involve a high degree of stability through a long period of time." The great base-levellings and the great sea transgressions which are little more than alternative expressions for the same thing have as their fundamental assumption a sufficient stability of the surface to permit baselevelling to accomplish its ends.

Chamberlin states these stages as (1) That of climacteric base-levelling and sea transgression favoring the expansional evolution of shallow water life and wide migrations and comminglings leading to cosmopolitan faunas.

(2) The stages of retreat which are the first stages of diastrophic movement after the quiescent period marked by abundant erosion and deposition of deep soil mantles, limited life area, and lessened migration.

(3) The stages of climacteric diastrophism and greatest sea retreat marked by restrictional evolution of shallow water faunas, increased land deposits, broadest continents, diversity of land surfaces and climatic extremes.

(4) The stages of progressive degradation and sea advance, marked by the reëxpansion of the narrowly provincial shallow water faunas formed in isolated areas in the previous period.

The tetrahedral hypothesis thus presents itself as a welcome introduction or preliminary to Chamberlin's suggestion of diastrophism as the foundation of correlation, since it gives a cause for a rhythmical recurrence of short periods of diastrophism with long intervening periods of quiescence. In harmony with this hypothesis is the remarkable generalization of White and Knowlton,[15] that a uniform warm humid climate extending beyond the polar circles has been the rule from early paleozoic, interrupted by relatively short periods of climatic extremes when great glacial areas coëxist with a torrid zone.[16]

[14] Putnam and Gilbert's pendulum studies indicate that the part of our continent uplifted in late Tertiary is still above the level of equilibrium.

[15] *Science*, XXXI., 760.

[16] Variations of the sun's heat have been adduced as cause of varying climate and even the passage of the solar system through cold areas in space.

The remarkably interesting new book by Professor Chamberlin[17] gives what I had suggested above as desirable and feasible, to wit, a more nebular trend to the planetesimal hypothesis. It makes clear the reality of the forward rotations of a satellite by the interaction of elliptical rather than circular orbits, and builds up with convincing clearness such a simple spiral nebula as would evolve into our solar system. He lets the approaching star exert its disrupting agency on our sun, then larger by the mass of the planets, as a tidal attraction which sets free the enormous expansive energy of the sun itself so that great masses of incandescent matter—exaggerated protuberances—were thrown off, and thrown off in rotation because of the unequal character of the expelling force. Such masses form the knots on the arms of the spiral nebula and by contraction on cooling initiate the planets. By exaggerating—which he does not do—the size of these knots in relation to the final planet's we get all the advantages without many of the disadvantages of the old nebula theory.

He then goes on to develop the thesis that the major influence in producing the larger inequalities of the earth's surface has been *the variation in the rate of rotation of the earth;* thus proposing a supplement or substitute for the tetrahedral hypothesis.

Starting with the idea that rotation must have had alternate increases; when the equatorial band would bulge and the polar areas flatten; and decreases when the equatorial band would flatten and the polar areas bulge, there would be a secular seesaw motion between the rising and sinking areas along circular fulcrum lines at 30° N. latitude and 30° S. latitude. The tensile stresses during elevation in the polar areas would be relieved (on the law of least action) by three fissures radiating from the north pole at 120° from each other and ending at the fulcrum line. The tensions produced during the following equatorial expansion would be relieved by 6 fissures divaricating 2 and 2 from the three ends of the set of fissures above defined, and meeting 2 and 2 at the opposite fulcrum line and

Indeed a certain parson is reported by Lockyer to have claimed that there might be areas in space in which miracles were possible and that the earth may have passed through such an area at the beginning of our era.

[17] "The Origin of the Earth," 1916.

at the three ends of the corresponding set of fissures from the south pole, dividing the equatorial band into six about equilateral triangles, set saw-tooth-wise. Three alternating ones would be placed base to base with the three north polar triangles above defined. The three intervening ones would be placed base to base with the three triangles formed around the other pole by three lines similar to those first mentioned and drawn to the south pole from where the zigzag line touched the southern fulcrum line. The six quadrilaterals made each of two triangles base to base on the fulcrum lines; three touching the north and three the south pole, and interlocking saw-tooth-wise across the equator would by their see-saw motion on the fulcrum lines relieve the stresses rising from the variations in the rotation. It is further assumed that all other stresses, as shrinkage, tides, erosion effects, would be localized as elevations along these lines and reach a maximum with special protuberances at their intersection. These lines become then of great width and are the nuclei of the continents and are called yield tracts rather than fissure lines.

The formation of basaltic columns and especially the ball and socket structure, with protuberances rising at the points where three cracks meet, and connected by lower ridges along the cracks, is taken as an instructive illustration of how the rising in ridges along these fissure tracts would occur and the especially marked protuberances at their junction would be formed, and is considered almost a proof that the process has really taken place. There seems, however, only partial resemblance between the two cases. The tensile strains are here alternating; in the basalt coincident and continuous. The trap column furnishes an analogy only for the action at the poles and only for the first half of the cycle, and it is not exact there. As expansion proceeds tension is relieved by three fissures radiating from the pole but this tension and fissuring are not equal along the three lines to the next angles as in the trap but decrease outwardly to zero. When the second half of the cycle begins it may first close up the fissures and then bring the polar regions into a state of compression with maximum at the pole, a state of things not occurring in the trap, where there is no compression and so no elevation. This compression might relieve itself by folding or mashing along lines of weakness with little regard to the 120° law or to the former fissure lines, which might be sometimes cemented so as to be lines of greatest strength. It would not need to fold at the same places in successive compression periods. The other points where three lines join on the fulcrum line are wholly unlike the corresponding points on a trap column. They are indeed points where three almost nonexistent lines meet, since tension and motion die out as the fulcrum line is reached. During the subsequent compression period also these points are places of minimum compression and so of minimum elevation, but they are the points where the greatest protuberances—the continental shields—must be.

It is, moreover, hard to see how the three polar fissures can exert any influence across this dead space to locate the corresponding fissures which stretch across the equator, since the maximum tension by which these fissures are formed is at the far distant equator where it would be more probably relieved by fission along three lines at 120° (after the manner of trap), radiating from centers on the equator and at convenient distances apart, rather than by lines or bands slanting across the equator 8,000 miles apart.

I have seen where the triassic sandstone has been stripped off the trap and found no elevation at the junction edges of the surface of the columns or depressions at their centers and the same is true of mud cracks. There is rather a slight depression where the columns join. The ball and socket structure is a deep-seated one, and the ridges along the edges of adjacent columns and the elevations at the corners are not upthrusts in any sense. The six-sided column has first formed by shrinkage and rupture, and no further action takes place across the ruptured surfaces, then later shrinking and consequent fissuring inside each column separately have produced a "spheroidal parting" inside each individual column and it is this curved parting which forms the apparent hollow when the column falls in pieces, or when several columns have been eroded to a common level forms the adjacent hollows bounded by the intervening ridges and corner projections. There is no trace of a longitudinal motion of the central part of the basalt column up or down or sidewise. Indeed the blocks into which the column breaks will be concave upward for a while and then be followed by a double concave block and then will be convex upward for a time and then be followed by an exfoliating spherical mass as large as the cross-section of the column. There are samples of all these shapes in the collection at Amherst.

Thus no support can be drawn from analogy of the ball and socket structure of trap for the explanation of the large earth features as a result of variations in rotation.[18]

It is further difficult to see how this oscillation on unknown but very long period and of unknown but very slight amplitude can "attract" the other deforming agencies and form bands of fissuring and elevation radiating at 120° and culminating where the movements pass through the zero point. The amplitude and period and total duration of these oscillations are left wholly indeterminate and as we exaggerate the nebular character of the original knot and minimize the mass and period of falling and variation of falling of the planetesimals, which is the cause of variation in rate, we may have conditions where the whole effect would be small or even negligible. It is further interesting to note that when a line of tension is drawn from the south pole to the fulcrum line at the south point of Australia, it is then continued northwest with the full width of Australia across the East Indies, bending north in Asia with the full width from Afghanistan to eastern China, and there is no corresponding northeast line to divide the Pacific. In the same way the line drawn from the south pole to South America goes northwest with the full width of South America and bends north in North America with a width from southern California to Georgia and there is no northeast line to divide the Atlantic. In the case of Africa the treatment is different, and the line from the south pole is made to branch, although at much too small an angle at the south point of Africa, and the branches to run up the two coasts to Afghanistan and the Atlas mountains and then converges to the north pole and a hypothetical ocean is made to occupy the area from Arabia to Scandinavia. It is more consistent and consonant with the other arrangements to have made Africa a "yield tract" exactly analogous to South America and Australia. The line along the east border of the continent, closely parallel to the corresponding line

[18] Polished cross-sections of trap columns show a wholly homogeneous texture. R. B. Sosman, "Types of Prismatic Structure in Igneous Rocks," *Jour. Geol.*, XXIV., 228, 1916.

along the east border of the other continents, would be the base line of this yield tract as far as Somaliland and the tract would run northwest to meet the fulcrum between the Atlas Mountains and Asia Minor and its northern meridional part would include Europe and have on its right a diminished ocean in the depressed Aralo-Caspian Basin, and unlike the others, a northeast band across Arabia naturally separating this small ocean from the Indian Ocean. In this case each "yield tract" has a Mediterranean in its center and Italy in the center of the one trends closely parallel with Cuba and Sumatra in the center of the others.

We may further notice that the elevated fissure tracts that are thus built up are coincident with the tetrahedral elements of the earth's framework. We may welcome any new light on this dark subject and feel sure that the rotational and tetrahedral theories are supplementary and not antagonistic, the latter would seem however to be the preponderant and precedent influence since it would tend to make the two poles as unlike as possible, as is the case: while the rotational hypothesis acting on a reasonably homogeneous earth would make the poles essentially similar and symmetrical, as is not the case. The tetrahedral hypothesis would demand continents widening to a maximum where they surround the polar ocean, as is the case. The rotational theory would demand three northern continents tapering northwardly into points directed toward the corners of an arctic continent at the north pole, which is not the case. The tetrahedral hypothesis centers on the common explanation of the 4 great coigns. The other has two explanations for them: one for the south polar continent, another for the other three, placing them where the supposed causative forces are at their zero point. The drawing of six circular oceans leaves much to be desired and one superfluous ocean surrounds the north pole.

A great elliptical ocean is drawn covering quite closely the present seat of war and with a major axis on the Berlin-Bagdad Railroad. An ultra-pacifist would readily see the desirableness of submerging this region, at least temporarily.

We may go further and say that if the five great depressions were originally made in part at least by the tetrahedral deformation they would have located the five great gyrals or "permanent highs" as they are assumed to have been located by the rotation process, and would have gained the advantage of any sorting action of the air and water currents in concentrating the heavier matter over the sea bottoms and the lighter over the land. This would tend to increase the tetrahedral depressions and promote the breaking down of the elevations and the spherical recovery.

The chapter is introduced by a diagram from Darwin showing that the tidal stresses are eight times as great in the central as in the equatorial regions. This dynamical basis for the theory is largely non-existent, since as shown by Barrell[19] the citation is from an earlier and erroneous calculation later corrected by Darwin, who shows that the central stresses are only two and two thirds greater than the equatorial.

Barrell says further concerning the theory:

> "It is not clear that earth strains due to the causes invoked could initiate such a primary segmentation, in fact calculations on the stresses which the reviewer has made to test this sub-hypothesis pointed to quite a different method of yielding. The distribution of continents and oceans does not accord very closely with it, and the evidence of isostacy does not indicate that the density differences between continents and ocean basins reach below the outer fiftieth of the earth's radius. This hypothesis of juvenile shaping should therefore be accepted with much reserve and does not appear to be as well supported as are the conclusions of the previous chapters."

The remarkable paper by Professor Lane[20] fits all the crevices of the tetrahedral theory. There is a surface layer for orogenic purposes, a deeper plastic (asthenospheric) layer to facilitate flowage, a deeper layer for epeirogenic purposes, indeed, for tetrahedral purposes and provision for periodic collapses. A nut with its acute distal point and its obtuse proximal end is a suggestive model of the tetrahedral earth; a triangular beechnut would have been simply perfect.

Two tables have been published giving the periods of elevation and depression of the North American continent. The table of Shimer is based largely on the geological maps of Chamberlin and

[19] *Science*, XLIV., p. 244, 1916.

[20] A. C. Lane, "On Certain Resemblances between the Earth and a Butternut," *Scientific Monthly*, 1915, p. 132.

Salisbury[21] and that of Schuchert[22] averaging the results of his extensive and valuable work on the paleogeography and paleometeorology of North America. The two tables are in substantial agreement with the table of Arldt (see p. 447). The larger disturbances given by Schuchert agree with Arldt's cycles except that the Grand Canyon revolution is local and the Caledonian cycle is less marked in North America than the others. He brings out very clearly the brevity of the elevation and the great length of the intervening times of depression.

"Granting all this," says Schuchert[23] (after reviewing all the theories to explain the "climates of geological time" except the tetrahedral hypothesis), "there still seems to be back of all these theories a greater question connected with the major changes in paleometeorology. This is: What is it that forces the earth's topography to change with varying intensity at irregularly rhythmic intervals? . . . Are we not forced to conclude that the earth's shape changes periodically in response to gravitative forces that alter the body form." The tetrahedral hypothesis is certainly trying to force this same conclusion.

The idea of a spherical recovery and extensive transgression and exceptionally equable climate far poleward would take away largely the need from the biological side of many assumed continental connections across the deep oceans as bridges for migrations. Their migrations could take place during equable climates by long circuitous land connections extending far poleward, and would remove many apparent conflicts with the supposed tetrahedral configuration of the earth, which appear in many restorations of early geological periods. This was written in 1913 and the important and authoritative article by Mathew on "Climate and Evolution,"[24] brought so full confirmation of this suggestion and so strong condemnation of the indiscriminating bridge building which has been customary for

[21] H. W. Shimer, "Broader Features of the Geological History of North America," *Technology Quarterly,* Vol. XX., p. 287, 1907.

[22] "Textbook of Geology," Pt. 2, p. 980, 1915.

[23] "Climates of Geologic Time," Pub. Carnegie Inst., No. 192, p. 289.

[24] W. D. Mathews, "Climate and Evolution," *An. N. Y. Acad. Sc.,* Vol. 24, pp. 171–318.

fear, as Colman says, "some stray marsupial might get his feet wet in migrating to a new habitat," that I copy here his thesis and conclusions.

"THESIS.

"1. Secular climatic change has been an important factor in the evolution of land vertebrates and the principal known cause of their present distribution.

"2. The principal lines of migration in later geological epochs have been radial from Holarctic centers of dispersal.

"3. The geographic changes required to explain the present distribution of land vertebrates are not extensive and for the most part do not affect the permanence of the oceans as defined by the continental shelf.

"4. The theories of alternations of moist and uniform with arid and zonal climates, as elaborated by Chamberlin, are in exact accord with the course of evolution of land vertebrates, when interpreted with due allowance for the probable gaps in the record.

"5. The numerous hypothetical land bridges in temperate, tropical and southern regions, connecting continents now separated by deep oceans, which have been advocated by various authors, are improbable and unnecessary to explain geographic distribution. On the contrary, the known facts point distinctly to a general permanency of continental outlines during the later epochs of geologic time, provided that due allowance be made for the known or probable gaps in our knowledge.

"SUMMARY OF EVIDENCE.

"The geologic evidence for the general permanency of the abyssal oceans is overwhelmingly strong. The continental and oceanic areas are now maintained at their different levels chiefly through isostatic balance, and it is difficult to believe that they could formerly have been reversed to any extensive degree. The floor of the ocean differs notably in its relief from the surfaces of the continents, and only in a few limited areas is the relief suggestive of former elevation above sea-level. The continental shelf is so marked, obvious and universal a feature of the earth's surface that it affords the strongest kind of evidence of the antiquity of the ocean basins and the limits beyond which the continents have not extended. The supposed evidence for greater elevation in the erosion channels across its margin have been shown to be better interpreted as due to 'continental creep.' The marine formations now found in continental areas have all been deposited in shallow seas. No abyssal deposits have ever been certainly recognized among the geologic formations of the continental platform."

It would thus seem possible that with the continuous escape of heat and volatile bodies a slight constant tendency of the earth toward tetrahedral deformation might combine with the other more active forces and like the action of rotation in deflecting rivers prove effective when the other forces are balanced against each other.[25]

The continuous escape of juvenile waters suggested by Suess may have promoted shrinking and have thus aided in regularly increasing the depth of the ocean basins.

And only part of this juvenile water may have been absorbed in the hydration of minerals so that the amount of the ocean waters may have increased. We may also accept the conclusions of Walther that the earlier oceans were shallow and that the great and increasing deepening of the great permanent ocean bodies which the tetrahedral theory demands began with the Triassic, since all paleozoic survivals were shallow water forms.

Indeed the slow process by which the agglomeration of planetesimals condensed into a globe of double the rigidity of steel would permit the postulated repeated recurrence of periods of tetrahedral deformation and spheroidal collapse, at first barely discernible among the other deforming agencies but gradually becoming relatively more important until at last in the grand Tertiary cycle the deformation should be so great as to cause the final stage of the movement of the pole to its present place and impress the strong tetrahedral features on the face of the present earth.

Finally one might say there is a certain three-fold hierarchy in earth movements—orogenic or mountain making; epeirogenic or plateau making; tetrahedrogenic or continent making.

[25] It should be distinctly borne in mind that the tetrahedral deformation is not a crystalline action any more than is the formation of hexagonal trap columns. Indeed the tetrahedral deformation of a spherical mass is exactly like the hexagonal deformation of an extended mass. Both are governed by the law of least action in a very similar way. There are isometric tetrahedral crystals and there are six-sided hexagonal crystals. They are often perfect and perfectly embody a physical law. The other cases represent a tendency and act only when the remaining agencies are balanced and should be judged by their best results. One should no more overlook the tetrahedral tendency because it is often imperfectly realized than the hexagonal tendency in all shrinking bodies.

EARLY MAN IN AMERICA.

By EDWIN SWIFT BALCH.

(*Read April 13, 1917.*)

One hundred years ago, only one man—one may say without exaggeration—knew that there had once been a stone age in Europe. This was John Frere, who as far back as 1797, collected many flint spear heads near Hoxne in southern England and recognized their antiquity and their human origin. It was not until the first half of the nineteenth century that two or three other men realized that certain stones which they found in digging had been man-handled and used as weapons or tools. One of these men was Dr. Schmerling of Liège, who in 1833 published a paper describing his investigations in the cave of Engis, where he found worked flint implements, weapons and ornaments of ivory and bone, and fossils of extinct animals together with a fossil human skull and other fragments of the skeleton. Another man, the Rev. J. MacEnery, between 1824 and 1841, obtained from that most interesting cavern Kent's Hole near Torquay in southern England, numerous artifacts associated with the bones of extinct animals. The scientific world of those days, however, was unable to appreciate that the human race could possibly date back to the time indicated by the extinct animal fossils found in the same strata as the flint artifacts, so Frere's, Schmerling's and MacEnery's discoveries were rejected and temporarily forgotten.

In the early part of the nineteenth century also, however, there lived near Amiens a Frenchman, Boucher de Perthes, who was molded out of most combative clay. He started digging in the gravels of the Somme Valley and in 1832 he noticed in the gravel pits some curiously shaped stones which he finally recognized must have been shaped by man. And in the year 1847, he said so in a big volume the very title of which, "Antiquités Celtiques et Antédiluviennes," shows how hesitatingly he was groping at a subject at that time almost under the ban of religion as well as of science. For this he was told, to put it in the words with which we now greet discoverers, that he had handed a gold brick to the public. But this did not upset Boucher de Perthes's equanimity one iota. He was not only combative, but he was pertinacious and tenacious. He continued his researches and ten years later he brought out another big volume. Thereupon a few other scientists woke up and took notice and went to the Somme Valley to dig. And they also found flint artifacts in situ and in very short order it was seen that Boucher de Perthes was right in his contentions. And now Boucher de Perthes is universally recognized as the man who forced recognition of Paleolithic man in Europe on a recalcitrant world.

One hundred years ago, everybody in America—one may say without much exaggeration—knew that there was even then an American stone age. And some doubtless had this knowledge drilled into them by finding a stone-headed arrow sticking in their ribs. And they therefore were sure that stones were fashioned into weapons and that they were used by our so-called Indians and were not prehistoric. But history repeats itself. Just as Dr. Schmerling had discovered a fossilized man in Belgium, so did Dr. Lund, a Dane, report finding in 1844 in a cavern in the province of Minas Gereas, Brazil, some fossilized human bones together with bones of extinct animals. He concluded that South American man extended "far back into historic times, and probably even beyond these into geologic times."[1] The evidence presented by Dr. Lund, however, was not so absolutely convincing that the human bones were cotemporaneous with those of the extinct animals for the scientific world of that day, any more than in the cases of Frere, Schmerling and MacEnery, to be willing to accept the possibility of such antiquity for the human race, so Dr. Lund's discovery also was temporarily relegated to the limbo of oblivion.

But there was a man in North America who had the same characteristics as Boucher de Perthes: the faculty of observation, the ability to reason from his observations and the pertinacity to stick to them in the face of any and all opposition. This was Dr. Charles

[1] Aleš Hrdlicka, "Early Man in South America," p. 165.

Conrad Abbott, who lived on his family homestead near Trenton, New Jersey. More than fifty years ago he began to collect the relics of the past in the neighborhood. He noticed that some of the stone artifacts were much rougher than others and he reasoned from this that therefore they were older. And in a paper "The Stone Age in New Jersey," published in 1872,[2] he announced his belief that these ruder artifacts were paleolithic. He says of them either that there were execrable workmen among the tool-makers or else that the age of the crude specimens far exceeds that of the finely wrought relics. He discovered also that in every class of relics there is always a gradation from poor or primitive to good or elaborate, indicating a lapse of years from ancient to modern times, from a paleolithic to a neolithic age. He further surmised that the earlier implements were so rude that the people who fashioned them may well have been too primitive to wander from another continent, and therefore that the first inhabitants along our Atlantic coast and inland may have been autochthones. And thereupon Abbott was promptly told that he also had handed a gold brick to the public.

But Abbott, like Boucher de Perthes, weathered the storm and continued his researches and nine years later, in 1881, he published a book "Primitive Industry," based on his rambles over fields and along the banks of the Delaware and on his patient observations in railroad cuttings and canal excavations. And in this book he was able to announce[3] that there are three stages of stone culture in the Delaware Valley. Taking these downwards or backwards they are as follows: (1) In the surface soil there is a polished stone neolithic stage with jasper and quartz implements of the historic Indian and a few rough argillite implements; (2) some distance below this, in alluvial deposits, generally of yellow sand, there is a stage of rough argillite implements; (3) a good distance below this again, in the Trenton gravels, there is a stage where there are a few very rough argillite paleolithic implements.

Now the difficulty of seeing these facts in the field at Trenton is enormous. I have visited Abbott many times at Trenton, and have rambled over his ancestral acres and along the banks of the

[2] *American Naturalist,* 1872, Vol. 6, p. 146.

[3] Page 517.

Delaware with him and have thus had the advantage of having him point out to me himself the three horizons. I have picked up numerous Indian implements on the surface soil, perhaps the best of which was a large arrowhead or spearhead which I detected in Abbott's asparagus bed. And I have dug also into the second stratum, the Yellow Sand Drift, and found a couple of rough argillite flakes myself. An implement in the lower gravel horizon, however, I was never lucky enough to find in situ, for these are exceedingly rare and only reward a searcher after many long days. But I cannot but marvel how anyone ever traced single-handed these three archeological horizons. The two lower ones are so modest, so retiring, that even when pointed out to you, it is hard to believe they are there. And how Dr. Abbott, to whom they were not pointed out, ever was able to recognize their existence and point them out to others, seems to me the most wonderful discovery in the realm of American archeology.

The state of knowledge, it will be noticed, was precisely the opposite in Europe at the time of the discovery of paleolithic stone implements there, from what it was in America at the time of the discovery of paleolithic stone implements here. In Europe nobody knew anything of a European stone age. In historic times, the Greeks, the Romans, the Gauls, the Brits, had all used bronze or iron weapons, but not stone weapons and implements. And the result was that as soon as Boucher de Perthes had been proved correct in his assertions that the flints he found were weapons and implements, everyone knew definitely that they were prehistoric: they could not be anything else. In America on the contrary, everyone knew that there was an American stone age, and that they were still in it. And the result was that most archeologists in America asserted for years after Abbott's discovery, that all the stone implements found here are neolithic and historic. Nevertheless Abbott was correct in his assertions and it may be truly said of him that he is the Boucher de Perthes of America, the man who has forced on science the recognition that there is a Paleolithic American man.

Some years after Dr. Abbott's discovery a new worker appeared in the Trenton district. This was Mr. Ernest Volk. He had come over as a young man from Germany and settled at Trenton. He became interested in Abbott's discoveries and started in to verify them for himself. In 1889, he began to work under the general direction of Mr. F. W. Putnam for the Peabody Museum of Harvard University and he has kept up his researches to the present time. And his patient, persevering labors for so many years have absolutely confirmed all of Abbott's contentions. Working in the fields, and watching excavations in the Delaware River channel, in the sewers of Trenton and other places, Volk has independently proved that there are three stages of culture at Trenton: on top a historic Indian stage with many jasper and some argillite implements, and some of these implements polished and so placing the upper horizon in the Neolithic period; a middle horizon in the Yellow Sand Drift with only some chipped argillite implements, thus placing this stage in a paleolithic stage of culture; and a much lower horizon connected with the Glacial gravel and bearing a few chipped argillite implements and some rough quartzite ones, the latter especially showing an early paleolithic stage of culture.[4]

Until recently Abbott's and Volk's results were accepted by the minority and were rejected by the majority of American archeologists. Now the position taken by so many leading American archeologists is, however, perhaps not extraordinary. In the first place they started from the preconceived notion that all the early inhabitants of this country were historic Indians. And it is hard to throw off a belief which is justified by the most apparent facts endorsing it unless overwhelming evidence is produced against it. In the next place, none of these archeologists took the only means possible of verifying for oneself the evidence presented at Trenton, namely a long investigation, patiently carried out for weeks and months on the spot. They flitted in and out, something like, as you will remember, the guests did who tried to pull out the sword from the tree in Richard Wagner's Walküre. "Gäste kamen und gäste gingen" but the sword remained in the tree just the same.

Another cause also influenced strongly American archeologists

[4] Ernest Volk, "The Archeology of the Delaware Valley," Papers of the Peabody Museum of American Archeology and Ethnology, Harvard University, 1911.

from accepting Abbott's and Volk's results. And this was the human remains found in various parts of North and South America in Pleistocene deposits, which human remains always seemed to be historic Indian. Besides the one find made by Dr. Lund in eastern Brazil several discoveries of the same kind were made in North America. One, for instance, was made in 1846 at Natchez, Mississippi, by Dr. Dickeson and was turned down by Sir Charles Lyell. Another was made in 1902 at Lansing, Kansas. A third was made in 1906 at Long Hill near Omaha, Nebraska. Now all these bones and especially the skulls showed almost exactly the characteristics of historic Indian remains. And it was argued from this that since these remains showed no evolution in the type therefore they could not be really old. For it must be remembered that the persistence of type has only been accepted recently. It was indeed believed for a number of years that the modern European had probably evolved directly from the much lower type of Moustérien Neanderthal man. Now, however, from numerous discoveries at Moulin Quignon, at Galley Hill, at the Olmo, at Ipswich, and other places, it is known that the modern European type dates back to the Chelléen and Acheuléen horizons of the early Paleolithic, while the Neanderthal man's ancestor has been traced in an earlier, perhaps Eolithic, horizon at Heidelberg. But since the reasons formerly influencing anthropologists to reject as genuine the finds of human remains in the American Pleistocene can no longer be held to be valid, it can now be affirmed that it is not only possible but nearly certain that the type of the historic Indian comes down in America through tens of thousands of years, possibly through the entire Pleistocene epoch.

For many years the status of Early Man in America remained thus *in statu quo,* Abbott and Volk standing squarely by their guns and occasionally firing the hot shot of facts at other archeologists, the minority of whom accepted the facts, while the majority denied them. And it was only about five years ago that confirmation came to Abbott and Volk, and it came first from an unexpected quarter, namely Kansas.

About the beginning of the twentieth century, Mr. J. V. Brower made a large collection of artifacts in Kansas immediately south of the Kansas glacial moraine. Mr. Brower discerned that some of these artifacts were unusual in character, but he did not follow up the matter and died soon after. Then his collection was placed in the Minnesota Historical Society at St. Paul, Minnesota, and fortunately it attracted the attenion of the late Dr. H. N. Winchell, who devoted the last years of his life to its study. He established an important point in regard to the paleoliths of Kansas, namely that some of them closely resemble the Chelléen implements of Europe, possibly even some of the pre-Chelléen implements. Without being identical, these implements show that man went through a Chelléen stage of culture in Kansas at an early time, perhaps even before the Kansas Glacial period.

This is a notable and important fact. For the European Chelléen dates to far back, quite probably to a hundred and fifty or two hundred thousand years ago. And the Chelléen implements are about the earliest in which man shows a distinct sense of form. This sense of form and the technic of chipping stone, man combined for the first time in the next stage of culture, and taking certain curiously shaped natural flints, Acheuléen man chipped them into a semblance of the form of certain animals. Such stones, found first by Boucher de Perthes in the Valley of the Somme, have been found also within a few years by Mr. W. N. Newton in the valley of the Thames. And considering that the Acheuléen horizon is almost surely more than a hundred thousand years old, these stones carry back the beginnings of art to that time. The wonderful drawings and carvings of the later Paleolithic are clearly the continuation of these Acheuléen attempts at embryo fine art, and they also are truly the combination of the technic of chipping flints into implements and of an acute sense of form. But it is possibly not far out of the way, to date the birth of the fine arts at about 125,000 years B. C.

But Winchell's greatest contribution to our knowledge of stone implements is unquestionably his study of their patination, and in this respect he made an advance even over any European archeologist. He found that implements varied in their patination or weathering, that some were more patinated than others, and as he went deeper into their study, he found that some implements offered two or even three sorts of patination. And he finally concluded that some implements had been chipped and then perhaps left lying lost for thousands of years until they were found by some later Early man and rechipped into a better form and then lost again to be picked up finally for one of our museums. And by his study of patination principally, Winchell was led to the conclusion that there were at least four successive peoples responsible for the artifacts of Kansas, and he divided the cultures backward into a Neolithic, an early Neolithic, a Paleolithic and an early Paleolithic, and toward the end of his work he even suggests it may be necessary to divide these cultures still further.[5]

Then came a confirmation of Abbott's and Volk's results at Trenton in regard to the Paleolithic man of the Yellow Drift horizon. Three years ago the American Museum of Natural History sent a commission of several of their staff, Dr. Wissler, Dr. Spiers and others to Trenton. Dr. Abbott gave them the privilege of digging on his estate. And having unlimited resources they dug an immense, most educational, trench across the fields and every shovel full of dirt was passed through a sieve. And their results showed that Abbott was perfectly right in his contentions. On top they found the remains of the Leni Lenape Indians in abundance: pottery, bone, shell and copper implements, polished and engraved stone objects, notched and grooved sinkers, pitted and pitless hammerstones, some large chipped blades and many different forms of arrow points. In the Yellow Sand horizon, on the contrary, there were but few forms of artifacts, some pitless hammerstones, some implements of a large blade type, and only a few forms of chipped stone arrow points. In other words there is a complex culture preceded by a simple culture. And this simple culture is homogeneous and cannot be confused with any other.[6]

Finally within the last two years there was made a discovery of

[5] H. N. Winchell, "The Weathering of Aboriginal Stone Artifacts," the Minnesota Historical Society, 1913.

[6] Leslie Spier, "New Data on the Trenton Argillite Culture," *American Anthropologist,* April–June, 1916.

Clark Wissler, "The Application of Statistical Methods to the Data on the Trenton Argillite Culture," *American Anthropologist,* April–June, 1916.

the utmost importance at Vero, Florida. Under the direction of Mr. E. H. Sellards, State Geologist of Florida, the excavation of a new canal was carefully watched, and in a Pleistocene horizon containing bones of numerous extinct Pleistocene mammals, mastodon, *Elephas columbi, Equus leidyi, Megalonyx* and others, there were also found in several places human bones in the same state of fossilization as the bones of the extinct animals. For two reasons therefore, association in the same horizon and fossilization to the same degree, it is impossible to deny that a Pleistocene man existed in Florida. And he was also certainly a Paleolithic man, for some chipped flint flakes were found with the human bones. Most notable of all, however, a bone was found on which there were some engraved marks which suggest vaguely the marks of the Azilien horizon in southern France and on which also there was a small crude drawing, the first apparently from Pleistocene times found in America. This drawing, it seems to me, is one of the most important archeological finds ever made in the history of man and the history of art.[7]

This drawing seems to be an attempt to delineate a human head and bust. What is specially interesting about it is that, in the first place, it is decidedly rectilinear and not curvilinear. That is also the character of historic Indian art and slight as this drawing is, it certainly suggests that it was done by some one with historic American Indian characteristics, which points to the draughtsman being an ancestor of our present Indians. And if this drawing is genuinely Pleistocene, and if it is, as it seems to be, rudimentary American Indian art, there is almost a certainty that we shall never find on the American continent any art like that of the later European Paleolithic. In regard to the age of this drawing one may perhaps theorize somewhat as follows. The fossils found in the same horizon as this drawing are certainly Pleistocene. Now although we have figure-stone flints, that is embryo sculpture from the Acheuléen, the earliest drawings so far known to us are from the Aurignacien. The probability therefore is that this drawing

[7] E. H. Sellards, "Human Remains and Associated Fossils from the Pleistocene of Florida," Eighth Annual Report of the Florida State Geological Survey, 1916.

does not antedate the Aurignacien and may coincide with the Solutréen or Magdalénéen, a supposition which may also be considered to hold good of the surrounding fossils. But although this drawing is only a tiny relic, yet if it is genuinely Pleistocene, it opens up vistas hitherto hermetically sealed, for one must logically conclude that drawing may have begun as early in America as in Europe.

The discoveries in Kansas and in Florida coming on top of the discoveries in New Jersey, prove beyond all cavil that there are several horizons of culture in America. There are certainly three horizons at Trenton, there are certainly two at Vero, there are probably four stages, if not horizons, of culture in Kansas. Now comes an important question, do these horizons coincide? The upper or historic Indian neolithic stage is undoubtedly the same everywhere. But does the lower horizon at Vero coincide with the lower horizon at Trenton and are they synchronous with the Chelléen culture of Kansas?

The progress of prehistoric archeology in Europe has been largely due to recognizing the sequence of one horizon after another. These horizons, identified by their fossils and their stone implements, are, in all cases, found in their proper order of position above or below each other. There may be many or few of these horizons together but in every case the later horizons are above the earlier ones. If one designates the horizons in Europe by numbers, and numbers them from the top downwards, 1, 2, 3, 4, 5, 6, 7, 8, 9, etc., horizon 3 is always above horizon 5, horizon 5 is always above horizon 7 and so forth.

In America we know positively that there are three horizons at Trenton. If we take these as the starting point and number them downwards 1, 2, 3, we can safely say that horizon 1, that of the Neolithic historic Indian, extends, with local variations of culture, throughout the whole of North America and perhaps, although this is less certain, of South America. But of horizon 2 and horizon 3 we do not yet know whether they coincide with any of the lower horizons or stages of culture in other places in America whose existence is equally definitely established. We cannot say that the lower horizon at Trenton coincides with the lower horizon at Vero, nor can we say that either of them coincide with the Chelléen stage of Kansas. May be they do, but may be they antedate or postdate one another. Instead of three horizons, it may be that there are five horizons already discovered in America. And, it seems to me, this straightening out of the sequence and relative time of the horizons is the most immediate problem to attend to in connection with early man in America.

My own beliefs and opinions about the present status of knowledge about early man in America may now be summed up as follows. Early man was here. He lived during at least a part of the Pleistocene period for tens of thousands of years south of the Glacial moraines. He probably went through an Eolithic period and certainly through a Chelléen period in some places and therefore was truly a Paleolithic man. He may have made rudimentary fine art. Paleolithic American man was the ancestor of the Neolithic historic Indian and although less advanced in culture much like his descendant in anthropological characteristics. Whether he was an autochthone in America or whether he came from some other place and if so when, we do not as yet know positively, although his affiliations seem to be to the west. And it is to four men above all others that we owe our knowledge: Abbott, the discoverer of paleolithic implements and horizons, Volk, the corroborator, Lund, the first finder of probably Paleolithic bones, and Winchell, the investigator of patination. These four men will always remain stars in American archeology and especially so Dr. Abbott, who, by following Voltaire's famous dictum "Il faut cultiver son jardin," will go down to history as an immortal.

A DESCRIPTION OF A NEW PHOTOGRAPHIC TRANSIT INSTRUMENT.

By FRANK SCHLESINGER.

(*Read April 13, 1917.*)

A camera lens of wide field is mounted at one end of a rigid tube built up of small angle irons. At the other end is the plate carrier. Adjustments for collimation, base and focus are provided. On the under side of the tube not far from the objective is a ball which fits into a socket mounted on a pier, and these form the polar axis of the instrument. The lower end of the tube rolls on a glass plate attached to the same pier, the latter pointing to the intersection of the celestial equator with the meridian. To the camera is attached a driving clock regulated to the sidereal rate. The glass plate is adjusted to the celestial equator and in this way round star images are obtained on the photographic plate. Near the lower end of the camera is attached an electric contact which operates on a hinge without lost motion. As the driving clock moves the camera across the meridian this contact falls by its own weight into a number of slots in succession, cut into a brass rod that forms the other terminal of an electric circuit. In this way we obtain upon a chronographic sheet eight sharp and short signals every minute. The same circuit contains a sidereal clock and thus we have the means of finding at what times the camera passed the slots in the brass rod.

The method of observation is as follows: two or three minutes before a certain group of equatorial stars comes to the meridian, the driving clock is started and the lens is uncovered just before the contact falls into the first slot. The exposure lasts say five minutes, the camera being covered just after the contact has passed over the last slot. Without disturbing the plate in any way the camera is moved back to its original position so as to point again a few minutes east of the meridinan. Some time later the process is repeated on another group of equatorial stars, and the plate is then taken out of the camera and developed. It is clear that the two sets of chronographic records, together with the measurement in right ascension of the two exposures, will give us the right ascension of one group if that of the other is known; similarly for the declinations, except of course that the clock is not involved.

The method is liable to several sources of error: (1) accidental errors in the measurement of the plates and of the chronographic records. (2) Errors in the assumed rate of the clock. (3) Errors due to the movement of the pier in the interval between the two exposures. It is certain that the first of these is smaller than in the best work that is possible by visual methods, and in addition we are freed from personal equation in all its forms. This observatory possesses an excellent Riefler clock whose rate for ten hours (the longest interval between exposures that it is feasible to employ), we should be able to determine with a probable error not exceeding 0.005 second of time. Several years ago we set up a stationary camera upon a pier pointed at the polar regions and secured exposures every few minutes on a number of stars. The measurement and preliminary discussion of these plates proved that the pier is liable to very small movements during the course of a single night, and the error from this source is not greatly to be feared.

We have constructed such an instrument as this in the observatory shops from such material as we happened to have at hand. A trial of it has encouraged us to reconstruct it in more permanent form, and in particular we are having made for it an accurate driving sector and worm. It is proposed to put the method and instrument to a very severe test by extending the observations through an entire year, coming back to the group that forms our starting point by means of six steps.

The camera is being tried in the equator only because this simplifies the construction. A slight and obvious modification will make it applicable to any declination whatever. In this more general form the device, if successful, will enable us to ascertain the right ascension and the declination of stars in any portion of the sky providing that we know beforehand the positions of any other stars in about the same declinations. The instrument is intended for coöperation with the meridian circle in the determination of the positions of several hundred comparison stars in a narrow zone, upon which in turn can be based the compilation, by photographic observations, of zone catalogues of many thousands of stars.

Allegheny Observatory of the
University of Pittsburgh.

STUDIES OF INHERITANCE IN PISUM.

II. The Present State of Knowledge of Heredity and Variation in Peas.[1]

By ORLAND E. WHITE.

(*Read October 5, 1917.*)

PART I.

Introduction.[2]

Since the publication of Lock's summary of the genetic work on *Pisum* in 1908, numerous new studies by Tschermak, Hoshino, Pellew and others have very much increased our knowledge of heredity and variation in this genus.

The object of the present review is to summarize this new knowledge and correlate it so far as is practicable with the older knowledge, so that those who are interested may know just how much progress has been made and on what basis of fact the Mendelian analysis of *Pisum* rests.

The Materials.

The genus *Pisum,* according to the *Index Kewensis,* consists of seven species, possibly only five of which are markedly distinct. The species with their geographical ranges are:

P. arvense Linn., Sp. Pl., 727.—Europe, Asia.
P. elatius Bieb., Fl. Taur. Cauc., II., 151.—Reg. Mediterr.; Oriens.
P. formosum Alef., in Bonplandia, IX. (1861), 237.—Reg. Caucasus, Persia, Asia Minor, Syria.

[1] Brooklyn Botanic Garden Contributions, No. 19.
These studies on peas are being carried on in collaboration with the Office of Forage Crop Investigations and the Office of Horticultural and Pomological Investigations, U. S. Department of Agriculture.

[2] The writer will welcome corrections and especially desires to have his attention called to any genetic work on peas that has been overlooked.

P. fulvum Sibth.—Asia Minor, Syria.
P. humile Boiss.—Syria, Palestine.
P. Jomardi Schrank.—Egypt.
P. sativum Linn.—Europe, Asia.

P. arvense, P. elatius, and *P. Jomardi,* as grown from seed obtained through the Foreign Seed and Plant Introduction division of the U. S. Department of Agriculture, from various botanic gardens, seedsmen and other sources, are very similar, all having colored flowers, colored seed coats and a similar habit of growth. All three species when crossed produce fertile hybrids. Many students consider the differences between *P. sativum* and *P. arvense* not marked enough to warrant calling them by distinct specific names. Such students regard *P. arvense* as a sub-species of *P. sativum.* The purple-seeded Abyssinian pea is a very distinct form of *P. sativum* or *P. sat. arvense,* differing strikingly in seed and leaf characters from all other forms of this species. *P. formosum* is a perennial alpine form, lacking tendrils and very distinct as regards general habit and seed characters. *P. fulvum* has rusty cream-colored flowers and seeds with black seed coats. *P. humile,* though resembling small-leaved forms of *P. arvense,* gives partly sterile hybrids in crosses with the latter. Experimental work embraced by this review deals largely with forms of *P. arvense, P. sativum* and *P. elatius,* of which there are at least some five hundred varieties known.

About 250 of these varieties have been grown for three years in the experimental breeding plots of the Brooklyn Botanic Garden, where many of the experiments described in succeeding pages have been repeated and confirmed. Most of the descriptions of *Pisum* characters in the following pages are based on notes on these varieties. For help in bringing together this collection, which includes forms from all over the world, I am indebted especially to the Offices of Foreign Seed and Plant Introduction and Forage Crop Investigations of the U. S. Department of Agriculture, Arthur Sutton of Sutton & Sons, P. de Vilmorin, Haage & Schmidt, W. Bateson, C. Pellew, A. D. Darbishire and various botanic gardens of Europe and Asia.

As a whole, the differential characters of these species are surprisingly large in number, though each variety by itself differs from all other varieties, as a rule, in comparatively few of them. In describing these characters and the experiments in connection with them in Part II., they have been arranged in four groups—seed, plant, floral and pod characters. In each of these groups, striking hereditary differences are common.

Thus, the *seeds* vary from 2 mm. to 1 cm. in diameter, with a seed-coat color range from colorless through various shades of green, reddish orange, brown, gray to deep purple. These colors are further varied by color patterns of three types—marbling, striping and stippling. In *plant characters,* still more striking variations are apparent, such as differences in disease-resistance, in height (38–300 cm.), in productiveness (3–4 small pods to varieties with 50–150 pods), in stem color and shape, in leaf shape and color, in number of pinnæ per leaf, in the presence and absence of tendrils, in internode length and number and in time of flowering. The *flowers* differ in size, color, shape, number per peduncle, in position on the flowering axis and in time of pollen maturity. Three colors of *pods* are known. Differences in pod length and breadth range from about 10 by 1.7 cm. to 3 by 0.8 cm. (dry pods) with all degrees of intermediates between. Differences in shape, texture, thickness, toughness, time of maturity for market (45 to 125 days from time of planting) and in number of ovules per pod are striking.

A large number of these variations, as the data presented under Part II. disclose, yet remain to be experimentally studied.

The Relation of Environment to the Material.

It is axiomatic that all organisms live in an environment of some sort. Since the general acceptance of the Mendelian and genotype conceptions of heredity, what part of the organism's characteristics are due to environment and what part are due to heredity have become very important questions for study and experimentation. The Mendelian and genotypical conception that organisms are the expression of fixed and immutable factors or genes, which always (barring mutations) give rise to the same character, provided the environmental conditions remain constant, has led to a new conception of what constitutes a character. A character from this new view point is a joint expression of factors or of a group of factors and a particular environment. Characters are not inherited, since they cease to exist when unexpressed. Latency, semi-latency, and patency of characters are terms that should be scrupulously avoided in the interests of clear thinking. The older school of biologists and systematists in particular have always regarded all character expressions of a particular kind, such as the white color of flowers in different plant species, the character of stems—whether fasciated or round, the number of floral parts, etc., wherever found, as identical. For example, fasciation, according to de Vries, is a very ancient character, which has been transmitted to many of the higher forms of plant life in a latent condition. In a publication now in press in Germany (98.5) the writer believes he has set forth sufficient evidence to show that fasciations in plants from a genetic standpoint are of many kinds, some of which are hereditary under almost any normal plant environment, while other types only appear as a response to special environments, such as very rich soil, overwatering, or the stimuli derived from insect depredations. Further, these two or more kinds of genetically distinct fasciations, though morphologically indistinguishable, may be present at the same time in a group of plants such as peas. Further discussion of this case will be given in the part devoted to the genetics of *Pisum* stem characters. Morgan and his students (61) evidently look upon a character in this same fashion. They regard the recessive and dominant white color characters of certain breeds of silkworms and poultry as two different kinds of white due to two different genetic factors. White in both races is indistinguishable except in breeding tests. They cite numerous other cases among which is one from Baur illustrating the part environment instead of hybridization may play in showing up this difference. The red primrose (*Primula sinensis rubra*) reared in shade and moisture at a temperature of 30°–35° C. has pure white flowers, while the same plants grown at 15°–20° C. have red flowers. White and red flowers will occur on the same plant if the plants are first allowed to bloom in the cooler temperature and later to continue their blooming under the higher temperature. Another race of primrose (*Primula sinensis alba*) always has white flowers, even at 20° C. The white flower color character of both races, our systematists and comparative morphologists would say, was the same character (in the absence of the experiments cited above), but many geneticists would look upon them as two genetically distinct characters, one of which is altered by a change in environment. Acceptance of the conception of a character as advanced above may mean a very radical change in the weight which has been placed in the past on comparative morphology and taxonomy as methods for studying the evolutionary history of plants and animals.

The Categories of Variation.

Adopting the conception of a character as given above and assuming that plants and animals are made up of hereditary units or factors, variations or character changes in organisms may occur in three ways:

1. Variations due to changes of environment.
2. Variations due to "gain" or "loss" of factors or character determiners through crossing.
3. Variations due to mutation.

1. Variations due to changes in environment are perhaps most clearly illustrated by the change from white flowers to red flowers in *Primula sinensis rubra* following the change in temperature. So far as experimental work goes, change of the same material from one environment to another may take place repeatedly and each time the materials react to the new condition in the same way. Pink-flowered hydrangeas have blue flowers when placed in a soil containing sufficient alum salts. The unbranched varieties of peas are said to branch profusely under the climatic conditions of the Pacific coast region of the United States. Cabbage refuses to head in the tropics. Lock (54) found that seeds of certain pea varieties sown in Ceylon in January and constantly watered produced remarkably stunted plants, which flowered at half the usual height (of seeds sown in November in Ceylon) and bore almost no seed. Examples showing the direct influence of a changed environment could be given by the hundred, did space permit.

2. Changes due to crossing will be illustrated at length in the part devoted to the genetics of *Pisum*.

3. Changes in pea varieties due to mutation will also be discussed under the heading of mutation. Mutations, in the sense used in this paper, are relatively sudden, abrupt variations in a strain of plants which has bred true for more than two generations in the same environment. These variations remain comparatively constant in succeeding generations and form the basis of a new strain or variety. Such characters in peas as white flower color, lack of parchment in the pod, yellow foliage, and absence of tendrils have, so far as we now know, resulted from mutation. Mutations are comparatively common in some organisms and rare in others. Morgan and his students (61) have records of over 200 character changes in the fly, *Drosophila*, resulting from mutation. In peas, this phenomenon, judging by the records, is comparatively rare. Any type of character may be altered or replaced by mutation, the change occurring either as a small or as a large variation.

The Material and the Technique.

"The value and utility of any experiment," says Mendel, "are determined by the fitness of the material to the purpose for which it is used." Mendel (60), Correns (15), and Lock (53) have each expressed themselves strongly regarding the exceptional value of peas as material for the experimental study of heredity. The fact that they possess easily recognized constant differentiating characters, flowers which ordinarily are self-fertilized, and are capable of giving perfectly fertile F_1 hybrids was the chief reason that Mendel chose them. Mendel's reasons coupled with certain other facts, such as the direct economic value of the results, and the quick maturity of the plants, have led to their choice for the present series of studies.

Planting.—Peas are easily grown, and mature as many as three generations a year if both greenhouse and field plots are used. They are sown the 1st of April in this latitude, or earlier if practicable because the late varieties mature poorly under our summer conditions. Wrinkled seeded varieties rot before germination more easily than round seeded varieties. The peas are sown in rows, from 10 to 15 cm. apart in the row, the rows being 1.2 meters or more apart. Only undiseased plump seed are planted, unless there are special reasons for planting all the seed. The seed are all counted, so that any distortion of ratios from this source can be checked up. Wire netting may be used to keep the tall varieties off the ground. Peas should not be planted on the same ground two successive years, mainly on account of increased liability to pea diseases the second year. Darbishire (21) planted his pea plots to vetch for two years before using them again. Peas may be grown successfully in four-inch (10 cm.) pots or in benches in the greenhouse during the winter months. A bamboo stick or string should be provided for each greenhouse-grown plant. The greenhouse temperature should not be higher than 45°–55° F. Higher temperatures promote trouble with red spider and with various pea diseases.

Crossing.—Crossing in peas is easily accomplished by the removal of the stamens from a half-grown bud and the immediate application of the foreign pollen to the stigma. Pollen may retain its viability in a dry Petri dish for a week or more. Tschermak (81) made successful crosses with 14–21 days' old pollen of Allerfrüheste Mai. Varieties such as Dwarf Gray Sugar and other early-blooming sorts discharge their pollen while the bud is still greenish, while in many of the late-flowering sorts, the flowers are nearly mature before self-pollination takes place (78). Mutilation of the flower rarely causes the flower to fall, and if the crossing is done during sunny weather, most of the crosses will be successful. Under greenhouse conditions, peas have scattering flowers even after the first crop of pods are ripe. These scattering flowers may be utilized to furnish pollen for crosses with late-flowering forms. In field plots, crossed flowers should be protected by square-bottom paper bags. In greenhouse cultures, this precaution is generally unnecessary, especially in winter. Diluted grain alcohol is used to kill stray pollen on hands and the instruments after each cross. Usually the pollen to be applied is carried on the stigma and this foreign stigma brushed across that of the flower to be crossed. In labeling the cross, each plant of a variety is given an individual number, and care is taken so that each plant used in crossing also bears several uncrossed pods. The maternal parent is designated first.

Self-fertilization.—Because peas are naturally self-fertilizing, protection of the flowers of both pure strains and hybrid generations is ordinarily unnecessary. The few recorded changes of chance crossing are probably due to the pea weevil (*Bruchus pisi*) (60, 78) or to thrips (3, 78). In case the pollen of a flower is ineffective, the stigma may extend itself beyond the keel and chance crossing come about in this way. No cases of the latter type are recorded and the possibility of error from this source is rare (60).

The source of error from chance crossing in a locality may be tested out by growing several hundred plants of a variety with green cotyledons side by side with a row of a pure yellow cotyledon strain. When the seed of the green cotyledon strain are mature, the per cent. of crossing can be calculated from the number of yellow seeds found on the green-seeded plants. In an examination of over 10,000 seeds of several green-seeded varieties at the Brooklyn Botanic Garden, not a single case of cross fertilization came to light. Bateson and his students (5), Messrs. Sutton (5), Tschermak (81) and Mendel (60) each record a few cases, the per cent. in each case being much less than ½ per cent. The few non-conformables in Lock's experiments (54) on cotyledon color are attributed by him to errors in labeling, planting and to improper maturing.

Because peas are naturally self-fertilizing, pure lines may be selected from almost any of the commercial varieties with the assurance that they will be constant as regards visible characteristics and relatively free from heterozygosis almost at once. Most of the varieties at the Brooklyn Botanic Garden have given constant strains after at most two years of selection, while the great majority were constant from the start. In judging constancy, only characters such as flower color, seed shape and color, foliage color and shape of pod, which are but slightly influenced by small environmental changes, were used. Tschermak (78), Macoun (57.5), Hurst (42), Sherwood (72), Knight (50), Darwin (22) and many other experimenters have often remarked upon the exceptional constancy of pea varieties. It should be noted that pea varieties commonly grown for forage purposes have generally become very much mixed mechanically with each other as well as with various vetches through carelessness in handling and harvesting. Often it is possible to select ten or more constant varieties from a handful of such seed.

Labeling and Recording.—The system of labeling used in the work carried on at the Brooklyn Botanic Garden consists in giving the commercial stock of a variety as received a number such as Pisum 12; the plants grown from seed of P12 are numbered P12–1, P12–2, P12–3, etc. The next generation of P12–1 being recorded as P12–1–1, etc. Crosses are designated thus: P12–1 × P14–1, the F_1 progeny as (P12–1 × P14–1)–1, –2, –3, etc. In F_2 and subsequent generations all seeds planted are counted, and plot sketches kept of the arrangement of the plantings. A printed description blank covering all the common characters of peas is used for records of individual plants, and less detailed blanks for cultures studied for special characters.

Harvesting.—In studying seed characters extreme care should be taken to allow proper conditions for maturity. Harvesting immature peas may lead to considerable errors in studies on cotyledon and seed-coat color. Pea vines may be allowed to mature until no green remains and they are dry and brittle. This insures maturity. In order to avoid breaking such brittle material, the vines should be thoroughly wetted with a hose before handling. Each plant should be labeled with a tag label as gathered. Green cotyledon varieties tend to fade to yellow if left exposed to light for a considerable time (54) and damp wet weather at harvest time may bring about the same result much sooner (1, 60, 21).

Environment.—No factor is of more importance in a detailed genetic study of the characters of a group of plants such as *Pisum,* than environment. Environment, being the co-partner of heredity in the make-up of a character, should have just as precise a description as the characters themselves, or else be eliminated altogether by growing the material under as near as possible the same conditions. If environment were as easy a proposition to handle as in the case of chemical experiments, one could define it in the case of each experiment with such exactness that it could be easily reproduced. Unfortunately this is not practicable, because of the many factors which compose it. Under greenhouse conditions, it is more practicable than in field cultures. However, even here, aside from the temperature, watering, etc., factors such as soil and light vary so over an area when large cultures are grown, that it is largely a figure of speech to speak of absolute uniform environment for the whole area.

In order to secure the greatest uniformity practicable in environmental conditions, all cultures which are studied from a comparative standpoint are planted in the same batch of soil, at the same time, and given the same cultural care. A few characters of *Pisum* such as flower color, presence of parchment and presence of tendrils are very little affected by environmental fluctuations. The majority of *Pisum* characters, however, react to environmental fluctuations so as to give rise to error in any intense study, unless the fluctuations are known well enough to be taken into account. By growing a large series of cultures, both hybrid and pure line, under approximately the same set of conditions by the method mentioned above, and securing as near as practicable the same conditions for several years, one may become so familiar with the factors composing such an environment and the reactions of the plants to such an external set of conditions, that the environment itself may be used as a standard by which the modifications of the same plants grown under other environments may be described. Such an environment may be called a *standard environment,* as it is the criterion by which the effect of all other conditions on characters is decided. Whether such a standard can be made precise enough to be of much value in genetic work remains to be seen. If one describes character changes by revolving round a circle, one gets nowhere, and without a standard starting place, one simply revolves. The older biologists used the term normal to designate in a vague way what I mean by standard. Normal environment, however, may mean almost any common environment in experimental work. Thus there is no gain in preciseness through its use.

PART II.

The Genetics of *Pisum*.

Genetic studies on the genus *Pisum* may be divided into two groups—those made before and those made since the rediscovery of Mendel's law in 1900. The pre-Mendelian studies resulted in a great deal of practical good, but were of slight scientific value, since no laws of heredity were discovered. The post-Mendelian work is as yet too young to have given great practical results. Laws have been discovered however, which ultimately may lead to undreamed practical possibilities.

Heredity Studies on *Pisum* Prior to 1900.

According to Darwin (22), as early as 1729, white- (yellow cotyledons) and blue- (green cotyledons) seeded varieties of peas had been observed (probably through insect crossing) to give rise to pods containing both blue (green) and white (yellow) peas. In 1787 Andrew Knight (50) had crossed various races of peas and originated many new varieties, some of which, *e. g.*, Knight's Tall Wrinkled Marrow, are said (42, 72) to have persisted in a practically unmodified form, but under different names (British Queen), down to the present day, representing, if true, a striking illustration of the constancy of an old variety, through a hundred years or more of inbreeding. Knight, in many ways, was a forerunner of Mendel, as he had observed the dominance of tallness in peas over dwarfness, purple flower color over white flower color, gray brown seed coats over uncolored seed coats and the breeding true of recessives and part of the dominants. But he was unaware of the significance of these facts and of the importance of determining the ratios of the various kinds in the second and third hybrid generations. He is credited, however, by Sherwood (72) with having given us the start in wrinkled seeded varieties of peas, as before his time wrinkled peas appear to have been unknown.

Goss in 1822 (36, 21) also anticipated Mendel by his observations on the cotyledon colors of peas, *i. e.*, the dominance of yellow over green cotyledons in the first hybrid generation and the occurrence of green and yellow peas in the same pods in the second hybrid generation, as well as the subsequent breeding true of part of the yellow seeds and all of the green seeds in later generations. Appended to Goss's description of his results is an editorial comment giving the results of crossing green and white (yellow) peas by one, Mr. Seton. Seton used the green-seeded Dwarf Imperial as the maternal parent in a cross with a (white) yellow-seeded variety. Four peas were obtained, which, though subsequently proven to be true hybrids, did not differ in appearance from the uncrossed seeds borne by the Dwarf Imperial plant. Thus even at that early stage in the history of genetics, complication and confusion appeared on the scene. Bateson (21, p. 198) has since shown such varieties as the Imperials to have opaque green seed coats and yellow cotyledons. Seton's observations were on seed coat color, while Goss dealt with cotyledon color. Like Knight, however, Goss did not see the significance of his results nor did he determine the numerical proportions of the two colors of seed in the F_2 generation.

Gaertner (35) also made pea crosses, as well as crosses of many other plants. He interpreted the dominance of yellow cotyledon color over green as due to xenia (the direct and immediate effect of the male parent on the maternal tissues), not apparently aware that the characters yellow and green seed color were those of the embryo of a new generation.

Darwin (22) grew and crossed peas and noted the extreme vigor of F_1 hybrids as compared to the parent forms growing beside them, and studied variation and inheritance in several characters of peas. He had, however, never heard of Mendel's work.

Laxton (22) and others had noticed the rather remarkable constancy of pea varieties, a number of which were known to be twenty or more years old. Laxton (the ancestor of the present well-known family of pea and fruit breeders) also furnished Darwin with data on the relation of environment to the production of double flowers in peas, as well as data on the inheritance of such characters as purple pod and seed color.

Masters (59) wrote letters to the *Gardner's Chronicle* against the practice (unfortunately still quite common) of changing the names of old varieties, so as to increase their sales. Judging by the printed replies, his accusations were very much resented by the seedsmen. Masters introduces one of his communications by this quaint reference to his own qualifications as a pea specialist, "And first let me give you my pretensions to pass an opinion upon the matter, that, with your readers (to whom I am unknown), I may stand in a fair position. Be it known, then, that forty years ago, my father, of good memory, employed my then young eyes to detect the differences of the peas he intended for seed, and many a patient hour was devoted to this most necessary of operations under his guidance" (1850). Masters also claims (22) to have raised four distinct sub-varieties from one plant—

Plants bearing blue and round seeds,
Plants bearing blue and wrinkled seeds,
Plants bearing white and wrinkled seeds,
Plants bearing white and round seeds.

The remarkable part of Master's claim, however, is that though he grew the four varieties separately for several successive years, each kind always produced all four kinds mixed together. In other words, not one of these varieties bred true as regards the four characters mentioned, while according to most of the recent studies, wrinkledness and green cotyledon color (blue) should be constant. White (98) has recently secured results which possibly may throw some light upon Masters's claim as far as the inheritance of cotyledon color is concerned.

Though facts were apparently plentiful (such as they were), regarding the effects of environment and the heredity of characters in peas and other plants, efforts to formulate them into a *law of heredity* that would stand the test of experimental inquiry were, prior to the studies of Mendel, apparently futile. Heredity, says an old writer, is a collection of facts without laws, while Balzac wrote "heredity is a maze in which science loses itself."

Mendel's own results on the inheritnace of characters in peas were published in an obscure Austrian natural history society's proceedings, and except for a few lines in Focke's book (28) on hybrids, and a bibliographical reference in Bailey's "Plant Breeding," they remained lost until 1900, when the three botanists—Correns (14), Tschermak (78), and de Vries (23.5)—rediscovered the law and resurrected Mendel's paper from oblivion. The subsequent impetus this rediscovery and resurrection gave to the scientific study of plant breeding is abundantly exemplified by the thousands of papers and books published since 1900 containing results of experiments on hundreds of varieties of plants and breeds of animals. In corn alone, the inheritance of over thirty characters has been studied and found to be consistent with Mendelian principles. In tobacco, cotton, sweet peas, corn, wheat, oats, and poultry results of considerable practical value have been obtained by the use of Mendelian methods.

Mendel's Law.

The fundamental principle of Mendelism is very simple and rests upon the assumption that animals and plants are made up of units (called factors, genes, determiners, etc.), and that these units may separate in the formation of the "germ-cells" (pollen and eggs) of the hybrid offspring without having had any permanent influence upon each other. The assumption that such units or factors exist is based upon experimental data derived from crossing two plants or animals from true breeding strains differing in two or more characters and the growing of at least three subsequent hybrid generations under approximately the same environment as the original two ancestors of the cross. For example, when two strains of peas, one constant for purple flowers and green cotyledons and one constant for white flowers and yellow cotyledons, are crossed, the first or F_1 generation is uniformly all purple-flowered with yellow cotyledons. Self-fertilized seed from any of these F_1 plants, if sown in sufficient numbers, will produce approximately 9Pfl.YC : 3Pfl.GC : 3Wfl.YC : 1Wfl.GC plants, showing that the determiner for green cotyledons in addition to separating from its F_1 associate—the determiner for yellow cotyledons—also is inherited independently of its ancestral associate—purple flower color. Mendel himself regarded purple and white flowers in peas as a pair of characters, one of which completely dominated the other. Geneticists now largely hold to the presence and absence hypothesis, by which the purple is regarded as due to the presence of a factor or determiner for purple in the one strain and the white-flower character as due to the absence of this determiner or factor for purple color. Data from genetic experiments, most geneticists believe, are more simply expressed by the presence and absence concept.

Since the promulgation of Johannsen's genotype hypothesis, many geneticists believe these Mendelian factors to be unmodifiable by selection and selection itself to be but a process of sorting out or freeing hybrid or mixed populations from heterozygosis.

Mendelian Studies of Peas.

Sixteen years have elapsed since the study of heredity assumed the dignity of a separate science under the name of *genetics*. During these sixteen years much has been accomplished through experimental studies on peas and other organisms. Many complications in the application of Mendel's law to data from these studies have arisen, most of which have served to place the Mendelian conception of heredity on a still firmer foundation [see (61)].

Among peas, over thirty-two different types of characters have been experimentally studied, amounting in all to over 75 single characteristics of *Pisum*. In about half the cases, the knowledge gained is somewhat fragmentary. In the other half, owing to the painstaking work of Mendel, Bateson, Vilmorin, Darbishire, Lock, Correns, Gregory, von Tschermak and others, the characters have been put upon a factorial basis. In the list of characters studied which follows, the factors are designated according to the presence and absence conception, small letters standing for absences. Where the use of the letters for the factors given by the investigator of the character concerned, is practicable, they have been retained. In cases where this is inconsistent with the scheme of a complete analysis of the genus *Pisum* upon a factorial basis, new letters have been substituted. In many cases these refer to adjectives descriptive of the part they play in the formation of the character.

In the case of some of the factors given in Tables I. and II., the data hardly justify their consideration. However, since the data upon which each factor determination is based are to be given in the following pages, the writer justifies putting them in the tables in the belief that further research concerning them will be more quickly inspired.

For the cause which this paper represents, it probably would be better if all the crosses thus far made were given under each character description. Space at present, however, forbids this. So that in the following pages, under the character description, will be given the varieties studied, the results of the crosses in terms of dominance and ratios, the factorial interpretation, the effect of the environment, if any, on the factorial expressions, and any remarks or adverse criticisms.

Reciprocal crosses in plants give the same results in all but a few cases, and these few cases in *Pisum* are described. Otherwise the reciprocal of a cross, although often made, is not specifically consid-

TABLE I.

CHARACTERS IN *Pisum* UPON WHICH EXPERIMENTAL STUDIES HAVE BEEN EXTENDED ENOUGH (IN MOST CASES) TO FORM THE BASIS FOR GENETIC FACTOR REPRESENTATION.

No.	Type of Character.	Characters and their Corresponding Factors.	Reference to Bibliography.
	Seed characters		
1.	Seed coat color...	Gcjh (brown to yellowish green, gray), gcJ (colorless), U (purple), light orange brown (GcjH), dark brown (GcJ)	(1, 2, 3, 14, 21, 33, 43, 50, 54, 55, 60, 78, 79, 81, 83, 86, 90)
2.	Seed coat color pattern		
	Purple spots.....	EF (purple spots), Ef, eF, ef (no purple spots)	(1, 2, 3, 14, 21, 34, 43, 51, 54, 55, 60, 79, 81, 83, 86, 89)
	Violet eye.......	N (violet eye), n (absence)	(86)
	Black eye	Pl (black eye), pl (absence)	(14, 56, 57.5, 90)
	Mapling.........	M (mapling), m (absence)	(1, 3, 21, 43, 54, 55, 60, 86)
3.	Seed coat surface	L_1L_2 (indent), L_1l_2, l_1L_2 (smooth)	(3, 37, 43, 54, 55, 81, 83, 86)
4.	Seed shape	R (round), r (angular, wrinkled) (smooth)	(1, 2, 3, 14, 19, 21, 23, 33, 37, 42, 43, 48, 54, 56, 59, 64, 72, 79, 80, 81, 83)
5.	Seed size........	Not sufficiently studied	(1, 57.5, 86, 89, 90, 96)
6.	Cotyledon color. .	YGI, Ygi (yellow), YGi (green)	(1, 2, 3, 7, 14, 21, 22, 33, 35, 36, 38, 42, 43, 52, 53, 54, 56, 59, 60, 78, 80, 81, 83, 90, 96, 98)
7.	Cotyledon starch	R (simple oval), r (compound, round)	(Same as No. 4)
8.	Starch modifier...	Very slightly studied	(48)
9.	Starch water content	R (low), r (high)	(3, 19, 21, 23, 39, 48)
10.	Cotyledon starch content	R (high), r (low) (high sugar content)	(Same as Nos. 4 and 9)
11.	Wet, cold weather germinating ability	R (excellent), r (low)	(Various seedsmen)
	Plant characters		
12.	Height..........	TLe (tall), tle (dwarf), tLe, Tle, (half dwarf or talls?)	(1, 2, 3, 7, 21, 22, 33, 43, 49, 50, 52, 54, 56, 60, 79, 80, 81, 83, 85, 90)
13.	Leaf axil color....	CD (colored axil), cd, Cd (no axil color)	(3, 16, 43, 54, 55, 56, 60, 74, 81, 86)
14.	Stem...........	Fa (non-fasciated), fa (fasciated)	(1, 3, 8.5, 21, 25, 56, 60, 74)
15.	Inflorescence.....	Fa (axillary), fa (umbellate)	(1, 3, 8.5, 21, 25, 56, 60, 74)
16.	Stem thickness...	T (robust), t (slender)	(49, 54)
17.	Internode length.	Le (long), le (short)	(1, 49, 54, 78)
18.	Time of flowering	Very complicated, not sufficiently studied	(3, 9, 39, 40.5, 43, 49, 54, 60, 66, 81, 83, 84, 85)

TABLE I.—*Continued.*

No.	Type of Character.	Characters and their Corresponding Factors	Reference to Bibliography.
	Plant characters		
19.	Flowers per single peduncle	Fn (one flower or 1–2 flowers), fn (two–three flowers per peduncle)	(90)
20.	Leaf terminals...	Tl (tendrils), tl (no tendrils, Acacia)	(64, 88, 89, 90)
21.	Leaf size........	Not sufficiently studied	(48, 54)
22.	Foliage and stem color	O (green), o (yellow)	(3, 21, 43, 60)
23.	Bloom..........	BlW (glaucous), blw, Blw, blW (glabrous)	(86, 90, 92)
24.	Productivity.....	Very complex, not sufficiently studied	(39, 44, 54, 66, 68–70, 76–77, 93, 94–95)
	Flower character		
25.	Flower color.....	AB (purple), Ab (rose or pink), aB, ab (white)	(1, 2, 3, 16, 21, 33, 40.5, 43, 53–56, 60, 78, 81, 82, 83, 84, 85, 86, 90)
	Pod characters		
26.	Color...........	P_1P_2 (purple), Gp (green), gp, P_1p_2, p_1P_2 (yellow)	(3, 14, 21, 22, 34, 43, 56, 60, 83, 86, 90)
27.	Apices..........	Bt (blunt), bt (acute)	(1, 3, 5, 42, 54, 56, 80, 81)
28.	Shape...........	PV (round, smooth, inflated), pv, Pv, pV (constricted)	(1, 2, 3, 21, 22, 43, 54, 56, 60, 80, 81, 86, 90, 99)
29.	"Chenille"......	S (free), s (chenille)	(92)
30.	Pod texture......	PV (parchment), pv, Pv, pV (non-parchmented)	(Same as No. 28)
31.	Edible..........	PV (non-edible), Pv, pv, pV (edible)	(Same as No. 28)
32.	Curved or straight	Not sufficiently studied	(5)
33.	Broad or narrow.	" " "	(43, 54, 56, 80, 81, 90)
34.	Ripening........	" " "	(43, 77)

ered. Where the expressions constant or breeding true are used in regard to inheritance of characters, mutation phenomena are always excepted.

TABLE II.

LIST OF *Pisum* FACTORS, ALPHABETICALLY ARRANGED, AND THEIR CORRESPONDING CHARACTER EXPRESSIONS.

Factor.		Expression.
1.	A	Salmon pink or rose flower color. With CD gives reddish leaf axils.
2.	B	Purpling factor + A gives purple flowers. With CD + A gives purplish leaf axils.
3.	Bl	Glaucous foliage, stems and pods (with W).
4.	Bt	Pods with blunt apex.

5.	C (A)	With D gives leaf axil color.
6.	D	With C gives leaf axil color.
7.	E (A)	With F gives purple dotting on seed coats.
8.	Ef	Modifies the expression of Lf toward earlier flowering.
9.	F	With E gives purple dotting on seed coats.
10.	Fa	Axillary flowers, round stems.
11.	Fn	One-two flowers per peduncle.
12.	Gc (A)	Yellowish green to grayish brown seedcoat color (weak chromogen factor), brown hilum.
13.	G	Green cotyledon pigment.
14.	Gp	Green pod color.
15.	H	Brightener or inhibitor of expression of Gc.
16.	I	Factor which causes green cotyledon color to fade.
17.	J	With Gc gives dark brown seed coat color.
18.	K(?)	Partial inhibitor for R (starch).
19.	L_1 (A)	With L_2 gives indent peas.
20.	L_2	With L_1 (A) gives indent or dimpled peas.
21.	Le	Long internodes; with T gives tall plants.
22.	Lf	Primarily responsible for late flowering.
23.	M	Brown or maple mottling on seed coat; or "ghost mottling" in absence of A.
24.	N	Violet eye on seeds.
25.	O	Green foliage, stems, and pods.
26.	P	Inflated, parchmented, non-edible pods with V.
27.	P_1	With P_2 gives purple pods.
28.	P_2	With P_1 gives purple pods.
29.	Pl	Black eyed peas.
30.	R	Round, smooth seeds with simple, oval starch grains, low water content.
31.	S	Pods with seeds separated or free.
32.	T	Tall, robust plants; large number of internodes (over 20).
33.	Tl	Leaves with tendrils.
34.	U	Dark self-colored purple seed coat.
35.	V	With P, parchmented, smooth pods.
36.	W	With Bl gives glaucous foliage, pods, etc.

Factors A, C, E, Gc and L_1, so far as our present knowledge is concerned, appear *absolutely* coupled and it is much simpler to regard them all as one factor (*i. e.*, A) with many separate expressions.

1. Seed Coat Colors.

The seed coat characters include the various testa colors and patterns. Testa color and pattern are so closely associated that they are described together. Unlike similar patterns in seeds of other plants, such as beans, the colors do not appear to be independent of the pattern, except possibly in the case of the eye or hilum pattern color. One never finds purple marbling or maple-brown stippling among the seed coat colors of *Pisum*. The stipple pattern is always purple and the marbling pattern is always brown. The seedcoat colors of the varieties of peas thus far genetically studied are five in number—colorless to greenish white, deep to pale green, dull green or gray to brick red or grayish brown, dark brown, orange brown and violet or dark purple.

Colorless seed coats are always associated with white flowers, uncolored leaf axils. When such seed coats are separated from the rest of the seed, they are somewhat transparent with traces of yellow and green present. This is the common seed coat color of white-flowered varieties.

Green seed coats genetically are at least of two different kinds, one common to white-flowered varieties, such as the Imperials (21), Fillbasket and Telephone (1); the other present in a variety with colored flowers and received under the erroneous name of *P. Jomardi*. In the first case, the green testas may bleach on ripening, especially in piebald cotyledon sorts such as Telephone (1). Fillbasket testas (1) rarely bleach. Nothing is known concerning the genetic behavior of the *P. Jomardi ?* type. Telephone green is soluble in alcohol.

Gray seed coat color is always associated with colored flowers. The color varies from dull green through gray to brick red to dull brown, the variation resulting from environment. The redness and brownness are due to exposure to the sun or moisture when ripening (1). In dull years, Bateson says scarcely any turn red. Peas grown in the greenhouse and harvested in winter very rarely, in my experience, turn brown or red. The red can be eliminated by boiling, which will leave the seeds thus treated gray (1). Gray chemically (55) is determined by a greenish pigment contained in all or almost all the seed coat cells. With but three or four possible exceptions, all colored flowered varieties have seeds with gray pigment.

Orange brown or light yellow orange seed coat color is characteristic of several varieties of field peas with colored flowers described by Tschermak (86) as *P. arvense* nos. VI., IX. and X. With age and exposure, they turn browner.

Dark brown seed coat is a dark chocolate brown typical of the red-flowered Kneifel pea with purple pods experimented with by Tschermak (86) and Haage and Schmidt's Kapuziner.

Violet or *dark purple* seed coats are of two different kinds, one apparently what Emerson (27.5) would call a recurring mutation, which results from an extreme variation of the purple spot pattern to a self-purple and the subsequent breeding true of them (34). The other type of purple seed coat is a constant characteristic of several varieties of field peas, particularly of No. 24894 (29), the "black Abyssinian" pea of the U. S. Department of Agriculture. The genetics of the first type is taken up under the seed coat color patterns of *Pisum*. That of the latter type is only mentioned, so far as I am aware, in Vilmorin's list (90) where it is recorded as a dominant to various other seed coat colors.

The seed coat patterns of *Pisum* are three in number—a purple stippling or dotting, a brown marbling, and an eye pattern.

Purple dotting or *stippling* is only found in association with races with colored flowers and gray seed coats, although many colored-flowered varieties do not have seeds with purple dots. The dots themselves often transgress the limits of dots, resulting in splotches and, in extreme cases, wholly self-colored peas (1, 22, 34, 81, 86). In the seeds with gray seed coats which have turned red or brownish, the purple dots are often obliterated (1). The purple color according to Lock (55, 56) is a cell-sap pigment, confined to certain large cells of the sub-epidermal layer. This fact accounts for its diffusion into blotches and traces and its complete obliteration when the seeds are left exposed to damp, sunshiny weather conditions. Fruwirth (34), however, describes this pattern in the Blauhülsige variety as due to brownish, weak violet pigment granules in the palisade cells. Lock says this pigment is easily soluble in boiling water.

Brown marbling or the *maple* pattern, as the English call it, is associated only with colored flowers as far as the color is concerned. Lock, however (54, 55), finds the pattern itself ("ghost mapling") without coloring, may be associated with white-flowered plants. The brown pigment of the maple pattern is largely confined to the cell walls of the outermost layer of I-shaped testa cells (55). The pattern color deepens with age and is insoluble in boiling water.

The "*eye*" *color* pattern is characteristic of both colored and white-flowered pea races. The color is present as a deep black at the point of attachment, with a dark sooty tint usually present over the seed as a whole. Some varieties have brown coloring (81) in place of the black while other varieties are without color at this spot. The brown hilum color according to Tschermak is always associated with colored flowers and colored seed coats, so it may be considered as simply another of the numerous expressions of factor A.

Violet eye is due to a violet hilum pigment, characteristic particularly of a race of Victoria peas with which Tschermak experimented.

Brown marbling, purple dotting or stippling and black eye may all be associated in the same pea seed coat. In fact, a couple of wild species obtained direct from Asia have seeds characterized by all three of these color patterns.

Varieties Studied.

Varieties with *colorless* or almost colorless seed coats as described under colorless: Grünbleibende Folger, Désirat, Auvergne, Yellow-podded Sugar Pea, Express, Emerald, Victoria, Svalöf Small Green-seeded *Pisum*, Prince of Wales (Tschermak, 81, 86); Grün Späte Erfurter Folger (Correns, 14); Laxton's Alpha, Veitch's Perfection, Sunrise, British Queen, Victoria Marrow, Trés nain de Bretagne, Earliest Blue, Ceylon Native No. 1, Satisfaction, Ringleader (Lock, 54, 55, 56); Serpette, British Queen, Victoria Marrow, Ringleader, Nain de Bretagne (Bateson, *et al.*, 1), White-flowered Mummy (Macoun, 57.5).

Green seed coat varieties: Telegraph, Telephone, Fillbasket (Lock, Bateson and Kilby, 1, 54).

Gray seed coat, violet stippling: Graue Riesen, Svalöf *P. arv.,* IV. (Tschermak, 81, 86); Sutton's French Sugar Pea (Lock, 53); Blauhülsige (Fruwirth, 34).

Gray seed coat, maple marbling: *P. arv.,* IX., *P. arv.,* X. (Tschermak, 81, 86); Irish Mummy (Bateson, 1).

Gray seed coat, violet stippling, maple marbling: Ceylon Native Pea No. 2 (Lock, 54).

Gray green, bright orange tint: Svalöf *P. arv.,* VI., *P. arv.* No. VII., *P. arv.,* IX. ?, *P. arv.,* X. (Tschermak, 81–86); Pahlerbse with purplish pods, Purpurviolettschottigen Kneifelerbse (Correns, 14).

Dark brown seed coat: Red-flowered Kneifelerbse with purple pods—Tschermak, 86.

Brown hilum: P. arv., VI., *P. arv.,* VII., *P. arv.,* VIII., *P. arv.,* X.—Tschermak, 81, 86.

Violet eye: P. arv. No. IX., violet-eye Victoria—Tschermak, 81, 86.

Black eye: In most cases varieties not given. Black-eyed Marrowfat—Macoun, 57.5; Haage & Schmidt's Kapuziner, Bohnenerbse (H. & S.), Lyngby Fall Pea (U. S. Dept. of Agr.), Benton (U. S. Dept.), Prince (S. P. I. 22046, U. S. Dept.)—White (unpublished data).

Results from Crossing.

Colorless × colorless seed coat always gives colorless or transparent seed coats (1).

Colorless × green or white (opaque) gives various results, but never fully opaque seed coats. In some cases the F_1 hybrids are colorless, in others intermediate as regards opaqueness and the presence of pigment.

Opaque × opaque (1) always gives F_1 progeny with opaque seed coats.

Colorless × gray brown seed coat always gave all gray browns in F_1. In the F_2 generation, the following results have been obtained:

Investigator.	Gray Brown.	Colorless.	Total.	Ratio.
Mendel	705	224	929	3.15 : 1
Lock	87	24	111	3.62 : 1
Bateson and Lock	50	19	69	2.63 : 1
	842	267	1,109	3.15 : 1
Lock F_3	231	85	316	2.71 : 1

F_4 generation grown by Lock but actual figures not recorded.

In addition to the figures given above are those from crosses made by Correns, Tschermak and others. These data are omitted here because either the exact figures are not given in the original papers or that these figures are scattered through so many papers and so often repeated as to make their accurate collection impracticable.

In F_3, a certain proportion of the F_2 segregates with colored seed coats breed true, another portion break up, giving again the 3 : 1 ratio, while the F_2 segregates with colorless seed coats breed true.

In certain crosses made by Tschermak (86) between colorless and gray brown (whitish brown) seed coat varieties, F_1 progeny with dark brown seed coats were obtained, which in F_2 gave dark browns, grays and colorless seed coat segregates, approximating the proportion 9 : 3 : 4.

Colorless × gray seed coat with purple dots gives in the next (F_1) generation, all gray purple dotted seed coats. In F_2, the following results have been obtained:

Investigator.	Gray and Purple Dots.	Gray.	White.	Total.	Ratio.
Lock (53, 54)	68	19	24	111	9 : 5.7
Tschermak (86)	71	46		117	9 : 5.8

F_2 heterozygotes in F_3 gave:

Investigator.	Gray and Purple Dots.	Gray.	White.	Total.	Ratio.
Lock	178	53	85	316	9 : 6.9

In F_4, Lock (55) tested out the genetic nature of non-purple dotted colorless seed coat F_3 segregates which had bred true in F_4

by crossing them with various F_4 segregates breeding true to gray seed coat color.

In F_5, from 60 crosses of colorless $F_4 \times$ gray F_4,

9 crosses gave 21 gray purple dotted: 23 gray,
23 crosses gave only gray purple dotted,
28 crosses gave only grays without purple dots.

Tschermak (86) has made numerous crosses between pure varieties and extracted F_2, F_3 and F_5 segregates with and without the character purple dotting. In these crosses, *colorless* $\times$ gray without purple dotting in some cases gave all purple dot progeny in F_1 (agreeing with the results of Lock's crosses above). In other cases, using different varieties, Tschermak always secured only non-purple-dotted progeny both in F_1 and in F_2, except in certain very exceptional cases. In these exceptional cases purple dotting appeared sporadically on the seed coats of gray segregates which had bred true to a self gray for several generations, while on the other hand there were cases in which purple dotting was expected, but failed to appear when certain crosses were made (86, S. 160). Varieties (86) practically breeding true to the absence of purple dotting also occasionally have a few seeds with purple dots, and these appear on plants the majority of the seed of which is without the purple dots.

Colorless $\times$ orange-brown or greenish orange tinted (*e. g., P. arv.* Svalöf No. VI.) gave in F_1, in Tschermak's experiments (86) progeny with dark brown seed coats with purple dots. In F_2, 4 classes appeared—dark brown with purplish reddish dots, dark brown with no dots, whitish brown (gray) with no dots, colorless. The numbers were small, hence the ratios are not of much importance, except in showing that the dark browns were in greater number than the other two classes. The gray segregates were constant and in back-crosses with the colorless seed coat parent gave only dark browns, grays and colorless seed coat segregates, with or without purple dots, as in Lock's crosses of F_4 colorless and F_4 gray seed coat segregates given above. If large enough numbers had been obtained Tschermak (86, S. 161) believes the orange-tinted grandparental type would have appeared again.

Correns (14) crossed a colorless seed coat variety with two varieties having orange-red seed coats and obtained in F_1 progeny with seed coats varying from almost colorless ? to intense orange-red—the variation in coloring often occurring in the peas of the same pod. All were more or less purple spotted. These gave, in F_2, 3 classes, the two grandparental types and the F_1 type. The statement regarding the presence of purple dotting on these F_2 segregates is rather obscure.

Lock (53, p. 326) does not consider orange-brown testa color as a separate character from gray-colored testa, and Bateson thinks Corren's exceptional results in F_1 of the cross just described may be due to environment. The writer has distinctly orange-red seed coat peas with white flowers in his collection from Chile and he hardly believes that present data justify Lock's contention, because these peas do not mature as gray under the conditions in which ordinary gray seed coat varieties have gray seeds.

Colorless × dark brown seed coat varieties should according to Tschermak's formula for at least one such variety [redfl. Kneifelerbse, S. 181 (86)] give all dark brown seed coat progeny in F_1 with or without purple dots, depending on the colorless variety used. I have not, however, been able to find the published record of the data upon which this formula is based. True breeding (86) dark brown seed coat segregates crossed with colorless give dark brown in F_1.

Colorless × gray with maple pattern gives in F_1 maple pattern either with or without purple dots. The presence of the purple dots in F_1 of such a cross as this is altogether dependent on the kind of colorless seed coat variety used, as the genetic evidence from Bateson (1), Tschermak (86) and others shows that a gray maple pattern seed coat variety may be crossed with colorless and give maple and purple dots. The same maple variety may again be crossed with a colorless, but this time a different one and give only maple. Bateson (1) found British Queen to be a colorless seed coat variety of the first type and Victoria one of the second type. Tschermak [see Bateson (1)] secured 2 cases where Victoria × unspotted varieties gave purple spots in F_1, while reciprocals of the same cross gave unspotted seed coats. In Tschermak's latest publication (86) on the subject, two varieties of Victoria are recognized, one of which will give purple dots in F_1 as above and one of which would only give maple as found by Bateson.

Tschermak (86) secured in F_1 from maple × colorless, brown maple seed coat without purple specks. These F_1's gave in F_2, 52 maples : 17 dark brown selfs : 1 ghost maple : 6 colorless.

In F_3,

F_2 *maples* gave in one case all 4 classes; in another case only 2 classes—maples and colorless.

F_2 *dark browns* gave 6 brown : 1 colorless in one case; in another 7 browns : 1 colorless.

F_2 *ghost* maple gave 9 ghost maple : 3 colorless. Ghost maples are hard to distinguish from whites, so Tschermak believes the F_2 classes above approximate the ratio 9 maple : 3 brown : 3 ghost maple : 1 colorless.

F_2 *ghost maple* segregates × a pure colorless *P. sativum* race gave in F_1, 4 ghost maples : 2 colorless.

In F_2, one of these ghost maples gave ghost maples which bred true in F_3 and F_4, while another one ("spur" ghost maple) gave 2 like itself and 7 without mapling. One of the colorless F_1 individuals gave 2 ghost maples and 6 colorless. In a similar cross, only spurious ("spur") maples and colorless were obtained in F_1, the "spur" ghost maples giving 2 "spur" maples : 7 colorless in F_2. Tschermak believes these "spur" maples are due to the inactivity of the determiner for mapling. Fruwirth and Tschermak both have observed exceptional cases where mapling has appeared in the descendants of non-mapled peas.

In back-crosses of segregates from mapled ancestors,

Brown × colorless never gave maple,
Brown × brown never gave maple.

Certain peculiar ghost maples on plants with rose or pink flowers × white-flowered ghost maples gave in F_1 and F_2 no maples.

In reciprocal crosses between segregates of *P. arv.* × *P. sat.* involving the maple pattern, F_3 brown × ghost maple and reciprocal [Table 22 (86)] gave in F_1, except in one case, always browns, the exception giving 5 maple: 4 purple dotted non-maple. In F_2, in some cases, the browns bred true, in others only brown and colorless resulted; while still others gave maples, browns, ghost maples and colorless. One of the last type gave 20 maple: 6 brown: 5 ghost maple: 5 non-mapled. Non-maple × non-maple segregates involving maple or ghost maple ancestry [Table 23 (86)] gave no maples in F_1.

Lock's (55) results are in general accord with Tschermak.

Maple × *colorless* gave in F_1, maple. In F_2, 38 maple: 12 gray: 19 colorless were obtained, approximating a 9:3:4 ratio. 2 of the 19 colorless had ghost maple seeds, but there should have been a large proportion of these ghost maples. Lock says ghost maple is for some reason almost unexpressed in this particular cross (maple × Victoria Marrow).

Crosses of F_3 offspring of all 19 colorless with either pure strains of gray or gray with purple dots (no maple) resulted in

7 colorless producing 17 maples: 15 non-mapled.
22 colorless producing all maples (over 50),
7 colorless producing all non-maple (over 26).

Colorless × gray, maple, purple spots gives in F_1 always gray with both mapling and purple spotting. In F_2, Lock (55) obtained 11 gmp: 2 gm: 6 gp: 2 g: 4 white or colorless (one of which was ghost mapled).

In F_3, 467 offspring of these various classes were grown, none of which gave results in opposition to the interpretation of the genetics of seed coat colors given at the end of this review.

3 gmp F_2 plants gave:

	82 gmp	: 20 gm	: 21 gp	: 9 g	: 37	colorless
Ratio,	27	: 9	: 9	: 3	: 16	
Expected,	71.3	: 23.8	: 23.8	: 7.9	: 42.2	

4 gmp F_2 plants gave:

	75 gmp	: 24 gm	: 48 colorless
Ratio,	9	: 3	: 4
Expected,	81	: 27	: 36

F_4 whites derived from F_2 segregates of the cross just described were crossed with F_4 grays derived from the same source.

In F_5, 6 such crosses gave: 9 maples: 14 non-mapled,
28 such crosses gave all maples (over 75),
27 such crosses gave all non-maples (over 75).

Colorless × purple is only mentioned by Vilmorin (90), in which purple is said to be dominant.

Gray × gray, according to the data of Tschermak and Lock, may give only gray in F_1, F_2 and succeeding generations.

Gray × gray with purple dots, excluding exceptional cases such as are mentioned under colorless × gray with purple dots, always gives gray with purple dots in F_1 and grays with and without purple dots in F_2 in an approximate ratio of 3:1. The purple-dot pattern in the F_1 of both these crosses and those of colorless × gray with purple dots is much intensified, and in both cases the stippling pattern may vary so as to produce peas with wholly purple seed coats. These are found sometimes in pods containing some purple and some purple-specked seeds. In other cases a whole pod of a plant may contain all purple seed coat peas. Occasionally a seed may be half purple and half gray or maple. F_2 plants from seeds with purple seed coats do not give results differing from the purple stipple seeds. Bateson (1) thinks such purples are not present in pure stocks of purple-specked seed coat races, and that crossing in some manner promotes their appearance (see Darwin, Bateson, Lock, Tschermak, Fruwirth for further data on this subject). Fruwirth (34) experimented with the variety Blauhülsige, a purple-podded race of peas, which had in respect to seed coat color, four types of peas on the same plant, often mixed together in the same pod. These were either pure yellowish green, yellowish green with purple flecks or dots, purple with small greenish yellow flecks, and self purples, in respect to seed coat color. These are evidently degrees of variation of the same character. As they occur in a pure variety, Bateson's belief as to the effect of crossing as a stimulus to such extreme variation is not supported. Observed also by Lock on both pure and cross-bred strains (56).

Gray × gray with maple marbling gives in F_1 maple marbling, which in F_2 in simple crosses gives 3 maples: 1 gray. However, such simple crosses are rarely to be had and the crosses usually involve the purple-dotted pattern.

Gray with purple dots × gray with maple marbling gives in F_1 gray, purple-dotted, mapled seed coats. In F_2, Tschermak obtained 13 gpm: 13 gp: 12 gm: 2 g. From segregates similar in genetic composition to the F_1, Tschermak (86) secured

in F_3—29 gpm: 9 gp: 16 gm: 6 g,
in F_4—20 gpm: 9 gp: 12 gm: 1 g,

making in all three generations from F_1 plants or segregates of the same composition,

	62 gpm	: 31 gp	: 40 gm	: 9 g	
Expected,	79.8 gpm	: 26.4 gp	: 26.4 gm	: 8.8 g	
Ratio,	9 gpm	: 3 gp	: 3 gm	: 1 g	
Approximation,	6.9 gpm	: 3.4 gp	: 4.4 gm	: 1 g	

As maples and maples with purple dots are often hard to separate, the disproportion of gpm and gm may be due to this difficulty.

9 of the F_2 gpm were tested and in F_3:

1 gave all four classes,
1 gave gpm, gm, g (brown self),
4 gave gpm, gp, gm,
2 gave gpm, gp,
1 gave gm only, only one plant being grown.

Bateson (1) crossed gray with purple dots × maple (Irish Mummy). F_1 as given above and F_2 resulted in 4 classes, no ratios or numbers given. The 4 classes are brownish gray with purple dots, maple and purple dots, maple, gray and light purple specks. The first and last classes are probably the same, the difference resulting from environment. Great difficulty is experienced in discriminating between true browns and brown due to weathering.

Gray with purple dots × self purple gives in F_1, self purples (34). In F_2 these gave:

35 self violet or purple: 11 gray green, violet dots: 3 gray green.

The maternal parent of this cross had seeds varying on the same plant through all these classes. The paternal parent was a self-violet variety.

Vilmorin (90) also notes that self violet is a dominant to the various testa colors.

Brown hilum is always associated with colored flowers and apparently gives a simple 3 : 1 ratio in F_2, with dominance in F_1.

Black eye pattern, according to Correns (14), is both dominant and recessive in F_1 in crosses involving its presence and absence. Black-eyed Marrowfat × white-seeded Mummy (57.5) presumably gave only blackeye in F_1 and three classes of F_2 segregates—black eyed, sooty whites, and whites or colorless. Vilmorin (90) lists blackeye as a dominant. Blackeye is associated with both colorless and colored flowered and seed coat races.

Violet eye (86) × non-violet eye gives all violet eye in F_1. In F_2, Tschermak's crosses gave 53 violet eye : 23 non-violet eye, a ratio of 2.3 : 1, approaching nearest to the 3 : 1 ratio. In F_3, all F_2 non-violet-eyed segregates tested, bred true. Two F_2 violet-eyed segregates in F_3 gave 7 violet eyed : 6 non-violet eyed. Non-violet-eyed races crossed with non-violet-eyed segregates from violet-eyed and non-violet-eyed ancestry gave always non-violet-eyed progeny. Non-violet-eyed segregates from crosses involving violet eye always gave non-violet-eyed progeny. F_3 non-violet-eyed segregates × heterozygous F_3 violet-eyed segregate gave 5 violet-eyed : 3 non-violet-eyed offspring. Total results obtained by adding together all progeny of heterozygous plants in Tschermak's data give 78 violet eyed : 38 non-violet, or a ratio of about 2 : 1.

Violet eye, as is also presumably true of black eye, is not coupled in its inheritance with the substances which determine flower color, seed coat color, seed coat pattern and leaf axil color. Sufficient proof of this statement is given by Tschermak's (86) experiments.

All other seed coat patterns are associated in their inheritance in one way or another with the causes which determine the gray-brown colors of the seed coats, the color of the leaf axils, and flower color. Mapling, although a character inherited independently of the characters just enumerated, as shown by Tschermak and Lock, is largely dependent upon them for full expression. Purple spotting and gray are absolutely associated with these characters. Brown hilum color is also coupled with colored seed coats and colored flowers. Colorless seed coats, on the other hand, are always associated with white flowers. These various associations of the characters just mentioned, in their inheritance are, so far as our data go, *absolutely* without exception.

From the foregoing array of facts one may gather that the heredity of seed coat color is somewhat complicated as compared with that of other pea characters, but this is largely due to the ease with which such characters can be studied and consequently the amount of work that has been accomplished on them.

Interpretation.

From a Mendelian standpoint, the heredity of seed coat color and pattern, as deduced from the foregoing mass of data, is comparatively simple.

Brownish, grayish green or gray seed coat color may be represented by the factor Gc which is absolutely coupled with the factor A for colored flowers. In the absence of Gc, seed coats are colorless. The factor J acts upon Gc so as to produce dark chocolate brown. It is independent of Gc or A and is carried by either colored-flowered, gray seed coat varieties or white-flowered, colorless seed coat varieties. In the latter, it remains without expression. The orange tint or color is regarded by Tschermak (86) as due to a factor H, which alters the gray color to orange-red or orange-yellow. So far H has not been found in white-flowered races though there is reason to suspect its presence there (see p. 511). The factor U, which provisionally stands for self purple seed coats, is also probably coupled with A, although there are very little data on the subject. Varieties with colored flowers then, carrying only the factor Gc, will have gray seed coats; if J is added, brown seed coats; if both J and H are added still brown seed coats, but if J is eliminated and only Gc and H are present, orange seed coats. If the factor U for self purple is added to Gc, the seed coat is self purple. No data are available as to other combinations of U.

Purple spotting is represented by Tschermak (86) as due to two factors, one coupled absolutely with A and Gc, the other independent, hence present in both white-flowered and colored-flowered varieties. Lock (54, 55) represents similar results by one factor operating only in the presence of the factor for gray seed coat color.

Representing purple dotting by one factor simplifies the interpretation and amounts to the same thing as Tschermak's two factors since he regards one—the factor E—as absolutely coupled with Gc and A. The other factor (F) is inherited independently of Gc and A, hence may be present in either varieties with colored flowers and colored seed coats or in white-flowered varieties with colorless seed coats. As it expresses itself only in the presence of Gc, its presence in white-flowered races can only be determined by crosses with non-purple-dotted gray seed coat races. The exceptional cases noted above where purple-dotted seed coat fails to appear when expected, are interpreted by Tschermak (86) as due to lack of interaction between the factors F and Gc even though both are present. Non-purple-dotted seed coat races then may be either Gcf (Ef), gcf, gcF—the first colored flowered and the two latter with white flowers. GcF (EF) is, exclusive of the exceptional cases noted, always purple dotted.

Mapling is represented by one factor (54, 55, 86) M, which completely expresses itself only in the presence of Gc, but which may give a faint expression (ghost mapling) in gc white-flowered races. Exceptional cases similar to those found in connection with the inheritance of the purple dot pattern are interpreted by Tschermak (86) in the same way, namely the disassociation in the same plant of M and Gc. M is inherited independently of Gc, F, N and probably Pl.

Brown hilum color may be regarded simply as another expression of Gc since they are absolutely coupled.

Black eye and violet eye, so far as present data go, are to be regarded as due to the factors Pl and N, both of which are inherited independently of Gc, F, M, and of each other, and able to express themselves in either white- or colored-flowered races. The dominance of black eye over non-black eye in one cross and its recessiveness to non-black eye in another cross involving a different non-black-eyed variety is to be regarded as due to the interference of another factor or factors not yet delineated.

Data as to the relation of these various factors to each other in inheritance are still much to be desired, especially in the case of Pl, U, H and J. While Tschermak has done much toward throwing light on seed coat color and pattern inheritance through making all sorts of crosses, back-crosses, reciprocal crosses and so on, his numbers in most cases have been lamentably small, consequently the approximation to the expected ratios on which the factor representations are based has not been close, and such ratios as 2:1 where 3:1 were expected are comparatively common.

The above interpretations account for practically all the experimental data on seed coat color in *Pisum*. There are no data, so far as I am aware, opposed to these interpretations, barring the smallness of the numbers by which the poor approximation to expected ratios is explained.

2. Cotyledon Color.

Varieties and species of *Pisum* as regards the cotyledon color of the ripe seed may be divided roughly into two classes—those with green cotyledons and those with yellow cotyledons. Between the extremes of these two classes, there are all gradations of cotyledon color from the darkest green through light green, yellowish green, green piebald with yellow spots, light yellow, bright yellow and dark orange yellow. Each of these classes is characteristic of a certain group of varieties, each variety possessing and breeding true to one of the above colors and to no other. Environment may alter the color generally characteristic of a variety so as to place it in another class. Some varieties are altered by common environmental changes much more than are others. Mendel (60), Hurst (42), Lock (55), Bateson (1), Darbishire (21), Tschermak (80, 81) and White (98) have all discussed this color variation in cotyledons both in relation to environment and to heredity.

Green Cotyledon.—Green cotyledon color varies from dark green in such varieties as Wisconsin Blue and Alaska to light green or yellowish green as is characteristic of Telephone, Blue Prussian and Duke of Albany. As first noted by Hurst (42) green wrinkled peas are always a shade lighter and tend to be more yellowish than the green smooth-seeded varieties. Varieties such as Scotch Beauty and other smooth-seeded dark greens do not fade to yellow upon exposure to moisture and light as easily as the wrinkled varieties or such smooth varieties as Express. Dark greens give the best results in crosses with yellow cotyledon varieties if demonstration material for illustrating Mendel's law is desired. Lock found that green seeds exposed to light in a dry bottle for a length of time faded and became yellowish. Mendel and Tschermak both found that injury from the pea-weevil would produce yellowish blotches and even wholly yellow seeds. Such greens as Laxton's Alpha will always give some piebald and even some yellow seeds if the pods are left on the vines till they are all ripe (1). Piebald peas remain green if kept in the dark, and a dry place, but fade on the exposed surface on exposure to light. Piebald seeds of one pod are all tinged on the same surface. Tinged seeds of dark green types or varieties normally giving no piebalds are less viable than piebald peas of green-seeded varieties (1). Numerous selection experiments were made by Bateson (1) but tinged or piebald seeds produced no more seeds like themselves than did normal green seeds.

Telephone seed of all types retains its series of color gradations. Some varieties of peas such as Sutton's Nonpareil (1) are heterozygous for cotyledon color and of course these statements do not apply to them.

Yellow Cotyledon.—Yellow cotyledon color varies from light yellows and yellowish greens to deep orange-yellow, such as is characteristic of Späte Gold, and, as in the case of the greens, this color shading is a varietal characteristic, some varieties having light yellow peas and no other shade, *e. g.*, Goldkönig and *P. humile* of Sutton. The yellow color may remain somewhat greenish if the pods are not properly matured and certain varieties are extremely particular in this respect. Späte Gold is a dark green pea when immature but changes very rapidly to bright deep orange-yellow when mature. Even after the pods have the appearance of maturity and are dry, the change sometimes has not resulted. Improper maturing due to lack of sufficient light and in some cases to an over-supply of moisture is the usual cause of ununiform coloring in yellow peas. According to Bunyard (21, p. 131) both yellow and green cotyledon varieties have yellow and green pigment in their immature seeds, but the yellow cotyledon varieties possess an additional hereditary substance—an enzyme perhaps, which causes the green pigment to fade when the seeds mature. Green when present is epistatic to yellow and thus masks it. Yellow cotyledon color is apparently the ancestral color of all our peas, as all the wild species of *Pisum* have only yellow cotyledons.

Varieties Studied.

No attempt will be made to give a list of all the varieties upon which genetic studies of cotyledon color have been made. Sufficient to say that at least a hundred are involved and these have been collected from all over the globe wherever peas are grown.

Orange Yellow to Yellow.

Très nain de Bretagne, Debarbieux, Sabre, Victoria Marrow, British Queen, Early Giant, Purple Sugar Pea—Bateson (1).

Ceylon Native Pea Nos. 1 and 2, Ringleader, French Sugar Pea —all Lock (54).

Purpurviolettschottigen Kneifelerbse, Bohnenerbse—Correns (14).

Grau Riesen, Désirat, various Svalöf *P. arv.* nos., Victoria, Couturier, Auvergne, Buchsbaum, Prince of Wales—Tschermak (79, 80, 81, 83).

Black-eyed Marrowfat, First of All, Späte Gold, Petit Pois, Wachs Schwert, Mummy, White Marrowfat, Elephanten, Abyssinian Black, *P. elatius,* Gold von Blöcksberg—White (98).

Light Yellow.

Goldkönig, *P. humile* ? of Sutton—White (98); Satisfaction—Lock (54).

Dark Green to Green.

Fillbasket, Express, Blue Peter—Bateson (1); Nonsuch, Earliest Blue, Eclipse—Lock (54); Grünen Erfurter Folger—Correns (14); Grünbl. Folger, Express, Greenseeded *P. sativum* of Svalöf, Serpette, Plein le Panier, Blue Peter, Fairbeard's Champion—Tschermak (79, 80, 81, 83).

Market Split Pea of New York City, Acacia, Velocity, Alaska, Scotch Beauty, Express, Nott's Excelsior, Laxtonian—White (98).

Piebald Greens.

Telephone, Telegraph—Lock (54); Telephone—Tschermak; Telephone, William I, American Wonder, Laxton's Alpha—Bateson (1); Telephone—White (98).

Results from Crossing.

Yellow × yellow always gives yellow in F_1 and succeeding generations, except in crosses with the light yellow cotyledon variety Goldkönig in which case a certain proportion of green cotyledon seeds are obtained in F_2, yellow being dominant in F_1. The ratio of yellows to greens in such crosses either approximates 3:1 or 13:3. The actual results (98) obtained from crosses of Goldkönig with four or five other yellows in F_2 were:

457 distinctly yellow: 23 yellowish green: 86 green.

Considering the last two groups together, the proportions are 457 yellow: 109 green or a ratio of 13:3, the theoretically expected being 459.2 yellow: 106.2 green. These peas were reclassified after mixing several times with the same result. No F_3 results have been obtained as yet.

Orange yellow × light yellow gives dominance in F_1 of the former (90).

Yellow × green gives all yellow in F_1 in all cases except where the variety Goldkönig is used. Where Goldkönig is used as a yellow, all F_1's are green. White (98) has tested out five different varieties with green cotyledons and always secured F_1 seeds of a distinct green color. Several cases of dominance of green were obtained by Lock (54), Tschermak and Bateson (1), but they are mostly explained by these experimenters themselves as either errors in labeling or in improper maturing. Repetitions of such crosses, using the same varieties, did not give these exceptional results.

In F_2, excluding Goldkönig from consideration, yellow × green gives yellows and greens again in the proportion 3 yellows: 1 green. In F_3, all the greens breed true and give only green progeny. Of the yellows only about one third breed true to yellow, the other two thirds giving rise again to yellows and greens in the proportion of 3:1. The true breeding yellows and greens are believed to continue breeding true, indefinitely, while the impure yellows in each generation continue to give rise to yellows and greens in the ratio of 3:1. Darbishire has followed this study through to the F_{11} or F_{12} generation and finds nothing to controvert this statement. The yellow and green seeds that came from such a cross appear to be the same sort of colors that the grandparental ancestors had. The tendency of yellows to be greenish because of immaturity, and of greens to fade is no more marked in the progeny than in their pure forbears.

The actual results from crossing pure yellow and green cotyledon plants are given in the following table:[3]

Hybrid Generation.	Observer.	Yellow.	Green.	Percentage of Green.
Second	Mendel	6,022	2,001	24.9
	Correns	1,394	453	24.5
	Tschermak	3,580	1,190	24.9
	Bateson	11,903	3,903	24.7
	Hurst	1,310	445	25.4
	Lock	1,438	514	26.2
	Darbishire	1,089	354	24.9
	White	1,647	543	24.8
Third	Correns	1,012	344	25.5
	Tschermak	3,000	959	24.2
	Lock	3,082	1,008	24.6
	Darbishire	5,662	1,856	24.7
Fourth	Correns	225	70	23.7
	Lock	2,400	850	26.1
Total	58,254	43,764	14,490	24.9

Mendel (60) tested out 519 F_2 yellows by growing an F_3, the result being: 353 seeds gave yellow and green seeds (3:1), 166 seeds gave only yellow seeds, the ratio of the former to the latter being 2.13:1.

Darbishire (21) tested out in the same manner 140 F_2 yellows, which in F_3 gave: 98 F_2 seeds with both yellow and green progeny, 42 F_2 seeds with only yellow progeny, the proportions being 2.3:1.

Back-crosses (56) of F_1 or of similar heterozygous plants from later generations with the yellow parent gave all yellow as follows:

Mendel, 192 yellow:0 green,
Tschermak, 126 yellow:0 green.

[3] These data are taken from Darbishire (21) and White (98).

Heterozygous yellows or F_1's × the green-seeded parent gave a ratio of 1 yellow : 1 green as follows:

Mendel, 104 yellow : 104 green,
Tschermak, 101 yellow : 100 green.

As regards the F_2 generation from green × Goldkönig yellow, the data are as yet very scant. White (98), however, from an F_2 progeny of 14 crosses found 253 seeds had green cotyledons and 74 had yellow or yellowish with slight green tinge, the proportions approximating 3 green : 1 yellow or just the reverse of the common result. No F_3 generation data are as yet available. All green and yellow cotyledon varieties used in crosses with Goldkönig crossed with each other gave the usual 3 yellow : 1 green ratio.

In applying Mendel's law to data such as the above, one must always bear in mind, as pointed out recently by Pearl, that Mendelism is essentially a statistical method and the law a statistical deduction, requiring large numbers and dealing only in averages. The danger of drawing conclusions from small numbers is well shown in a survey of the extreme variation in F_2 ratios derived from single F_1 plants.

For example, the greatest variation in

Mendel's records (60) was 32 Y : 1 G and 20 Y : 19 G,
Bateson's records (1) was 60 Y : 9 G and 32 Y : 20 G,
Corren's records (14) was 92.3 per cent. Y : 7.7 per cent. G and 55.8 per cent. Y : 44.2 per cent. G,
Lock's records (54) was 14 Y : 1 G and 7 Y : 8 G.

Bateson (1) conducted experimental inquiries to determine the significance of these fluctuations, but found them to be purely fortuitous, as did Mendel (60) before him.

Interpretation.

In the light of the above data the hereditary differences between yellow cotyledon and green cotyledon varieties of peas may be designated by G and I. G represents the hereditary determining substances or factor for green pigment, while I is a factor or determiner which causes the green pigment to disappear when the seed is mature. Y stands for yellow pigment and so far as known is common to all varieties of peas, whether green or yellow seeded. Green when present masks or covers up yellow pigment, hence is epistatic. The factor formulas for all varieties of peas so far genetically studied then are:

YYGGII = true breeding yellow cotyledon races,
YYggii = Goldkönig (on the present data),
YYGGii = true breeding green cotyledon varieties.

On the basis of these three formulas and by various combinations of these three types of varieties, all the various ratios described in preceding pages, as well as others, may be obtained. All genetic data, so far as I am aware, accord with this interpretation.

3. Cotyledon Form (Seed Form) and Composition

The seeds of peas as regards shape are either smooth round to roundish, or wrinkled and angular. The cotyledons of the seed are mainly responsible for these differences. Smooth, roundish peas, however, are often pitted or dimpled and this dimpling is of two types. One type is largely due to such environmental conditions as premature harvesting, while the other type remains pitted under practically all common environmental conditions. The latter type is designated " slightly wrinkled " by Tschermak and " indent " by the English geneticists. Indent, while a character which modifies the external appearance of the seed and cotyledon, belongs in reality to the generation preceding that to which the cotyledon characters—wrinkledness, color, etc., belong. Associated in inheritance with seed form are certain types of starch and certain germination, sugar content and color modifying characters, and because of this association they will all be considered under this heading. Indent peas and smooth peas will be treated separately.

Smooth round peas without indenting are most commonly characteristic of varieties with white flowers and colorless seed coats, although many varieties with colored flowers and colored seed coats have perfectly smooth seeds. Particularly is this true of most of the wild sorts, all of which have colored flowers. The starch grains of the smooth-seeded varieties according to Gregory (37), Darbishire and others are simple, oval or potato-shaped and of large size with well-marked hilum centers and distinct lines of stratification. Darbishire (19), and Kappert (48) found small round grains associated with the larger oval ones, and occasionally these are divided by a single split or fissure which cannot be increased in size through the action of diastase and ptyalin (48). Kappert (48) also has observed these longitudinal fissures with short side splits occasionally among the large oval grains. The size of the starch grains vary considerably in different cell layers of the same seed, the smallest being found in the outer layers, where the protoplasm is most dense. Measurements of starch grains, given in the following table, show a considerable variation, though the data are too scant to be of much weight.

Investigator.	Variety.	Ave. Length.	Ave. Breadth.	No Grains Measured.
Gregory........	Several varieties	.06–.34 mm.		
Darbishire......	Eclipse	–.0322 mm.	.0213 mm.	232
Kappert........	Laxton's Vorbote	–.0363 mm.	.0246 mm.	50

Darbishire divides the length by the breadth $\times$ 100 and secures the breadth-length index (in Eclipse 66.14) or the breadth in terms of per cent. of length. The breadth-length index for Laxton's Vorbote is 67.8–69.1 and for Emerald Gem starch grains 74.3 (48), indicating that starch grains of some smooth-seeded varieties are less oval than others. The long oval starch grains are characteristic of the early as well as of the late stages of seed development.

According to Denaiffe (23), Halsted, Darbishire (19), Kappert (48) and others, round smooth peas take up less water upon germination than wrinkled peas. Darbishire found the average absorptive capacity (or the amount of water an immersed dry pea would take up in twenty-four hours, expressed as percentage of weight of the dry pea) of 12 Eclipse peas to be 86 per cent. Kappert found as regards absorptive capacity so much variation in the seeds even of the same sort on the same plants that he regards the methods used by Denaiffe and Darbishire as extremely inexact. Kappert gives the water loss of air dry seeds of smooth-seeded peas in terms of per cent. of green (fresh) seed weight. For the following varieties this is:

Laxton's Vorbote	5 seeds	44–58.21 per cent. loss.
Emerald Gem	6 seeds	44–58.66 per cent. loss.
Carter's First Crop	4 seeds	40–54.87 per cent. loss.

He considers the variation in water loss between seeds of the same sort or variety as due in part, at least, to differences in environment. Chemical analysis of air dry peas of 2 different varieties of smooth seeded peas—Carter's First Crop and Bohnenerbse—showed a water content of from 10 to 12 per cent. or from 1–2 per cent. more water than in similar analyses of wrinkled peas. In fresh green seeds the difference in water content amounts to as much as 8 per cent. more in wrinkled than in smooth seeds. Chemical analyses show also that smooth-seeded peas possess a relatively small amount of water and alcohol soluble material. Difference in sugar content between the two types, however, is small (.7 to 3.4 per cent.) varying in smooth-seeded peas from 1.96 to 3.29 per cent. There appears to be about twice as much sugar and dextrine in dry wrinkled peas as in dry smooth peas. Smooth round seeds appear to always have deeper colored cotyledons than wrinkled peas.

Indent peas are known to differ from smooth round peas only in being indented. Both the cotyledon and the seed coat are affected and the characteristic only appears on peas with colored seed coats and colored flowers. The starch grains are indistinguishable (37, 1).

Wrinkled, angular peas differ from indent and smooth round peas in at least four characters, *viz.*, the shape and surface of the seed, the shape and constitution of the starch grain, the water content of the leaves and green immature seeds and the sugar content. Seeds of smooth-seeded varieties are sometimes unclassifiable because of pitting, but, so far as I am aware, seeds of wrinkled seeded varieties never vary toward greater smoothness (barring sports and rogues). Wrinkling is always associated with round compound starch grains. These starch grains are made up of from two to eight or more divisions or separate irregularly shaped small particles cemented together by a yellowish substance which is not colored blue by iodine (19). The most common grains are 4–6-particled. Both Kappert (48) and Darbishire (19) occasionally found potato-shaped grains similar to those of round-seeded peas among the compound starch grains. Small round grains are always present. Kappert (48) found the starch grains of very young peas (2–3 weeks old) to be free from splitting, and through observations on later stages, he found all gradations from simple round grains to the characteristic compound or radially split grain of 2 to 8 particles. This led him to conclude that compound starch grains are simply radially split simple starch grains and with only one starch formation center instead of 2 to 8 such centers as is commonly supposed. The so-called compound grains may be further broken up through the action of diastase and this led Kappert to believe the starch of wrinkled peas was more soluble than that of smooth-seeded peas, a supposition made more plausible through the greater amount of sugar and dextrine present.

Both Gregory (37) and Darbishire (19) found the compound starch grains of the wrinkled peas they studied to be smaller than the starch grains of smooth-seeded peas.

The data from measurements of several varieties are given below:

Investigator.	Variety.	Diameter.	No. Grains Measured.
Gregory (37)........	Several	.06–.2 mm.	...
Darbishire (19)......	British Queen	.0248–.0269 mm.	105
Kappert (48)........	Goldkönig.........	.0245–.0268 mm.	20

The breadth-length index for starch grains of wrinkled peas of course is higher being 92.2 for British Queen and 91.5 for Goldkönig.

Denaiffe (23), Darbishire (19), Kappert (48) and others all agree that more water is taken up by dry wrinkled peas than by smooth peas. Chemical analyses as given by Kappert show that the water content of the air dry smooth and wrinkled peas differs only by 1 or 2 per cent. in favor of the former. However, fresh wrinkled peas before they are ripe are said to have possibly as high as 8 per cent. more water than smooth peas, and it is largely because of this greater water loss that the wrinkled condition of the cotyledons and seed coat is brought about and not because of difference in sugar content as contended by Darbishire (19). Difference in sugar content from the writer's knowledge of pea varieties, is probably very variable. Correlated with the larger water content of unripe wrinkled peas is a larger water content of their leaves as compared with leaves of smooth seeded varieties.

Seed of wrinkled varieties of peas as compared with smooth seeded peas, usually lose their power of germination and rot more quickly under unfavorable conditions, such as cold, wet weather. Wrinkled peas are a shade lighter in cotyledon color than smooth peas from the same pod or plant and grown under the same environmental conditions.

Varieties Studied.

Because of the large number of genetic experiments on these characters, only a partial list of the varieties studied can be given.

Smooth Round.

Eclipse, Genoa round, *P. arv. hibernicum,* Bohnenerbse, Sangster's No. 1 (?)—Darbishire (19).

Express, Fillbasket, Très nain de Bretagne, Carter's Telegraph, Victoria Marrow, Maple—Gregory (37).

Express, Très nain de Bretagne, Victoria Marrow, Blue Peter, Fillbasket—Bateson & Kilby (1).

Ceylon Native No. 1, Ringleader, Ceylon Native No. 2, Sutton's Telegraph (?)—Lock (54).

Laxton's Vorbote, Emerald Gem, Carter's First Crop—Kappert (48).

Harrison's Early Eclipse—Hurst (42).

Emerald, Yellow Pod Sugar Pea and numerous others—Tschermak.

Over 20 varieties (unpublished data)—White.

Indent.

Purple fl. Field Pea, Purple Sugar Pea, Sutton's Purple Podded Pea —Gregory (37).

Purple Sugar Pea, Graue Riesen—Bateson & Kilby (1).
Graue Riesen, Svalöf *P. arv.* No. IV., and No. X.—Tschermak (86).
Irish Mummy, Gray Sugar and others (unpublished data)—White.

Wrinkled, Angular.

British Queen, Laxton's Alpha, Telephone—Darbishire (19).
William I. ?, Telephone, Laxton's Alpha, Serpette nain blanc, Dark Jubilee, Early Giant, British Queen, Windsor Castle—Gregory (37).
Laxton's Alpha, Serpette nain blanc, Telephone, Veitch's Perfection—Bateson & Kilby (1).
Telephone, Satisfaction, Nonsuch, British Queen—Lock (54).
William Hurst, Laxton's Alpha, Goldkönig—Kappert (48).
British Queen—Hurst (42).
Prince of Wales, Telephone and others—Tschermak.
Goldkönig, Quite Content, Nott's Excelsior, Laxtonian, and many others—(unpublished data) White.

Results from Crossing.

Round smooth, white flowers × round smooth, white flowers always gives round smooth seeds and white flowers in F_1 and succeeding generations.

Round smooth, white flowers × round smooth, colored flowers in F_1 (of cotyledons) gives round smooth seeds, but in F_1 of seed coats (F_2 of cotyledons) gives all indent seeds. In F_2 of seed coats (F_3 of cotyledons) the number of F_2 plants bearing all indent seeds to those with only smooth seeds approximates 9:7. The *reciprocal* of this cross in F_1 (of cotyledons) as well as in F_1 of seed coats (F_2 of cotyledons) gives all indent seeds, while in F_2 the results are the same as when the white-flowered smooth-seeded variety is used as the maternal parent.

According to Tschermak (80, 81, 86), Lock (54), Bateson (3) and others who have experimented with indent varieties, the indent seeds are always borne on plants with colored flowers and there has never been an exception to this association recorded. According to the same observers, white-flowered plants in such crosses always have smooth and never indent seeds. Plants with colored flowers, however, often have smooth seeds and it is to be inferred from Tschermak's data and formulas (86) that in crosses of round smooth, white flowers with round smooth, colored flowers, the F_2 generation consists of three classes—indent, colored flowers; round smooth, colored flowers; round smooth, white flowers. As regards the seed characters, only two classes are present—indent and smooth. From crosses of four round-seeded, colored-flower varieties with five round-seeded, white-flowered varieties, Tschermak (86) secured in F_2:

181 indent : 96 smooth or 1.89 : 1.

In F_3 part of the indent and part of the smooth seeds bred true, while a part of each class again gave both indent and smooth seeds. From this and other data of Tschermak's one may consider the above F_2 numbers as a very poor approximation to a 9 : 7 ratio—the actual results expected had the approximation been perfect being 155.7 indent : 121.1 smooth.

Round smooth, white flowers × indent, colored flowers in F_1 (of cotyledons) always gives round smooth seeds, while the F_1 of the reciprocal cross, where the maternal parent has colored flowers, consists of indent seeds (Tschermak 80, 81), [(Correns), Bateson 3]. The F_1 of seed coats (F_2 of cotyledons) consists entirely of indent seeds and colored flowers, while in F_2 of seed coats (F_3 of cotyledons) indents and colored flowers to round smooth and white flowers occur in a ratio approximating 3 indent : 1 round smooth. The above description of the facts applies to all but one cross of this type. In this exceptional case, the round smooth white-flowered Nain de Bretagne was the pollen parent in a cross with an indent variety. The F_1 was indent, as usual, but the F_1 of seed coats (F_2 of cotyledons), instead of giving all indent seeds, as is commonly the case, gave quite definitely indents and rounds in the ratio of 3 : 1. Three such F_1 plants gave 339 indent, 119 round smooth, and 39 uncertain or of an intermediate type. Further, one F_2 plant apparently grown from the round seeds had only round seeds with colored seed coats (F_2 of seed coats, F_3 of cotyledons) (Bateson 3, p. 262).

Round smooth, white flowers × wrinkled, white flowers give in F_1 (of cotyledons), all round smooth seeds, which in F_2 give approximately 3 round smooth : 1 wrinkled. There is no case of coupling known between these two cotyledon characters and flower color, so the ratio is 3 : 1 whether the flowers are white or colored. In F_3 about one third of the round seeds produce only plants having round seeds, while two thirds of the round seeds again produce plants which have round seeds and wrinkled seeds in the proportion of 3 : 1. The wrinkled seeds always breed true. The results from crossing round smooth and wrinkled seeded varieties as obtained by five well-known geneticists are:

Hybrid Generation.	Investigator.	Round.	Wrinkled.	Per Cent. of Wrinkled.
F_2	Mendel	5,474	1,850	25.2
	Tschermak	884	288	24.6
	Bateson	10,793	3,542	24.8
	Hurst	1,335	420	23.9
	Lock	620	197	24.1
F_3	Tschermak	2,087	661	24.0
	Lock	769	259	25.2
F_4	Lock	2,328	812	25.8
Total	32,319	24,290	8,029	24.85

Back-crossing heterozygote F_1 with pure round smooth parent gave:

	Round.	Wrinkled.
Mendel	192	——
Tschermak	38	——

Back-crossing heterozygote F_1 with pure wrinkled seeded parent gave round smooth and wrinkleds in the ratio of 1 : 1 or

	Round.	Wrinkled.
Mendel	106	102
Tschermak	26	18
	132	120

No coupling or "correlation" of other common characters such as tallness, flower color, cotyledon color, fasciation and pod color with wrinkledness have been recorded. Partial coupling between wrinkledness and lack of tendrils ("acacia") has been studied by Vilmorin (88, 89), Bateson (88) and Pellew (64). This will be discussed in connection with foliage characters.

Darbishire (19) regards the shape and constitution of the starch grain, the water absorptive capacity of the seed and the shape of seed (round, smooth or wrinkled) as four separately inherited characters. This deduction is based on a series of observations on crosses of round and wrinkled varieties which demonstrated the F_1 nature of the starch grains, as regards shape and constitution, and the water absorptive capacity of the seeds to be intermediate between the two parents used. Although round smooth, the F_1 seeds had about equal proportions of simple and compound starch grains—and the latter instead of having on the average 6 particles per single grain as in the wrinkled parent averaged only 3 particles. Five seeds each of 48 F_4 plants were used instead of F_2 seeds for determining segregation phenomena. Sixteen plants were pure round-seeded segregates and had starch grains of the ancestral round parent type. Twenty plants were heterozygotes and had pure round, heterozygote round and wrinkled seeds. Only the round seeds were examined. Out of each of the 20 lots of 5 seeds, at least one had starch grains similar to the F_1 and in several cases all were similar to the F_1 seeds as regards shape and degree of compoundness. The homozygote rounds were easily distinguished from the other rounds. The heterozygote round seeds, while either roundish or irregular in shape, varied greatly in the proportion of compound to simple grains they possessed. In 2 cases, where countings were made, one gave 203 compound and 305 simple, while the other had only 28 compound out of 304 counted. The degree of compoundness of the starch grains varied in different seeds, some being many particled and some seeds with only few-particled grains. No progeny test of the correctness of the determination of homozygous and heterozygous rounds by observation of their starch was made, but the results were checked up by the approximation to the ratio of 2 heterozygote : 1 homozygote seed. The 12 plants with wrinkled seeds had the wrinkled ancestor type of starch grain, except in two or three seeds out of 45 examined, in which a few simple grains were observed.

As regards water absorptive capacity, F_2 peas with round compound starch grains and F_2 peas with long simple grains both had the same absorptive capacity as the F_1 pea with both kinds of starch grains. From these facts, Darbishire holds the intermediate nature of the F_1 starch grains is not responsible for the intermediate absorptive capacity of the F_1 seed. High and low absorptive capacity is to be regarded as a separate pair of characters. Darbishire has not shown, however, that wrinkled F_2 seeds differ markedly in absorptive capacity, which should be the case, unless the character of the wrinkled pea completely masks any such difference in absorptive capacity.

Kappert (48), working over the same problems, secured results only partially agreeing with those of Darbishire. He agrees with Darbishire as to the intermediateness in form and constitution of the starch grains and the absorptive capacity of the F_1 seeds. He also finds great variation in absorptive capacity of the F_2 round seeds, but offers a choice between two explanations—differences in environmental influences during development owing perhaps to position of seed in the pod, or Darbishire's interpretation. Kappert finds this variation in water absorptive capacity true of round peas in the same pod in pure round-seeded varieties as well as in round-seed segregates, and this is true when only seeds of same size, weight, etc., are considered. Denaiffe, Darbishire and Kappert all agree that wrinkled seeds in general have a higher water absorptive capacity than round smooth peas, and hence there must be a close correlation of some sort between the character of the starch and ability to take up water. Both Darbishire and Kappert found the water absorptive capacity of F_1 peas to be nearer that of the round smooth parent, while the starch grains should be considered as more nearly approaching the wrinkled type, except in Kappert's crosses involving "Laxton's Vorbote" (round smooth) and "Goldkönig" (wrinkled). In these crosses, the F_1 starch was very similar to "Laxton's Vorbote."

Kappert finds no grounds for Darbishire's statement that both simple and compound starch grains are found in about equal proportions in F_1 seeds, but thinks the starch grains Darbishire took for simple were split on the narrow side, which Darbishire would have noted if he had turned them over, as Kappert himself has done repeatedly. Splitting of starch grains, according to Kappert, may take place fortuitously and not necessarily because of an inherent tendency to split up, and both these influences may be operating in the seeds of the same cross. As regards shape and constitution of the starch grains in the hybrid seeds, Kappert secured distinctly different results depending on the round smooth parent used. Laxton's Vorbote and Goldkönig gave starch grains approaching those of the round smooth seeded parent, while Emerald Gem (round smooth) and Goldkönig gave *round, radially* split starch grains in large numbers, though the splitting was much less than in pure Goldkönig starch. Further, in F_2 Kappert was not able through microscopic examination of the starch grains to separate with certainty the homozygous rounds and the heterozygous rounds. Seeds of the same pod (all round) gave a continuous series of seeds with clearly intermediate starch grains to seeds with only simple starch grains. From the camera-lucida drawings of F_2 round seeds from two pods, one from each cross as noted above, those having Laxton's Vorbote as the round ancestor differed considerably in extent of split or compound grains from those with Emerald Gem as the round-seeded ancestor, leading the writer to believe in genetic differences between the round seed varieties. Kappert himself is uncertain as to whether the continuous gradation in extent of splitting results from hereditary or environmental differences.

Round smooth, colored flowers × round smooth, colored flowers always gives in F_1 all round smooth and colored flowers and from unpublished data of my own, only round smooth are present in later generations. Bateson (3, p. 263), citing Tschermak (81, p. 30, case 9), mentions an exception to this statement. The case cited is Tschermak's cross *P. arv., VI.* (round) × *P. arv., IX.* (round)? which gave *distinctly* dimpled seeds in F_1 of seed coats (F_2 of cotyledons). Tschermak's description in the same paper of the seeds of *P. arv., IX.*, is "roundish, rarely few dimpled seeds," indicating that there may be some doubt as to whether the *P. arv., IX.*, parent used was not indent instead of round. In later publications (86, see formula for *P. arv., IX.*) he describes this variety as definitely round-seeded. In another place in the same paper (81) devoted to assembled results, the crossing of two smooth-seeded *P. arv.* varieties is stated to always give smooth-seeded offspring in the first seed generation, which I take to be F_1 of seed coats (F_2 of cotyledons and of Bateson). Tschermak, so far as the writer can discover, makes no mention of the results of this cross as exceptional.

Round smooth, colored flowers × wrinkled, white flowers in F_1 (of cotyledons) is indent, which in F_2 of cotyledons (F_1 of seed coat) give approximately 3 dimpled: 1 wrinkled (54). According to Lock, dimpled and wrinkled seeds are very hard to distinguish, as of course true wrinkling occurs in colored seed coats.

Indent × indent (colored flowers always) gives in F_1 and later generations always indent and colored flowers.

Indent × wrinkled, white flowers in F_1 gives indent. Reciprocal in F_1 (of cotyledons) gives round smooth seeds. In F_2 (F_1 of seed coats) of both crosses, indents to wrinkles appear in a ratio of 3:1 and the plants all have colored flowers.

The wrinkled seeds when sown give 3 wrinkled with colored flowers: 1 wrinkled with white flowers. The indent seeds if sown [(F_2 of seed coats) F_3 of cotyledons] likewise give rise to 3 colored-flowered plants: 1 white-flowered plant. The colored-flowered plants have either all indent seeds or indent and wrinkled seeds in the ratio of 3:1. The white-flowered plants have either all round seeds or 3 round: 1 wrinkled.

Indent × wrinkled, colored flowers. No data.

Wrinkled, white flowers × wrinkled, white flowers always gives wrinkled seeds and white-flowered progeny.

Wrinkled, colored flowers × itself. No data.

Back crosses (81) of various combinations involving indent ancestry gave no exceptional results, as viewed from the interpretation given for all the crossing data.

Interpretation.

The preceding data concern two sets of characters—(1) round smooth cotyledons of low water absorptive capacity with simple, long starch grains and angular wrinkled cotyledons of high water absorptive capacity with radially split (compound), round starch grains; (2) indent and non-indent seeds. In the first set, round smooth and the characters associated with it are to be regarded as the expressions of a factor R, in the absence of which the cotyledons are angular, wrinkled, etc. The partial dominance of shape and constitution of the simple long starch grains in F_1 is perhaps modified by other factors not yet determined or due to the presence of R in simplex condition. It is very evident from the diverse results of Darbishire and Kappert as regards F_1 starch characters that dominance of the simple or the "compound" type is inhibited in one case at least.

So far as is known, the factor R is inherited independently of all other *Pisum* factors excepting the factor for tendrils (Tl) with which it is partially coupled. Interpreted as above, round-seeded varieties of peas have the formula RR while wrinkled varieties have the formula rr.

Indenting in peas, as interpreted by Tschermak, Bateson, Lock and others, is due to two or three (?) pairs of factors, one of which is the pigment-producing factor A, which gives rise to pink flowers and gray seed coats. Indent peas only occur on plants with colored flowers, all of which have the factor A. A may be substituted for Tschermak's factor L_1 since L_1 and A are *always* associated. Taken thus the real indenting factor may be designated as L_2, in the absence of which in plants with colored flowers, the seeds are non-indent. When A and L_2 are both present the flowers and seed coats are colored and the seeds are indent. When A is absent but L_2 present, the flowers and seed coats are white or colorless and the seeds non-indent.

Thus all varieties of peas so far experimented with, having colored flowers, colored seed coats and indent seeds, may be represented by the formula AAL_2L_2, those with colored flowers, colored seed coats and *non-indent* seeds by AAl_2l_2 and those with white flowers, colorless seed coats and non-indent seeds by aaL_2L_2, because the latter in crosses with colored-flowered, non-indent types give in F_1 (of seed coats) all indent peas.

Considering the two sets of characters together, the factor A is found to mask the factor R or is epistatic, to use Bateson's term. The absence of R, *i. e.*, r or wrinkledness, on the other hand is epistatic to A. The varieties of peas thus far genetically studied on the basis of the interpretation given above, fall into four classes which are

Round smooth, colored flowers $= AAl_2l_2RR$,
Round smooth, white flowers $= aaL_2L_2RR$,
Indent, colored flowers $= AAL_2L_2RR$,
Wrinkled, white flowers $= aaL_2L_2rr$.

Excepting the two exceptional cases mentioned under crossing results, all the data are in conformity with the interpretation and the formulas given, and the various results given from crossing may all be obtained through combinations of these four genetic types of varieties. The two exceptional cases need further confirmation, as one at least is doubtful as to fact.

Satisfaction is the only wrinkled pea with the aaL_2L_2rr formula so far studied, while the other varieties are numerously represented in the studies of Bateson, and Tschermak. Tschermak (86) gives the formulas for seven smooth round or indent with colored flowers and five smooth round, white flowered varieties with which he experimented. In his formulas, A and L_1 are separate factors, but since they appear always to be associated it is simpler to regard them as one.

4. Seed Shape.

Though only slightly studied, except as regards the two or more factors controling cotyledon shape (round smooth, angular wrinkled, indent), seed shape is known to be determined in part by still other sets of factors, which are not associated with those of cotyledon form and indent. Hurst (42) suggests that angularity, squareness, flattened sides (flat peas) and deep dents on the sides (not indent) are directly determined by the pressure of the peas of a pod against one another and by the constriction of the pod itself. Generally speaking, he thinks the roundest peas have plenty of room in the pod, while the most wrinkled angular peas are tightly packed together. Irregularity in shape may be caused by a struggle for growth room among the peas of the same pod, and thus alter their hereditary tendency to roundness. Lock (54) in the F_2 of certain crosses between varieties with narrow pods and round seeds and varieties with wide pods and flat seeds, found as a rule that flattened seeds were associated with wide pods and cubical or spherical seeds with narrow pods. In exceptional cases, wide pods had round or cubical seeds and when an F_3 from them was grown, both wide and narrow pods were obtained, thus showing them to be heterozygous for pod width.

Observations of my own on over two hundred varieties, and crosses between several of them, in general, confirm Lock's observation as to the association of round or cubical peas with narrow pods and flat (whether angular wrinkled, or roundish angular and smooth) with wide pods. The diameter of the pod, however, is not necessarily to be regarded as a character which modifies the expression of the factors for seed shape, since it can well be that some of the factors which determine seed shape are coupled or partially coupled with those determining pod diameter. In the former case the seed and pod characters under discussion would be regarded simply as different expressions of the same factor. Wrinkled peas are practically always flat or cubical, but smooth peas may be cubical with rounded edges (drum-shaped), bean shaped, flat and rectangular with rounded corners, conical (if end pea in the pod) and spherical. Bean-shaped peas are characteristic of one variety (Bohnenerbse of Haage & Schmidt), but occasionally a single typical bean-shaped seed appears among a crop of round seeds. When planted, only round seeds are produced, so the variation, in the latter case, is largely due to special environmental conditions of some sort.

5. Seed Dimension and Weight.

These two characters are mutually dependent upon each other. Greater size generally means increased weight, though not necessarily so, especially when the composition of the seed, either chemical or morphological, is altered. Both round and wrinkled pea varieties have large and small seeds. The smallest seeds are found in some of the western Chinese varieties introduced into the United States by our Department of Agriculture, though several of the wild species have seeds of about the same size. The so-called wild *P. arvense* types of Europe and several forms of *P. elatius* have comparatively large seeds. Some of the largest seeded pea varieties are French Giant Gray Sugar, Champion of England, White-eyed Marrowfat, and Black-eyed Marrowfat. As compared with the latter, the wild *P. elatius* seeds are intermediate in size between them and the small Chinese peas and such wild peas as *P. humile* and *P. quadratum.* Size and weight of pea is to some extent associated with size of plant and pods, though small dwarf plants such as Laxtonian bear relatively large pods and seeds. Delicate-stemmed plants such as Benton, *P. quadratum, P. humile,* Abysinnian Black, *P. Jomardi,* Velocity, Express and many of the Hindu and Chinese varieties do not bear large seeds or large pods. Pods and seeds of small, intermediate or of large size may be associated with tall or large, robust-stemmed plants.

In crosses, Bateson (1) finds that small and large seeds generally give intermediates in F_1 and F_2, although he has seen one cross suggesting segregation. Macoun (57.5) crossed two peas of about equal size (Black-eyed Marrowfat and White-flowered Mummy) and in F_2 secured the parental types and intermediates as well as seeds very much smaller than any of the common cultivated varieties. The latter bred comparatively true in F_3. Vilmorin (90) states large size of seed to be dominant to small size. Tschermak (81, 86) has gone into the subject with customary Teutonic thoroughness, but has published his results only in part. In general, he finds the F_1 generation of large $\times$ small seed to have seeds of intermediate weight, though nearer in weight to the small-seeded parent. In F_2, a continuous series between the two parents was obtained, with a great scarcity of the two grandparental types. Repeated experiments with large numbers always gave the same results, though in a few cases seeds still smaller than those of the small-seeded grandparent appeared. In F_3, at least one of the F_2 intermediates remained constant.

In back-crosses of the F_1 with the small parent, the F_1 seeds were small to possibly still smaller than the small parent, while the same F_1 back-crossed with the large-seeded parent gave intermediates, occasionally some seeds of which were larger than the F_1 of (large $\times$ small) itself.

As an illustration of his actual results, large *P. sat.* (ave. wght. 0.3305 gm.) $\times$ small *P. arv.* (ave. wght. 0.08649) in F_1 gave intermediates, ave. wght. 0.1648 gm., which in F_2 gave a continuous series which Tschermak classified in 4 groups—those with seeds averaging in weight that of the small grandparent (I.), of the large grandparent (IV.) and those with seeds weighing on the average either more (III.) or less (II.) than the average weight of the F_1 seeds. The F_2 results from about 12 F_1 plants were:

I.	II.	III.	IV.	Total.
10	398 + 10 ?	105 + 10 ?	2	525
12	205	53	1	271
22	603 + 10 ?	158 + 10 ?	3	796

The F_2 progenies of the 12 or more F_1 plants were similar in composition, only those with the largest numbers giving the extreme variants. It is not clear as to whether parents, F_1's, and F_2's were grown under the same conditions, and in one case at least the F_1's and F_2's appear to have been obtained in different years. In my own experiments, seed size is quite sensitive to environmental differences, peas of the same pure line being almost twice as large under certain conditions than under others. The effect of environmental changes also varies with different varieties.

In crosses between large- and small-seeded varieties made at the Brooklyn Botanic Garden, the F_1 generation generally has as large seeds as the large-seeded parent, while crosses of large seed × intermediate (true breeding) seed has given in F_1 intermediates. In studies of such a character as seed size or weight, which has so many true breeding variations, a marked difference in results from crossing of different varieties is to be looked for, and while some of these crosses should give simple results, in other cases results of the most complex character are to be expected.

Interpretation.

Crossing data on this character are too scanty to give much time to interpretation. Tschermak (86), while not definitely committing himself, is inclined to interpret his results as due to several factors, possibly four, though by combining groups I., II. and III., IV., a ratio varying from 3.5 : 1 to 4 : 1 is secured. One of the many objections to considering seed weight to be determined by the presence or absence of a single factor is the breeding true in F_3

of some of the F_2 intermediates. On the four-factor interpretation, the extreme scarcity in F_2 of the large-seeded grandparental type is accounted for by regarding its factorial composition as due to all four factors in a homozygous condition (AABBCCDD). Combining the F_2 classes I., II. and III., the F_2 ratio of small and intermediate seed weights to large seed weight is 793:3 or 264:1 which is somewhat close to the theoretically expected ratio (255:1). Likewise the relation of the small-seeded F_2's to the remainder of the F_2 progeny on a four-factor basis is theoretically 7:248:1, while Tschermak's actual numbers were 22:771:3 or 7.3:257:1. According to his provisional hypothesis, the 22 small-seeded F_2's represent not only those which will breed true (aabbccdd) but also small-seeded forms which will give intermediates (aabbccDd, aabbCcdd, etc.). Tschermak finds no evidence in his experiments for believing that sterility is in any way responsible for the small F_2 numbers of the large-seeded segregates. He also finds no reason for believing in a differential relation of the environment which would be so much more unfavorable to the large-seeded types.

6. Height, Stem Diameter, Internode Length and Internode Number.

As described by Mendel and most geneticists since 1900, the heredity of height or length of stem in peas represents a very simple problem, the presence and absence of a factor for tallness. While Mendel's description and interpretation of results from crossing talls and dwarfs accounts for most of the facts derived from studying the genetics of two varieties differing in height, it fails to account for all the facts when pea varieties in general or as a whole are under consideration. Height in peas is generally arbitrarily divided into dwarfs (23–90 cm.), half drawfs (90–150 cm.) and talls (150–300 cm.). As pointed out by Lock, Keeble and others, height of a given variety in any given year is very much influenced by environmental conditions, so that in any detailed study of the heredity of height, parents, F_1 and subsequent generations should be grown side by side, as this method insures a minimum amount of variation in the environment. The environmental conditions which modify height are numerous, including defective or diseased cotyledons, partially successful attacks of strangling fungi, temperature and humidity variation, lack of sunlight, variation in soil richness, etc. Dwarfing of tall varieties may be brought about and the flowering period delayed as much as three weeks (26) by cutting off part of the cotyledon in germinating peas. Lock (54) found the climate of Perideniya directly modified the height and growth habit of various varieties of English peas with which he experimented. Further the difference between the height characters of the Ceylon-grown English peas and the same varieties grown in England remained constant through five generations. At the Brooklyn Botanic Garden, Black Abyssinian peas when grown in the field plots bloom early and reach a height of never more than 60 cm. while under greenhouse conditions in the winter time under a temperature of 48° F.–55° F. and growing two plants per 10 cm. pot, they reach a height of over 120 cm.

Height is best described in terms of internode length and number, and stem diameter, as in reality the length of a plant stem is due to various combinations of these three elements. Described by this method, and only taking into consideration height in peas under the general climatic and soil conditions of Long Island, it appears best to modify the height ranges assigned to talls, half dwarfs and dwarfs as given by Bateson (1) and Keeble (49).

Tall peas (150–360 cm.) have robust stems made up of a large number (40–60) of short internodes or a much lesser number (20–47) of long internodes. This class also has very long roots (1).

Half-dwarfs (60–150 cm.) have either robust or delicate stems made up of a small number (10–24) of long internodes or a larger number (20–40) of short internodes. This class is very unsatisfactory, as it represents a very large number of diverse intermediate types.

Dwarfs (23–60 cm.) have either robust or delicate stems made up of a comparatively small number (8–18) of short internodes. This group is easily and accurately distinguished from either of the above, even in young stages 3 weeks or so old.

Varieties Studied.

Talls.

Purple Sugar Pea, Victoria, Laxton's Alpha and others—Bateson (1).

British Queen—Hurst (42).

Telegraph, Ceylon Native No. 1, Telephone, French Sugar Pea—Lock (54).

Numerous varieties—Tschermak.

French Sugar, Market Split Pea, Wachs Schwert, ***Pisum elatius***, Mummy and others—White (unpublished data).

Half Dwarfs.

Fillbasket and numerous varieties—Bateson (1).

Ringleader, Ceylon Native No. 2 (?), Satisfaction—Lock (54).

Express, Serpette, Plein le Panier (Fillbasket), numerous varieties—Tschermak (81).

Autocrat, Bountiful—Keeble and Pellew (49).

Numerous varieties—White (unpublished data).

Dwarfs.

Numerous varieties—Bateson (1).

Eclipse—Hurst (42).

Ceylon Native No. 2 (?), Earliest Blue and others—Lock (54).

Couturier, numerous varieties—Tschermak.

Nott's Excelsior, Laxtonian and others—White (unpublished data).

Results from Crossing.

Most of the crosses involving height were not grown with enough regard to environmental conditions, so that the data, although plentiful, are valuable only for making broad generalizations. In crosses between talls and dwarfs, the F_1 is generally even taller than the tall parent.

Talls × talls gives only talls in F_1 and succeeding generations.

Talls × half dwarf give talls in F_1. In F_2 Tschermak (81) obtained 48 talls; 18 half dwarfs or a ratio of 2.3 : 1. Bateson (1, 3) apparently secured all three classes in some cases in F_2, *i. e.*, tall, dwarfs and half dwarfs. Lock (54) secured only talls and half dwarfs, but the half dwarfs were of two types in some cases—those with a relatively small number of long internodes and those with a relatively large number of short internodes. The talls were made up of a large number of long internodes.

Talls × dwarfs in F_1 give talls, often considerably taller than the tall parent. In F_2, talls and dwarfs appear in a ratio approximating 3:1. Lock (54), Hurst (42), Bateson and others have confirmed Mendel's original results. Mendel obtained in F_2 from a total of 1,064 plants, 787 talls and 277 dwarfs or a ratio of 2.84:1. Of 100 F_2 talls, 28 bred true in F_3, while 72 F_2 talls gave both tall and dwarf offspring, approximating a ratio of 2:1. The dwarfs bred true. Two more generations of this cross were grown by Mendel without securing exceptional results.

Half dwarfs × half dwarfs gives in F_1 in some cases only half dwarfs, or talls due to heterozygosis (1, 54) which give rise in F_2 and succeeding generations to half dwarfs. In other cases (49), involving a different set of varieties, the F_1 is extremely tall, while the F_2 generation consists of talls, two types of half dwarfs and dwarfs in a ratio approximating 9:3:3:1. Keeble and Pellew crossed two half dwarf varieties differing for the most part in only three characters—length and number of internodes and in diameter of stem. Thick stems, short internodes in large number (I.) × thin stems, long internodes in small number (II.) gave in F_1 plants with thick stems, long internodes in large number. In F_2, 5 F_1 plants gave rise to 192 progeny of 4 types as follows:

	Tall.	Half Dwarf (I.).	Half Dwarf (II.).	Dwarf.
Actual	114	33	32	13
Expected	108	36	36	12
Ratio	9	3	3	1

The dwarfs in this particular case all had thin stems and short internodes.

Half dwarfs × dwarfs in F_1 in some cases give intermediates (1, 3); in other cases half dwarf height is dominant. In a case of the latter type, Tschermak (81) obtained half dwarfs and dwarfs in F_2 and the dwarfs remained constant in F_3.

Dwarfs × dwarfs always gave dwarfs in F_1 and succeeding generations.

INTERPRETATION.

The inheritance of height in peas is an extremely important subject from a practical standpoint and well worth a most detailed and thorough study. In most cases, data now obtainable are extremely fragmentary and too general in character. However, so far as our present knowledge goes, two factors are involved and according to Keeble and Pellew—one (T) determines stem thickness, while the other (Le) gives rise to long internodes. The combination of TLe produces talls in F_1 and F_2, while the absence of these factors in F_2 gives dwarfs with thin stems. Many dwarf varieties have thick robust stems, though all known to me have comparatively short internodes and only few in number. Hence it seems to me that T stands not for thickness of stem but as a factor for large number of internodes. Interpreted in this manner, the formulas for various heights in pea varieties would be:

Tall, large number of long internodes, TTLeLe,
Half dwarf, large number of short internodes, TTlele,
Half dwarf, small number of long internodes, ttLeLe,
Dwarf, small number of short internodes, ttlele.

Both the interpretation of Keeble and Pellew as well as the one just given fail to account for the usual results from crossing talls and dwarfs. If talls are bifactorial in composition, in F_2, instead of talls and dwarfs being the only classes, half dwarfs should be extremely common, while dwarfs would appear not more than once in every 16 segregates. However, the classification of F_2 populations involving talls and dwarfs has been based in all probability in most cases on the length of the internodes, all segregates with long internodes, regardless of number, having been classed as talls, while those with short internodes were classed as dwarfs. In this way, the usual 3 : 1 ratio would be obtained, as only the factor Le is involved. The length of the internodes are shortened by the absence of the factor Fa and increased in number. This explains the talls with a large number of comparatively short internodes. As pointed out by Bateson (1), the groups designated talls, half dwarfs and dwarfs are composed of many pure lines differing in a minor degree as to height, number of internodes, etc.

7. Fasciation, Umbellate Inflorescence.

Most varieties of peas have either robust or slender, angular or roundish stems, which are small at their base and three or four times the basal diameter at their top or flowering region. The flowers of such varieties are in ones, twos or threes on axillary peduncles along a large stretch of the stem. These are the *common* or "normal" characteristics of peas.

Fasciation in peas greatly alters the above characters by increasing the maximum width of the stem at the top from 1 cm. to as much as 4 cm. The stem in this region either presents the appearance of a flattened, pressed cylinder or of an irregular cylinder, with side splits and an opening in the top. Leaves as well as branches grow out from this inside tissue region. The leaf arrangement or phyllotaxy ceases to be regular in the fasciated region of such plants, and the flowers instead of being axillary are bunched together at the top of the stem in what may be called an irregular umbel or bouquet. Not uncommonly in these fasciated plants, growth is so uneven on opposite sides of the stem as to cause a curling up of the stem making it resemble one side of an Ionic capital or a ram's horn. Both Lobel and Gerarde mention and picture a fasciated variety of pea in their herbals, and according to all observers the character is strictly hereditary. In my own experience, seed of a fasciated variety obtained from Eckford of Wem, England, has always bred true to fasciation under every and all sorts of conditions. Fasciation does appear in other plants and in peas, however, which is not inherited, but is mainly due to environmental conditions. Further this type (8.5) is morphologically indistinguishable from the inherited type. Blodgett (8.5) cites a case in which 90 per cent. of the peas of fields grown for canning purposes were afflicted with this trouble, making the crops worthless except for green manure purposes, since fasciated peas bear but few pods and only when conditions are just exactly right. I have seen this same type of fasciation in greenhouse cultures a couple of times.

Varieties Studied.

Irish Mummy of H. Eckford, Wem, England. This is the common fasciated variety, which in the seed catalogues of different countries takes different names. In England fasciated varieties are called crown peas. I have experimented with several other fasciated varieties which were obtained from Russia and Sweden.

Results from Crossing.

Fasciated stems, umbellate inflorescence × non-fasciated stems, axillary inflorescence gives in F_1 absolutely "normal" stems with axillary inflorescences. In F_2, Mendel obtained from 858 plants, 651 with normal stems and axillary inflorescences and 207 with fasciated stem and umbellate inflorescences—a ratio of 3.14 : 1. Lock (56) and others have confirmed Mendel's results, although Lock notes there is considerable variation in the degree of fasciation in the segregates. Bateson and Punnett (3) secured various intermediate types in F_2.

Mendel carried his study of this cross through the F_4 generation. In F_3, of 100 "normal" F_2 plants, 33 bred true to normalness, while 67 gave both normal and fasciated plants in a 3 : 1 ratio. In F_4 no exceptional results were obtained.

Interpretation.

Considering only genetic results, the hereditary difference between "normal" stemmed and fasciated stemmed peas is the presence and absence of a single factor Fa. When Fa is present, the stems are normal. In its absence, they are fasciated.

8. Leaf Axil Color.

Generally associated with leaf axil color is color at the point of attachment of the pinnæ, colored margins in the young leaves and color at the base of the stem. The color is either red associated with pink flowers, or reddish purple associated with reddish purple flowers. Owing to changes in environment, particularly the amount of sunlight, the color varies in intensity even among the axils of the same plant. Although always associated with colored flowers and colored seed coats, there are forms of *Pisum* with colored flowers and unpigmented axils. In the absence of pigment, the leaf axils and other structures noted above are greenish white or yellowish green, with which are associated white flowers and colorless seed coats.

Varieties Studied.

Colored Axils, Colored Flowers.

Purple Sugar Pea, Purple-podded Pea, Irish Mummy (*P. sat. umbellatum* or Egyptian Mummy, Crown pea, etc.), Purple-flowered Field Pea—Lock (54, 56).

English Gray Field Pea—Darbishire.

Graue Riesen (Purple Sugar), Svalöf *P. arv.*, Nos. VI., VII., VIII., IX., X.; Red-flowered Kneifelerbse and others—Tschermak (81, 86).

Non-colored Axils, Colored Flowers.

Svalöf *P. arv.*, No. IV.—Tschermak (86), Tedin.

P. humile ?, *P. quadratum* ?—Sutton (74).

Non-colored Axils, White Flowers.

A large number of white-flowered varieties have been used in studying inheritance of axil color. Among them are,

Laxton's Alpha, Veitch's Perfection, Sunrise, British Queen, Victoria Marrow, Très nain de Bretagne and others—Lock (54, 56).

Victoria Marrow, Emerald, Yellow-podded Sugar Pea, and others—Tschermak (86).

Results from Crossing.

Colored axils, colored flowers × non-colored axils, colored flowers in F_1 gave all colored axils, colored flowers. In F_2, Tschermak (86) obtained in such crosses,

Actual, 132 colored flowers and leaf axils: 49 colored flowers, non-colored leaf axils.

Ratio,	2.7 : 1
Expected,	135.75 : 45.25
Ratio,	3 : 1

Colored axils, colored flowers × the same always breeds true in F_1 and succeeding generations.

Colored axils, colored flowers × non-colored axils, white flowers gives in F_1 colored axils, colored flowers. In F_2 the following results have been obtained:

Investigator.	C. Ax., Col. Fl.	Non-C. Ax., White Fl.	Ratio.
Mendel	705	224	3.15 : 1
Lock	184	65	2.83 : 1

In F_3, Mendel grew the progeny of 100 of the F_2 colored flower, colored axil segregates and found 36 bred true, while 64 again gave both the F_2 classes in similar proportions. In F_4 Mendel secured no exceptional results.

Lock's results (56) from selfing F_2 colored flower, colored axil segregates confirmed Mendel's results, part of them breeding true and a greater proportion giving both classes again.

Back-crosses of F_1 × colored flowered, colored axil parent gave all progeny with colored flowers and axils.

F_1 crossed with a white-flowered, non-colored axil variety gave 44 progeny with colored flowers and axils and 26 with white flowers.

F_2 white-flowered segregates × pure-colored flower, colored axil varieties gave all colored flower, colored axil offspring.

Non-colored axils, colored flowers × the same breeds true.

Non-colored axils, colored flowers × non-colored axils, white flowers in F_1 gives all colored flowers and colored axils. In F_2, Tschermak (86) obtained from a population of 545:

Class.	Col. Fl., Col. Ax.	Col. Fl., Non-Col. Ax.	White Fl., Non-Col. Ax.
Actually obtained	336	83	126
Actual ratio	9.8	2.5	3.7
Theoretically expected	306	102	136
Theoretical ratio	9	3	4

The proportion of segregates with colored flowers and colored axils to those with colored flowers and uncolored axils was 336:83 or 4:1, whereas the theoretically expected proportions were 314.25: 104.75 or 3:1.

Extracted white-flowered segregates derived from the splitting up in later generations of the F_2 segregates with colored flowers and non-colored axils, crossed with either colored flower, non-colored axil segregates or with the pure ancestral colored flower, non-colored axil variety always gave progeny with no color in their axils.

White flowered races crossed with each other never have given progeny with colored axils.

Interpretation.

All the data so far obtained indicate that color in the leaf axils, pinnæ, and stem base are explainable on a two factor basis, one of the factors (C) being absolutely coupled with the pink pigment flower factor (A). The other factor (D) is inherited independently of A or of any other factor so far as our present data go. Since A and C are absolutely coupled, it is simpler to consider them both as one factor (A). Regarded thus, colored axils result from the joint activity of A and D. In the absence of D, the plant will have no axil color, though the flowers and seed coats may be colored or non-colored (white). The factor D may be present in varieties with colored flowers or varieties with white flowers. Interpreted in this manner, all the above data are simply explained and all the various combinations mentioned may be obtained. The formulæ for the various varieties of peas would then be:

1. Colored flowers, colored axils { AAbbDD / AABBDD
2. Colored flowers, non-colored axils { AAbbdd / AABBdd
3. White flowers, non-colored axils { aaBBDD / aaBBdd

Tschermak (86) has given the formulas for 7 varieties with colored flowers and 5 varieties with white flowers. All the white-flowered varieties so far experimented with are aaBBDD, the aaBBdd class being represented only by Tschermak's true-breeding segregates from crosses of 2 × 3.

9. Flower Color.

Flower colors in all the cultivated varieties and species of peas are easily separated into three sharply defined classes, between which there are no intergrades. These color classes are white, salmon pink, and reddish purple. The wild forms of *Pisum* most closely related to our common cultivated forms all have colored flowers of the reddish purple class. This last class is the only one in which the color varies according to the variety. The degree of variation is small and largely confined to a small group of wild or near wild Asiatic varieties of which *P. humile* Boiss. and *P. humile* ? of Sutton (74) are wild types. In this group of purple-flowered forms, the colors are dull and of about the same shade in both standards and other parts of the flower, the common purple-flowered forms being bi-colored (*i. e.,* lighter color shades in the standards). Benton is the most pronounced in light-colored standards of any of the bi-colored purple-flowered sorts. Environmental changes commonly met with in pea cultures have very little modifying effect on flower color, though wet, cloudy weather causes pink-flowered plants to produce white flowers.

Varieties Studied.

A large number of varieties have been studied, many of which are designated under the sections devoted to leaf axil and seed coat color. Reddish purple and white-flowered varieties are most commonly cultivated. The pink-flowered variety most easily procured is "Irish Mummy," known also as Mummy, Egyptian Mummy, *P. sat. umbellatum,* etc. Many field peas and "sugar pod" peas have colored flowers while the great majority of the garden peas are white-flowered.

Results from Crossing.

Lock (56) and especially Tschermak (84, 86) have given admirable summaries of the work on this set of characters, making it unnecessary to go into great detail here.

Purple flower × purple flower gives only purple-flowered offspring in F_1 and succeeding generations.

Purple flower × pink flower in F_1 gives all purple-flowered offspring, which in F_2 give both purple- and pink-flowered segregates in proportions approximating the 3:1 ratio. In F_3, the pinks and part of the purples breed true, the remainder again breaking up in the expected Mendelian proportions.

Purple flower × white flower in F_1 give all purple-flowered progeny. In F_2, generally only purple- and white-flowered segregates in an approximation to the 3:1 ratio are obtained. Mendel's results from a total of 929 F_2 were:

705 purple red:224 whites or a ratio of 3.15:1.

In F_3 the whites tested and approximately one third of the 100 tested purple reds bred true, while about two thirds (64 F_2 ind.) gave purple reds and whites again.

In crosses of certain true breeding white segregates with purple-flowered races, purples are obtained in F_1, while in F_2, purples, pinks and whites occur in proportions approximating 9:3:4.

Pink-flowered varieties crossed with each other generally give nothing but pinks in F_1 and succeeding generations.

Pink flower × white flower in F_1 commonly gives all purple-red-flowered offspring, which in F_2 give purples, pinks and whites in a ratio of 9:3:4. Lock (56) and Tschermak (86) obtained the following results:

	Purple.	Pink.	White.	Total.
Lock	141	43	65	249
Tschermak	407	104	155	666
Total	548	147	220	915
Expected	514.35	171.45	228.6	

In F_3, the F_2 whites and part of the F_2 purples and pinks breed true, but the greater proportion of the latter two classes break up again, the purples giving either purples, pinks, whites; purples and whites, or purples and pinks, while the heterozygous pinks only give pinks and whites in a ratio of 3:1, the actual results obtained by Lock (56) being 113 pinks:50 whites. Out of 16 F_2 pinks 6 bred true in F_3 while 10 were heterozygous for pink and white.

Back-crosses of the F_1 of this cross with pure white-flowered varieties gave 44 purple and 26 white-flowered plants, the theoretically expected being 35 of each. Back-crosses of this same purple F_1 with the pure pink strain gave 21 purple and 17 pinks, where an equal number of each was expected. Back-crosses of F_2 purples and whites with pure white and pure pink varieties gave results showing there were two genetic sorts of whites.

White flower × white flower always gives white-flowered progeny.

Tschermak has carried out and published (84) the results of a very complete series of back-crosses of F_1's, F_2's, F_3's, F_4's and F_5's with pure varieties and of the segregates of each type from several of these generations with each other. This work of Tschermak's, together with that of Mendel and Lock has put the genetics of flower color in *Pisum* on a very strong basis of fact.

All these and other studies on *Pisum* flower color have shown colored flowers to be always associated with colored seed coats, colored leaf axils, indent seed, etc., while white-flowered races are always characterized by their absence. Further, of the two colored flower types, purple flowers are always associated with reddish purple axil color and purple dots on the seeds, while pink-flowered varieties are associated with reddish leaf axils and reddish dots on the seed coat. Both purple- and pink-flowered forms are known or have been obtained through crossing which lack axil color or dotted seed coats, though all have the gray-brown seed coat for which the factor $\breve{Gc}$ stands.

Exceptional Cases.—In several cases both Tschermak and Fruwirth have secured purple flowers in F_1 from crossing two pink-flowered plants, where only pink was expected. Tschermak tentatively regards these pinks which give rise to purples as individuals which were really purples genetically, but for some reason the union of the factors A and B failed to produce purples when they were expected. Later B became active again. These exceptions are still under investigation.

Interpretation.

According to Tschermak, flower color in peas is due to the presence and absence of two factors—a chromogen factor A and a color modifier or blueing factor B. When A only is present the plants have salmon-pink flowers, when both A and B are present the pink color is modified to a purplish red. When both A and B are absent the flowers are white. When A is absent and only B is present the flowers are also white, so that B cannot express itself in the absence of A. All white-flowered varieties so far tested have shown the presence of B by giving purple flowers in F_1 in crosses with the pinks. Tschermak and Lock, however, have obtained true breeding white-flowered segregates lacking this factor.

When the necessary factors for axil color and dotted seed coats are present together with A, these respective regions are red pigmented, which if B is added, are modified to purple. In the light of the present genetic data, then, varieties of peas in respect to flower color have the following formulas:

Purple flowers	AABB
Pink flowers	AAbb
White flowers	aaBB
White flowers (segregates only)	aabb

10. Time of Flowering.

Varieties of peas vary from about 35 to 150 days or more in the time it takes them to reach the flowering period from the date of planting, when all are planted the same day and grown under similar conditions. As might be expected, different varieties of peas react somewhat differently to changes in environment as regards the time it takes them to reach the blooming period. Grown in 10 cm. pots in the greenhouse in the winter time this period is considerably lengthened in several varieties, while with other varieties there is practically no change—the same length of time being required as in the field cultures. Between the earliest and the latest blooming varieties, there is a continuous range of varieties with blooming periods at most not more than four days apart, so that in a random collection of a hundred varieties, one might record another variety in bloom almost every day. Between the individuals of a variety such as are many of the dwarfs, the individual variation in time of flowering is small, ranging over three to four days. Among the so-called "half dwarfs" and tall varieties, individual variation within the variety has a much wider range. Dwarfness, although generally associated with earliness, is also associated with medium late blooming varieties, but tall varieties are but very rarely early bloomers.

Lock (54), Tschermak (85) and Hoshino (40.5) have each noted that white flower color is genetically associated with earliness while colored flowers are associated with late flowering. The association is not of an absolute nature in either case, as some of the latest flowering forms such as Späte Gold are white-flowered. None of the earliest varieties, however, have colored flowers, but this may be a coincidence, since varieties with colored flowers have not been selected for earliness and early flowering forms may have arisen which remained unnoticed.

Horticulturists and seedsmen divide varieties of peas on the basis of time of bloom into early, second early, medium, medium late and late. This classification is too general for scientific purposes, though of much practical value.

Varieties Studied.

Numerous varieties—Tschermak (85).
Ceylon Native No. 1, French Gray Sugar Pea—Lock (54).
Bountiful, Autocrat—Keeble and Pellew (49).
Victoria Marrow, various Finnish and Russian Field Peas—Relander (66).
"Early White-flowered Dwarf," "Late French Large-podded," "Mans"—Hoshino (40.5).

Results from Crossing.

Crosses of an earlier flowering variety with a later flowering variety generally give an intermediate in F_1 in this respect. Relander (66), however, finds that if the flowering periods are very close together the F_1 blooms at or very near the same time as the earlier flowering parent, but where the blooming periods are far apart, only intermediates are obtained in F_1. Keeble and Pellew (49) secured intermediate F_1's from crosses of two varieties with flowering periods about a month apart. In Tschermak's (85) crosses, the F_1's were either intermediate or near the late flowering parent. In one case the F_1's were all as late flowering as the late flowering parent. In Hoshino's crosses, the F_1 was nearest the late-flowered parent. In all studies of F_1 crosses in respect to flowering time, the numbers have been extremely small, Relander and Hoshino employing the largest.

In F_2, the usual result is a complete or almost complete intergrading series with occasional small breaks. The classification of such a series into early, intermediate and late is generally arbitrary, though often based on the blooming period of the two parents and the F_1 when these are grown under the same or similar conditions. With such a method of classification, Tschermak obtained from crosses involving seven different varieties, the following results:

Actual,	60 early :	190 intermediate :	88 late,
Expected,	63.3 early :	190 intermediate :	84.4 late,
Ratio,	3 :	9 :	4.

Keeble and Pellew from crosses involving two varieties obtained 63 early : 128 intermediate : 1 late. Lock (54), classifying them in three 5-day frequency classes, obtained 63 early : 186 intermediates : 279 late.

Lock (54), Tschermak and Hoshino (40.5) have noted an F_2 association between colored flowers and lateness on the one hand and white flowers and earliness on the other. The modifying relation or coupling, whichever it may be, is only partial, as the following F_2 results show:

Class.	Early.		Intermediate.		Late.	
Flower color	white	purple	white	purple	white	purple
Tschermak	25	22	48	94	4	64
Ratio	1 :	.88 :	1 :	1.96	1 :	1.16

White flowers : purple flowers 77 : 180 or 1 : 2.34.

Lock	29	34	79	107	104	175
Ratio	1 :	1.17	1 :	1.35	1 :	1.68

Purple flowers : white flowers 383 : 123 or 3.13 : 1.

The expected relation of the purple- to the white-flowered class, providing there was no coupling, is of course 3 : 1 in each of the classes—early, intermediate and late.

Tschermak (85) and Keeble and Pellew (49) have obtained some curious results regarding the relation of tallness and dwarfness to the time of flowering. In the one case (Fig. 3B) given by Tschermak the F_1 is tall and almost as late flowering as its late-flowering parent. In F_2 32 talls and 10 dwarfs result. Classifying the talls by their blooming time, the result is 9 early:15 intermediate:8 late. The 10 dwarfs were 6 intermediate:4 late, no earlies being obtained where most expected.

Keeble and Pellew found lateness in blooming correlated with short internodes and earliness with long internodes. Classified on this basis, their results are:

Class.	Early.	Intermediate.	Late.
	53L : 10S	93L : 35S	0L : 1S
Normally expected ratio.....	3 : 1	3 : 1	3 : 1

Classified so as to show the relation of both the character of the stem (thin or thick) and the length of internodes to time of bloom, the results were:

63 Early	*128 Intermediate*	*1 Late*
22TL	92TL	—
2Tl	31Tl	—
31tL	1tL	—
8tl	4tl	1tl

Providing neither linkage (coupling) nor modifying effects were present, *i. e.*, independent both in inheritance and development, the theoretically expected ratio in each of these classes is 9:3:3:1.

In F_3, Tschermak found some of the F_2 earlies and all lates remained constant or bred true. Some of the early class gave both early and intermediate. The intermediates in some cases bred relatively true, in other cases giving intermediates and lates and in still other cases giving all three classes.

In several cases in F_2 and F_3, segregates flowering either earlier than the early ancestor or later than the late flowering ancestral variety, were obtained and these remain constant in later generations.

The F_4 generation results bore out the F_3 expectation.

Hoshino's studies involved 30,000 F_1, F_2, F_3 and F_4 generation plants, and his results are similar to those obtained by Lock and Tschermak, as regards flower color and time of flowering, but in a cross between an early flowering dwarf variety and a late flowering tall one, he found no evidence of coupling between the factors for height and flowering time, as did Keeble and Pellew. An F_2 population from such a cross gave 23 ED:89 ET:76 LD:183 LT (Table I.).

Interpretation.

Tschermak has provisionally interpreted his results as due to the presence and absence of two factors, with the possibility of there being a third, although he states this character is probably much more complicated.

The two factors are a "Zug" or pulling factor and a "Treib" or driving factor, there being possibly two of the latter. The "Zug" factor produces intermediates with a tendency to be late-flowering, while the "Treib" factor modifies the "Zug" factoral expression so as to give early flowering forms. By itself, it cannot alter the *status quo*. In the absence of both, constant late-flowering forms are produced.

The second "Treib" factor postulated is a positive present in all peas, giving constant lates in the absence of the other two factors or constant earlies in the presence of the other factors. The various varieties experimented with, on the two factor conception, would be represented by formulæ as follows:

Constant early ....AABB,
Constant intermediate............AAbb,
Constant late ....aaBB or aabb.

Combinations of AABB $\times$ aabb would give in F_1 an intermediate AaBb. In F_2 the expected ratio of early, intermediates and lates would be 3:9:4. Further explanation is long and complicated. In view of the numberless varieties with differences in the length of time it takes them to reach the blooming period, it appears to the writer that some cases should be of simpler composition than others—the early, intermediate and late classes being interpretable as combinations of a single pair of factors, which in F_2 would give a 1:2:1 ratio.

Hoshino (40.5) also interprets his genetic data on time of flowering by means of two factors, one of which, $\breve{\text{Lf}}$ (A), determines the "proper" time of flowering in the late parent, while $\breve{\text{Ef}}$ (B) modifies the expression of $\breve{\text{Lf}}$ toward earlier flowering, and is hypostatic to Lf. The absence of Lf is epistatic to the absence of Ef, and determines the time of flowering of the early parent, while the absence of Ef causes the early variety to bloom a few days later. Gametic contamination of some sort is believed to be involved, but the factors are distinctly stated not to be "inconstant" in the sense in which Castle (10) uses the term. Lf ("A") is partially coupled with factor A for flower color, the proportion of non-cross-over to cross-over gametes approximating 7:1.

11. Number Flowers per Single Peduncle.

Flowers in *Pisum* are borne either singly, in twos or in threes on a single axillary peduncle, unless the factor for normal stem is absent. *P. elatius* is an excellent example of the "flowers per peduncle 2–3" type, while most of the commonly cultivated varieties are two-flowered or 1–2-flowered. Such early forms as Velocity, First of All, and Black Abyssinian are almost totally single flowered.

According to Hurst (44), the tendency to bear pods (and consequently flowers) in pairs is inherited. Vilmorin (90) states 1-flowered and 1–2-flowered peduncles to be dominant to 2–3-flowered peduncles, these two characters being determined by the presence and absence of a single factor. In the table, this is designated Fn. Strictly one-flowered types and their relation to the 1–2-flowered type apparently have not been studied.

12. Foliage and Stem Color.

The foliage and stem color of peas is either green or yellowish green, each color generally being associated with unripe pods of the same color, although a few purple and yellow podded varieties of peas are known with green leaves. Green or purple podded yellow-leaved varieties are unknown. Gold von Blöcksberg and Goldkönig are typical yellow-leaved varieties.

The writer obtained from crossing yellow foliage, etc., × green foliage, etc., green foliage, green podded F_1 progeny, which in F_2 gave 681 with green foliage, green pods and 222 with yellow foliage, yellow pods, the expectation being 677:226. Of 45 green foliage, green podded F_2 segregates tested in F_3, 14 bred true, while 34 gave both yellow and green foliage and podded F_3 progeny, the total ratio being 427 GF : 146 YF. 15 F_2 yellow-foliage segregates gave all yellow-foliage F_3 progeny. F_4 gave no exceptional results.

Interpretation.

Varieties with green foliage and green pods differ from those with yellow foliage in the form investigated by the presence of the factor O. Hence all varieties of peas investigated with green foliage are OO, while those with yellow foliage are oo.

13. Tendrilled and Non-Tendrilled Leaves.

With one exception, all cultivated varieties of peas have leaves in which part of the pinnæ have been replaced by tendrils. This one exception—the Acacia variety—has wrinkled seeds and no tendrils, the place of the tendrils being taken by extra pinnæ. The variety breeds true as regards both the characters mentioned. Its origin is unknown, though the variety was first studied by Vilmorin (89, 90).

Results from Crossing.

Tendrilled, round seed × Acacia, wrinkled seed gave in F_1 all tendrilled, round-seeded progeny. In some crosses, the F_1 tendrils are slightly strapped-shaped, especially in the youngest tendrilled leaves. Otherwise dominance of tendril is complete.

The F_1 plants bore F_2 round and wrinkled seeds in the usual 3 : 1 proportions and the F_2 proportion of tendril and Acacia plants was as expected, approximately 3 : 1. In such a cross, providing these two pairs of characters were independently inherited, four classes in a ratio of 9 : 3 : 3 : 1 would be expected. When the seed and leaf characters were thus considered the four expected classes were found, but the proportions were awry, the two middle classes being all but absent. In other words, the F_2 round seeds gave almost exclusively tendrilled plants, while the F_2 wrinkled seeds gave practically all Acacia or non-tendrilled plans, showing that round and tendrils, wrinkled and Acacia were almost completely linked or coupled together in their inheritance.

In the F_2 generation, or from heterozygotes of the same composition as F_1, the following results have been obtained:

Investigator.	Round Seeds Gave		Wrinkled Seeds Gave	
	Tendril.	Acacia.	Tendril.	Acacia.
Vilmorin	113	2	5	70
Vilmorin (case 2)	170	1	4	99
Bateson	210	4	1	64
Pellew (64)	1466	20	15	564

The first three series of results are less accurate than that of Pellew because the classification of rounds and wrinkleds was not made by examining the starch, hence errors occurred—wrinkleds being sown for round and *vice versa*. By the starch examination method, there could be no such mistakes, as wrinkleds *always* have "compound" or much split roundish starch grains.

Tendrilled wrinkled × constant round-seeded Acacia segregates (64) gave in F_1 the usual results, but in F_2, the round seeds gave 502 tendrilled, 270 Acacia, while the wrinkled seeds gave 264 tendrilled, 0 Acacia.

Pellew tested out other pairs of characters with tendrils and Acacias to see if there was any coupling, but none was found. Among these pairs tested were tallness and dwarfness, yellow and green cotyledons, purple and white flowers, glaucous and emerald foliage and fasciated and normal stems.

Interpretation.

The factor (R) for roundness of seed, etc., and its absence (r) for wrinkled seed, etc., have already been considered. Tendrilled and non-tendrilled plants (Acacia) are due to the respective presence and absence of the factor $\underset{\smile}{Tl}$. The peculiar ratios obtained as regards both sets of factors show that partial linkage or coupling exists between R and $\underset{\smile}{Tl}$ on the one hand and r and $\underset{\smile}{tl}$ on the other. The interpretation of the manner in which this partial coupling is brought about is too extended to consider here. Suffice to say that Bateson (3.5) and his students explain it by somatic segregation and the increased rapidity of growth of the germ cell area which is to give rise to the large classes, as compared to that which gives rise to the small classes. This is called the reduplication hypothesis. Morgan and his students (61, 62, 73) explain the same facts in a wholly different manner on the basis of the linear arrangement and "linkage" of groups of factors together in the same chromosome, and the occasional crossing-over of factors to the opposite or homologous chromosome during the maturation divisions. To the writer, the latter appears to be the more simple interpretation and better supported by the facts.

14. Bloom.

With comparatively few exceptions, all varieties of peas have a waxy surface covering on their leaves, stems, pods and other plant parts. The varieties from which this is absent are known as Emeralds and very easily become diseased. Emerald varieties studied by Vilmorin (89) are Emereva, Johnson's British Empire and Pois à brochettes.

Results from Crossing.

Glaucous (*waxy*) × glaucous gives glaucous.

Glaucous × emerald in F_1 is always glaucous (89, 86, 92). In F_2, the following results have been obtained:

Investigator.	Glaucous.	Emerald.	Total.
Vilmorin	138	39	177
Tschermak	35	18	53
Actual	173	57	230
Ratio	3	1	
Theoretically expected	172	57	

In F_3, of 15 F_2 glaucous, 5 gave all glaucous, while 10 gave 133 glaucous : 32 emeralds. 15 F_2 emeralds tested in F_3 gave all or 199 emeralds.

Emerald × emerald (89, 92) gave glaucous in F_1 which in F_2 gave glaucous to emeralds in the ratio of 9 : 7. Vilmorin crossed Emereva (emerald) with two other emeralds noted above with the same results. The following results were obtained from 2 F_1 plants in F_2:

Plant A,	27	: 20 emerald,
Plant B,	23	: 21 emerald.
Actual,	50	: 41
Calculated,	51.1	: 39.8

In F_3 6 F_2 glaucous plants gave in one case all glaucous, in 5 cases both glaucous and emerald. Of 3 F_2 emeralds tested in F_3, only emerald progeny resulted.

Interpretation.

The above data show that two factors are involved in the inheritance of bloom; in the absence of either or both, the plant is emerald. No emeralds have been obtained as yet in which both factors for bloom are absent. Regarded thus, in respect to bloom and its absence, varieties of peas with bloom are BlBlWW, while emeralds may be either blblww, BlBlww or blblWW. Emeralds of the first type should be obtained as segregates.

15. Productiveness.

Productiveness is to be regarded as a composite character or one made up of a very large number of other characters. Length of vine, number of internodes, number of pods per single peduncle, number of pods per plant, length of pods, number of pea ovules per pod, number of peas matured per pod are a few of the hereditary characters, the combined results of which are called productiveness. In addition to these there are a host of environmental conditions which either raise or lower the hereditary productivity of a variety. For a scientific study of the heredity of productiveness, it is necessary to eliminate as nearly as possible variation caused by environment, and this is most easily accomplished by growing the varieties to be studied and their hybrids under as near as practicable, one set of conditions. A study of this character under these conditions, so far as I am aware, has not yet been published.

Varieties of peas, as well known, differ remarkably in the average number of pods they bear, and these variations are governed, as usually studied, quite as much by environment as by heredity. Such early varieties as Morning Star, Excelsior, Velocity and others do well under ordinary conditions if they average four pods per vine, while some of the late varieties with large vines may average 30 to 50 pods. Variation in the number of pods per single vine is large even among the individuals of a pure varietal strain, but in some cases this may be regarded as almost entirely environmental. Further the extremes as to few or large number of pods never transcend certain limits, and supposedly these limits represent the character of the environment, whether most unfavorable or most favorable. Olin (63) records a plant grown in the Colorado mountains under exceptional conditions which was 3 meters high and bore 650 pods averaging 5 peas per pod. On the other hand, some of the wild forms average 4 pods per plant.

Hurst (44) grew 112 varieties under about the same conditions. From data on these, the heaviest yielders appeared to be those varieties with the largest number of pairs of pods, but he states this to be more apparent than real. Some varieties generally bear pods singly, while other varieties have them in pairs or in threes. Twenty plants of Velocity gave Hurst 202 singles and no pairs, while a score or more of plants of other varieties gave all the way from 4 doubles : 471 singles to 142 doubles : 593 singles.

Shaw (70) from a large series of biometrical studies on several pea varieties came to the conclusion that the number of pods per single plant was not a heritable character, but that it was correlated with vine length, which is heritable. Shaw's experiments and treatment of his material, however, were not of such a character as to throw much light on this subject. Shaw and others point out the probability that each node is potentially capable of producing pods. In most modern studies of heredity, however, one considers only the physical characteristics of a plant or a variety as they actually are under a given set of environmental conditions and not the potentialities or possible variations of this plant or variety under a thousand and one environments in which it might be grown.

The productivity of any variety of pea, as is well known, is increased by harvesting the green marketable pods, instead of allowing the first crop to mature.

Relander (66) has begun a careful study of the problem of productivity in peas by growing the parents and crosses in pots of similar size and soil contents under the same environmental conditions and taking data on the total dry plant, seed and straw weight per pot, weight per 1,000 seeds, the average number of pod-carrying internodes and pods per plant and the average number of seeds and seed "Anlagen" or ovules per pod. In crosses between varieties or pure lines differing in these respects, the F_1 progeny gave various results, depending on the varieties crossed and the character considered. In all crosses, the individuals of one pure line culture of the variety Victoria were used as one of the parents, the other parents being from pure lines of Russian and Finnish field pea varieties. The F_1 results as given by Relander are in figures with which figures from the two parent varieties are given for comparison. Table *A* roughly represents the character of the F_1 progeny in terms of the parent characters. Intermediate means only approximate intermediate condition, Relander's figures showing that the productivity in most of the cases marked intermediate was nearer that of the more productive parent.

TABLE A.

DIFFERENT F_1 VARIETAL CROSSES.

Character.	I.	II.	III.	IV.	V.	VI.
Total weight of dry plant per pot	H.E.P.	Int.	Int.	H.P.	H.P.	H.P.
Total seed weight per pot	H.E.P.	Int.	Int.	H.P.	H.E.P.	H.E.P.
Total straw weight per pot	Int.	Int.	Int.	H.P.	L.P.	Int.
Weight per 1,000 seeds (only fully mature, well-developed seed used)	Int.	Int.	Int.	Int.	Int.	Int.
Ave. no. of pod carrying internodes per plant	H.P.	L.P.	Int.	L.P.	Int.	Int.
Ave. no. pods per plant	H.P.	H.P.	H.P.	Int.	Int.	Int.
Ave. no. seeds per pod	Int.	H.P.	H.P.	H.P.	H.E.P.	H.E.P.
Av. no. of ovules or seed "Anlagen" per pod	All intermediate but nearer the high producing parent. No data on No. VI.					

H.E.P. = Higher than either parent.
H.P. = Dominance of more productive parent.
L.P. = Dominance of less productive parent.
Int. = Intermediate.

Relander interprets the differences in her results as due to differences in factorial composition of the different varieties she used. She does not believe that the increased productivity obtained in certain of her crosses is due to heterozygosis in the sense of East and Hayes (27).

16. Pod Color.

As regards color of unripe pods, varieties of peas may be classified into three groups—green-podded, yellow-podded and purple-podded.

Green-podded varieties are the most common and are typical of all the wild species. Green pods are never associated with yellow foliage.

Yellow-podded varieties often have bright yellow pods associated with yellow flower-bearing axes, green stems and foliage. All yellow-foliaged varieties, such as Goldkönig and Gold von Blöcksberg, have yellow or yellowish green pods. All yellow-podded varieties known to me have yellow cotyledons, although segregates have been obtained with yellow pods, yellow foliage and green cotyledons.

Purple-podded varieties such as Nero and Purple-podded Field Pea have colored flowers and gray seed coats. Tschermak (86) cites Vilmorin as saying that weak purple pigmentation has been found in pods on white-flowered plants. Lock (56), Tschermak (86) and Fruwirth (34) have found considerable variation among different pods of the same plant, some pods being wholly purple, while others are purple splashed with green in various degrees. Plants with all purple pods are also found. Fruwirth attempted to secure by selection a stable pure green-podded race from the green and purple-splashed podded plants. Ten generations gave entirely negative results. Strains having only purple pods were secured in these same experiments by planting seeds of wholly purple pods. Fruwirth regards the appearance of these true breeding purple-podded strains as bud mutations.

Results from Crossing.

Green pod × green pod always gives green pod (pure varieties).

Green pod × yellow pod gives in F_1 all green-podded progeny. In F_2 Mendel secured approximately 3 green-podded plants: 1 yellow-podded. Tschermak's results involving crosses of yellow pod with 8 very distinct varieties with green pods confirmed Mendel's results. In some of these crosses, Tschermak obtained colored-flowered, yellow-podded segregates which remained constant. Yellow-pod segregates always bred true, while the green-pod F_2 segregates in F_3 in some cases were constant, and in others gave both green- and yellow-podded plants.

Green pod × purple pod in F_1 always gives all purple-podded progeny (56, 86, 34, 90). In F_2, Lock obtained five different types of segregates—segregates with all purple pods, with all green pods, and segregates having green pods with various degrees of purple coloring. Some plants were very faintly pigmented. Tschermak obtained small F_2 numbers—10 purple in different degrees : 5 green. In F_3, the F_2 purple-pigmented plants gave 34 purple : 27 green. Fruwirth, on the other hand, obtained all green-pod progeny in F_1 of two crosses of green pod × purple or purple-splashed pod varieties, and in F_2 of one of them, 39 green-podded and 10 purple or purple-splashed segregates were obtained. According to Fruwirth, purple pod color is inherited independently of purple-specked seed coat pattern.

Yellow pod × purple pod gives in F_1 (86) purple pod, which in F_2 gives purples or purple-splashed : yellow in an approximation to a 9:7 ratio. Yellow-podded segregates always breed true.

No data have been published on crosses of F_2 yellow and F_2 green-podded segregates from combinations involving purple-podded varieties.

Interpretation.

So far as our present data go, all green-pod varieties of peas may be regarded as differing from yellow-pod varieties by the presence of a factor Gp. The factorial relation of purple-podded varieties to green- and yellow-pod varieties cannot be cleared up until more data are obtained. Tschermak regards purple-pod varieties for the present as bifactorial, differing from green- and yellow-pod races by the presence of two factors (P_1 and P_2). Through the presence of both of these factors purple-pigmented pods would result. In the absence of either or both the plant has green or yellow pods. Possibly there is more than a bifactorial difference between purple- and yellow-podded varieties, but Tschermak's numbers are too small to throw much light on this possibility. Purple-podded varieties need a much more thorough study before putting them on a factorial basis. Green- and yellow-podded varieties may be provisionally represented as the presence and absence of Gp.

17. Pod Apices.

Varieties of peas have either blunt (obtuse) or acute pods. Most curved varieties such as Black-eyed Marrowfat and Scimitar have acute pods, while blunt pods are characteristic of Nott's Excelsior, Gold von Blöcksberg, French Gray Sugar, Ringleader and others. These characters are generally most sharply defined in well-filled pods. In many varieties doubtful pods occur on the same vine with those easily classified.

Results from Crossing.

Blunt (*stumpy*) × acute in F_1 always gives all blunt-podded offspring (81, 1, 54, 56). In F_2, blunt-podded to acute-podded plants occur in approximately 3 : 1 proportions.

Interpretation.

The difference between blunt- and acute-podded varieties may be represented by the factor Bt, its presence denoting bluntness, its absence acute pods.

18. Parchmented or Non-Parchmented, Smooth or Constricted, Non-Edible or Edible Pods.

The great majority of pea varieties have pods the inner lining of which is tough, papery and membranous in both the mature and immature state. The ripe or mature pods of these parchmented varieties are very tough and generally do not crumple up in drying. In the wild species this parchmented character is exceptionally well developed while in a few cultivated varieties such as the thin-podded Goldkönig, the parchment is comparatively inconspicuous, so that the dry pods are slightly crumpled. None of these varieties are regarded as having edible pods.

Differing conspicuously from these parchmented varieties are the so-called sugar peas. The pods of this group of varieties are absolutely non-parchmented, and more tender, sweet and edible than string beans. When unripe, the pods have a granular translucency and are crumpled and constricted, so that the peas as they mature appear to be pushing out that part of the pod with which they are in contact. When dry, these pods shrink and become much more constricted, and very brittle. As a green vegetable they are very popular in continental Europe and in China. So far as known no wild forms have this character, though cultivated varieties of it are described as far back as our botanical records go.

Varieties Studied.

Parchmented.—See Tschermak (81, 86), Darbishire, Bateson (1, 3), Lock (54) and others (89, 99).

Non-parchmented.—Wachs Schwert, French Gray Sugar, Petit Pois, Dwarf French Gray Sugar, Giant Sugar (pods up to 11.25 cm. long).

Results from Crossing.

Parchmented × parchmented always gives parchmented in F_1 and succeeding generations.

Parchmented × non-parchmented in most cases gives complete dominance of parchment in F_1 (60, 86, 89, 90). In other cases, different varieties being used, the F_1 has been more or less intermediate, *i. e.,* parchmented but not as heavily as in the parchmented parent (1, 56).

In F_2, the proportion of plants with either fully parchmented or with more or less parchmented pods to those with complete absence of parchment in their pods approximate 3:1. The following results have been obtained:

Investigator.	Parchmented.	Non-parchmented.	Ratio.
Mendel	882	299	2.95 : 1
Tschermak	45	15	3 : 1
Lock	59	25	2.3 : 1
Totals, 1,325	986	339	2.9 : 1

Tschermak, Lock and Bateson have made many crosses involving these characters but the actual numbers are given in only a few cases. Bateson (1) and Lock (54, 56) both obtained intermediates in some crosses.

In F_3, from seed of 100 parchmented F_2 plants, Mendel found 29 that bred true and 71 that had both parchmented and non-parchmented offspring. The non-parchmented F_2's always bred true. In F_4, no exceptional results were obtained.

Mendel, Lock and Tschermak have always found parchmented pods to be inflated and non-parchmented to be constricted.

Non-parchmented $\times$ non-parchmented in some cases give only non-parchmented in F_1. In other cases (Vilmorin 89) in a large series of crosses between diverse varieties of non-parchmented peas, the F_1 progeny have been frequently parchmented. In F_2 these parchmented F_1's have produced approximately 9 parchmented : 7 non-parchmented progeny.

Interpretation.

Parchmented varieties of peas may be regarded as differing from those having non-parchmented pods by the presence of either one or two factors (P and V). No varieties or tested out segregates have been recorded representing the absence of both P and V, but from Vilmorin's results one should expect to find them. All parchmented varieties may be regarded as PPVV, while non-parchmented varieties so far investigated are either PPvv or ppVV. PPvv $\times$ ppVV would give parchmented F_1's and 9 parchmented : 7 non-parchmented in F_2, while either PPvv or ppVV $\times$ PPVV would give parchmented F_1's and a 3 : 1 ratio in F_2.

19. Adherence between Mature Peas in the Pod.

As well known, all varieties of peas except one have pods in which the seeds are entirely free from each other. This one exceptional variety known as "Chenille" has pods with free immature seeds, which when mature adhere more or less closely to each other as though stuck together with glue, and this particular character under favorable environmental conditions is completely hereditary. The variety was sent to Vilmorin from Switzerland in 1906 by M. Frommel and had emerald leaves. It has been suggested that the absence of wax (glaucousness) has been partly responsible for its origin, as the young growing peas in contact with each other, free from wax, tend to grow together as do grafts. But in other emerald varieties the peas do not adhere, so the attempted explanation is not very satisfactory.

Results from Crossing.

Free seeds, glaucous foliage, pink flowers × chenille seeds, emerald foliage, white flowers gave in F_1, glaucous foliage, purple-red flowers, and free seeds. In F_2 a total of 175 progeny gave 144 with free seeds and 31 with adherent seeds or a ratio of approximately 4:1. Considering the combinations of this pair of characters with those of flower color and foliage character in F_2, the results were:

Plants glaucous (138)	flowers colored	105	seeds free	
	flowers white	33		
Plants emerald (39)	flowers colored	29	chenille	28
			free	1
	flowers white	8	chenille	3
			free	5

These results show all is in accordance with ordinary Mendelian theoretical expectation both as to classes and numerical representation of classes, until the chenille and free seed pair of characters is considered. Here one notes (1) that glaucous plants have only free seeds whereas on a one-factor basis about 35 plants are expected to have chenille seeds; (2) that the chenille and free seed characters are distributed among the emerald plants in approximately 3:1 proportions, but just the reverse of what ordinarily would be expected, the dominant character in F_1 in this cross being free seeds.

In F_3 the F_2 plants of various kinds tested out gave as follows:

Character of F_2 Parent.	No. of F_2 Plants Tested.	Character of F_3 Progeny by Classes.							
		GCF.	GCA.	GWF.	GWA.	ECF.	ECA.	EWF.	EWA.
GCF......	4	no chenilles							
GCF......	5	45	1	12	1	1	[illegible]	1	2
GWF.....	1	no chenilles							
GWF.....	5	—	—	7[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
[illegible]	9	—	—	[illegible]	[illegible]	4[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	—	—	[illegible]	[illegible]	9[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	—	—	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]
[illegible]	1	—	—	[illegible]	[illegible]	—	[illegible]	[illegible]	[illegible]

[illegible] E = emerald, [illegible] er[illegible]
A = adherin[illegible] or [illegible]

[illegible] emerald foliage [illegible] seeds, [illegible] white flowered [illegible] green se[illegible] [illegible] 50 glaucous [illegible] eme[illegible] [illegible] chenille were [illegible] with [illegible] seeds. In F_3, the [illegible] segre[illegible]

[illegible]

[illegible]NTE[illegible]

[illegible] explanation so fa[illegible] [illegible] es[illegible] Hagedoorns (3[illegible] 5[illegible] the [illegible] [illegible] seeds and its absen[illegible] eds[illegible]

[illegible]

non-parchmented pods makes a decided difference in the number of chenille plants that are obtained in crosses. Seeds of purple red flower segregates are said to rarely cohere, even though the plants are sblw (abc).

It seems to the writer, however, that these results are more plausibly and simply interpreted as partial coupling or linkage of the factor S with either Bl or W, it being impossible to tell which until further data are obtained. The amount of crossing over is shown by the following grouping of the F_2 progeny and that of certain heterozygote families in F_3:

Linked, 90–97%.	Total.	Crossovers, 3.3–10.5%.	Total.
GF, 138 + 57 + 70	265	GA, 0 + 2 + 4	6
EA, 31 + 21 + 5	57	EF, 6 + 2 + 4	12

The percentage of plants with emerald foliage is much lower than that expected on a 3:1 ratio, and as chenille seeds and emerald foliage are coupled, this also brings down the per cent. of chenilles below the theoretical expectancy. Emeralds in the writer's experience as grown from seed kindly sent by P. Vilmorin, succumb much more easily to disease than the general run of glaucous varieties and perhaps this accounts for the low per cent. of emeralds obtained in Vilmorin's hybrid generations. The relation of flower color to free and chenille seeds is not clear on the present scant data, though the evidence does not favor the idea of partial coupling between one of the color factors and chenille, so far as the writer can discover. The approximation between the obtained frequencies (152 RpF:48 RpA:51 WF:6 WA) and those theoretically expected (144:48:48:16) indicate either independent inheritance or at most very loose coupling.

20. Pod Diameter.

Both pod diameter and pod length in peas present the same complex mixture of environmental and genetic variations as is found in such characters as time of bloom, productivity and height. Several of the wild varieties have the smallest and most narrow pods (0.8–0.9 cm.) while the sugar peas have the longest and widest

(2.0–2.6 cm.) pods. Between these two extremes are numerous varieties with pods representing all gradations in size, each variety having pods with a definite range of variation characteristic to it, when the varieties compared are grown under similar environmental conditions. The following list of varieties (by number) with their green pod diameter range will give a clearer idea of these differences:

P43	0.8–0.9 cm.
P35	1.1–1.1 cm.
P12	1.2–1.3 cm.
P87	1.2–1.3 cm.
P123	1.2 cm.
P83	1.3–1.5 cm.
P72	1.4–1.6 cm.
P76	1.4–1.5 cm.
P24	1.5–1.5 cm.
P92	1.5–1.6 cm.
P14	1.5–1.6 cm.
P116	1.5–1.7 cm.
P31	1.5–1.7 cm.
P81	1.5–1.6 cm.
P32	1.6–1.8 cm.
P60	2.0–2.5 cm.
P82	2.0–2.6 cm.

Results from Crossing.

Tschermak (81) and Lock (54, 56) crossed narrow-podded peas with wide-podded varieties and obtained in F_1 either intermediates or dominance of the large pod type.

In F_2, segregation was observed but the plants were extremely difficult to classify as the pod width per plant distribution gave a continuous series. For example, Lock crossed 13 mm. × 20 mm. and obtained 18 F_1 plants with pods of the following character:

Mm. frequency classes	12	13	14	15	16	17	18	19	20
No. of plants				3	6	6	2	1	

In F_2, 32 plants were grown, giving the following frequency distribution:

Mm. frequency classes	12	13	14	15	16	17	18	19	20	21
No. of plants	1	2	5	4	8	5	6	1		

In F_3, the narrow pod segregates did not breed true. Large seeds were to some extent correlated with wide pods.

In another cross (13 mm. × wide-pod Telephone), 14 F_1 plants had pods on the average as wide as those of Telephone. In F_2, 78 plants gave the following distribution.

Mm. frequency classes	12	13	14	15	16	17	18	19	20	21
No. of plants		5	14	9	17	22	9	2		

In the F_2 of a reciprocal of this same cross, 42 wide and intermediate and 13 narrow were obtained. A correlation between narrow pods, small seed and leaves and wide pods, large seeds and large leaves is noted.

In still another cross of the 13 mm. variety × French Sugar (over 20 mm.), the F_1 pods were intermediate. Of 84 F_2 plants, 19 were classified as narrow-podded and 65 as wide-podded.

In F_3, seeds of the various F_2 types gave

9 F_2 narrow pod produced only narrow (13–16 mm.),
4 F_2 narrow pod produced very narrow and narrow pods,
9 F_2 wide pod produced only wide (17 mm. and over),
22 F_2 wide pod gave both narrow and wide pods.

In this cross, as in the others, wide pods in the main were associated with large seeds and narrow with small seeds.

Interpretation.

Lock (54) interprets his data as showing segregation in F_2, but until a much greater mass of data is obtainable, it is useless to speculate on the factorial nature of this character. In some cases one should expect a simple one factor difference, while in other cases the results are probably very complex.

21. Maturity of Green Pods for Market.

This character is complex and closely associated with the time of blooming, etc. Hurst found a variation of 52 days among the 112 varieties he grew under similar environmental conditions. Tedin (77) crossed varieties of peas breeding true to the same ripening period and secured forms with decidedly longer and shorter time of maturity periods.

Sterility.

Sterility in peas is almost unknown even in crosses between such so-called species as *P. arvense, P. Jomardi, P. elatius, P. sativum.* The only recorded cases of sterility in this group are between a form of *P. humile* Boiss. (Sutton, 74) and various varieties of *P. arvense* and *P. sativum.* Sutton made 40 crosses, using in each case *P. humile* as one parent and 10 varieties of white-flowered (*P. sat.*) and 7 of colored (*P. arv.*) as the other parents. The results were various, but apparently each combination produced seed. When planted some failed to germinate or died immediately after germination, others reached the flowering stage but no seed were produced and still others produced seed, which failed to germinate. In a few cases, the F_2 seed germinated, and the plants flowered but no seed resulted. In four cases, the F_1 plants were completely fertile, two of the hybrids having white-flowered *P. sativum* ancestry and 2 having colored-flowered *P. arvense* ancestry.

In crosses involving this same form (the seed of which Mr. Arthur Sutton kindly sent me) and forms of *P. elatius, P. sativum* and *P. arvense,* the writer obtained plants completely fertile in F_1. In the crosses, however, great difficulty was experienced in making them "stick," and the majority of cross pollinations resulted in failure. Many of the F_1 generation seed failed to germinate, though only plump seed were planted.

Mutation.

As compared with such organisms as the pomace or fruit fly, *Drosophila* mutations are very rare in peas. All horticulturists and breeders remark on the extreme constancy of pea varieties, some of which have been in existence for at least a quarter of a century without showing any striking modifications, and one variety, the British Queen, is said by Sherwood to be practically a century old. Several of the varieties mentioned by Darwin (22), such as Victoria Marrow, Pois géant sans parchemin, Scimitar, Auvergne, Champion of England, are still in existence to-day and very little changed, so far as one may decide by the descriptions written in his day. Tedin (77) who has made detailed studies of a large number of varieties at Svalöf and who is on a special lookout for mutations has found them rare and none of them of much practical value.

Fruwirth (34) in conducting selection experiments on a variety of pea with pods and seeds varying in all degrees in the amount of purple pigment it possesses, discovered a very curious type of bud mutation. The pods on a single plant generally varied from pure purple to purple streaked with green. Plants with all purple pods also occurred. The seeds were either pure yellowish green, yellowish green with purple flecks, purple with small yellowish green flecks, or wholly purple. Seeds of all these colors occur together on the same plant or even in the same pod or each type occurred pure on single plants. Pedigree cultures for ten generations showed that bud mutations or sports arose whereby pure strains were established with yellowish green seeds. Other bud sports or mutations gave rise to true breeding purple-podded strains. That these were not the result of selection as is ordinarily understood by that term is shown by their abrupt origin and their breeding true at once.

Another mutation of the same type is the wild vetch-like "rogue" which many varieties of cultivated peas throw in varying percentages. Bateson and Pellew (5) have investigated the genetics of this "rogue" mutation with the following results: The varieties investigated were Ne Plus Ultra, Early Giant and Duke of Albany. Thoroughly typical plants of these varieties occasionally throw rogues and intermediate forms. The rogues, when fertile (rarely sterile), have exclusively "rogue" offspring. The intermediates from typical plants give a mixed progeny of a few typical plants and many "rogues." Some varieties and some strains of the same variety throw more "rogues" than others. Selected Gradus strains throw about one per cent., while some varieties such as Fillbasket appear never to throw rogues. Rogues crossed with rogues always give rogues.

These two cases of mutation appear to be similar to what Emerson (27.5) calls, in cases investigated by him in corn, "recurring somatic variations," or what East (26.2, pp. 40–43) refers to as recurring mutations, meaning of course that it is impossible to free a variety from the recurrence of the mutation (in East's case, semi-starchy seeds in varieties and segregate lines of sweet corn).

If mutations are so rare in peas as our present knowledge seems to indicate, how have all the numerous genetic differences among them come about? In the absence of records, so far as can be judged from what has been observed in other organisms, it is most plausible to believe that most of the so-called factors originated as mutations and were subsequently shuffled among a large number of forms, largely through artificial crossing. From the lack of intermediates and from their Mendelian behavior, it is almost inconceivable that such characters as non-parchmented pods, lack of tendrils, pink flowers and emerald foliage could have originated in any other manner.

Selection.

In the American Cyclopedia of Horticulture, under peas, L. H. Bailey states that varieties of peas left to themselves soon lose their distinctive characteristics, because of their great variability. This statement is contrary to all the information I have found in the writings of English horticulturists and others on peas (22, 42, 51, 57.5, 96, 72). In fact, most of our new varieties of peas are obtained through crossing, there being so little variability in varieties by which one may bring about improvement through selection.

In the work at the Svalöf Experiment Station, improved varieties are secured through selection, but in reality this is simply isolation of pure lines which have either arisen unnoted as mutations, or as unselected segregates from crosses far back. Tedin's (24) character basis by which he isolates new forms is the average weight of seeds, their number per pod and the total number of pods per plant, etc. Upon isolation, these new forms immediately form constant varieties.

Fruwirth (34) is the only one who has made a modern scientific study of selection in peas. The Blauhülsige variety, as already stated, has either wholly purple pods or purple pods streaked with green. Both color types occur on the same plant and some plants have only purple pods. The seeds of this variety are pure purple, purple flecked with greenish yellow, yellow green flecked with purple or wholly greenish yellow. All types occur on the same plant or each on separate plants, but the progeny of each type give rise to all the other types. After 10 years of pure line selection and 2 years of mass selection for a pure purple-seeded race, no results have been secured. Selection toward a pure constant green-seeded race also resulted in failure. Selection for the same length of time toward a pure constant green-podded race gave only negative results.

"Rogues."

The term "rogue" is applied by seedsmen to any variation or off-type plants in a field of pure-bred plants of a variety. For example, tall peas in a plot sown to dwarf peas, colored-flowered individuals in a white-flowered variety, yellow seeds in a green-seeded variety, late bloomers in an early-flowering variety are all designated as rogues and carefully eliminated. In many cases, these rogues are due to careless handling of the seed; in others, to the presence of heterozygotes which subsequently produce recessives—the heterozygotes having arisen through rare insect crossing or through never having been selected out when the variety was first placed on the market, *e. g.*, Nonpareil and others with yellow and green cotyledons. Again, these "rogues" may come about through "recurring mutation" phenomena or through regular mutation. In Tschermak's studies on flower color and maple seed coat, certain factors appeared in exceptional cases to be present but inactive. Thus among pink-flowered peas, plants with purple red flowers might occasionally appear. Still another way in which "rogues" could easily occur has its basis in a change in environment and in the fact that all factors or factor combinations do not react alike to such changes, so that while under one environment a variety might breed true, under another, variations would appear, due to unsuspected factorial differences.

Most of these rogues can be eliminated permanently by removing the cause, but those that result from recurring mutations can, so far as we now know, only be reduced to a minimum and kept there only by constant watchfulness.

Coupling (Linkage) and Crossing-Over.

Varieties of peas so far investigated have seven pairs of chromosomes (Cannon, 11). If the genetic factors of animals and plants are located in the chromosomes as believed by Morgan (62) and others (61, 62.5, 26.5, 73), all the factors of a single variety of peas should be inherited as though linked or coupled together in seven groups, each group representing the factor composition of one of the seven pairs of chromosomes. This grouping in peas can be determined with the least trouble by crossing a variety having seven or more different factors with a variety lacking these factors, making the cross a sufficient number of times to insure a large F_2 population (4^7 or 16,384 individuals at least) or by making all the possible combinations of the seven-factor pairs through separate crossings. In F_2, in the former case, if each factor is inherited independently of all the others and large enough numbers of progeny are grown, there should be 128 F_2 combinations which remain constant in F_3 and later generations and 2,187 combinations all together (60), each of which would be represented in a definite proportion of the progeny. Each of the seven factors should be present in approximately three fourths and absent in one fourth of the total offspring. If 8 factor differences were involved, the various numerical terms would be proportionally increased. But in the event that a cross involving 8 factors did give the theoretical expectation for the independent Mendelian segregation of eight pairs of factors, the chromosome theory, as at present held, would either be disproven or modified, for there would be only seven pairs of chromosomes involved in carrying the eight pairs of factors through the mazes of the maturation divisions, where segregation is believed generally to take place.

More accurate data on this subject are obtainable by back-crossing the F_1 hybrids with the recessive classes, but back-crossing in peas on a large scale is impracticable, as so few seeds are obtained from each cross. The large size of pea chromosomes, as compared to those of *Drosophila,* may be assumed to indicate, on present theories, a looser linkage of the factors of each group, as compared with the close linkage of the *Drosophila* groups. This loose linkage, if it exists, increases the difficulties of classifying the factors in groups and in determining their relation to each other within the group.

Inheritance studies on *Pisum* so far have disclosed only four linked groups of factors (ACEGcL$_1$Lf, RTl, GO, SBl or SW), and several other doubtful groups in which some of the factors are not as yet clearly delineated. In the first group, the evidence is complete enough to show the coupling is absolute except for the factor Lf and hence for simplicity's sake, the first five factors may be regarded as one. G and O also appear to be partially coupled, although the data are scant. R and Tl as shown by Vilmorin, Bateson and Pellew are only partially coupled, there being a small per cent. of the combinations rTl and Rtl in F_2. These are interpreted by Morgan and his students as cross-overs or combinations due to the simultaneous breaking of the chromosomes with respectively rtl and RTl at a point between the two kinds of factors and the subsequent union of the parts so as to bring r and Tl, R and tl together. This breaking occurred in about 1.5 per cent. of the total cases as regards the factors R and Tl. S and Bl or W are also in all probability partially coupled, similar to the case just described. The work of Morgan and his students on *Drosophila* has shown that by assuming that the linked factors of a group are arranged in an end-to-end straight-line series, definite places in the chromosome may be assigned to each factor, and their relative distances from each other may be given in terms of a standard unit equal to 1 per cent. of crossing-over. When a large number of the factors of a single chromosome have been studied the relative frequency of the cross-overs of the various factors may be approximately calculated and predicted.

When the relations in inheritance of the various factors to each other in such a group as *Pisum* are worked out, a definite basis for predicting correlation between different characters will have been found. On this basis, it will be possible to calculate with comparative ease the somatic characteristics of F_2 hybrid populations involving large numbers of factors, because so many of these characters will be associated together by linkage and may be considered as the expression of a single factor. Supposing the inheritance of a hundred factors in *Pisum* is involved in a cross about which it is desirable to have forehand knowledge. If each is independent of all the others in its inheritance, it is obvious that accurate predictions in regard to the combinations would be made with great difficulty, but if these are linked together in large groups, predictions can be made with fair accuracy and considerable ease.

Crossing-over makes predictions regarding F_2 hybrid populations somewhat more difficult than if the factor linkage was absolute, but at the same time they bring about new combinations in predictable proportions which, in a system where the coupling was absolute, would not be possible.

Further, on the chromosome-linkage-factor-crossing-over hypothesis, the amount of variation in a group of similar organisms (a species), eliminating that caused by environmental changes, would be in proportion (1) to the number of factor differences between the various forms or varieties of the group; (2) to the number of pairs of chromosomes; (3) possibly to the relative sizes of the chromosomes (small chromosomes making crossing-over much more difficult) and (4) to the amount of cross fertilization which took place (either natural or artificial).

As Morgan points out, the interpretations of the genetic data on *Drosophila* crosses advanced by him and his students hold whether the chromosomes are or are not the bearers of the factors.

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ECOLOGY AND PHYSIOLOGY OF THE RED MANGROVE.

(Plates IV–IX.)

By H. H. M. BOWMAN.

(*Read April 13, 1917.*)

General Statement.

When the plan for the pursuit of these studies was considered in the winter of 1914, the main idea was to make an effort to learn a little about the physiology of these interesting viviparous plants. Especially was it the aim to study the transpiration and absorption relations of these trees growing in salt water. Accordingly the splendid resources of the Carnegie Institution of Washington were offered and in June of 1915 the work was begun at the Institution's Marine Laboratory located in the Dry Tortugas.

During the first summer considerable ecologic observation was made during a month's stay at Key West, Florida, the institution having furnished the investigator with a launch and two men. Many observations were taken on the growth habits of the plants, the character of the bottoms on which they grew, the depth relations, tidal effects, the flowering and fruiting conditions, growth rates of hypocotyls and of aërating roots, water densities, dimensions of roots and aërial structures, heights of trees and general distribution about Key West and adjacent islands.

In July, after going to Miami and thence down through the Florida Keys on board the institution's yacht, *Anton Dohrn,* and notes on the mangrove being taken at various keys on the trip, the real laboratory work was commenced at the Tortugas. During the six weeks' season of the laboratory, several trips were made up to the Florida Keys for suitable plants and also for material on which to work during the winter. At this time it was determined to enlarge the scope of the work and to study some of the anatomical and histological features of *Rhizophora mangle,* and with this end in view material was carefully collected of all parts of the plants and preserved for future study. Meanwhile, the transpiration work was pursued and some attempt made to correlate the structure of special organs with the physiological functions in these plants which grow in such peculiar conditions.

In the winter of 1915–16 the study of these structures was carried on at the botanical laboratory of the University of Pennsylvania and again in June, 1916, a full season was spent at the Tortugas Laboratory on the physiology and also the biochemical relations of certain products in the hypocotyls. Short reports of the two summers' work were published in the year books of the Carnegie Institution.[1]

While considerable work has been done on the mangroves of the tropics in general, this has been mostly of a purely morphological nature, or ecological. The mangroves of our own tropical coasts have not been given as much attention as these plants might deserve; while the physiological relations have only in a few notable instances been made the subject of detailed study. The most extensive work has perhaps been done at the Buitenzorg Botanical Garden in Java by Haberlandt, etc.

In South Florida, although the climate is not like that of Java, the facilities afforded for study of mangroves is fairly good, but a great handicap has been found in the pursuit of this research, viz., that owing to the character of the soil and other considerations there are no mangroves in the Dry Tortugas and all the material had to be brought from the Lower Florida Keys with a consequent loss of many seedlings. Other studies which would have been made, particularly on the embryology of *Rhizophora,* have been deferred for the present until a tropical laboratory can be secured, where the plants can be secured conveniently, quickly and in abundance.

During the summer season of 1916 fortune favored the work at Tortugas in as much as seedlings were found in considerable quantity on the beaches of the islands composing the group. These viviparous seedlings had been drifted westward from the Marquesas

[1] Bowman, H. H. M., *Carnegie Institution Year Books,* 1915, p. 200; 1916, pp. 188–192.

and other islands by the current during the early spring season of higher tides and, on being washed ashore, took root to eke out a precarious and mostly fleeting existence.

Almost the entire first half of the season of 1916 was devoted to the biochemical research mentioned above. This work of testing for various chemical substances in the hypocotyl or storage organ of the seedling and the attempt at detecting enzymes in the organ could most conveniently be pursued at this time. During the interval which occurred from the time, in the early part of the season, when the young plants needed for the transpiration work were gathered and planted in the culture jars until they became established in their laboratory condition, the chemical work was carried on. Only after the plants had recovered from the shock of transplanting and were reacting normally to their changed environment was it deemed advisable to begin the transpiration work.

At the close of the 1916 laboratory season in August, the investigator accompanied the officers and crew of the yacht on her return trip north through the Florida Keys to be placed in winter quarters at Miami. On this journey of several days' duration, many distribution notes were taken and maps made of the keys and the absence of *Rhizophora* on certain keys carefully marked.

After the yacht had been moored up to her dock in the Miami River and shrouded in canvas for the winter, eight days were spent making observations on Biscayne Bay, the Miami River and Arch Creek on the admirable newly constructed launch possessed by the institution, the *Darwin*. These observations were made with the assistance of the yacht's chief engineer, Mr. John Mills, whose skillful operation of the launch, often in shallow and difficult channels, and whose help with the instruments was much appreciated. Tests by the hydrometer were made on the density of the water, both top and bottom layers, from the open Atlantic, across Biscayne Bay and up the Miami River and Arch Creek as far as any mangroves extended. Material was gathered for later study of both salt and fresh water trees and numerous transpiration records were taken on the pneumatophore prop roots of the mangrove under conditions and environments difficult for growth.

In conclusion of this statement the writer wishes to acknowledge the valuable aid given him by Professor J. W. Harshberger, whose wide experience in plant ecology and helpful guidance in the preparation of this paper have been of great assistance, especially on the geographic and ecologic aspects of the work. The author's thanks are also due the colleagues of Professor Harshberger in the University of Pennsylvania for their very kind help and suggestions, to Dr. J. Hepburn, of the U. S. Food Research Laboratory, for his expert advice in regard to enzymes, to Mr. Robert E. Dengler, Fellow in Greek, for his assistance in translating the classic and Renaissance references, to Mr. W. R. Taylor for aid in making the illustrations, to Dr. A. G. Mayer, of the Carnegie Institution of Washington, for many helpful suggestions, and to Engineer John Mills, and Captain L. M. Wilson, of the Tortugas Laboratory for their patience, consideration and excellent practical aid rendered on many field excursions in the Gulf.

History.

The historical references to the subject of these studies are quite varied and reach far back into antiquity. Just as perhaps all science may be traced back to the Greeks, so in this instance we can turn to them for some early knowledge of the existence and peculiar habits of this plant, the *Rhizophora mangle.*

The earliest reference in ancient manuscripts is contained in the chronicle of Nearchus (325 B.C.). This old Greek sea-captain was the commander of Alexander the Great's fleet and fragments of his observations have come down to the present through the writings of Arrian. Nearchus sailed from the Indus Delta on the 21st of September, 325 B.C., and arrived in Susa, Persia, February, 324 B.C., shortly after Alexander himself had reached there by marching overland.

On this jounrney Nearchus[2] describes the habitat of the mangroves. Whether these trees are the *Avicennia* or *Rhizophora mucronata,* both of which grow in the region traversed by Nearchus, is not quite certain, but, by the description of the species in Theophrastus[3] and in the light of Bretzl's[4] recent work, in which the

[2] Nearchus, "Arr Anab.," VI., 6, 7.

[3] Theophrastus, "Historia Plantarum," IV., 7, 4–7.

[4] Bretzl, H., *Botanische Forschungen des Alexanderzuges,* 1903.

present species of the Red Sea, the Persian Gulf and the Indus Delta have been compared with those mentioned in the classics as noted on Alexander's March, there is now little doubt that the *Rhizophora* has been accurately described by these early mariners.

Theophrastus, 305 B.C.,[5] the pupil and successor of Aristotle, in his "Historia Plantarum" quotes Aristobulus as having seen in "the desert Gedrosia, trees that are about 30 cubits tall and have a flower that looks like a white violet and has a far-reaching odor." Nearchus also noted the relation of the plants to the tides, for he is quoted as observing them in Sec. 4, **ἐν δὲ ταῖς νήσοις ταῖς ὑπὸ τῆς πλημμυρίδος καταλαμβανομέναις**, *i. e.*, in the islands which are reached by the flood tide, and also in Sec. 5 (**καθ' ὃ ἡ πλημμυρὶς γίνεται δένδρα ἐστίν**) he says: "Wherever the floodtide reaches, there are these trees."

Howevei, in Sec. 4, 7, Theophrastus gives the fullest description of the *Rhizophora*, "**ἔχειν δὲ τὸ δένδρον φύλλονμὲν ὅμοιον τῇ δάφνῃ, ἄνθος δὲ τοῖς ἴοις**, etc.," and the tree has a leaf like a laurel, but a flower like a violet both in color and odor, and a fruit the size of an olive, and this fruit is also fragrant. It does not cast its leaves, but the flower and the fruit both appear in the fall and they drop off the fruit in the spring." Bretzl thinks that the Greeks on account of being with Nearchus at the Indus Delta in September and in the Persian Gulf in February were in a position to be acquainted with both these phenomena. The mention of a violet-like odor is persistent not only in these early Greek writings, but also in the works of much later botanists, even down to the eighteenth century.

Theophrastus admirably describes the habit of the mangrove in growing out in rather deep water, where he says in Sec. 5: "These trees are all washed by the sea up to their middle," and in Sec. 4 "and they are held up by their roots like a polyp, for whenever there is an ebb-tide these (the roots) may be seen." He describes the pneumatophore prop roots of the *Rhizophora*, and again he says: "Some have their roots always flooded by the sea as many as grow in hollow places whence the water does not flow away and nevertheless the tree does not perish at the hand of the sea." Theophrastus also reports the ecological relations of the *Rhizophora* and

[5] Theophrastus, "Historia Plantarum," IX., 4, 2.

explains its xerophytic structure as due to the physiological dryness of its habitat: δηλοῖ δὲ ἡ στενοφυλλιά . . . , πάντα γὰρ ταῦτα ξηρότητος, "it is clear the narrowness of the leaf is due to the dryness."

Besides the many fragmentary references in Theophrastus to the mangrove, similar to those given above, he gives a very complete picture in Sec. 4, 7, 5, where, after mentioning the evergreen appearance of the trees and the times of fruiting and flowering, he says: "and there are other trees growing in the sea, evergreens, and they have fruit like beans and about the Persian Gulf, in the part toward Karmania, as far as the flood tide reaches, there are trees of quite some size, with leaves shaped like purslane, and it has a fruit much like an almond in color on the outside, but it is rolled together as if it were contracted; and these trees are all watered up to their middle by the sea and are held up by their roots like a polyp. For whenever there is an ebb tide these can be seen and the water is not wholly in this place and there are left certain channels through which they (the natives) sail, these are of sea water from which it is clear as some think, that they (the trees) are nourished by it and not by fresh water unless some is drawn by the roots from the earth, and that salt water is beneficial for them, for the roots go to no great depths."

This description might describe the mangrove thickets and swamps of the Florida Keys just as accurately as it fits those of the Persian Gulf and shows how observant were these early Greeks. Not only is it accurate as to general description, but Bretzl has been able to locate the actual stations for present species by these descriptions in Alexander's march.

Pliny the Elder (77 A.D.)[6] in his "Natural History," XII., IX.,[20] "Gentis supra dictas Persis attinget . . . intus contortis nucleis," does not contribute anything to the account of the Alexandrine companions and the above passage shows the influence of Theophrastus (325 B.C.) even to the very phrases. "Adjoining the countries which we have previously mentioned is Persis, lying along the shores of the Red Sea, which, when describing it, we have mentioned as the Persian Sea, the tides of which penetrate far into the land. The trees in these regions are of a marvelous nature, for,

[6] Pliny, S. C., "Nat. Hist.," XII., IX., 20 (37), Bohn trans., III., p. 117.

corroded by the action of the salt, and bearing a considerable resemblance to vegetable substances that have been thrown up and abandoned by the tides, they are seen to embrace the arid sands of the seashore with their naked roots just like so many polypi. When the tide rises, buffeted by the waves, there they stand, fixed and immovable, nay, more, at high water they are completely covered, a fact which proves to conviction that they derive their nutriment from the salt contained in the water. The size of the trees is quite marvelous; in appearance they strongly resemble the arbute; the fruit which on the outside is very similar to the almond, has a spiral kernel within."

In 70 A.D. Plutarch[7] published his "Moralia" and under the heading of **ΑΙΤΙΑ ΦΥΣΙΚΑ**, Nature studies, discussed the topic or question ***Διὰ τί τὸ θαλάττιον ὕδωρ οὐ τρέφει τὰ δένδρα;*** or "What is the reason that seawater nourishes not trees?" The passage is given in full, as the argument is sustained very quaintly throughout the paragraph. "Is it not for the same reason that it nourishes not earthly animals? For Plato, Anaxagorus and Democritus think plants are earthly animals. Nor, though sea water be aliment to marine plants, as it is to fishes, will it therefore nourish earthly plants, since it can neither penetrate the roots, because of its grossness, nor ascend, by reason of its weight, for this among many other things, shows sea water to be heavy and terrane, because it more easily bears up ships and swimmers. Or is it because drought is a great enemy to trees? For sea water is of a drying faculty; upon which account salt resists putrefaction, and the bodies of such as wash in the sea are presently dry and rough. Or is it because oil is destructive to earthly plants and kills things anointed with it? But sea water participates of much fatness; for it burns together with it. Wherefore, when men would quench fire we forbid them to throw on sea water. Or is it because sea water is not fit to drink and bitter (as Aristotle says) through a mixture of burnt earth? For a lye is made by the falling of ashes into sweet water, and the dissolution ejects what was good and potable, as in men, fevers convert humors into bile as for what woods and plants, men talk of growing in the Red Sea, they bear no fruit but are nourished by rivers casting up

[7] Plutarch, "Moralia," 911 *D–F*, Goodwin trans., III., p. 495.

much mud, therefore they grow not at any great distance from land but very near to it."

In the paragraph in which he has discussed the qualities of sea water and the difficulties of its utilization in the plant economy Plutarch almost suggests the theories of absorption and the ionization of solutions. The occurrence of the "woods and plants" in the Red Sea is also mentioned at another place in the "Moralia."[8] "And the provinces of Gedrosia and Troglodytes, which lie near the ocean sea, being by reason of drought barren and without any trees, there grow, nevertheless, in the adjacent sea, trees of a wonderful height and bigness, and green even to the very bottom, some of which they call olive trees, others laurels, and others the hair of Isis. And those plants which are named anacampserotes being hanged up after they are plucked out of the ground not only live but—which is more—bud and put forth green leaves."

The influence of Nearchus and Theophrastus is seen in the reference to the olive and laurel but the "anacampserotes" are not mentioned in the earlier authors. The word meant "bringing back love" and the plants were used in making love philters. The plants are, from the description, evidently the seedlings of *Rhizophora* which have just been rooted, but whether the ancients really regarded those seedlings as having an aphrodisiacal effect can not be accurately determined.

Arrian, 136 A.D.,[9] is the last of the classic writers to mention the mangrove. In his "Anabasis" he quotes Aristobulus and Nearchus in describing the plants observed on Alexander's march through Asia, but the references are essentially all alike and perhaps Theophrastus in his "Historia Plantarum" summarized all the observations on *Rhizophora* of his day and all the later authors copied the accounts as reported by Alexander's companions. There are not any mangrove references then in literature from Arrian's time, 136 A.D., until almost the middle of the thirteenth century.

In 1230 the Moorish botanist, Abou'l Abbas en-Nebaty,[10] after exploring Spain, Barbary coasts and Egypt made a long expedition

[8] Plutarch, "Moralia," ed. Bernardakis, 5, 455, Goodwin, V., 278.

[9] Arrian, "Anab.," VI., 22, 4 f.

[10] Abou'l Abbas en-Nebaty, Introd. to "Ibu el-Beithar" (Leclerq), V. Notices des Manuscrits, T. 23.

into Arabia, Syria and Irak. On his return to Spain he published his work, "Al Rihla," "The Journey," and died at Seville in 1239. This book, "Al Rihla," is not extant, but Abou's disciple, Ibn el-Beithar, has preserved citations from the book, as well as other Moorish writers, Ibn Hassan and Abou Hanifa. The references to the *Rhizophora* are very clear and it is due to these Moors that the mangrove was given the name *kendela,* which is an Arabic word. Both Abou Hanifa and Ibn Hassan describe the plant *kendela* and the former says[11] that "The water of the sea is injurious to every species of wood except the *quorm* (*Avicennia*) and the *kendela* (*Rhizophora*)," and under species "1981 kendala" he says: "It is a plant which grows in the country of the Deibol (on the sea of Oman) and which spring up in the sea. In that country it is employed in the tanning of hides, known under the name of leather of Deibol, which is red and thick. It furnishes also a red bark which is used as part of medicaments for the mouth and of those which are used to stop hemorrhages."

The name *kendela* was later spelled *candela* or *kandila* by the sixteenth and seventeenth century botanists and applied to the mangrove on account of the resemblance of the prolonged hypocotyl, as it hangs on the tree, to candles.

From 1230 to 1526 is another long gap in the literature on the mangrove. About this latter year Oviedo[12] put forth his book dealing with his travels in the Indies. The observations of this early Spanish explorer and those of his successor give us the first glimpse of the vegetation of the western hemisphere from a purely botanical standpoint. Later botanists quote Oviedo and Clusius[13] (1584) and Peter Martyr[14] (1577) and several particularly mention Oviedo's experience with the fruit of *Rhizophora*. "I nevertheless," he says, "from its use (as food) fell into sickness although I am not so delicate nor accustomed in time of want to abstain from those foods which I see others eat, but neverthless, although there was no

[11] Abou Hanifa, "Ibu el-Beithar," Leclerq. Notices des Manuscrits, T. 23, 25, 26.

[12] Oviedo, G. F., "Primera Parte de la Historia Natural general de las Indias," 1526.

[13] Clusius, Carolus, "Rariorum Plantarum Historia," 1601.

[14] Martyr, Peter, "Edens. History of Travel," 88, 143, 1577.

urgent necessity it did not offend me to taste it, so that I might describe it the more accurately, and so for that reason I tasted the fruit but it seems that it should be called rather, the food of brute animals and wild men of the woods." From the writings of Clusius and Oviedo thus it seems that the natives of the West Indies used the hypocotyl as a source of food in famine times, probably on account of the starch they contain, but as Piso says they must have had a special method of preparing them to eliminate some of the tannin.

In 1648 Piso[15] and Marcgraf noted the mangrove as it occurred along the shores of Brazil. Under the chapter heading "Devariis specibus Mangues, sive Mangles et earum qualitatibus," Piso describes their habitat as "in swampy places by the sea in the Indies and all the tropics." He quotes Clusius and also says there are three species of mangles. "Prima, *Cereiba,* quæ Mangue est alba; Secunda *Cereibuna,* quæ non radices ex ramis in terram agit, nec tam tortuoso plexu luxuriat." And the third, which is our *R. mangle,* is called *Mangue Guaparaiba.* It is, according to the account, of larger size than the two preceding species and bears useless pods in the summer months, which are filled with bitter pulp.

In 1650 Bauhin[16] in his "Universal History of Plants" quotes Oviedo and Lobez in giving a description of the tree and says: "F. L. (Lobez) mentions a certain tree growing in the province of Malay which they call 'Mangin,' bearing roots above, like stems," Clusius questions whether this be our Indian fig but we (Bauhin) put the mangin or mangle because of the closeness of the name to mangle, with which tree it also seems to correspond, as Ferdinand Lobez describes it." Du Tertre, 1667,[17] mentions the mangrove and Rochfort, 1681,[18] in the book of travels in the Antilles describes the tree, called paratuvier, and its rooting habits, and says: "Wild boars and other savage beasts live in them, and they afford places of shelter for the inhabitants, who lie in wait to surprise a person ap-

[15] Piso, G., and Marcgraf de Liebstad, "Hist. Nat. Brasiliæ," pp. 113–114, 1648.

[16] Bauhin, J., "Hist. Plant. Universalis," 1650.

[17] Du Tertre, J. B., "Historie generale des Antilles," Vol. IV., 1667.

[18] Rochfort, F., "Histoire Naturelle et Morale des Isles Antilles," p. 100, 1681.

proaching along the coast." Rochfort also gives a very poor illustration of a tree with a boar at its root.

Van Rheede, 1678,[19] saw the tree in Malabar where it was called pee-kandel and grows there with five other species of kandel, now all identified as various viviparous trees. The bark was used as a cure for diabetes.

Ray, 1693,[20] gives a long and fairly accurate account of the tree under the head "Mangle Pyri foliis, cum siliquis longis, Ficui Indicae affinis. J. B. (Bauhin) Mangues, seu Mangles; tertia species Guaparaila dicta, Pison. Paretuvier, Rochfort. Oviedus."

"*The Mangrove Tree.*—This tree is among those which are commonly found in Western India, very much selected for the making of buildings and other uses. It grows in marshy places, on the shores of the sea, on the salt flats of rivers. . . . The leaves are similar to the larger leaves of a pear, but thicker and a little larger, opposite to each other, and have a thick mid-rib and many lateral veins, light green. It bears many small flowers on oblong calyces. The pods are two palms long and more, and these are thick, like those of *cassia,* equal to the first and of a rusty color; having a pulp like curds or similar to the marrow of bones, which the Indians, on account of a lack of other foods, feed upon. Even though it is bitter, they prepare it into a healthful food."

Ray then quotes the experience of Oviedo and Clusius in eating it, and goes on to say "the fallen fruit is the food of land crabs rather than men. But the nature of the tree is wonderful, for several grow at the same time and many branches seem to turn down and become roots . . . , which take hold and in turn grow other branches and these, in truth, are no less firmly established than the original trunk of the tree. . . . The wood is heavy and solid and has a brownish bark which is used for tanning leathers instead of oak, as there is no kind of oak found in these lands." The writer goes on and dilates on the uses of the tree and says: "The root of the tree which is soft and moist is split and peeled and applied warm to the poisonous wound of the fish, *Niquus.* It quiets the pain and restores the injured member, but although it may provoke pain

[19] Van Rheede, H., "Hortus Malabaricus," 1678.
[20] Ray, John, "Hist. Plant.," Vol. II., p. 1772, 1693.

in the forehead, it is really a splendid remedy first discovered by the fishermen and given to us by them."

This old chronicler cannot forbear mentioning the honor bestowed on him by Bauhin in naming a fig tree for him and says, "J. Bauhin, who otherwise is not accustomed to be sparing in the subdividing of species, classifies this tree as similar to that famous Indian fig called the Tree of Ray." Among other observations, Ray mentions the yellow tetramerous blossoms as having a honey-like odor and he also is the first to mention the efflorescence of salt on the foliage, for he says: "When the sun shines the leaves of this tree contain a very white salt on their upper surfaces, but when the sky is cloudy, or at night the salt is dissolved and clings like dew, but in the day time being dry and very white it can be collected with the fingers, and from two or three leaves enough can be secured to salt one's broth." As food for animals, Ray says: "Doves and other flying creatures feed on it when there is a lack of better food and from them (the fruits) the flesh of the doves gets so bitter as scarcely to be edible." And in addition to its tanning abilities, the writer says—"it is used daily by the fishermen for dying their nets."

Plukenet, 1669,[21] described *Rhizophora* briefly: "Mangle arbor Pyrifoliis salsis and uliginosis locis in America proveniens; fructu oblongo tereti, summis ramis radicola." He named it the swamp mangrove tree and it is in his writings that it is first called the oyster tree. He quotes Lobez and says also it is called mangu in the Moluccas.

Dampier, 1697,[22] and Gomara[23] both have noted it in their travels and given short descriptions, which are copied by other writers.

Plumier, 1703,[24] mentions it as one of the new genera recently found in America and quotes Piso as the author of the genus. In his description Plumier says the pistil ripens into a turbinate fruit, which sends out a long fusiform seed with its head buried in the fruit. This is the closest observance of the true viviparous nature of the seedling in any of the literature noted thus far. Plumier's

[21] Plukenet, L., "Almagesta Bot.," p. 241, 1769.

[22] Dampier, W., "A New Voyage Around the World," 1697.

[23] Gomara, B. A., cf. Sloan.

[24] Plumier, C., "Nov. Plant. Amer. Gen. Mangles," p. 13, tab. 15, 1703.

figure of the plant is very good and shows the parts dissected. The lenticels on the hypocotyl are also well illustrated.

Labat, 1724,[25] a French missionary, mentions three kinds of paletuviers and says the English and Spanish call them mangles. He says the three kinds are the red, the white and the black; the red and the white being called Raisinier, on account of its raisin-like edible fruit, and the Mahot, respectively. The black paletuvier is evidently the *Rhizophora mangle.* He mentions its laurel-like leaf and states that it grows "5 cens" out in the sea supported on prop roots. "The wood makes good fuel and oysters are borne on the roots which are small but of a good taste."

Sir Hans Sloane, 1725,[26] who was a close observer and a good botanist, describes the mangrove at great length as he saw it in the West Indies. He also mentions almost all the previous voyagers and travelers who have seen this curious tree, as well as his contemporaries, Catesby, Plumier, Dampier and Plukenet. His description is very clear and to the point in that it evidently applies to the "Mangle grande" type. "This Tree rises to thirty or forty Foot high having a Trunc as big as one's Body, and a greenish white, smoothe Bark, with some white Spots here and there. The Tree has very many pendulous Branches swelling towards their Ends, where are placed nine or ten Leaves, set on round them by half Inch long Footstalk, they are four Inches long and two broad, of a dirty green Colour and having one very large eminent Rib running the length of the Leaf; the Flowers stand on an inch long Footstalk, are composed of four thick yellow Petala and as many brown, with some yellow Stamina in the Middle being within covered with a yellow Farina, to which Pod-like Substances, having a Swelling at their Beginning, otherwise exactly like Bobbins with which Bone-Laces are wrought, that Protuberance is rough and a little redish in Colour, about an Inch long, having within a Cavity fitted to receive the small Ends of the Pod-like Substances, and into which they are set, each of them is about six Inches long, beginning slender, swelling by Degrees to near the end where it is Biggest. . . . It has a

[25] Labat, Pere, "Nouveau Voyage aux Isles de l'Amerique," Vol. II., p. 136, 1724.

[26] Sloane, Sir Hans, "A Voyage to the Islands Madeira, Barbados, Jamaica, etc.," 1725.

smooth greenish brown Rind, but a Pith and a fungous mealy Substance and within no Cavity or Seeds and which never ripens or is otherwise than woody."

Sloane then goes on and narrates in detail how the "pod-like substance" germinates and produces other trees. His idea is that a single seed is planted in this "substance" and this grows out until it reaches the mud and becomes a tree. He quotes Piso, Oviedo, Marcgraf, Du Tertre, and says he differs from some of them (Oviedo) in regard to the "Pulp." He has made a thorough search in earlier literature in regard to the "Oyster Tree" and the occurrence of oysters living on the roots and adds his own contribution to the story of the "Oyster Tree." "In the Isle of Trinidad is a Salt River that had Stores of Oysters on the Branches of the Trees, which were very salt and well tasted. All their Oysters grow upon these Boughs and Spraies and not on the Ground." Sloane also adds some new uses to the already manifold application of the mangrove cited before. Among some of the uses he suggests that perhaps the dried buds have been mistaken by mariners for cloves, thus hinting at food and drug adulteration even at that early date. After mentioning the employment of the wood for building purposes and fuel, he says: "The Bark tans Leather well for Shoe Soal, not for Upper Leathers, or Insides, as it is thus tan'd burning the Skin. . . . The Roots serve for dying of Linens and Leaves for Dung. The bark is used by Tanners and Landresses for cloaths, mixed with Oyl like Dirt it is good against Weariness, and with Milk or fresh Butter, outwardly applyd helps them who are diseased in their Livers."

Catesby, 1731,[27] is the last in this series preceding Linnæus to describe the mangrove in the history of his travels. The type Catesby noted is probably only the "chico mangle," as he says they were only 20 to 30 feet tall. His remarks about the general appearance of the tree and flowers is much like Sloane's, but he describes the fruit as being like a "pear at the small end of which hangs a single seed about six inches in length in form like a Bobbin." Catesby, however, is the first to mention the seedlings as floating

[27] Catesby, M., "Nat. Hist. Carolina, Fla. and Bahama Islands," Vol. II., p. 63, 1731.

some distance after dropping from the trees. He also describes the ecology of a mangrove swamp in the Bahamas very well. "In shallow salt Water, these impenetrable Woods of Mangroves are frequented by great Numbers of Alligators, which being too big to enter the closest Recesses of these Thickets, the smaller Ones find a secure Retreat from the Jaws of their voracious Parents. These watery Woods are also plentifully stored with ravenous Fish, Turtles and other Animals which prey continually one upon the other, and the Alligator on them all; so that in no Place have I ever seen such remarkable Scenes of Devastation as amongst these Mangroves in Andros, one of the Bahama Islands, where the Carcasses of half devoured Animals are usually floating in the Water. They grow in most parts of the Earth under the Torrid Zone and are found but little north or south of the Tropicks."

In all the preceding history of the mangrove, the literature naturally falls into two divisions. That from Nearchus (325 B.C.) and Theophrastus (305 B.C.) to Arrian (136 A.D.) embraces the references as found in classical literature, while that from the time Abu 'l Abbas en-Nebaty (1230) to Catesby's (1731) with a few exceptions, who were largely compilers of botanical works, the literature consists of the narratives of travelers, voyagers and explorers. With the stimulus given to systematic studies by the writings of Linnæus and the then recent discovery of new plants in all parts of the world the works of the latter half of the eighteenth century are mostly systematic.

Taxonomic Relations of *Rhizophora mangle*.

Linnæus[28] in his earlier writings ("Systema Nat.," 1736) had a rather vague conception of the limits of the genera *Rhizophora*. He treated it in the "Systema" and in his "Philosophia Botanica," 1751,[29] under a head "LXII. Candelares" with *Nyssa* and *Mimusops*. These accordingly were later changed and No. 62 was cancelled in the "Philosophia." In the "Species Plantarum," 1753,[30] he gathers all the confused and tangled synonyms and descriptions

[28] Linnaeus, C., "Systema Nat.," p. 442, 1735.
[29] Linnaeus, C., "Philosophia Bot. 62 Candelaria," 1751.
[30] Linnaeus, C., "Species Plant.," Vol. I., p. 634, 1753.

of the early botanists and arranges them in an orderly manner. He recognizes seven species of *Rhizophora,* which he created as a separate genus. These seven species were *R. conjugata, R. gymnorhiza, R. candel, R. mangle, R. cylindrica, R. corniculata* and *R. caseolaris,* all of which are Oriental except *R. mangle.*

For *R. mangle,* Linnæus gives as equivalent the *Mangle foliis acutis* of Jacquin; *Mangle segmentes calycum* of the Wachend ult. 90; *Mangle aquatica* of Plumier; *Mangle pyri foliis* of Sloane and Bauhin; *Mangium candelarium* of Rumph and *Pee-Kandel* of Rheede. In the "Systema" it is No. 592 of the Dodecandria Monogynia and furnished the essential characters of the plant.

Rumph, 1750,[31] a contemporary of Linnæus, gives a lengthy description of his *Mangium candelarium* or *Mangi Mangi* as it occurred in Amboyna of the Moluccas. He also calls it *Mangium candelarium et arcuatum* on account of the resemblance of the hypocotyl to candles and of the prop roots to bows. He also quotes Rochfort's account of this tree or the "Paretewier Tree" and says "Oviedus perceived a great pain in his abdomen from eating the fruits," but mentions a method by which it is prepared for food in the East Indies.

Browne, 1756,[32] in his history of Jamaica mentions the tree as "mangle," and Jacquin, 1763,[33] describes it as *Rhizophora pedunculis bifidis* and faithfully pictures the mangrove thickets of the Antilles region.

Forskahl, 1775,[34] in the Red Sea region says: "Arabes narrarient semen in arbore dehiscere et cotyledones nudos emittere, quod vix credibile mihi videtur," but as he did not actually see this, he did not really describe the plant.

Gærtner, 1788,[35] uses the name of Linnæus, but mentions all the synonyms of preceding authors. Of the embryo he says "inversus, viridus intra semen germinans ejusque integumenta, procresente sua radicula rumpens," showing he realized the significance of vivipary.

[31] Rumph, Geo. E., "Her. Amboin.," Vol. III., p. 108, 1750.

[32] Browne, Patrick, "Civil and Nat. Hist. Jam.," 211, 1756.

[33] Jacquin, N. J., "Select. Stirp. Americ.," 1763.

[34] Forskahl, P., "Flora Ægyptiaca Arabica, Haunice Descrip. Cent.," II., p. 37, 1775.

[35] Gaertner, J., "De Fructibus et Seminibus Plant," 1788.

Jussieu, 1789,[36] used the system of Tournefort, but modified it by adding the new idea of classification which he promulgated by basing it on the positions of stamens and pistils. He placed *Rhizophora* in class XIII. of his fifteen classes. He also recognized but two species—*R. mangle* and *R. gymnorhiza* with *R. caseolaris* as doubtful.

Sarigny, 1796,[37] in Lamarck's Encyclopedia gives a good and accurate account of the family of paletuviers, but recognizes the Linnæus species.

Lamarck, 1804,[38] also recognized the Linnæan species and gives five with *R. mucronata* as a new species. The old *R. corniculata* of Linnæus having now been renamed by Gærtner, *Ægiceras majus* and others discarded so that the Linnæan genus has now been to this extent reorganized. The five species of Lamarck are *R. mangle, mucronata, cylindrica, conjugata* and *candel.*

St. Hilaire, 1805,[39] follows the nomenclature of Linnæus, Jussieu and Lamarck and for *R. mangle* gives the range as both the Indies. It remained for De Candolle to complete the Natural System of Classification and in his Theorie Elementaire de la Botanique, 1813,[40] laid the basis of our modern system. *Rhizophora,* in his "System," is put in Order 57 Myrtineæ. In the "Prodromus," 1828,[41] for the Rhizophoreæ he gives four genera, *Olisbe, Rhizophora, Carallia* and *Cassipourea,* containing in all 14 species. He also treats the old East Indian species of other authors and not synonyms with *R. mangle* of the West Indies.

Velozo, 1827,[42] uses the same nomenclature as Linnæus, but shows an excellent representation of the plant and especially the lenticels on the hypocotyls. The dissection of this organ is also admirably figured.

[36] Jussieu, Antoine Lauret, "Gen. Plant.," p. 213, 1789.

[37] Sarigny, M., "Lam. Dist.," 4, 696, 1796.

[38] Lamarck, J. B. A., "Encyclopedie Methodique, Botanique," Vol. 6, 187, 1804.

[39] St. Hilaire, J. H., "Exposition des Fam. Nat. et la Germination des Plants," 1805.

[40] De Candolle, A. P., "Theorie Elementaire de la Botanique," 1813.

[41] De Candolle, A. P., "Prodromus Syst. Naturalis," Vol. III., 31–34, 1824.

[42] Velozo, di Miranda J., "Floræ Fluminensis Icones," 1827.

Bartling, 1830,[43] devised a system of classification in which the Rhizophoreæ were removed from the Order Myrtineæ and put under one called Calycifloræ, *i. e.,* on account of its structure it was placed with the Vochysieæ between the Onagraceæ and the Combretaceæ.

Endlicher, 1836,[44] used a modified system of Jussieu's, but the changes were largely in the great subdivisions, the genera are still those of Bartling more particularly.

Brongniart, 1843,[45] transposes and enlarges the family of Rhizophoreæ and places it in an order *Œnotherinæ* with Lythraceæ and Myrtaceæ as a doubtful member.

Meisner, 1843,[46] groups the Melastomaceæ, Lythraceæ, Onagraceæ, Combretaceæ and Vochysieæ with the Rhizophoraceæ as class 16, Calcycanthemoe.

Lindley, 1845,[47] reorganized the group and under the head Myrtales united ten families, one of which was the Rhizophoreæ, thus recogninzing its affinities with the Myrtales, on account of its "plurilocular ovary, polypetalous flowers, valvate calyx, indefinite stamens and flat cotyledons much shorter than the radicle, which germinates before the fruits fall." He recognizes five genera.

Grisebach, 1864,[48] mentions only *R. mangle* as being found in the western hemisphere and says that Meyers's *R. racemosa* is synonymous.

Hemsley, W. B.,[49] in his reprint on the "Voyage of the *Challenger*" regards the *R. mangle* as the only *Rhizophora* in the Americas.

Hooker, 1879,[50] in the Flora of British India does not include *R. mangle,* but it is known to occur in the Pacific Islands and follows there certain lines of dissemination.

[43] Bartling, Fr., "Ordines Nat. Plant.," 1830.

[44] Endlicher, S., "Gen. Plant. Sec. Ordines Nat. Pis.," 1836.

[45] Brongniart, Adolphe, "Enumeration des Genres des Plantes cultives," 1843.

[46] Meisner, C. F., "Plant Vascularium Gen. Secund Ordines, 1843.

[47] Lindley, John, "Vegetable Kingdom," p. 726, 1845.

[48] Grisebach, A. H. K., "Flora of British West Indies," p. 274, 1864.

[49] Hemsley, W. B., "Voyage of H. M. S. *Challenger,* Bot. Bermudas," p. 32.

[50] Hooker, D. J., "Flora of British India," Vol. II., p. 435, 1878.

Engler and Prantl, 1898,[51] regard the group Rhizophoreæ as having only five genera with *Rhizophora* composed of three species —*R. mangle, R. conjugata* and *R. mucronata.* This classification is that used in all Floras containing the species.

Small[52] in all his manuals[53, 54] mentions only *Rhizophora mangle,* as well as Chapman[55] and other systematic writers.

The family Rhizophoraceæ then belonging in the Myrtales order, falls naturally into two subfamilies—Rhizophorideæ and the Anisophylloideæ. This is recognized by De Candolle,[56] and Van Tieghem[57] and all the later writers on the family. Some authors, however, divide the family into a triple grouping, with a third head the Legnotideæ, and still others as Baillon[58] arrange the family in a different grouping. This latter author divides fourteen genera into four divisions—I. Rhizophoreæ, II. the Baraldieæ, III. Macarisieæ, which is equivalent to the group Legonatideæ of Bartling and Cassipoureæ of Meisner, and IV. the Anisophylleæ. The affinities of the plants in this family have manifold connections such as the Onagraceæ, Loranthaceæ, Cornaceæ, Lythraceæ, as may be seen by the placing of these genera by the earlier authors cited above, and before R, Brown's, 1814,[59] arrangement had been placed in the Caprifoliaceæ. All the groupings have been based largely on the relative positions of the perianth and the gynœcium, Baillon's group of Rhizophoreæ having concave receptacles and ovary inferior. Style simple and seed exalbuminous, with macropod embryo, germinating in fruits on the trees, embraces four genera. These are the ones mostly given in modern floras of oriental countries and are *Rhizophora, Ceriops, Bruguiera* and *Kandelia.* They are all representatives of tropical Asia and Africa, except *Rhizophora,* which is cosmopolitan in the tropics.

51 Engler, A., and Prantl, K., "Die naturlichen Pflanzenfamilien," Teil III., abt. 7, p. 42, 1892.

52 Small, J. K., "Flora of S. E. United States," p. 834, 1908.

53 Small, J. K., "Shrubs of Florida," p. 89, 1913.

54 Small, J. K., "Flora of the Florida Keys," p. 105, 1913.

55 Chapman, J., "Flora of Southeastern United States," p. 152, 1897.

56 De Candolle, C., "Prodromus," III., p. 31.

57 Van Tieghem, Ph., *Ann. Soc. Nat.*, Ser. 7, T. VII., p. 376, 1888.

58 Baillon, H., "Nat. Hist. of Plants," Vol. VI., p. 287.

59 Brown, R., "Flind, Voy.," II., p. 549, 1814.

Engler and Prantl, however, whose classification is still the authority perhaps includes under the division of the family Rhizophorideæ-Gynotrochinæ, five genera, *Crossostyles, Gynotroches, Rhizophora, Ceriops* and *Kandelia*.

But though the genera of the Rhizophoraceæ do not fall very naturally into an arrangement, it is now fairly well decided that the seven species of the Linnæan genus, *Rhizophora*, have been condensed so that only three species are recognized, viz., *R. mangle, R. conjugata* and *R. mucronata*. Of these three species as noted before only *R. mangle* is indigenous in the Americas, although Martius, Euler and Urban,[60] 1882, in the "Flora Brasiliensis" mentions Meyers's species *R. racemosa*. This is a synonym or a subspecies of *R. mangle*. Guppy, 1906, "recognizes *R. mangle* under two distinct types—the "Grande" and the "Chico" types. This will be discussed in a subsequent paragraph.

The main features which demarcate *R. mangle* from its related species are the shapes of the leaves, the length of the petioles and the number of flowers in the cymes; and the texture of the petals, whether they be thick lanate, or thin and glabrous. There has been some slight confusion in the nomenclature of these three species, although recent floras have straightened out the tangle. Timmens, 1894,[62] in his "Flora of Ceylon," mentions the two Oriental species, and gives as one—*R. mucronata* Lam. as synonymous with *R. candel* Moon Cat and *R. macrorhiza* of Griffiths. The other of his two species is *R. candelaria*, which is synonymous with *R. conjugata* of Linnæus and *R. mangle* Moon Cat and Linnæus in part.

Hooker,[63] in "Flora of British India," also gives *R. mucronata* as the *R. mangle* of Linn., but this is not correct. The *R. mangle*, which is the equivalent of *R. mucronata* Lam., is *L. mangle* Roxb., which is quite different from *R. mangle* of Linnæus. This error of nomenclature has been made by Roxburgh and perpetuated in the older works.

[60] Martius, Euler and Urban, "Flora Brasiliensis," Vol. XII., par. II., p. 425, 1882.

[61] Guppy, H. B., "Observations of a Naturalist in the Pacific," Vol. II., 1906.

[62] Timmens, H., "Flora of Ceylon," Part II., p. 151, 1894.

[63] Hooker, D. J., "Flora of British India," Vol. II., 435, 1879.

King[64] has this point clear in his Malayan Flora, where he says *R. mucronata*—*R. mangle* Roxb. (not Linn.) and also *R. macrorhiza* Griff. while *R. conjugata* Lam.—*R. candelaria* of De Candolle.

R. mangle Linn. is a purely American species, but has been found by Guppy associated with the Oriental species in some of the islands in the South Pacific.

Morphology and Histology.

The gross morphology of *Rhizophora mangle* is synopsized in any flora or manual of the species of the tropics in which the plants are found. But it is well perhaps to set down the chief features of their structure here. (See Plate IX.) The red mangrove may be a large tree 60 to 80 feet tall, or smaller shrub 6 to 18 feet tall. This varies with the region and has given rise to the two types based on size, *i. e.*, the "*Mangle chico*" and "*Mangle grande*." The primary root soon dies out, secondary roots are put out by the seedling. Later adventitious prop-roots are put out from the base of the stem and from a mass of arched stilts about the tree. The branching is opposite and from the lower branches aërating roots are let down to the substratum, these also assist the prop-roots in anchoring the tree. The twigs are stiff, cicatrized and thick, and the wood throughout the tree is very hard and dense.

The leaves are opposite, clustered on the ends of the twigs and furnished with large inter-petiolate and caducous stipules. They are decussate, petiolate, elliptic, entire, glabrous thick and coriaceous.

The flowers are yellowish or whitish, coriaceous and axillary; collected into bi- triparous, rarely simple and more generally ramified cymes at the summit of a common peduncle. These flowers are usually pedicellate, articulate and have mostly two connate bracteoles forming a sort of involucre. The flower is regular with a concave obconical receptacle. The sepals are four in number inserted on the margin of the receptacle, coriaceous and valvate; and the petals are also four, alternate with the sepals and valvate. The stamens are mostly eight, with four larger ones oppositipetalous, and have many short filaments or none at all. The anthers are unique. The anther

[64] King, Geo., "Materials for a Flora of the Malayan Peninsula," Vol. 3, p. 313, Calcutta, 1902.

furrows are lateral or subintrorse and the pollen sacs are areolate-multilocellate.

The ovary is half inferior, bi-locular and at the vertex produced into a cone. Style subulate, sometimes rather short, at the apex stigmatose and bidentate. There are two ovules in each cell, placed in a collarterally descending position, the micropyle being extrorsely superior.

The fruit is berry-like, coriaceous and indehiscent, surrounded below the middle by the reflexed persistent calyx. Only one ovule matures into a seed. The embryo is exalbuminous with fused cotyledons. The radicle or hypocotyl perforates the apex of the seed and germinates within the fruit; at length pushing out through the pericarp, greatly elongates while still on the tree. An absciss layer is finally formed at the junction of the cotyledonary sheath and the shoulder of the hypocotyl, and the seedling drops from the parent tree into the mud or water.

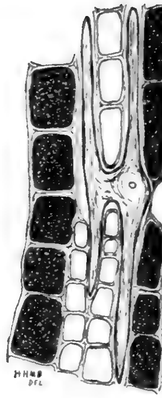
The Roots.

The roots of the *mangrove,* even as mentioned by the ancient Greeks, are a peculiar feature of the genus, being, as Theophrastus says, like "polypi." The primary root put out by the radicular end of the hypocotyl soon stops growth and the root function is given over entirely to secondary roots. The cause of cessation of growth by the primary roots has been suggested by Warming,[65] Johow,[66] Schimper,[67] and others, as due to the bites of crabs, snails or other mechanical injury. At any rate the primary root does not long persist and the plant is soon anchored by a rich mass of secondary roots. The structure of the roots is very interesting. There are really two types of roots, those prop-roots arising from the base of the tree and bending out to form the curved stilts, and the adventitious roots dropped from the lower branches are one kind and are known as the aërial or aërating or pneumatophore roots, while those

[65] Warming, Eug., "Rhizophora Mangle, Tropische Fragmente," *Engler's Jahrb. für Syst.,* Bd. 4, p. 520.

[66] Johow, Fr., "Vegetationsbilder aus West Indien und Venezuela, Die Mangrove Sümpfe, Kosmos," Bd. I., pp. 415–426, 1884.

[67] Schimper, A. F. W., "Indo-Malayische Strandflora," *Bot. Mitheilungen aus des Tropen,* Heft 3, 1891.



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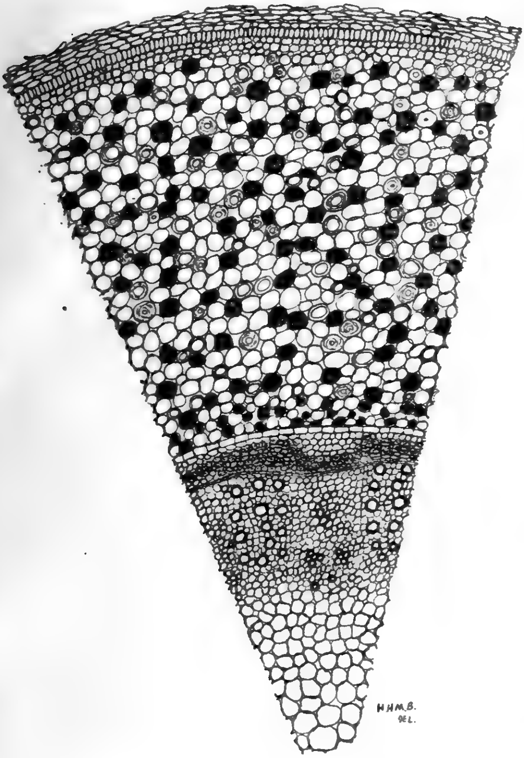

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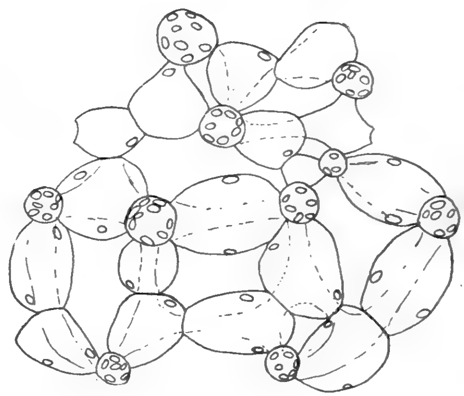

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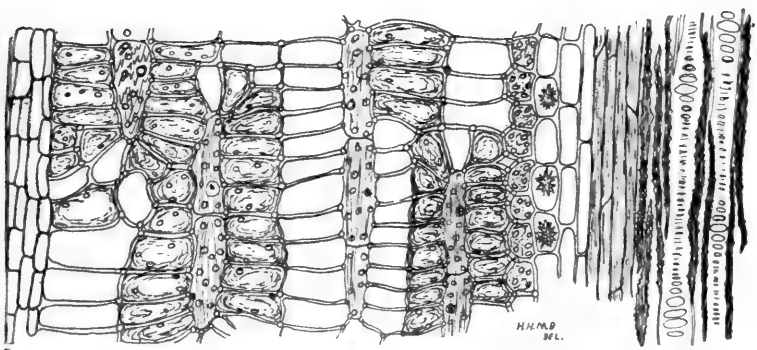

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FIG. 1. Transverse section of prop-root, showing cortex containing idioblasts, tannin cells and parenchymatic cells. Cork ouside and the endodermis on the inner margin of the cortex. The vascular cylinder and medulla inside. × 106.

FIG. 2. Camera lucida drawing of longitudinal section. Cortex cells showing sections of idioblasts and tannin cells. × 470.

FIG. 3. Enlarged transverse section of cortex cells of absorptive root. Large elliptic cells transfusion tissue smaller circular cells, longitudinal cells containing starch. × 600.

FIG. 4. Drawing (cam. luc.) of longitudinal section absorptive root. × 96.

which are subterranean or submarine, buried in the mud, and which have assumed a purely absorptive rôle, are called the absorptive roots in this paper. Van Tieghem[68] has described and figured the root of the *Rhizophora,* and shows especially the development of these secondary roots. He says: "An arch of the pericycle of the width of three cells in the external layer and corresponding with a wood bundle, increases and cuts off two rows of cells, but especially does the external layer increase, and it is this alone, by two tangential wall formations, which differentiates the three regions of the rootlet from the original cells. The internal row does not go beyond the base of the central cylinder. The superimposed arc of the endodermis dilates its elements, but not radically, and encloses the developing rootlet by an absorptive pouch. In this pouch, which is dilated to a great extent, the rootlet elongates rapidly the width of the cortex, but remains very narrow. More slowly it then enlarges at the summit and the pouch is absorbed laterally, but the terminal part is left adhering like a cap as it emerges from the root."

This interesting process may be seen on both the hypocotyls of seedlings and the origin of the dependent prop-roots from the branches. These little root caps adhere for quite a long period, especially in the aërating roots. If the tip of one of these pendant roots is injured, there will be a division just back of the tip and the geotropic growth will continue as two or three branches. These branches usually push out at the lenticel with which these aërating roots are well supplied. The same thing occurs on the hypocotyl which also is supplied with lenticels. If the roots at the radicular end are destroyed adventitious roots are put out up farther on the hypocotyl, perhaps just a few centimeters below the plumule. What the stimulus may be is not exactly known in this case, but in as much as oxygen has been shown to be stimulating in the production of root hairs in plants, it may be presumed that the supply of oxygen received through the lenticel acts as a stimulus for the production of the rootlet from the pericambial tissue just at the point beneath the lenticel. The initial stimulus for the production of these adven-

[68] Van Tieghem, Ph., and Douliot, H., *Ann. des Sci. Nat. Botanique,* Ser. 7, Tome 7, p. 212.

titious roots is, of course, the injury or removal of the tip of the root.

Root hairs are lacking in *Rhizophora,* as in most all aquatic plants, but their function is fulfilled by many tiny roots which grow out from the subterranean or submarine absorptive roots. These absorptive roots are quite different from the aërial part of the prop-roots or those dependent from the branches (see Fig. 4 and 6, Pl. VIII.) These roots are mostly rather short and thick, fleshy, and whitish or pinkish in color, and of a soft texture.

The extra thickness of these subterranean absorptive roots is due to the greater development of the primary cortex. In the absorptive root this is of large loose cells with very large open intercellular spaces in which idioblasts or trichoblasts are lacking. Externally as Solereder[69] has shown, the periderm consists in this absorptive root only of cork cells, while the same tissue in the aërial portion has both cork and "parenchymatic separation tissue" alternating.

The cortex of large round cells has been studied by both Van Tieghem and Solereder, and even figured; but it is supposed that the material was not fresh and the delicate cells of the cortex were shrunken (Pl. IV., Fig. 3). These cells are closely connected with the absorption of water, presumably growing as the plants do in salt water of a rather high concentration, shrunk on being placed in reagents of different densities. At least in the preparation of material for this paper such has been the case and only in material freshly sectioned and mounted in glycerine water could the true idea of the structure of this cortex be gained. The cells compose a loose network and have very large open spaces between them. Some cells are converted contiguously in strands, others radiate about short groups of cells, which are much elongated in the direction of the axis of the root (Pl. I., Fig. 4). These elongated cells are often quite full of starch grains, while the large roundish turgid cells radiating from them contain relatively few starch grains and more mucilaginous protoplasm which stains slightly with water eosin. These round cells, when slightly shrunken due

[69] Solereder, H., "Systematische Anatomie der Dicotyledonen," p. 384, 1889.

to a partial plasmolysis, show, on focusing at different levels, the lower wall and its line of juncture with a cell beneath or on the side, this artifact produces a double line of tension or wrinkle on the wall which seems like a tube or channel contained within the cell. Warming regarded these as thickenings for support within the cells which prop the cells apart and assist the soft tissue of the root in maintaining its shape and as they do not appear along the wall separating an intercellular space this artefact seems to really confirm this view. But since these "verdickungsleisten" are not seen in freshly sectioned and water mounted material, Warming's theory of lateral mechanical support for these cells is not tenable. Material carried up in balsam or glycerine jelly does show this peculiar irregularly "branched thickening," but it can only be regarded as an artefact. The tissue of this cortex seems to function as a transfusion tissue. Warming and Solereder also both state that the trichoblasts are lacking in the absorptive and tertiary roots, but on close examination some may be found scattered in the xylem elements of the vascular bundle.

In the aërating prop-roots and those dependent from the branches which have not yet reached the water the cortical area is filled with trichoblasts and large tannin-containing cells (see Figs. 1 and 2, Pl. IV.). These trichoblasts are frequently branched and double or H-shaped, the branches running up in the intercellular spaces. The tannin cells are larger than the cortical parenchyma cells and on longitudinal section appear as long chains of dense, dark, solidly filled cells.

The endodermis is easily recognized in either transverse or longitudinal sections by its loose clear structure, the walls being thin and rather more regular than the cells of the cortex, and show the slight irregularities in the wall that Warming mentions and calls "the Caspar spots." In the older roots the endodermis is crushed by the secondary growth so as not to be recognizable.

The central vascular cylinder of these aërating roots shows several interesting peculiarities. If sections are made from regions just behind the root cap and then a region several centimeters back and finally of an older root, striking differences are noted. In the figure given (Fig. 1, Pl. IV.), the section has been cut about three centimeters behind the cap. The conductive bundle cylinder is composed of about 30 or 40 alternating strands of xylem and phloëm tissue. As Warming has also shown, however, a most unusual departure is made from this regular root arrangement in that there are often more than one phloëm strand between two xylem patches, as seen in transverse section. This is supposed to occur by the splitting of strands. The phloëm strands contain both sieve tubes and phloëm parenchyma. The xylem in its earliest state, *i. e.*, protoxylem, has very few spiral tracheæ, just behind this externally is a small group of soft bast elements, the tracheæ being surrounded by a sclerenchyma ring or sheath. In this development, the method of growth is centrifugal. Beyond this group of phloëm elements is the xylem strand and this has the peculiar structure of a double bundle, but both are enclosed in one sclerenchyma sheath. What causes this splitting in the xylem it is not possible to say. Among the xylem elements are scattered large pitted and scalariform vessels. The phloëm is now very well developed.

The pith of the root is of large thin-walled cells, typical medullary tissue with intercellular spaces in which lie many trichoblasts. The pith also contains tannin cells.

The Stem.

The twigs and branches of *Rhizophora* show little that is peculiar in the general arrangement of the structures. In the wood, however, there are prosenchymatic vessels which are pitted and also there are some vessels which have ladder-like perforations. These appear as holes with transverse bars across which in most instances number about four or five. The medullary rays are rather broad and where the bundle vessels come in contact with the ray tissue the walls of the former are pitted.

The cork formation, according to Solereder and Möller,[70] is superficial, and of the spongy type. In the pericycle there is a dense ring of sclerenchyma, which makes the twigs very difficult to cut.

[70] Möller, J., "Holzanatomie," *Deutschr. Wiener Akad.*, p. 103, 1876.

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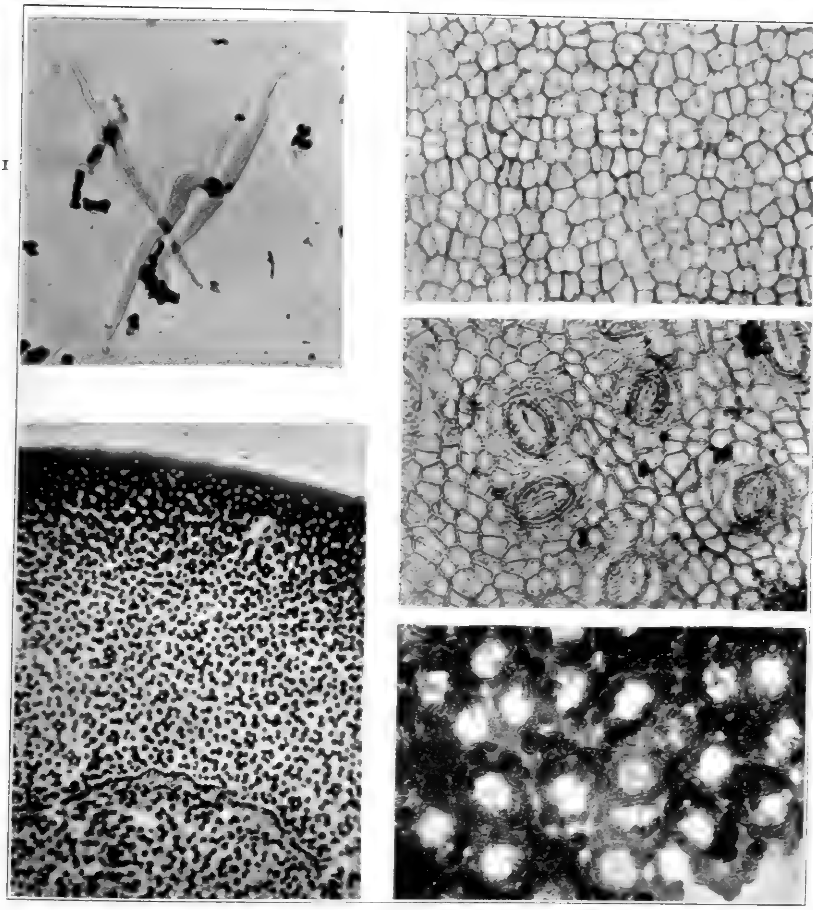


FIG. 1. Idioblasts from macerated leaves. Micro-photograph, × 175.

FIG. 2. Transverse section hypocotyle stained with copper acetate. Tannin cells black. × 18.

FIG. 3. Micro-photograph of upper epidermis. × 175.

FIG. 4. Lower epidermis, showing stomata. Micro-photograph, × 175.

FIG. 5. Lower epidermis with cells of the hypodermis shown. Dark cells stained for tannin, light areas stomata. Micro-photograph, × 175.

THE LEAF.

It is in the leaf that a great many of the adaptations of the *mangrove* to its special environment are seen. The leaves, as mentioned before, are opposite and assume somewhat a perpendicular position. Johow[71] regards this position as a protection against the light, the great intensity of which has, according to him, a destructive effect on the chlorophyll. Each pair of leaves is provided with two interpetiolar stipules which are twisted in the opposite direction from that of the leaf which it encloses. The unfolding of the leaf blade from the stipule occurs as in the figs. The stipules are provided with glandular hairs, which secrete a resin-like substance that Eggers[72] says covers the plumule in the seedling stage and protects it against the action of the water when the seedling floats in the sea.

Warming[73] figures a diagram of the cross section of a petiole in which there is a ring of vascular tissue and inside this ring are several other vascular bundles with the phloëm turned in the reverse direction. In his opinion these strands arose as splits from the bundles on the upper side.

The leaf blade is elliptic and has a very prominent midrib, as Sloan[74] observed in his early description. The epidermis is very heavily cutinized, especially on the upper side which entirely lacks stomata (Fig. 3, Pl. V.). The stomata are slightly sunken and provided with an antechamber (Fig. 4, Pl. V.). According to Warming the stomata originate at different times, the younger between the older ones, and are scattered in every direction. A most striking feature of the leaf tissue is the large, mostly four-celled water-storage hypodermis. This is a true hypodermis, as may be seen in examining young leaves still rolled in the stipules, which even here show a number of layers of these cells. The upper layer of the hypodermis or mostly the two uppermost layers are filled with tannin (Fig. 5, Pl. V.). The function of these tannin

[71] Johow, Fr., loc. cit., p. 419.

[72] Eggers, H., "*Rhizophora mangle* L., Videnskabelige, Meddelelser," p. 180, 1887.

[73] Warming, Eug., "*Rhizophora mangle* L., Tropische Fragments," II., *Engler's Botanische Jahrbucher für Systematik*, Bd. 4, 1883, p. 319.

[74] Sloan, H., "A Voyage to the Island Madeira, Barbados, Jamaica, etc.," 1725.

layers as a light screen will be considered in the physiology. On account of the development of the hypodermis, the palisade lies deep in the mesophyll, in fact almost in the middle of the leaf. There are usually three layers of very narrow elongated palisade cells. Interspersed among them are many branched and often much twisted trichoblasts. These branches ramify about in intercellular spaces and push the cells aside as they grow. The spongy tissue of the leaf is rather loose and is composed of cells varying a great deal in size. Some are large and contain tannin and others contain only a thick mucilaginous protoplasm. Large spherical, many pointed crystals of calcium oxalate fill up cells scattered in the spongy tissue, as well as the water hypodermis (see Fig. 4, Pl. VII). Warming thinks the shining, thick epidermis of the leaves helps to reflect the intense light and doubtless this is true and, as will be shown in the physiology, this reflection serves an important service.

On the under surface of the leaves are many small black specks, which Warming regarded as the opening of glands located deep within the spongy tissue. These were filled with a secretion which looked brown in the material he examined, *i. e.*, material pickled in alcohol. It has now been shown that these tiny specks are not glands, or glandular hairs, or disks, but really small bodies of cork which are formed from the epidermal cells.

The Flower.

The inflorescence has already been described as usually di- or trichæsial cymes, and its relation to the axis and the bracts has been well described by other authors. The four stiff woody sepals which persist and grow in size as the fruit develops are heavily impregnated with stone-cells or trichoblasts. In the lower part of the receptacle below the junction of the sepals and the ovary, *i. e.*, just beneath the ovules, there is a large mass of very loose tissue, which Griffith[75] noted in his early papers on the species. This tissue has very large intercellular spaces to permit the rapid growth of the embryo to take place without unduly crushing the cells of the fruit. The four petals placed alternately with the sepals are early deciduous. They, as well as the sepals, are valvate and on their

[75] Griffith, W., *Trans. of the Med. and Phys. Soc. of Calcutta.*

inner faces are thickly supplied with unicellular hairs. These hairs have been shown in the illustrations of Baillon,[76] but in most of his other diagrams there are great errors, as Warming, who has done most excellent work on the species, is careful to point out. In the bud the petals are slightly curved down over the tips of the anthers. The tissue of the petals does not contain trichoblasts, but the cells do contain protoplasmic constituents, which take stains more readily than the cells of the other parts of the flower.

The eight anthers are almost sessile and at the base of the very short filaments there is a ring of nectary glands (see Fig. 1, Pl. VI.), which secretes abundant nectar that is eagerly collected by insects. In sections these nectar glands are seen as dense deeply stained masses which have delicate vascular connections with the strand which passes up into the anther and also into the petals. The anthers, as mentioned before, are multilocular, and this feature has been described by many previous botanists. Griffith[77] early gave a good description of the method of dehiscence by the pulling away of the valves and exposing the core filled with loculi, "resembling *Viscum* in this circumstance." Goebel[78] describes such chambers in the anthers of *Gaura* and *Clarkia* in the Onagraceæ and regards them as the homologues of the trabeculæ of the sporangia in *Isoetes,* their function being to nourish the sporogenous tissue. Wight[79] also gives a very clear description of this form of pollen arrangement and dehiscence and figures it in another place.[80]

The anther on close examination has two introrse faces and the two slight grooves down the length of these faces, where the thin exothecial membrane ruptures and then rolls back in ordinary anthers. The pollen alveoli are small round cavities embedded in the connective tissue, which is much enlarged in these anthers. The two delicate channels on the faces of the anthers finally disappear with the growth of the tissue in many cases and dehiscence may be by a suture at the medial line or at their lateral lines.

Warming has pointed out the two special features in the forma-

[76] Baillon, H., "Natural History of Plants," Vol. VI., Fig. 256.

[77] Griffith, W., loc. cit., Pl. 640, Fig. 11.

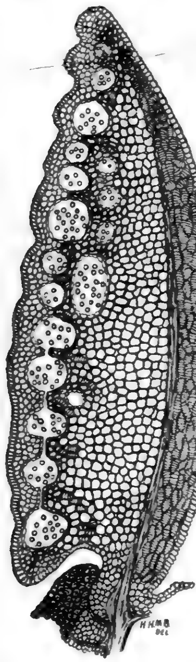
[78] Goebel, K., "Organographie der Pflanzen," p. 731, 1898.

[79] Wight, Robt., "Illustrations of Indian Botany," Vol. 1, 207, 1840.

[80] Wight, Robt., "Icones Plant. Indiæ Orient," 1, tab. 238–240.

tion of the chambers and later of the pollen from the very young parenchymatic tissue. These are first that the two pollen sacs fuse in the upper part of the anther where there is no bilateral arrangement by a median line, but a line of chambers occurs in the middle plane of the apex; the second is that not all the cells of the young anther parenchyma or endothecium become sporogenous as they do in other anthers, but some cells become the alveolar walls. Warming further remarks that in his opinion this is not an old phylogenetic condition but a recent adaptation and is seen in not only the mangroves, *Rhizophora, Ægiceras,* etc., but in other families as the Onagraceæ above mentioned and the Orchidaceæ (*Phaius* and *Bleteia,* etc.), as well as *Viscum* of the Loranthaceæ.

The mechanism of the dehiscence, however, is just as interesting as the formation of these peculiar anthers and their pollen. This feature was brought out in examination of the cellular structure of the bud. As the other workers on the species have shown, the anthers in transverse section are triangular, or obovate-triangular with the dehiscing faces introrse and the back or outer side of the anther is a broad expansion of the connective (Fig. 2, Pl. VI.). This connective area, as well as the partitions of the pollen loculi contain a peculiar kind of cell. All the previous investigations have overlooked these cells. They happened to be brought out in sections which had been double-stained in safranin and methyl-green to contrast the lignified walls of the idioblasts. While examining these sections there was noticed in the outer cells of the connective area of the anther a layer of cells which contained peculiar lignified, transverse ring thickenings inside the cellulose wall (see Figs. 3 and 4, Pl. VI.). In these anthers this reinforced area extends clear to the tip and the cells composing it are rather elongated. According to our interpretation, these cells play an important mechanical part in the dehiscence of the pollen. As the pollen ripens in the loculi, the thin exothecium shrinks and while this is taking place the strain produced on this thin-walled cell layer, particularly along the middle line of the pollen loculi, by the rigidity of the areas composed of the reinforced cells, a rupture occurs at the weakest places, *i. e.,* at the middle line where the partitions are thinnest. When the split has occurred all along the line the exothecium falls



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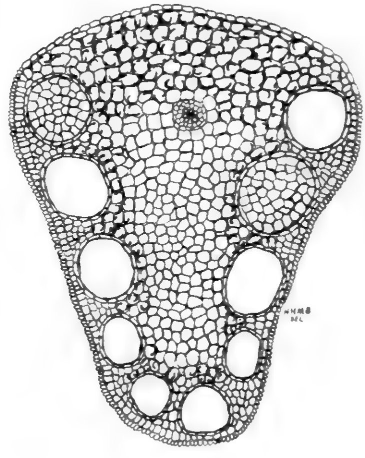
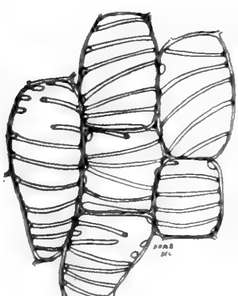


2

FIG. 1. Longitudinal section of anther showing area of reinforced cells on outer side, vascular tracts, pollen loculi with reinforced cells in the septa, and thin exothecium separating off. Pollen grains in loculi and dark cells of nectary at base of stamen. (Cam. luc.) × 70.

FIG. 2. Transverse section of anther showing pollen loculi, vascular bundle, and areas of reinforced cells. (Cam. luc.) × 340.



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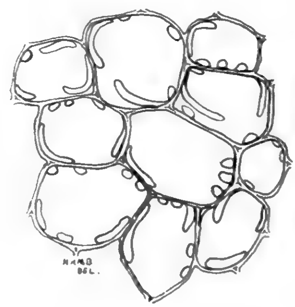

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FIG. 3. Longitudinal section of cells of reinforced area of anther showing lignified rib thickenings. (Cam. luc.) × 500.

FIG. 4. Transverse section of reinforced area of anther, showing lignified ribs. (Cam. luc.) × 500.

away, just as described by previous writers, and exposes the pollen in the loculi to the air and contact of insects. The cells here described with their lignified thickenings are also densely filled with dark-staining protoplasm, similar to those of the petals. According to Warming the cytological development of the pollen grains does not present any unusual feature and the cursory examination of it in the preparation of this paper, which is not concerned with cytological details, seems to confirm Warming's statement.

The pistil is relatively simple and has a two-celled ovary with the spongy tissue above mentioned beneath it. In each of these two cells there are seen two ovules, one of which becomes a seed. The ovary tapers gradually into the erect and elongated woody style which has a bifid stigma at the tip. The ovary, the ovules, the egg and fertilization apparatus have a very special interest in *Rhizophora* owing to the plant's habit of vivipary. The endosperm itself has been the subject of investigation and considerable speculation. Baillon seems to have started the discussion by saying that the embryo is destitute of albumen, but is surrounded by a soft matter which assumed its rôle. These parts connected with the reproductive function are best considered under the next heading.

EMBRYOLOGY.

The embryology of the red mangrove has been attacked by several botanists with more or less success. The study of its vivipary has led up to these detailed studies, which have been made principally by three workers, Warming,[81] 1883, Karsten,[82] 1891, and the most recent by M. T. Cook,[83] 1907. The first merely touched incidentally on the embryology in as far as it was related to the general morphology. Karsten's work, while more detailed, was undertaken with a view to its relation to vivipary and the ecology of *mangroves* in the widest sense. Cook's paper summarizes the work of Karsten and while short is very good, but the author himself says that com-

[81] Warming, Eug., loc. cit., p. 528.

[82] Karsten, G., "Ueber die Mangrove-Vegetation in Malayahn Archipel.," *Bibliotheca Botanica*, Heft 22, 1891.

[83] Cook, M. T., "The Embryology of *Rhizophora mangle*," *Bull. Torr. Bot. Club*, Vol. 34, No. 6, p. 271, 1917.

plete series were lacking in his studies owing to deficiency in material. In this resumé, the rather specialized paper by Haberlandt[84] and to some extent the studies of Johow[85] cannot be overlooked. The former was particularly concerned with the nourishment of the embryo and the function of the endosperm.

In this paper the embryology has not been considered as being of primary consideration in relation to the studies of the physiology of the species and in view of the investigations already made on the embryology the main features will only be reviewed here to give a clearer understanding of the morphology. A few photomicrographs are given also by way of illustration.

The ovules all show a nucellus and in the tip of this, which in cross section is slightly irregular in outline, there is the archesporium. Cook says this is subepidermal and figures it as such. This archesporial cell cuts off two tapetal cells, but this number does not appear to be definitely known for the genus. However, Karsten's material *R. mucronata* is figured as having two tapetal cells and Cook's material *R. mangle* also. In the figure of the longitudinal section given in this paper the large horseshoe shape section of the integument is seen as the only one present. Cook has shown that there really are two integuments at the beginning where the archeporial cell is still small, but that later the inner one is destroyed. The integuments both grow rapidly and soon enclose the nucellus, while the archesporium divides into the megaspore cells. Here there seems to be a discrepancy in the number for the genus, as Karsten found four for *R. mucronata,* while Cook gets three for *R. mangle,* but as Cook says he only was able to secure one good preparation of this stage the constant number cannot positively be stated. As the embryo sac enlarges the nucellus completely disappears, as does also the inner integument with growth of the sac.

This stage, or one a little later, is shown in the figure where the outer integument is seen with a littte of the soft spongy endosperm inside and the enlarged embryo, with the tiny dark area where the plumule is beginning to form. The cells of the endosperm

[84] Haberlandt, G., "Ueber die Ernährung der Keimleinge, etc.," *Ann. du Jardin Botanique de Buitenzorg, Treub,* Vol. 12, p. 91, 1895.

[85] Johow, Fr., loc. cit.

seem to radiate from a more or less definite center of growth in the sac, as Cook has mentioned. This feature is seen in the figure of a transverse section of the ovules.

The function of this endosperm has engaged the attention of the various botanists mentioned above. The cells themselves are large and loose and are easily distinguished from those of the enclosing integument and Warming[86] says they appear as if empty of contents and that he never found starch in them, but had noticed sphærocrystals and it is furthermore remarked by this author that its function does not seem to be that of food storage, but its later development indicates a quite unusual function. This later development is the pushing out of the endosperm and the cotyledonary end of the embryo through the micropylar end of the sac or what now remains of it as the outer integument, into the ovarian cavity to form an arillar collar or outgrowth. As Warming and Johow[87] both agree, the function of this structure is not for the luring of animals for the purpose of seed dissemination, as other arils in *Myristica, Casearia* and *Euonymus,* but, as Warming says (p. 531), "Bei *Rhizophora* wird das extraovulare albumen wahrscheinlich dazu dienen, als Saugorgan dem Keimlinge Nahrung von der Mutterpflanze zuzuführen." This peculiar endosperm structure is seen not only in the Rhizophoraceæ but in other viviparous plants, as Treub[88] has shown for *Avicennia,* etc. Karsten[89] has shown the same conditions for *R. mucronata, Bruguiera, Ceriops, Ægiceras,* etc., and that these plants all follow the same development as was early recorded by Hofmeister[90] in the origin of the embryo sac from the nucellus, etc. Karsten divides the endosperm formation into two categories; first that form in which the embryo is soon anchored near the micropyle and only after this does the endosperm, in very small amounts, begin to form from unconnected cells of a foamy consistency. In the second category to which *Rhizophora* belongs

86 Warming, Eug., loc. cit., p. 531.

87 Johow, Fr., loc. cit., p. 421.

88 Treub, M., *Annales du Jard. Botanique de Buitenzorg,* Vol. 3, p. 79, 1882.

89 Karsten, G., loc. cit., p. 31.

90 Hofmeister, W., "Neuere Beobachtungen über Embryobildung bei Phanerogamen," *Pringsheim's Jahrb.,* I., p. 82, 1859.

the endosperm completely surrounds the unanchored embryo and permits of motion in different places by the growth of the embryo. Of both these cases Karsten says (p. 33, l. c.): "Die Rolle eines Reservestoffe speichernden Gewebes kommt aber dem Endosperm weder im ersten, noch im zweiten Falle zu."

It remained for Haberlandt, however, to do the most intensive work on these endosperm cells. The plants which he investigated at Buitenzorg were *Bruguiera, Ægiceras* and *R. mucronata.* For the first two genera he has learned that the endosperm forms many-celled haustoria, which grow into the tissue of the integument and absorb the food for the embryo (p. 95, l. c.). However when he came to *R. mucronata* he expected to see the same development even to a greater degree, on account of the rapid growth of the very long hypocotyl, but a quite different condition was found, different even from that found by Warming for our species, *R. mangle.*

The inner rounded end of the embryo is connected with the integument by a well-developed "Saugorgan" structure consisting of cells of several layers, with thin walls and rather elongated in outline, the upper layer of which is supplied with warts and papillæ, which apparently transfer food to the embryo. But the endosperm cells around the cotyledonary collar region have large thin-walled watery cells, among which the absorptive papillæ are more numerous. Haberlandt shows this in a series of excellent figures (l. c., Pl. XI.), but that these papillæ merely function as, or are absorptive organs, Haberlandt does not concede. His conclusion is that this tissue is an enzyme-secreting layer of cells which perhaps secretes diastase, and to prove this he placed starch grains on these papillæ and learned that in twenty-four hours the grains on the rounded head region were deeply corroded, while those of the collar were less so. The large watery cells of the latter region Haberlandt regards as water reservoirs for the delicate absorptive tissue of the "head" region. This he regards as a special adaptation to the physiologically dry habitat of the mangrove and a protection against transpiration.[91]

In the more recent work of Cook there is also mentioned (l. c., p. 273) the fact that the cells of the integument are much denser

[91] Haberlandt, G., loc. cit., p. 105.

than those of the endosperm and that the union between the two layers of cells is very close. Cook further has divided the periods of growth of the embryo into three definite periods; first, the first growth of the cotyledons, during which they enlarge and are the means of storing up the food for the later growth; second, the cotyledons almost cease growing, while the hypocotyl elongates and the plumule is forming, and the beginnings of vascular elements take shape; third, the second growth of the cotyledonary body which pushed out the region of union of the cotyledons and the hypocotyl so that the cotyledonary body projects like a green collar beyond the apex of the fruit. An absciss layer is then formed at the base of the plumule and the hypocotyl drops off.

Polyembryony.

The presence of four ovules in the young condition of the fruit and the habitual development of only one of these into a seed naturally leads the investigator to look for polyembryony in the genus. This condition actually does happen at rare intervals and has been noted by a few observers. Warming quotes Piso,[92] who figures this rare phenomenon of two or more radicles pushing out from one fruit. Baron Eggers[93] is also quoted as estimating from his observations on this species in the West Indies that polyembryony occurs three times in one thousand cases and Du Petit Thouars[94] is also reported to have observed this. Polyembryony may occur according to the wide usage of the term by some botanists, *i. e.,* two or more embryos may develop within one embryo sac by the formation of several embryos, one of which originates from the egg and it is this which Warming figures in Pl. VII.–VIII., or in the wider sense of two or more ovules germinating from one fruit. The difference may easily be seen on cutting away the fruit wall; if only one seed is present, it can only be interpreted as true polyembryony. In the second case two or more seeds would be noticed.

[92] Piso, G., loc. cit.

[93] Eggers, H., loc. cit., p. 180.

[94] Thouars, Albert du Petit, "Notice sur le Manglier," Desvaux's *Journal de Botanique,* t. 3, p. 27, 1813.

More recently Guppy has observed cases of polyembryony, but all of the cases which he observed seem to be of the second type, in which more than one seed germinated. This naturalist counted eight hundred fruits on trees of *R. mangle* in Fiji and found only nine cases of polyembryony, eight with two radicles protruding and one with three. In particular localities he found as many as two or three per cent. of the fruit showing polyembryony. Perhaps this indicates an hereditary factor and tendency in certain trees of a region for evolution to a condition of maturing and germinating all four of the ovules in a fruit. No cases of polyembryony seem to be reported for other species than *R. mangle*.

Embryonal Development.

The length of time required for the complete development of the embryo from the time of fertilization until the fall of the seedling has been estimated by some observers and actually recorded exactly by a few who pollinated the flowers. Even in Jacquin's time[95] it was recognized that it was a long and slow process, for he remarks that the time is twelve months to the dropping of the seedlings, and that it takes three months for the hypocotyl to appear at the top of the fruit.

While an opportunity was not given to observe this for *R. mangle* by the writer on account of the brevity of the laboratory season at Tortugas, some idea was gained of the relative rate of growth by marking the hypocotyl of very young seedlings with bands of India ink and measuring the distance of the ring from the apex of the fruit, as well as the spaces between other rings on the length of hypocotyl, after a period of a few weeks, June 11 to July 15. On the former date about 20 hypocotyls were marked in the above described manner with rings one centimeter apart. At the end of the time on July 15, during a return trip to Key West and Stock Island, where the trees were growing, it was found that twelve of the seedlings were still on the trees and had made various growths, viz., 5, 3, 5, 3, 6, 5, 3, 6, 5, 4, 5, 3 centimeters, or approximately 4.7 centimeters, growth in the thirty-four days which had elapsed.

[95] Jacquin, N. J., "Selectarum Stirpium Americanorum," 1763, p. 141.

A great deal of work has been done by Guppy[96] on plant dispersal and in one work he has devoted several chapters to the mangrove and on page 451 of the above book gives the "history of the reproductive process in *Rhizophora* from the fertilization of the ovule to the falling of the plantlet or seedling from the tree." He goes on to say: "I devoted great attention to this subject in the instance of *Rhizophora mangle,* being desirous of determining two points, in the first place as to whether there was any period of rest between the maturation and germination of the seed, and in the second place as to the period that elapsed between the commencement of germination and the fall of the seedling." "The principal change in the ovary for the first three or four weeks after fertilization is shown in its increased breadth. The increase in height is but slight during this period; and in fact after thirty days the ovary only added two millimeters to its original height of three millimeters. After this the growth of the fruit proceeds until the tip of the radicle pierces its summit, the fruit being then about eleven lines (2.8 cm.) long. *From the date of fertilization to the time the radicle pierces the top of the fruit a period of about fifteen weeks elapses.* (The fruit, it should be here remarked, continues to grow in length and breadth after the radicle has protruded, attaining a length of thirteen or fourteen lines (3.5 cm.) when the seedling or 'keimling' is ready to fall.)"

"It will be observed that there is no period of rest in the growth of the fruit up to the date of the protrusion of the radicle. It may also be shown that there is normally no pause between the epoch of the maturation of the seed and the beginning of germination or, in other words, that from the time of the fertilization of the ovule to the onset of germination there is no cessation in the process of growth of the embryo. That period of dormant vitality which almost all seeds pass through forms no normal feature in the life-history of this species of *Rhizophora.*"

In Guppy's more recent work[97] of 1917 in the West Indies and the Azores he gives a summary likewise of the period which elapses

[96] Guppy, H. B., "Observations of a Naturalist in the Pacific," Vol. II., 1906.

[97] Guppy, H. B., "Plants, Seeds and Currents in the West Indies and Azores," London, 1917.

between fertilization and the fall of the seedlings of the species in the former region and states it to be nine or ten months.

Before leaving this subject of morphology and histology, there are two anatomical features which deserve special mention and which occur in nearly every tissue of *Rhizophora*. These two peculiarities are the indioblasts or trichoblasts and the tannin cells. The trichoblasts were, according to Warming, perhaps first described by Decaisne,[98] who remarked their presence in a "root." They are perhaps better seen, however, in a hypocotyl, which if broken transversely the surface of the fracture is seen to be densely bristled with the tips of the thousands of idioblasts embedded in the intercellular spaces of the cortex, as well as the medulla and even vascular region (Fig. 2, Pl. V.). The most of the idioblasts in this organ, as well as those in stem and roots, are composed of four elongated and taper pointed branches joined in the middle by a short connection, the whole structure appearing as a letter *H* (Fig. 2, Pl. IV.). The idioblasts of the leaves, however, are more irregular and branched or even stellate in form with the branches ramifying among the cells. Sections of this type are seen in Fig. 1, Pl. V. In the older and more lignified tissues, as the stem and also in the hard calyx and ovary, the idioblasts more nearly resemble the stone cells of fruit pits and of the leaves of *Camellia* and *Osmanthus*, having the lumen almost entirely filled up. These structures, as Warming remarks, very soon render a razor entirely unfit for use in the preparation of histological material. The same author regards the function of the structures as mechanical in preventing shrinking and shriveling of tissues when exposed to the great heat of the sun. But as they are frequent also in parts which are not so exposed, as for instance the absorptive roots and the interior of the fruit and flower, etc., this theory of support against shrinkage due to heat is not necessarily true, but it may be conceded that their rôle is mechanical and they do support the large intercellular spaces found in some of the tissues. In discussing fibers and hairs, De Bary[99] says: "There occur in phanerogams fibers which are freely and

[98] Decaisne, J., *Annales des Sciences Naturelles*, 2, Series 4, p. 76, 1835.

[99] De Bary, A., "A Comparative Anatomy of the Vegetative Organs of the Phanerogams and Ferns," tr. Bower and Scott, pp. 130 and 220, 1884.

often abundantly branched and of a form which varies according to the special place of their occurrence. These usually occur in dissimilar lacunar tissue with their branches pushed into its interstices. In as much as these project like many-branched hairs into wide air-containing spaces (as *Rhizophora*) . . . and also occur in many tough leathery foliage leaves . . . they appear to serve as a strengthening apparatus for the tissue. De Bary further mentions their occurrence in the pith and cortex of *Rhizophora* (p. 220) but has overlooked them in other parts. He regards them as being closely related to sclerenchyma fibers and only differ from them in shape and distribution.

The tannin cells do not seem to have received so much attention from histologists as the idioblasts. Most investigators on *Rhizophora* have mentioned the occurrence of tannic acid in large quantities, but few have remarked on the localization of this substance. The large cells of the root-cortex, both of the aërial prop-roots and to some extent of the absorptive roots, are filled with large, rather polygonal cells, which contain tannin. The tannin in the cells appears as tiny brown granular masses, which stain a dense black when special preparations are made of tissues stained with copper acetate or ferric chloride. The pericycle region of the soft absorptive roots contains the most in the subterranean roots which perhaps have the least of any organ in the plant. In the leaves, as seen in Fig. 4, Pl. IV., the large special tannin cells are the first two layers of the hypodermis, just beneath the epidermis. The pericarp of the fruit and even the young embryo also show notable qualities of tannin in specially prepared material. The rôle played by tannin in the economy of *Rhizophora* will be discussed in the next chapter. The largest amount is found in the cortex of the stems and aërial roots.

Physiology.

The physiological relation of *Rhizophora* to its various media of growth is perhaps the main subject of consideration in this paper. The idea of work on the physiology, as expressed by transpiration and absorption, had its inception in the interest aroused by the apparent ability of these trees to grow almost equally well in either fresh or salt water. The transpiration as affected by the climate was not of paramount interest, as that has received much attention by such investigators in warm climates as Haberlandt,[100] Holtermann,[101] Giltay,[102] Wiesner,[103] Unger,[104] Stahl[105] and many others. As mentioned before, the *Rhizophora* trees grow along the shores of bays and the mouths of rivers, where the above conditions are found, so an attempt was made to study the effect of this environment as evidenced by the transpiration rates of plants in similar, but controlled conditions. At the same time various soils were experimented with.

Seedlings of the first or second year's growth were secured at Cayo Agua, one of the lower Florida keys, and brought to the Tortugas Laboratory on the laboratory yacht, a distance of about ninety miles. The seedlings were found in natural beds under the parent trees along the shores of this island. During the transit some of the seedlings died, but enough were saved to start several hundred cultures. These cultures were made in large heavy glass beakers about ten inches in diameter.

These seedlings were placed in a jar, in soil and mud, etc., according to the kind of culture, and the jars filled up with water. The water was of a definitely known concentration of sea water or pure rain water from the laboratory cisterns. The soils ordinarily used were either the native Tortugas sand, a very coarse calcareous sand composed of the remains of calcareous algæ, corals, echinoderms, gastropods, etc., or a reddish soil brought down to the laboratory from the vicinity of Maplewood, N. J. This latter soil appeared to be composed of a disintegrated, ferruginous sandstone.

[100] Haberlandt, G., "Ueber die Groesse der Transpiration im feuchtem Tropenklima," *Ebenda,* Bd. XXXI., 1898.

[101] Holtermann, K., "Die Transpiration der Pflanzen in den Tropen," *Sitzb. der kgl. preuss. akad. des Wissen. Berlin,* Bd. XXX., 1902.

[102] Giltay, E., "Die Transpiration in den Tropen und in Mitteleuropa," II., *Ebenda,* Bd. XXXII., 1898.

[103] Wiesner, J., and Pacher, J., "Ueber die Transpiration entlaubter Zweige," *Oesterr. Botan. Zeitschr.,* Wien, Bd. XXV., 1875, p. 145.

[104] Unger, F., "Neue Untersuchungen ueber die Transpiration der Pflanzen," *Ebenda,* Bd. XLIV., 1862.

[105] Stahl, E., "Einige Versuche ueber Transpiration und Assimilation," *Botan. Zeitung,* Bd. LII., 1894, p. 117.

A few cultures were also potted in a dark, bluish, gray mud taken up from the bottom of the moat at Fort Jefferson on the adjacent Garden Key. This mud, which seems very similar to that of typical mangrove swamps, gets its dark color from decaying organic matter in it and is also heavily charged with hydrogen sulphide arising from the decomposition, just as is the ordinary mangrove swamp mud.

Some of this mud was boiled to drive off the gas and other cultures were made of the unboiled mud to learn if there might be a difference in the rate of transpiration.

The water concentrations used in the soil experiments were pure salt water and 50 per cent. salt water.

Technique.

The methods of getting at the rate of transpiration which seemed the most feasible considering the available supply of material was that of Stahl. This method, while only a colorimetric method and hence not recognized as so exact as are perhaps volumetric methods, gave very interesting results with a few modifications to suit the conditions obtaining in the laboratory. A Ganong leaf-clasp was used for the transpirometer. The indicators for this little instrument are discs of Swedish filter paper saturated in 4 per cent. cobaltous chloride solution. These disc are inserted in the rings inside the thin glass sides of the instrument which is then clamped on a rod stand and the apparatus placed beside a culture jar. Full-grown leaves of about the same size on plants of the same age were used for tests. A small difficulty was encountered in the high humidity content of an island and tropical climate atmosphere, since the indicator discs necessarily had to be absolutely dry. This difficulty was overcome by keeping the discs in a calcium chloride desiccator of large size which conveniently held the whole instrument with its ball-and-socket adjustable arm. In making tests, the paper discs were placed in the clasp and dried over an alcohol flame until the characteristic pink color of the paper at ordinary atmospheric conditions was replaced by a deep blue of absolute dryness. The whole clasp was then quickly placed in the desiccator, which was cooled artificially by an ice chamber about it. This was found necessary to expedite the taking of tests, as the heat absorbed by the apparatus during the drying had a vitiating effect on the transpiration experiment unless cooled, and if allowed to cool to the room temperature slowly, too much time was lost between tests. After a minute or two, the apparatus, sufficiently cooled and dry, was quickly removed from the desiccator and clamped on the upright rod support beside the culture jar, the selected leaf placed in the clasp and the screws slightly adjusted to press the sides of the clasp on the surfaces. By a stop watch the time was then noted that was required to change the color of the indicator disc to a uniform pink, due to the effect of the moisture transpired through the stomata and epidermis of the leaf. As there are no stomata on the upper surface the change in color for the disc on the upper side of the leaf always lagged in the time interval from 65 to 80 seconds behind the lower or stomatal side. This interval was constant for nearly all tests and for this reason only the lower-side indicator was used for the records. An error in calculating the time interval required to effect the change in the indicator occurs in the loss of time required to adjust the instrument on the plant, during which the atmosphere has an opportunity, for a few seconds, to get in its influence on the instrument, but the transfer from the desiccator to the plant becomes routine after a few hundred tests and this time error of a few seconds may be disregarded, as it is constant for all the tests.

The successive tests were made at one time on each culture jar, separate leaves, one each, of the three plants in the jar being used. The time of taking the tests was as far as possible made in the middle portion of the day and every effort was made to avoid jarring or shocking the plants just before or during a test, on account of the accelerating effect of shock on the transpiration rate. The records were all marked in notebooks and the average taken for the three tests on one culture jar.

The cultures were kept on large tables holding about thirty jars in the laboratory, which was open on all sides and contained ventilator trap doors in the roof which were propped open during the day. The plants were thus sheltered from the direct rays of the sun and rain. However, during the long, still, calm days of June and July there is very little atmospheric variation in the Tortugas climate. The greater part of these two months is made up of clear, sunny days with almost no wind. The average wind velocity for the region, according to the U. S. Weather Bureau Records from Key West, is 9.6 miles per hour for the year, but most of the gales occur in the fall and winter months, September and October being called the "hurricane months."

The average temperature for the year is 76.8° F. with a maximum of 88° F. and a minimum of 77° F. during the months in which these tests were made, while the average relative humidity for the whole general region is about 73 per cent.

In both the soil and the water concentration series of experiments it was found advisable to siphon off the water from each culture jar daily. In doing this, two objects were attained—a fresh supply of water containing the various gases, etc., in solution was furnished the roots of the plants, simulating the tidal action of the sea in the natural beds in the mangrove swamps and also by this means the mosquito larva were removed to a large extent, the cultures of plants in fresh water and the higher dilutions of salt water being an ideal place for the breeding of mosquitos if left undisturbed.

In the water concentration series of cultures several hundred seedlings were potted in the jars similar to the above described soil experiment cultures. The soil used however to anchor the seedlings was uniform for all the series, that is, only the Tortugas shell sand was used.

The water concentrations employed for the series were as follows:

Series *A*—100 per cent. fresh water.
Series *B*— 75 per cent. fresh water.
Series *C*— 50 per cent. fresh water.
Series *D*— 20 per cent. fresh water.
Series *E*— 10 per cent. fresh water.
Series *F*— 5 per cent. fresh water.
Series *G*—100 per cent. salt water.

In 1915 a series of cultures was made on hyperconcentrated sea water of 140 per cent. concentration. The transpiration rate records for the culture showed a very slow rate of transpiration and in fact the whole metabolism of the plants was so retarded that the plants slowly yellowed, dropped the leaves and died after a few weeks. The rate on the basis of Stahl's method was 5.66, *i. e.*, approximately there was required 5.66 minutes to change the indicator of the transpirometer.

In addition to the cultures in water, there was a series planted in shell sand and merely kept moist with salt water, but also kept in the laboratory sheltered from the direct rays of the sun, wind and rain. Another series, however, was placed in boxes of sand, merely kept moist but placed on the landing dock of the laboratory in full glare of sun, etc. This situation most nearly approached the living conditions of *Rhizophora* seedlings drifted up on the beaches of the Tortugas Islands. As there are no mangroves in these islands except two young trees in a very sheltered position on Garden Key, an inquiry into the physiological behavior of these drifted plants was attempted to learn why the mangrove does not survive in this group. This subject will be discussed in the light of the above experiments in the chapter on ecology. However, it suffices to say here that the hard conditions of these cultures proved too much for the seedlings and one pair of tiny leaves would unfold after another with very short internodes and each pair would successively be burned up by the intensely hot sun and the glare of the reflection of the white sand in which they were planted together with the greatly reduced absorption from the merely moist, coarse, porous substratum. After a month of this heroic attempt at growth, the seedlings succumbed when the reserve food in the hypocotyl was exhausted, no foliage being put forth during their brief existence that attained sufficient size on which to take transpiration rate records.

In a previous season at Tortugas a number of cultures was made of seedlings planted in jars of the Fort Jefferson moat mud, but the water was not siphoned from these cultures daily and a fresh supply put on, so that in a short while the water became so charged with H_2S gas that it produced a toxic effect on the plants, from which they soon died. This toxic effect of the hydrogen sulphide gas was of course due to the higher concentration of the acid solution, the ionization being H + and HS —. In cultures of which the mud had been previously boiled to drive off the gas, the ultimate death of the plant was only postponed as the further decomposition of the organic substances in the mud soon produced enough H_2S to again render the culture toxic. It is presumed that the constant action of the waves and the daily tides so dilute the gas in the natural mangrove beds that the toxicity is removed. Many factors enter into this question, as the precipitation of sulphides by the inter-action of bases in the sea water, action of the products of denitrifying basteria in large quantity in the tropical waters and other complex chemical phenomena. On account of the early death of the plants no records could be made of these cultures, or at least in sufficient number to warrant any definite conclusions. All the cultures were allowed about three weeks to adjust themselves to the changed conditions in the laboratory from those of their natural beds, before any records were taken. By this adjusting process time was also given to eliminate any seedlings which were not healthy or showed signs of not reacting normally.

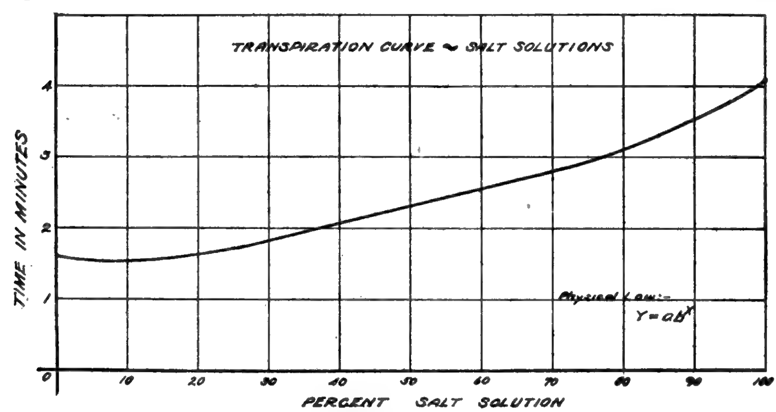
Lastly a series of two hundred young trees was planted on a small mound of mud in the moat at Fort Jefferson during the summer of 1915. The top of this little mound of debris was only moistened at the highest tide and this exposed part was largely composed of coarse broken corals and shells, pieces ten to fifteen centimeters in dimension. The little plants about one half meter high were set at varying levels on the mound, some on top in the dry coarse debris and the lowest almost submerged even at low tide. In 1916 on the writer's return to Tortugas only twelve of these trees were alive, the winter storms had so disturbed the mound that many were washed away, the remaining ones were growing and apparently in good condition. The significance of the experiment will be considered under the ecological relations.

Transpiration Records.

The result of about two thousand records made in both seasons of the years 1915 and 1916 are now set forth. The intervals between the stop-watch registrations were all calculated for each test, in minutes and fractions of minutes, and these intervals then averaged for each set of three tests on a culture, and then general averages made of the series and finally all the sets of records made at different times on each series were averaged for each series. These final averages, as expressed for each series, are as follows, in the Water Concentration Class of experiments.

Series *A*—100 per cent. Fresh—1.6 minutes.
Series *B*— 75 per cent. Fresh—1.7 minutes.
Series *C*— 50 per cent. Fresh—2.4 minutes.
Series *D*— 20 per cent. Fresh—2.8 minutes.
Series *E*— 10 per cent. Fresh—3.2 minutes.
Series *F*— 05 per cent. Fresh—3.9 minutes.
Series *G*—100 per cent. Salt —4.1 minutes.

By arranging the data in curves, a graphic idea may be gained of the rates of transpiration of these plants in their various concentration cultures, and by applying certain mathematical formulæ definite laws may be deduced for the phenomena. In a preliminary report on the work[106] before the data were all tabulated a formula was used with almost the same result as that given in the following curve.



Graph No. 1.

But a better formula appears to be the one here given $y = ab^x$. In the curve the time intervals in minutes are arranged as ordinates

[106] Bowman, H. H. M., "Physiological Studies on *Rhizophora*," *Proc. Nat. Acad. Sciences*, Vol. 2, No. 12, Dec., 1916, p. 685–688.

and the concentration percentages as abscissæ. That is, the curve indicates the period of time required by the plants to transpire equal quantities of moisture when planted in varying concentrations of water. When growing in fresh water, the plant transpires the unit quantity of moisture in 1.6 minutes, when growing in 100 per cent. salt water, to transpire the same quantity there is required 4.1 minutes. The effect then of increasing the salt content is to retard the time of equal transpirations of moisture. The physical law expressing this progressive increase of time interval, necessitated by the increasing concentration, has the mathematical form $y=ab^x$. That is the time, y, for a plant to transpire a unit quantity of moisture when the percentage of salt solution is x, is equal to constant b (approx. $=z$) multiplied by a constant, b (approx. $=1.79$), raised to x power. For the percentage concentrations used in this work the rate of transpiration then varies directly with the concentration.

The result of these experiments can only in a general way be compared with those of other workers on transpiration, because there are too many factors which were necessarily quite different in the materials and methods. The plants themselves are specially adapted to a water environment and protected against an excessive transpiration, while the ordinarily high salt concentration of the medium of growth makes absorption difficult. The rather high humidity of the air tends to reduce transpiration, while the heat and intense light of their habitat helps to increase it. The general results, however, do correspond with the experiments of Ricome[107] on plants of *Malcomia maritima* and *Alyssum maritimum*. This investigator cultivated the plants in normal soil and salty soil and transferred to plain Knop's nutrient solution and in Knop's solution to which one per cent. of salt (NaCl) was added. While the general temperatures and humidity were not the same, the light intensity was rather diffuse as in the present studies, but the methods of measuring the transpiration differed. Ricome found that both the absorption and transpiration were less in the plants grown in

[107] Ricome, H., "Influence du Chlorure de Sodium sur la Transpiration et l'Absorption de l'Eau chez les Vegetaux," *Comptes Rendus de l'Acad. des Sci. Paris,* T. CXXXVII., 1903.

salt soil than in the sodium chloride free soil and likewise for the Knop solution cultures. He finds that NaCl externally makes absorption through the roots difficult and that contained in the plant's tissues lessens transpiration. Other workers have also experimented with plants in solutions of different salts, as Burgerstein,[108] who grew plants in borax solutions of one to three tenths per cent. concentration and by comparison of the transpiration of similar plants in distilled water, he found that those in the borax solution transpired much less, but an objectionable feature in those experiments was the highly toxic effect of boric acid and borates, as Peligot[109] has shown, since the plants began to droop and die on the second day of the experiments.

Cuboni[110] who experimented with sprinkling branches of various trees and shrubs with thin solutions of calcium hydroxide and measuring the transpiration by photometric methods found that this substance had no effect, but as there was no absorption here the results cannot be compared. The available water for absorption is naturally the factor most concerned in transpiration and as the increasing density of the solutions makes osmosis and absorption more difficult the corresponding phenomenon is decreased in amount. Not all salts in solution however have this physical effect, if the works of Sachs[111] and Senebier[112] may be considered. The effect is also partly chemical, and the physical osmotic relations cannot be supposed to be due to the density of the solutions alone, thus Senebier, who was an earlier investigator on the subject, states that aqueous solutions of sodium sulphate, potassium nitrate and potassium tartrate occasion an acceleration in the water movement in plants, while Sachs claims a retardation for ammonium sulphate and sodium chloride. Both the experimenters worked with twigs and so the action by root absorption is not considered and the assump-

[108] Burgerstein, A., "Die Transpiration der Pflanzen," p. 146, 1904.

[109] Peligot, M., *Comptes Rendus de l'Acad. des Sci. Paris,* t. 83.

[110] Cuboni, G., "La Transpirazione e l'Assimilazione nella Foglie trattata con Latte di Calci, Malpighia," Vol. 1, p. 295, 1887.

[111] Sachs, J., "Ueber den Einfluss der chemischen und physikalischen Beschaffenheit des Bodens auf die Transpiration der Pflanzen. Landw. Vers-Stationen," Bd. I., 1859, p. 203.

[112] Senebier, J., "Physiologie Vegetal," Geneve, 1800.

tion may be made that the effects were more chemical than physical and so according to Sachs it would seem that sodium chloride has a retarding chemical effect in addition to the retardation of its physiological action in the osmosis of root absorption. However, as Burgerstein says (p. 152), neither investigator carried on a large series of experiments and Senebier moreover was only concerned with the amount of water as indicated by the absorption.

In connection with measuring transpiration of plants in various concentrations of salts as the series in this paper, Burgerstein[113] has made a series of interesting measurements, partly with woody twigs and partly with rooted seedlings in 0.10 to 1.0 per cent. solutions of the following nutrient salts: potassium, calcium and ammonium nitrates, magnesium and ammonium sulphates, potassium phosphate and potassium carbonate. In very dilute solution, .05 to 2.5 per cent., the transpiration, when compared with that of plants in distilled water, is increased, the higher the concentration of the solution is increased, until at a definite concentration a maximum is reached. For the corn plant (*Zea mays*) this is about 2.5 per cent. A further interesting feature of Burgerstein's work is that this maximum transpiration-concentration is lower for the alkaline salt solutions and higher for the acid reacting salts than for the maximum point of nutrient salts with a neutral reaction. In solutions above this degree of concentration the transpiration steadily declined, so that a general rule could be deduced that in .3 to .5 per cent. solutions the transpiration was already less than that of plants in distilled water.

As most of the cultures of the mangroves used in the experiments described in the present paper were grown in much higher concentrations than those of Burgerstein, the optimum concentration of very dilute solutions could not have been detected, or its climax of transpiration increase observed. However, in the curve No. 1 there is seen a slight sag as the percentage increases from fresh water toward the 10 per cent. solution. This may be interpreted as the slight increase in transpiration (here expressed in time rate)

[113] Burgerstein, A., "Untersuchungen ueber die Beziehungen der Nährstoffe zur Transpiration der Pflanzen. I. Reihe," *Sitzb. der kais. Akad. der Wiss. in Wien,* Bd. LXXXIII., p. 191, 1876.

due to the dilute solution, before the optimum concentration is reached, after which it showed a steady decrease in transpiration, or as here expressed in an increase in the time interval. In addition to these results as found by Burgerstein, Sorauer[114] noticed that in cultures kept in solutions of concentrations above this optimum or maximum point, not only was the transpiration decreased but the production of dry substance in the plants as well. The whole result of the series of experiments may be said to consist in showing the transpiration relation of the mangroves growing in solutions, as plants specially adapted to such halophytic aquatic conditions, that for increases of salt concentration in their media of growth there is a corresponding definite retardation of the transpiration rate which may be expressed in a mathematical formula.

Transpiration of Soil Cultures.

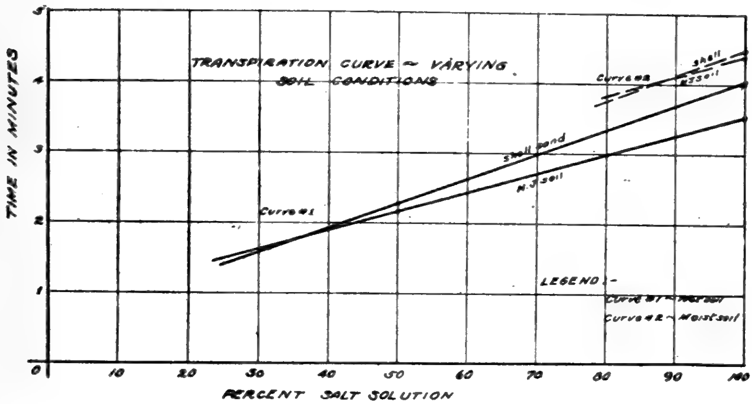
The second series of cultures as outlined under the description of the methods of handling the material is the series of soil experiments. The two soils above mentioned were used and two conditions of soil moisture content employed, *i. e.*, plants in boxes of soil merely moistened with water, and plants in jars kept flooded with water. The method of taking the records and the laboratory conditions as to light intensity, atmospheric humidity and temperature were the same as for the previous experiments, as was also the procedure of siphoning off the water from the jars and renewing the water daily to keep down the mosquito larvæ.

The factors entering into this series of experiments are really much more complex than those in the first set of cultures as that involved only the salt concentration of the water, the soil (shell sand) used to anchor the plants being in all the cultures the same. But with the use of two soils, the one of a complex chemical nature (New Jersey soil), and the two sets of soil moisture contents, the problem is more complicated. The results of the experiments are set forth in Graph No. 2.

The influences on the transpiration are here due perhaps more to the chemical action of elements in the solution than to physiolog-

[114] Sorauer, P., "Studien ueber Verdunstung, Forsch. an der Gebiet der Agrikultur-Physik von Wollny," Bd. III., 1880, p. 351.

ical effects of varying concentrations. As will be noticed the above graph shows two double curves—No. 1 for the flooded soil and No. 2 for the soil merely moistened. An interesting feature of the two curves considered together is that there is illustrated very clearly the relation of transpiration to soil moisture content. Stenström[115] expressed this relation in a principle which shows the connection



Graph No. 2.

between the soil moisture content, the atmospheric humidity and the transpiration of plants thus. $\frac{S.M.}{H} = T$, in which equation the letters stand for the above factors in the order named. Many physiologists have shown the relation between available water and transpiration and notable among these is Aloi,[116] whom Burgerstein quotes (p. 137, l. c., Bibl., 107) as showing that with a normal moisture content the transpiration was less than that of plants in a saturated soil. "Ueber den Einfluss der Bodenfeuchtigkeit auf die Wasserabgabe der Pflanzen stellte auch Aloi viele Versuche an, welche lehrten dass die Transpiration bei einer 'umidita normale' geringer war als in einem 'terreno molto umido.'"

[115] Stenström, K., "Ueber das Vorkommer derselben Arten in verschiedenen Klimaten an verichiedenen Standorten mit besonderer Berucksichtigung der Xerophil ausgebildeten Pflanzen," *Flora*, Bd. LXXX., p. 117, 1895.

[116] Aloi, A., "Influenza dell' Umidita del suolo sulla Transpiratione delle Piante Terrestri," *Atti dell' Acad. Gioenia di Science Nat. Catania*, Ser. 4, Tome VII., 1894.

Curve No. 2, showing the moist soil transpiration, is very short and unfortunately only about two hundred records were made on this series of cultures. The same characteristics are shown for both curves and the lines are parallel. The two sets considered together show clearly that the rate of transpiration depends upon the amount of moisture in the soil available for absorption by the roots.

Curve No. 1 shows three things—first that mangrove seedlings planted in dilutions over 35 per cent. salt transpire more rapidly when planted in New Jersey soil than in shell sand. Second, that similar seedlings under the same conditions in dilutions of 35 per cent. salt water transpire at the same rate when planted in either soil and third, similar seedlings planted in water less than 35 per cent. salt water transpire more rapidly when growing in shell sand. These three facts can only be explained by the chemical action of constituents of the soils reacting with those of the water. The balance of solution for these constituents is evidently reached at a concentration of about 35 per cent. salt water in the cultures indicated by curve No. 1, while the same condition of chemical equilibrium is apparently reached at a concentration of 88.5 per cent. salt water in the cultures of plants in merely moistened soil. While it is not known what the chemical constituents of the soils are, the water has been very carefully analyzed by the chemist of the U. S. Geological Survey for the Laboratory Director, Dr. A. G. Mayer.[117]

The explanation of the interaction of the chemical constituents of these two soils with the elements of the salt water in the varying concentrations used in these experiments is really a complex problem to be taken up by the chemist and physicist. However, it may be suggested with propriety here in a paper dealing with more purely botanical phases that the above interaction of the various elements in the soils and salt water during ionization in the solutions proceeds along the general action shown in the addition of chemicals to sea-water, discussed in a recent paper by Haas.[118] In this work by

[117] Mayer, A. G., Annual Report of the Director of the Dept. of Marine Biology, *Carnegie Inst. of Washington, Year Book* for 1910, p. 122.

[118] Haas, A. R., "The Effects of the Addition of Alkali to Sea-Water upon the Hydrogen Ion Concentration," *Jour. of Biol. Chem.*, Vol. XXVI., No. 2, Sept., 1916, p. 515.

Haas, strong sodium hydroxide solution (2.4813 N) was added to sea water in small amounts and titrated by means of the gas chain and the results given in a curve (p. 517) and in explanation of this curve, the investigator says: "The titration curve shows that on adding alkali to sea water the hydroxyl ion concentration at first rises rapidly and then very slowly until the magnesium hydrate has all been precipitated. After this further additions of alkali cause a more rapid rise in the concentration of the hydroxyl ion, but this rise is soon checked by the precipitation of calcium hydroxide. After the calcium hydroxide is all precipitated further addition of alkali will cause a corresponding increase in the concentration of the hydroxyl ion."

While we are not in this paper concerned primarily with the concentration of the hydroxyl ion, the formation of the successive precipitations proves very interesting and it is phenomena of this sort which very likely cause the transpiration of the seedlings to go on more actively in dilutions over 35 per cent. salt water when planted in New Jersey soil and also to accelerate the transpiration when planted in Tortugas shell sand in concentration less than 35 per cent. salt water. This latter group of results may be logically explained by the hypothesis that with the atmospheric humidity and temperature conditions the same, the transpiration would be accelerated in the less highly concentrated solution, according to the general law of transpiration, since the relatively pure calcium carbonate composition of the shell sand is less soluble than the more complex New Jersey soil. It is also less finely comminuted than the latter soil and as Reed[119] has shown in the transpiration of wheat seedlings that calcium carbonate added in small amounts to water cultures or soil cultures has an accelerating effect, then also the dilution of the sea water being less than 35 per cent. there are smaller amounts of salt in it, so that on the whole the behavior in regard to transpiration of these cultures is normal for the conditions.

The acceleration, however, of the rate of transpiration of cultures in New Jersey soil and concentrations over 35 per cent. salt

[119] Reed, H. S., "The Effect of Certain Chemical Agents upon the Transpiration and Growth of Wheat Seedlings," *Bot. Gaz.*, Vol. XLIX., 1910, p. 81.

water must be the manifestation of some such principle demonstrated by Haas's experiments.

The Physiology of the Prop Roots.

A small series of experiments was made at Miami, Fla., on the transpiration through the lenticels of the pneumatophore or prop roots of older *Rhizophora* trees. Some of these trees were growing along the shores of Biscayne Bay and some along the banks of the Miami River. The salt concentration of the bay is not as high as the ocean outside, due to the effect of the streams which empty into it and the river, of course, is approximately fresh water; however, the tide produces a noticeable effect in the river and for the comparatively short distance up the river that the mangroves extend there is perhaps a commingling of the fresh water of the river and the salt of the tide; however, the densities of both the bay and the river were measured with the hydrometer and the measurements will be discussed under the ecology.

Essentially the same technique was employed in taking these prop root transpiration records as that used for the leaf records made at Tortugas. The leaf clasp naturally could not be used conveniently for taking records from the roots, which are cylindrical in shape and of varying thicknesses. To overcome the difficulty of adjusting the transpirometer to this cylindrical surface a modified transpirometer was devised by the writer and made for him by a firm of instrument makers. This device consists of two curved glass sides held in a curved metal frame which is constructed with two grooves along the upper and lower edges respectively. Into these grooves the edges of the indicator paper is slipped and held in place inside the curved glass surfaces. The two curved glass sides are held together on one side by a neat but strong spring, which opens the instrument and permits its being clasped about a root when the two discs of hard rubber are pressed together behind the spring. The indicator paper was inserted and dried over the flame and put into the calcium chloride desiccator. When cool the instrument was adjusted to the root and the record taken. As no control could be had over the concentration of the substratum and water concentration in which these old trees were growing, the results here given merely illustrate the fact that these aërating or prop roots actually do transpire water vapor and that there is a perceptible difference in the rates of transpiration of trees growing in the comparatively fresh water of the river and those in the more highly concentrated salt water of the bay. The average for the series of river tests was 2.37 minutes required to change the indicator in the modified transpirometer, while the bay tests average was 3.66 minutes.

These prop roots are really aërating roots as Karsten[120] and Schimper[121] and others have shown in their experiments on other trees of the mangrove habit. In the activity of gas exchange as performed by aërating roots, there is, of course, considerable moisture transpired. This function of aëration of roots is well discussed by Karsten for the prop roots of *Bruguiera eriopetala* on experiments which he conducted at the Buitenzorg Botanical Garden. These experiments were very elaborate and were done in the field, for which a cement base had to be constructed in the mud of the swamp and bell jars and glass apparatus fitted on the roots *in situ*. Manometers were used to regulate pressure and the amounts of CO_2 exchanged in respiration were measured by precipitating it with barium hydroxide as barium carbonate and then back-titrating it with oxalic acid and phenolphthalein. These experiments established the fact that the roots do function as respiratory organs for definite areas of the plant body and regulate the air supply for these trees whose roots are sunk in the poorly oxygenated and water-saturated mud and slime of the swamp, and they also help to regulate the fluctuating conditions produced by the tides when part of the tree is submerged, and at other times exposed. Similar experiments and observations by Goebel[122–123] on *Souneratia acida* and *Avicennia officinalis,* and by Schenck[124] on *Avicennia tomentosa* and

[120] Karsten, G., loc. cit., p. 41.

[121] Schimper, A. F. W., "Botanische Mittheilungen aus dem Tropen," Heft 3, Die Indo-malayische Strandflora, 1891, p. 37.

[122] Goebel, K., "Ueber die Luftwurzelne von Sonneratia," *Ber. der Deut. Bot. Gesell.,* IV., p. 249.

[123] Goebel, K., "Pflanzenbiologische Schilderungen, I. Südasiatische Strandvegetation," p. 113.

[124] Schenck, H., "Ueber Luftwurzeln von *Avicennia tomentosa* und *Laguncularia racemosa,*" *Flora,* 1889, p. 83.

Laguncularia racemosa have broadened the knowledge of these organs.

Before leaving this subject of transpiration, mention may be made here of some potometric measurements. At the Tortugas Laboratory a few potometer records were taken with shoots of *Rhizophora* to form some actual quantitative estimate of the water transpired through the leaves. Shoots of an average weight of 3.2 grams were used and the same conditions of humidity, light intensity and temperature were arranged as for the transpiration records above mentioned. It was learned that the average transpiration of these shoots was approximately one cubic centimeter in thirteen and four tenths minutes. This data, however, has no direct relation to the data of the bulk of the experiments performed.

Biochemical Experiments and Tests.

As mentioned in the prefatory statement attached to this paper, certain biochemical investigations were carried on at the Tortugas Laboratory on the cellular contents of the *Rhizophora* seedlings, the two substances being dextrose and tannic acid. The purpose in undertaking the investigation was to gain some idea, if possible, of the rôle played by the tannin in the physiology of the mangrove, since this occurs in such large amounts in the plant's tissues. Several authors have suggested the various functions played by tannin in the plant's economy; Wiesner, for instance, believed that tannin is an intermediate product in the formation of resin, since it has been observed that in *Pinus,* as the tannin decreases in the spring, *i. e.,* during the season that the resin is most abundant, there is a corresponding increase in the resin. Basset[125] has suggested that the tannin content of fruits more particularly depends on certain enzymes. Buignet,[126] in his work on the banana, argues that from the diminution of starch and tannin as the truit ripens, there is ground for supposing that tannin assists in the formation of sugar. On the other hand, Gerber[127] in his studies on the relation of the

[125] Basset, B., Ref. Haas and Hill, 131.
[126] Buignet, A., *Ann. de chem. et de Phys.,* III., Ser. I., LXI., p. 281, 1861.
[127] Gerber, C., *Ann. de Sci. Nat.,* IV., 1897, pp. 1–280.

same substances in the ripening fruits of the Japanese persimmon considers the tannin decrease in the ripening process to be due entirely to the oxidation of tannin and that it does not at all contribute to the formation of carbohydrates. His reason for this conclusion is that in the conversion of tannin into carbohydrates more carbon dioxide would have to be liberated than oxygen absorbed, whereas in fruits the relation is the reverse.

Moore[128] contributes the idea that tannins may play an important part in the lignification of cell walls. Drabbel and Winterstein[129] make the suggestion that their rôle is important in cork formation, while Van Wisselingh[130] has given the latest suggestion in that they help materially in the formation of cellulose in some plants as *Spirogyra*. The bulk of facts known, however, about tannins do not lead one to suppose that they are used up in the plant generally since they are left in parts discarded by plants, as fallen leaves and not translocated, but even this does not assume much significance since sugar and starch, etc., are also often found in fallen leaves, and as Haas and Hill[131] remark, "A consideration of other facts does not tend to support the idea of tannin being of the nature of a reserve food." "Hillhouse,[132] for example, found that if a fuchsia having an abundant supply of tannin be grown in the dark there is no diminution in the substance in question."

Notwithstanding the conflicting opinions regarding tannin and the rôle it plays in the plant's physiology, it was decided to make a series of experiments on the tannin of the hypocotyl of young seedlings, since in these storage organs it occurs in such great abundance together with starch. With the hypothesis that perhaps the tannin of the hypocotyl is broken down to form sugar as the growth of the seedling proceeds, by the action of some enzyme as tannase, tests were made for such an enzyme and also on the relative reaction for dextrose and tannic acid. About ninety-five tests were

[128] Moore, A., *Journal Linn. Soc.*, London, Bot. 27, 1891, p. 527.

[129] Drabbel, A., and Winterstein, E., *Biochemical Journal*, 2, 1906, p. 96.

[130] Van Wisselingh, C., *Konen Akad van Wetensch. Amsterdam*, 1910, p. 685.

[131] Haas, P., and Hill, T. G., "Chemistry of Plant Products," London, 1913, p. 219.

[132] Hillhouse, B., *Midland Naturalist*, 1887–1888.

made by such methods as suggested by Abderhalden,[133] Euler,[134] and more particularly Thatcher,[135] who endeavored to isolate the enzyme, tannase, from several varieties of apples.

Methods.

The fresh green hypocotyls were cut up and weighed in ten-gram portions, *i. e.,* ten grams from each hypocotyl. These portions were then ground to a consistency of coarse saw dust by pounding in a mortar with a little distilled water. Each portion was then digested with 50 c.c. distilled water in a beaker on a water bath at 40° C. for a half hour and the extract pressed out. The semi-dry mass that remained was then further digested with 50 c.c. of distilled water, the extract pressed out and added to the first extract. This extract of 10 Gm. of hypocotyl was then filtered and divided into two equal portions and each one made up to 100 c.c. by the addition of distilled water. One flask of the filtrate was boiled several minutes, then to each flask of filtrate a tenth gram of Merck's standard tannic acid was added and both placed in an incubator at 40° C. for twenty-four hours. After allowing this interval for the enzyme to effect a change in the tannin content in the unboiled flasks, both the control flasks and the unboiled ones were treated with four drops of concentrated ferric chloride to cause precipitation of the tannin and the characteristic change in color. In some of the tests the precipitate, bluish black in color, was filtered off and then carefully washed, desiccated and weighed, but in all these tests there was not any evidence to indicate the presence of the enzyme tannase in the hypocotyl of these plants. The color reactions for the boiled was just as dense as those for the unboiled portions, while the weight of the desiccated precipitates likewise showed no appreciable difference, so the absence of the enzyme is apparently substantiated.

Simultaneously with the performing of the above experiments a complementary series of investigations was made to show the

133 Abderhalden, E., "Handbuch der Biochemischen Arbeitsmethoden," Berlin, 1910.

134 Euler, Hans, "Allgemeine Chemie der Enzyme," Wiesbaden, 1910.

135 Thatcher, R. W., "Enzymes of Apples," *Jour. Agri. Research,* 1910.

relation between the amounts of dextrose and tannic acid in the hypocotyls of different ages. A condensed report of this work was given in an earlier paper;[136] however, the methods, slightly more in detail, may be appropriately described here. The seedlings, as collected in the beds, were of assorted sizes, but all presumably of the crop of the spring or late winter months of the same year. These seedlings were carefully measured in regard to the length of the hypocotyl, stem, internodes, size of leaves, etc., and then assorted into groups of successively large growths. In making the extracts, ten grams of hypocotyl seedlings of uniform size were ground up in a morter with a little distilled water, just as in preparing the tannase tests. Some extracts were made by boiling and others by infusion, but no difference in strength was noted. After pressing through cheese cloth each extract was made up to the original fifty cubic centimeters with distilled water. The extracts at this stage were of a rather thick syrupy consistency and a clear orange red in color. To each fifty cubic centimeters then was added five c.c. of a saturated solution of lead acetate, a few drops at a time, this precipitated the coloring matters, phlobaphenes, etc., in the extracts and after standing four hours, each extract was filtered by means of a suction filter. The clear straw-colored filtrates were then treated with a steady stream of hydrogen sulphide gas for about ten minutes. This precipitated the lead as heavy black lead sulphide. After filtering off the lead sulphide and boiling to remove any H_2S remaining in the extracts, the filtrates were tested, one drop of cresol being added to each extract to prevent the growth of moulds.

As quantitive analyses were not feasible at Tortugas, colorimetric methods of testing were resorted to. For the testing for dextrose, Huizinga's Test was used. This is a reduction test, which was found to work very well with the *Rhizophora* extracts. One c.c. of the extract was pipetted into each of a series of test tubes and diluted with five c.c. of distilled water, then one c.c. of 0.1 KOH solution was added and one c.c. of a saturated solution of ammonium molybdate was pipetted also into each tube. The tubes were then boiled over an alcohol flame for 1.5 minutes and then to

136 Bowman, H. H. M., Report on Botanical Investigation at Tortugas Laboratory, Season 1916, *Carnegie Inst. of Wash. Year Book*, No. 15, p. 188.

each one was quickly added ten drops of concentrated HCl. A deep blue color, in varying degrees of intensity dependent on the amount present, indicated the dextrose.

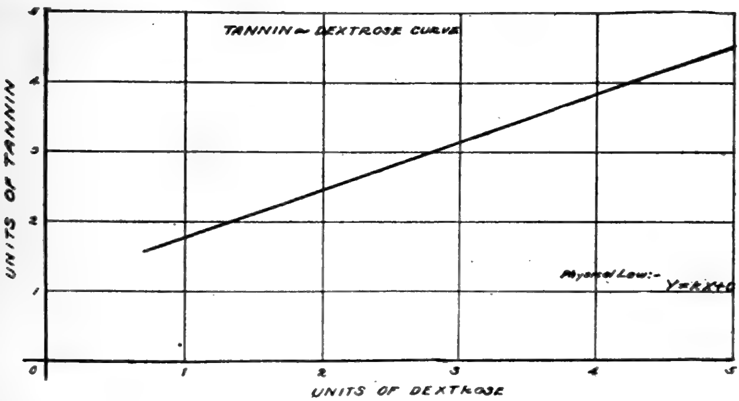
The tannin was tested for by means of Hager's Test, after experimenting with various tests, as Gayard's, Grigg's, Oliver's, Vogel's, Watson's and Young's, the one selected was found to be the best for the material in hand, just as Huizinga's Test for Dextrose seemed to be the best of nine other tests tried. The test for tannin consisted in placing one c.c. in each of a series of test tubes and diluted with five c.c. of distilled water. To each was then added one c.c. of a saturated solution of hydrogen sodium phosphate (Na_2HPO_4) and a single drop of rather strong ferric chloride solution, when a precipitate of a bluish violet color occurred in proportion to the amount of tannin present in the tubes.

Why these tests and reagents seemed to be the best for testing the substances in question in the mangrove extracts is not known, but it probably depends on the peculiar composition of *Rhizophora* tannin, etc. The tannin of the red mangrove, according to the classification of Haas and Hill, belongs to the Pyrocatechol Group, but as these authors state on account of the incomplete status of knowledge regarding the tannins as a whole and of the chemistry of this group in particular, it is a very difficult matter to classify them properly. According to Kraemer[137] the tannins of the above group produce protocatechuic acid on fusion with potassium hydroxide and phlobaphenes on treatment with acids. A very careful analysis of the bark extract of *Rhizophora* was made by Trimble.[138] His results showed that no gallic acid was present and that in the dry total tannic acid occurred to the amount of 23.92 per cent. and mucilage 1.72 per cent., glucose .81 per cent., albuminoids 7.02 per cent., starch 4.27 per cent. and cellulose 27.49 per cent. Although perhaps the reagents were adapted to this group of pyrocatechol tannins, the results of the tests signify merely a relative value, for the quantities of the substances in question. Thus the comparison colorimetrically of the individual tests of each plant with that of a

[137] Kraemer, H., "Applied and Economic Botany," Philadelphia, 1914, p. 204.

[138] Trimble, H., "Mangrove Tannin," *Univ. of Penna. Bot. Lab. Contributions,* Vol. 1, No. 1, 1892, p. 50.

tube of standard dextrose solution of known strength is the basis of these records. The standards are in five grades, each being a certain definite percentages of Merck's standard tannic acid, or Kahlbaum's standard dextrose. The amounts by this comparative method of testing were placed in the five arbitrary units, approximating the same color as that for 0.5 per cent. standard dextrose solution on the one hand, and a 0.125 per cent. standard tannic acid solution on the other, with successive dilutions by half of these standard solutions.



Graph No. 3.

The tests were made in series of twelve, that is a dozen seedlings of progressive increase in size were selected from which to make extracts at one time. More could not be handled conveniently at one time, since the length of time required to carry the extracts through the various precipitations, filtrations, etc., gave opportunity for mould spores to germinate in the flasks, a difficulty very hard to control in a warm, moist climate. About two hundred of these tests were made and the various series of twelve seedling-extracts were averaged to obviate errors in judgment regarding color intensity, etc. Graph No. 3 illustrates the relation of the two substances in question as they occurred in seedlings of progressively larger growth according to the above tests. The ratio may also be expressed by the equation $y = Kx + C$, where C approximates 1.05 and $K = 2/3$, the ordinates, Y, express units of tannin and the abscissæ, X, units of dextrose. By this graph then it is seen that the unit increases in tannin for plants of progressively larger growth vary as $\frac{2}{3}$ of the unit increases in dextrose, *i. e.,* the ratio is constant and the "curve" is really a straight line.

The result is rather contrary to the writer's expectations, since on account of the extraordinary amount of tannin in the hypocotyl, an agreement with the "reserve food" theory, as put forth by Buignet, etc., *i. e.,* the two substances in inverse ratio, was looked for. The results, however, conform to the opposite view as expressed by Gerber, that is that tannin does not play a definite part in the direct nutrition of the mangrove seedling.

Before leaving the subject of tannins and physiology in general it is interesting to note that in Reed's experiments,[139] tannic acid and pyrogallol when added to cultures of wheat seedlings produced large increases in transpiration. Warming[140] regards tannin as of some importance in water conduction and in another place says it functions especially as a protection against undue evaporation from plants during winter, and also suggests that it may be a means of rapidly restoring turgor. Regarding the function of tannin in the leaves of *Rhizophora,* the view is here expressed for the first time, so far as the writer knows, that the two layers of tannin cells in the water hypodermis serve as an insulation against light and heat and a protection to the water storage cells beneath it. Schimper[141] has shown that the strand plants need shade and cloudy skies for their best development, since the direct sunlight heats up the interior of the leaves and the increased transpiration thus brought to a very high degree is injurious to the plants. In conclusion it is here stated then that the tannin in the leaves acts as an additional protection against transpiration, and also that the tannin of the hypocotyl does not contribute directly to the nourishment of the seedling.

Ecology.

Practical work on the ecology of the mangrove in southern Florida was suggested by the work of Praeger[142] as published in the

[139] Reed, H. S., loc. cit., p. 107.

[140] Warming, Eug., loc. cit., p. 539.

[141] Schimper, A. F. W., "Plant Geography," 1903, p. 404.

[142] Praeger, R. L., "Buoyancy of Seeds," *Proc. Scient. Royal Dublin Soc.,* rev. by E. W. Berry, *Plant World,* Vol. 17, No. 4, p. 131.

Scientific Proceedings of the Royal Dublin Society and reviewed for *Plant World* by E. W. Berry. This work deals exhaustively with the buoyancy of seeds and his observations on seeds of over 900 British plants show that the more buoyant forms are inhabitants of streams, banks or seashores. The results showed that 85 per cent. sunk at once or within a week, 5 per cent. floated 1 to 4 weeks, 33 per cent. 1 to 6 weeks, 1.9 per cent. 6 to 12 months and 4.4 per cent. floated over 12 months. In consideration of these results and as the life and dissemination particularly of the viviparous seedlings is dependent on buoyancy it seemed worth while to undertake some investigation of this and related phenomena concerned with dissemination. Guppy has done such excellent work and made such complete observation on the buoyancy of the mangrove seedlings that no work on buoyancy was required, that writer's latest book[143] giving a summary of observations along this line. Harshberger's works[144–145] on the ecology of South Florida also were of a simulating effect and a helpful reference in the present work on the mangrove of the region, as well as Webber's notes[146] and the journals of the Agassizes.[147–148]

The relations of these mangroves to their environment have been a subject of much interest to ecologists and botanists in general from Theophrastus to the present, and many philosophical discussions have been given concerning their origin and adaptation to their habitats. In these adaptations, however, they only perhaps show in more marked degree what all plants of strand floras show, viz., strongly developed xerophytic characters, in spite of the fact that the environment is aquatic. These characters have been fully discussed by such writers as Holtermann[149] on the effect of climate

143 Guppy, H. B., loc. cit., p. 109.

144 Harshberger, J. W., "Vegetation of South Florida," *Trans. Wagner Inst. of Sci.*, VII., 3, 1914, pp. 74–80.

145 Harshberger, J. W., "Phytogeography of North America."

146 Webber, J. H., "Strandflora of Florida," *Science* (N. S.), VIII., 1898, p. 658.

147 Agassiz, Louis, "Florida Reefs."

148 Agassiz, Alexander, "Three Cruises of the *Blake*."

149 Holterman, Carl, "Der Einfluss des Klimas auf den Bau der Pflanzengewebe," Leipzig, 1907.

on plant tissues, and Warming,[150] Haberlandt,[151] Karsten and others who have all emphasized some special features of this ecologic relation.

The general impression of a mangrove swamp is very aptly described by Warming (*loc. cit.*): "The bottoms of the crowns of the trees are usually truncate and stand a small distance above the water, and beneath them are seen, where *Rhizophora*-vegetation forms the outermost fringe of vegetation, a tangle of countless brown roots more or less clothed with algæ. The soil, which in places is not covered with water at low tide, is soft, deep black mud, full of rotting, stinking organic bodies in which bacteria abound. The water between the trees may be covered with dirty film and bubbles of gas rising from the bottom burst at the surface." One may also add that the air is usually thickly filled with voracious mosquitoes.

In spite of this rather unpleasant, but truthful description, the mangrove formation holds a great many features of interest for the ecologist, as Karsten[152] says in describing the mangrove swamps of the Malay Archipelago—"Es ist ein Vegetationsbild von seltener Einförmigheit besonders für an tropischen Formenreichtum gewöhnte Augen und doch giebt es wohl wenige Gebiete, die bei näherer Bekanntschaft eine solche Fülle von interessanten Formen und Beziehungen zeigen." This uniformity to which Karsten refers in the oriental mangrove consists of nine widely diverse families, representing twenty-one species. Our American mangrove swamps, however, are much more "uniform" than this. Harshberger has summarized the species in the various kinds of mangrove thickets (*loc. cit.*, 144, p. 77) as they occur on the Peninsula of Florida for the most part with brief notes on the vegetation of the Keys. The whole aggregation of species which grow in all the types of mangrove formations, whether it be along the rivers, bays or open sea, on islands or everglades, embrace about twenty-eight species, including pteridophytes, floating aquatic plants, epiphytic lichens, etc. The trees of the typical mangrove habit, that is, those plants which

[150] Warming, Eug., "Œcology of Plants," tr. Vahl, Groom and Balfour, Oxford, 1909, p. 234.

[151] Haberlandt, G., "Eine Botanische Tropenreise," 1893, p. 182.

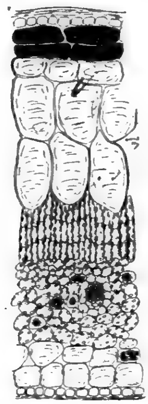
[152] Karsten, G., loc. cit., p. 3.

by their structural adaptations and, particularly, vivipary, constitute "the mangrove" in the sense of the French and German botanists, only comprise in the American mangrove thickets of Florida, four species. These are the red mangrove, *Rhizophora mangle* L., the black mangrove, *Avicennia nitida* Jacq., the white buttonwood, *Conocarpus erectus* Jacq., and *Laguncularia racemosa* Gärtn. This last species is not contained in Harshberger's lists and perhaps was not seen by him, although it occurs quite abundantly in the keys, particularly the more southern ones. Dietrich Brandis, writing on its range in Engler and Prantl, says, however, that on approaching its northern limit it becomes merely a low shrub, and hence easily overlooked. At Ragged Keys, for instance, trees were observed three to four meters tall growing on the outer edge of the fringe vegetation associated with *Rhizophora*. *Laguncularia* grows in fairly deep water along shore with the red mangrove, while *Conocarpus* and *Avicennia* are, for the most part, in shore on ground that is only submerged at high tide, or not reached by the daily tides at all. On approaching a mangrove island or shore this feature is easily seen, the rich olive or bright green of the two species growing in deeper water is noticed as a dense wall about two meters tall with a line of brown along the water's surface which is composed of the tangle of aërating prop roots of *Rhizophora,* and the small knotty pneumatophores of *Laguncularia*. In the background, stretching above these two outer species, appears the silvery white and light green of the *Avicennia* and the *Conocarpus*. At some places, however, *Avicennia* grows out in fairly deep water and produces its large area of apogeotropic slender yellowish-brown aërating roots also.

Physiological Considerations of the Ecology.

The adaptations of mangroves to their environment have been grouped by Warming (*l. c.*, p. 236)[150] under several heads as fixation, respiratory roots, germination and vivipary, means of migration, and xerophytic structures. This last heading is best illustrated in the leaves, as being perhaps the most plastic organ and hence most easily adaptable. The structure of the leaves of *Rhizo-*

phora has been described in detail in the chapter on morphology, but several studies were made on the leaves to learn to what extent the adaptation is carried in different habitats, or rather media of growth. To this end then, leaves were secured from trees growing in fresh water along the Miami River, from trees growing in pure salt water off shore in the Atlantic, northeast of Miami, and also from trees growing in the rather dry situations in the Marquesas atoll in the Gulf of Mexico, in soil only reached by the highest tides and in the same atoll, of trees growing off shore in salt water several feet deep. Sections were made of these leaves in various preparations, free hand, of fresh and pickled material, and also paraffine preparations, and comparisons made of the thicknesses of the leaves and the relative amounts and positions of the various tissues in the leaf. Drawings and microphotographs were made and are here given. In each of the two sets of preparations leaves were selected of the same dimensions and at about the same node back from the bud so that the compared leaves were as nearly alike as could be possible. As a rule, however, the leaves on trees in fresh water were slightly larger than those for the corresponding node in salt water trees. In Fig. 2, Pl. VII., is seen the illustration of the fresh water section. It will be noticed that the tannin cells of the hypodermis are shorter and rounder, the water storage cells are smaller and only in two rows, the palisade is thicker and the spongy parenchym not so deep and the stomata slightly larger than the corresponding features in the salt-water leaf section shown in Fig. 1, Pl. VII. The greatest difference seems to be in the amount of water storage tissue and the lengths of the palisade cells. In the salt-water leaf the palisade lies almost in the middle of the leaf, and the tannin cells are also rather larger and elongated; this detail also helps to strengthen the writer's view regarding the function of these layers of cells as insulation against the heat and light. The ranker growth of the river bank mixed with other trees help to make more shade for the trees in this situation. The sections of the inshore leaves, and the offshore leaves show much the same relation on a comparison of the sections, but in a less striking degree. The offshore leaf (Fig. 4, Pl. VII.) is the thicker, *i. e.*, showing a typical halophytic reaction, while the inshore leaf (Fig. 3, Pl. VII.) is slightly thinner.



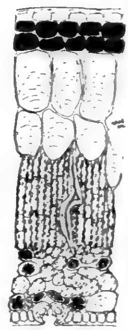


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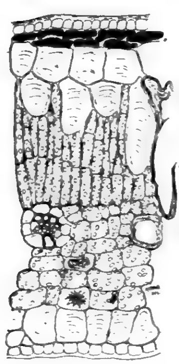
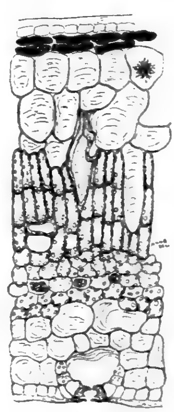
FIG. 1. Transverse section leaf from salt-water grown tree, showing distribution and relative quantities of the leaf tissues. (Cam. luc.) × 133. Dark cells containing tannin, clear cells water storage hypodermis. Columnar cells of palisade, and beneath them spongy parenchyma containing crystals and section of vascular bundle. Below a loose hypodermis.

FIG. 2. Transverse section of leaf from tree growing in fresh water. Regions same as Fig. 1. (Cam. luc.) × 133.





3 4

FIG. 3. Transverse section leaf from tree grown in shore. Regions same as Fig. 1. (Cam. luc.) × 133.

FIG. 4. Transverse section leaf from tree growing off shore. Regions same as Fig. 1. (Cam. luc.) × 133.

The difference in palisade and tannin cells is not so pronounced here as in the preceding set of comparisons, the main difference being in the amount of water storage tissue. On account of the slight quantity of rain water held in the soil, or of the chemical action of the soil producing a lessening in concentration of the salt water as it seeps inshore, the inshore leaves are thinner and show the tendency toward adaptation, as seen in the fresh-water leaves.

It might be mentioned in connection with these preparations that the drawings were made by means of a *camera lucida* and that the actual leaf thicknesses were as follows: Fresh-water leaf, .54 mm., salt-water leaf, .65 mm., inshore leaf, .42 mm., offshore leaf, .54 mm. The first pair of comparisons must not be based with the measurements of the second pair, as the material was collected at different times of the year, different regions and were perhaps different in leaf size or age.

Vivipary and Dispersal.

Perhaps the most peculiar of all the adaptations of mangrove-habit plants is that of vivipary, and this seems to be best developed in members of the Rhizophoraceæ that grow in the deepest water and softest mud. This adaptation has a very vital ecological significance in connection with dispersal, as remarked at the beginning of this chapter concerning Praeger's experiments, and the more recently published results of Guppy. Vivipary, according to Goebel's[153] view, is only found in plants which grow under very warm, moist conditions and this wet environment which quickly germinates seeds has produced the habit, that is the habit arose by the differences in the readiness to germinate in various seeds.

The first sign of vivipary then would be the falling to the ground of an immature seed, with the embryo still undeveloped, a condition somewhat analogous with that of the seeds of certain orchids; next would be the stage when the seeds germinate as soon as shed on the ground; third is a type represented by *Laguncularia* in which the seedling just begins to germinate on the tree, then fourth, where germination is completed on the tree, but the seedling immediately falls as in *Avicennia* and the climax is reached in

[153] Goebel, K., loc. cit., p. 123.

Rhizophora, where the germinated seedling stays on the parent tree for nearly a year. Guppy[154] has put forth the unique view that in a previous early geological age, under uniform warm, moist climatic conditions and a very diffuse light due to constant cloudiness, the viviparous habit was universal and that vivipary and the conditions of the present mangrove swamp are an index both to the meteorological conditions and to the forms of a very ancient vegetation. The seedlings, being viviparous then, by evolution through one of these processes presumably, although the writer rather inclines to the former conclusion that the habit arose by small beginnings, the dispersal of these depends on the ocean into which they fall.

The dispersal of the mangrove seedling has been discussed very fully by several authors, at greatest length perhaps by Guppy, as observed in the Fiji Islands and the Pacific, and more latterly in the middle Atlantic coasts. This author regards the currents as the source of dispersal, since in quiet water the seedling may drift for months, but when they are buffeted by each other or floating objects for any length of time, the plumule is injured and the seedling dies. The present writer, nevertheless, has found many drifted seedlings in the Tortugas which had been broken either at the plumule end or the radicular end and in spite of these mutilations put forth adventitious buds at the lenticels at one end, or roots at the lenticels near the radicular region. The nearest mangrove trees in this case were those of the Marquesas atoll at a distance of twenty-five miles from the Tortugas group. Intimately associated with the buoyancy of the seedlings is their position in the water. Guppy noted that they float vertically in fresh water and horizontally in salt water, while they incline at various angles in dilutions of various densities. A fortuitous agreement is seen in this relation between the specific gravity of the seedling and the density of the water, for the horizontal position keeps the plumule moist and uninjured by the fierce sunlight. The seedlings have no buoyancy until the hypocotyl has emerged from the fruit about six inches in the case of *R. mucronata* and the same has been observed by the writer for young seedlings

[154] Guppy, H. B., "Observations of a Naturalist in the Pacific," Vol. II., Plant Dispersal, 1906, p. 470.

of *R. mangle*. Guppy estimates that 95 per cent. of seedlings that fall into the sea do float, and has further carried out a most interesting series of experiments in England with seedlings brought from the tropics and kept dry for five months. These experiments, which show the prolonged vitality of the seedlings, recall the words of Plutarch quoted in the first chapter of this paper, where he described the "anacampserotes" as being plucked out of the sea and hung up to dry, and which bud and put out green leaves presumably when placed again in water.

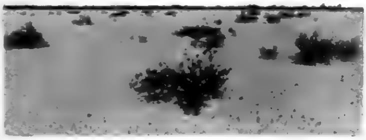
The manner in which seedlings come to take roots after having journeyed for weeks in the ocean currents is also of interest to an ecologist, because it is only on certain shores that the seedlings really can eventually form a mangrove swamp. In the Tortugas and other similar shores with wide beaches of coarse sand the essential conditions are lacking and the seedlings go through a short life cycle which the writer has reproduced under similar conditions at the laboratory and always with the same result. The plants are dropped from the trees in February, March and April in greatest number in the thickets of the Marquesas, Boca Grande, or islands even further east, these drift twenty-five to seventy-five miles westward with the counter Florida current and the high spring tides carry them up on the higher beach terraces formed in the coarse shifting sand of the Tortugas with masses of *Sargassum* and the broken leaves and rhizomes of *Thalassia* and *Cymodocea* which form long windrows on the beaches. If there is sufficient of this debris to conserve moisture during the dry summer months when it acts as sort of a mulch for the *Rhizophora* seedlings, the little plants grow and the plumule lengthens and forms several rather short internodes. These may last with a desultory growth into late summer and perhaps be all swept away from their bed in the shifting sands by the autumn storms and hurricanes. As a rule, however, the seedlings are buried more or less deeply in the sand with not sufficient debris, since this flotsam is lighter and is flung a little farther back on the beach than the seedlings are. During the summer the plumule expands and the leaves put out, but these leaves never get over two centimeters long and are soon burned up by the intense heat and light of the glaring white beach and killed by the drying wind.

These leaves are put out successively with very short internodes until the reserve food in the hypocotyl is exhausted and the seedling dies. The same sequence of events happened in the laboratory cultures described in a previous chapter in which some young seedlings were set out in boxes of sand about fourteen inches deep and watered daily with sea water. The plants eventually died through the exhaustion of reserve food and an inability to compensate the loss in food by the activities of new synthetic tissues. The plants were kept in full sunlight in coarse sand and merely watered with salt water, the amount in excess of that held in suspension in the soil flowing out of the box below.

Mangrove seedlings have an equally hard time in getting a foothold on rocky shores as described by Crossland.[155] He observed that the hard coral rock of the Zanzibar Reef formed a plane floor with very little mud and many small cracks, but was puzzled to see how the *Rhizophora* became planted in such small holes. While Crossland does not mention the density of the water, it seems that the water along these reefs must have been largely diluted with fresh water since he remarks that the seedlings floated vertically. By close observation, he noticed that the eddy and current gave a twirling motion to the seedling, which in turn produced a boring action on the shallow bottom until the radicle became lodged in a little crack. Success for anchoring on these reefs depended on quiet water and gentle ripples and suitable crevices on the bottom.

In connection with the dispersal and anchorage of seedlings, a number of observations were made on the character of the bottom, the depths of the water, etc., on the shores of Key West, Stock Island and other adjacent keys (Fig. 4, Pl. VIII.). Key West being composed of hard oölithic rock and mud flats of hard precipitated mud, the conditions observed by Crossland at Zanzibar are duplicated at some places and seedlings which take hold in the crevices of this hard oölite cannot be pulled up, but the root will break off, owing to the tenacious hold in the cleft. On these flats both *Avicennia* and *Rhizophora* seedlings were observed starting growth in 8–37 centimeters of water at high tide. On Stock Island the same conditions

155 Crossland, C., "Note on Dispersal of Mangrove Seedlings," *Annals of Botany*, XVII., p. 267.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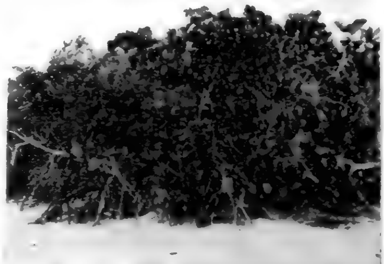
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FIG. 1. Stunted mangroves on sand flats in Andros in the Bahamas. Photo. by Small.

FIG. 2. Hurricane damaged swamp at Boca Grande.

FIG. 3. *Tillandsias* epiphytic on red mangrove in the Bahamas. Photo. by Small.

FIG. 4. *Rhizophora* on hard oölite flats on Stock Island at low tide.

FIG. 5. Mangroves growing in dry coral sand some distance in shore at Boca Chica.

FIG. 6. *Rhizophora* tree with roots dug out to show absorptive system and props, Mangrove Island near Key West.

obtain as Key West, measurements here of trees which were representative of all the trees about the lower Florida Keys showed the average tree to be 3–4 meters, growing on oölite with only 2–5 centimeters of mud covering the absorptive roots (Fig. 6, Pl. VIII.). These absorptive roots were 20–40 centimeters long and 1–2 centimeters in diameter, while the prop to which they were attached was of an average length of 1.8 meters, the shoot of the props being about 1.5–2 meters. The hydrometer seedlings for the water here, on June 25, was sp. gr. 1.0205 at 34° C. On June 5, at the same place where seedlings were grown off shore in 20 cm. of water, the seedlings were almost similar; T. 34° C. and sp. gr. 1.021.

At Boca Chica, the conditions were slightly different, the observations made on June 9 at low tide. The trees were growing in deep mud almost a meter deep and were about five meters tall, the roots being covered, at low tide, with 10–20 cm. of water. Hydrometer seedlings here showed a sp. gr. of 1.0235 at 30° C. On this island also were seen *Rhizophora* trees growing five to eight meters in shore in apparently dry shell sand, in a healthy condition (Fig. 5, Pl. VIII.).

At Cayo Agua on June 17 and 24 about the same measurements were made as at Boca Chica, except that here trees were found full of flowers and fruits at all stages as well as pendant seedlings. At no other island in the lower keys were flowers noted at this time of the year. On the west side of the island a hurricane of a previous winter had broken and washed up a considerable area of the swamp, and in this close mass of dead and white bleached twigs and branches, the ideal situation seemed to be afforded to the young seedlings to start growth. The dead twigs overhead provided a lattice of the right sort for optimum light intensity, while the decaying branches in the mud below offered quiet water and debris for anchorage. The same thing was seen in the hurricane damaged swamp at Marquesas (Fig. 2, Pl. VIII.).

At Mangrove Island, Crawfish Key and Ragged Keys trees five to six meters high were observed growing in deep mud. At the last mentioned keys the mangroves were associated with *Avicennia, Conocarpus* and *Laguncularia.* At Bahia Honda and Duck Island only the inner or Gulf side of the islands have a mangrove fringe on account of the sandy beaches on the outer shore. In rich alluvial soil of the river hammock along the Miami River, the *Rhizophora* and other trees form a jungle seven to eight meters tall, while back in the Everglades, *Rhizophora* only in the form of small bushes were observed scattered in the saw grass, *Mariscus jamaicense* (Crantz) Britton. This has also been observed by Harshberger (144, *loc. cit.*) and Dr. J. K. Small[156] who has published voluminous reports and floras of the region, and has kindly furnished some photographs, illustrating this peculiar condition of the mangrove here and on Andros Island in the Bahamas (Fig. 1, Pl. VIII.). This island is interesting to us because it is the place that Catesby described in his early chronicle. At Boca Grande, *Rhizophora* seedlings were observed starting to fill in a thickly vegetated salt meadow, which became flooded at high tide; this marsh was covered largely with *Batis maritima, Sesuvium portulacastrum, Borrichia,* etc., and among them were many thrifty young *Rhizophora* seedlings. It is supposed that these seedlings were carried into this meadow by unusually high tides.

Experimental Data.

Harshberger's experiments (*loc. cit.,* 144, p. 79) suggested a line of work on the station of *Rhizophora* in estuaries which have been carried out in Biscayne Bay and the Miami River. Since these experimeters have been made by the writer, Guppy's book (*loc. cit.,* 143) has appeared and this naturalist also has made some study of this subject in Fiji and Ecuador. In Fiji, Guppy found that where both *R. mucronata* and *R. mangle* grew luxuriantly on the coast the latter followed up the estuaries and river banks. Despite the fact then that *R. mangle* is a salt swamp plant it apparently can adapt itself to practically fresh-water conditions as the transpiration cultures in this work show for individual cases. Dr. Small also has told the writer that he has observed in the Everglades and the Bahamas *Rhizophora* growing, by the square mile area, miles from any salt water. In the face of these cultural experiments on a small laboratory scale and the observations of Small, the evidence afforded

[156] Small, J. K., "Exploration in the Everglades and on the Florida Keys," *Jour. N. Y. Bot. Garden,* 15, 1914, 69–79.

by the writer's own ecological notes along the Miami River, and Guppy's observations in the Black River, Jamaica, show the fact to remain that salt water is needed for the proper development of a typical mangrove vegetation. The trees observed in the Everglades and on other places in the interior of swamps having a fresh-water substratum are of small size and poorly developed.

To account for their origin and growth, even though poor, in such interior swamps, it is logical to suppose that they have been carried thither by currents flowing into the estuaries from the sea, and for their continued existence we may suppose that the soil is still sufficiently salt from previous inundations, or that the currents which carry the seedlings in are slightly brackish and so impregnate the soil with a little salt. It is regretable that no data are available on the salinity of the soils of such interior swamps where mangroves are growing in this stunted condition.

To return to the experiments made by the writer in the Miami River and Biscayne Bay, it has been long known that in certain estuaries there is an up-stream current of salt water which flows on the bottom, while a down-stream current of fresh water flows on the surface. In earlier observations along the Miami River, Arch Creek, etc., the writer noted the gradual decrease in stature and frequency of occurrence of mangroves as the river was ascended until after three or four miles they had disappeared entirely. It was supposed that this feature, which has often been remarked by other ecologists, was in some way connected with the salinity of the water, accordingly it was determined to make some top and bottom hydrometer readings. To do this the launch *Darwin* was employed and the deep-sea water-sampling instrument taken from the equipment of the institution's yacht, *Anton Dohrn*. This instrument is a very ingenious device designed by Dr. Mayer and the late Mr. Drew in the latter's work with bacteria in the sea water of the Tortugas region. The instrument consists of a glass cylinder enclosed in a heavy brass jacket. The top and bottom of the cylinder are closed by means of brass plates, which fit tightly and are operated by strong springs. The instrument is lowered into the sea and on the yacht it is attached to the sounding machine and lowered mechanically, and if samples are taken from deep sea water the instrument is filled with alcohol. When the bottom or any desired depth is reached a heavy weight is sent down the slender wire cable which attaches the instrument to the boat. This weight operates a clip which releases the spring and the alcohol is allowed to escape and the sea water flows in, another weight is sent down which falls on a different clip and the instrument is closed, and the sample drawn up in a few seconds. In these experiments, alcohol was not needed; as the depths in the river at no place exceeded nine feet, and as the launch was used in place of the yacht, the instrument was lowered by hand instead of the sounding machine. Samples were taken then from both the top and the bottom layers and hydrometer readings made of them. The readings were begun at 9.15 A.M. on the outer side of the harbor, in the Atlantic, one quarter mile off shore, the second made just off shore near the mangroves growing on the outer side of the Harbor near the Government Channel. Then another halfway across the Bay (Bay Biscayne) and the next at the mouth of the Miami River, from thence every half mile up stream until *Rhizophora* no longer appeared. These readings are tabulated below.

By these readings it is seen that there is a very decided difference in the salinity of the top and bottom layers. The distribution of the mangroves is also correlated with the comparison of the top and bottom readings and we may infer that the salt of the water which is carried up by the under-current is the factor in the physiological relations of the plant which compose the optimum conditions for its growth and as this decreases in concentration by dilution with the downstream current, the *Rhizophora* fringe gradually dwindles and disappears.

Dimorphism.

Before leaving this chapter on ecology, a word may be said regarding dimorphism in the genus, *Rhizophora*. Guppy has recorded very obvious dimorphism in *R. mucronata* in Fiji and in *R. mangle* in Ecuador, the double form in the first consisting of a fertile type and a sterile (selala) type in which the pollen is not viable. The second species consists in Ecuador of the "mangle grande" and the "mangle chico," a tall and a little mangrove. The

HYDROMETRIC READINGS IN BISCAYNE BAY AND MIAMI RIVER.

August 1 to 5 Inclusive.

	Temperature (Centigrade).	Specific Gravity.
Atlantic Ocean, nine-foot depths	*28.3°	*1.0150
	28.0°	1.0120
Off shore	28.3°	1.0120
	28.0°	1.0130
Half way across Biscayne Bay	28.1°	1.0105
	28.0°	1.0105
Mouth of Miami River	28.0°	1.0015
	27.6°	1.0080
Half mile up stream	27.5°	0.9975
	27.0°	1.0100
One mile up stream	27.2°	0.9980
	27.0°	1.0000
One and one half miles up stream	26.7°	0.9980
	27.0°	1.0000
Two miles up stream	26.5°	0.9977
	26.4°	0.9982
Two and one half miles up stream	26.1°	0.9980
	26.1°	0.9985
Biscayne Bay, seven-foot depths	28.0°	1.0090
	28.0°	1.0110
Arch Creek mouth	28.2°	1.0010
	27.8°	1.0045
Arch Creek, one mile up stream	27.7°	1.0000
	28.0°	1.0050
Arch Creek, two miles up stream	29.5°	0.9975
	29.0°	1.0050

mode of branching and trunk formation is the chief difference here. While the difference in the forms of the two "forms" has not been pronounced enough to engage the attention of systematists and taxonomists it is a very interesting field for genetical investigation, since Guppy suggests that the "selala" type might be a hybrid between *R. mucronata* and *R. mangle,* or perhaps there is a persistent dimorphism in *R. mucronata.* In conclusion the writer may say that only the "mangle chico" type of *R. mangle* is found in Florida and the keys, just as Guppy has found it to be the only type present in Jamaica and the West Indies.

* The upper readings of each pair represents that at the surface of the river, while the lower readings were those taken on the bottom samples.

Relation to other Organisms.

The mangrove swamps of the western hemisphere are somewhat different in appearance from the oriental forests according to the descriptions given by writers of eastern tropical botany. The main difference is seen in the absence in the western mangrove formation of a large epiphytic flora, a few *Tillandsias* being about the only plants which live on the branches of the *Rhizophora mangle* (Fig. 3, Pl. VIII.), as is seen in the photographs taken in the Bahamas.

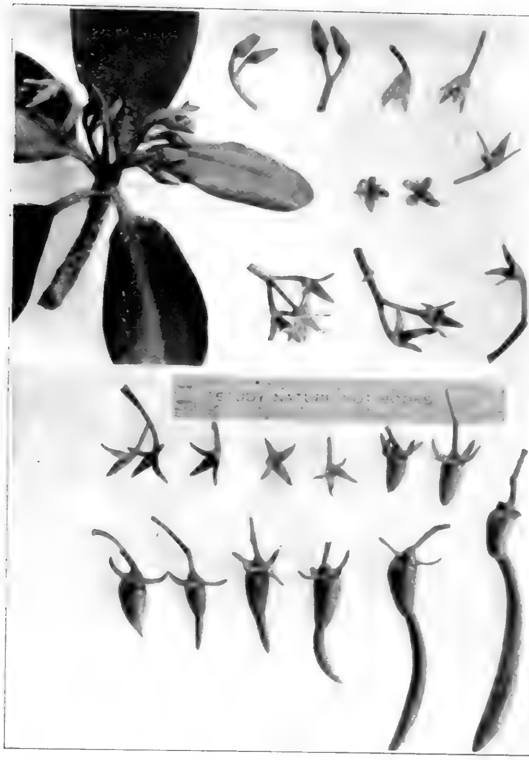
Other plants associated with the mangrove, *i. e.*, terrestrial, have been given by Harshberger in the lists of species for the formation, a great many of the species given there are rarely found in the purer *Rhizophora* formations of the islands and mangrove keys, but occur in the mangrove formation in the river hammocks.

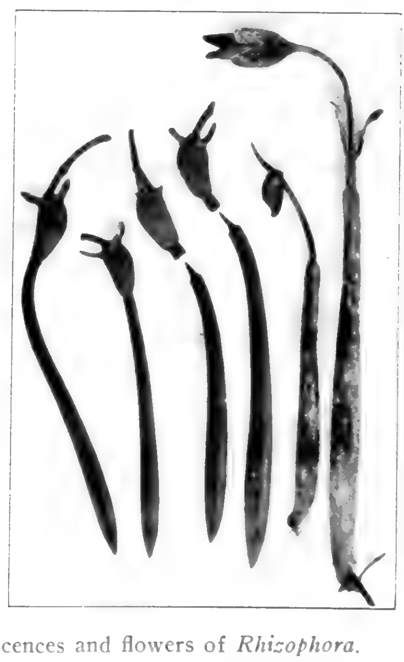
The animal life of the mangrove swamp is rather limited, also several species of cranes, the pelicans and a few other species build their nests among the low trees and thickets. The two forms most closely associated with the *Rhizophora* trees, however, are the crabs, of which there are also several species, mostly hermit crabs, and the oysters. The oysters, as mentioned in the old narratives of Labat and Sloan, have always been found growing on the submerged prop roots of the mangroves and their tangle of roots offers an ideal place for their development, and an easily accessible means of collecting them, a fact appreciated by the Seminoles, who use them for food in considerable number.

Distribution.

The geographical distribution of the family, according to Schimper, in Engler and Prantl,[157] is confined purely to the tropics, and in the American tropics there as only two genera, *Cassipourea* and *Rhizophora*. Of these, the former is indigenous to the West Indies, Central and South America, and the latter is represented by only one species, *R. mangle*, although, as remarked in the chapter on ecology, there are other plants in the hemisphere which belong to the mangrove association.

[157] Engler, A., and Prantl, K., "Die Natürlichen Pflanzenfamilien," III. Th, 7 and 8 Abt., p. 58.





Branch, inflorescences and flowers of *Rhizophora*.

Fertilized flowers, fruits and emerging seedlings.

Mature seedlings dropping from the fruits, showing the conical plumule on the proximal end of the freed seedling and the cotyledonary sheath or collar from which the plumule has just slipped out and seedlings with bud expanded, and several internodes of growth made.

The three species of *Rhizophora* are distributed over the world in the following manner: *R. mangle* of the American tropics, West Africa and the Pacific Islands; *R. mucronata* in Japan to Australia and East Africa, while *R. conjugata* is found throughout all tropical Asia. In Japan, according to T. Ito,[158] there are three genera of the family present, *Kandelia, Bruguiera* and *Rhizophora* with the northern limit of range 31° 20′ N. Lat. This is the limit for any of the mangroves in Japan, *i. e.,* the forests in Satsuma, and indeed for all Asia, it is of interest when a comparison is made for the northern range limit in America, which in Florida is about 28° N. Lat.; exception here is made, however, of the Bermudas which support an *Avicennia-Rhizophora* mangrove association.

As mentioned above, Australia and the Malay Archipelago is the southern limit of range in the eastern hemisphere. In South America the range limits for *R. mangle* are for the west coast very sharply defined. This is nothing but desert beach along the coasts of Chili and Peru until the frontier of Ecuador is reached. The *Rhizophora* shores begin at 4° 5′ Lat. and are practically continuous to the equator, except a sterile stretch north of Guyaquil, as noted by Guppy. On the eastern coast of South America the mangroves extend almost to the tropic of Capricorn. The stations and ranges in North America have been carefully worked out by Professor Harshberger.[159] *Rhizophora* occurs in all the shores of the Greater Antilles, Cuba and Mexico. In Guatemala there is only a strip occupied by them along the coast. In Haiti and Santa Domingo, the Virgin Islands and the Bahamas they go up into the bays and harbors, while the Florida Keys and the southern part of the Peninsula are girdled with a thick mangrove formation. On the west coast of the northern continent, the mangroves extend to Lower California, the range limit being 24° 38′ N. Lat., a little north of Matzatlan, while Hawaii and Tahiti have no mangrove flora at all. Regarding the presence of *Rhizophora* on the west coast of Africa, it is supposed that *R. mangle* has reached those shores by migrating from America, due to ocean currents. On the other hand, Guppy does not regard the presence of *R. mangle* in the Southern Pacific Islands

[158] Ito, T., "Rhizophoreæ in Japan," *Annals of Botany,* XIII., 465.
[159] Harshberger, J. W., loc. cit., 145.

as indicative of its having come from America, where it is widely distributed, but that in the past it occurred as commonly in Asia as in America, but now only survives in a few places of the Old World Tropics. His reasons for this view are not amplified and it would seem curious that *R. conjugata* and *R. mucronata,* which require the same living conditions and have the same methods of dispersal, etc., should have persisted or developed and *R. mangle* disappeared.

The distribution in Florida varies slightly on the east and west coasts. The northern limit is 27° 15′ N. Lat. on the east coast, *i. e.,* at Stuart, and Professor Harshberger has noted their scattered occurrence along the St. Lucie River. On the west coast the limit is 28° N. Lat., that is about at Elbow Key and Orange Grove a little north of Tampa, according to the triangulations of Swick,[160] made recently along the west coast of Florida. On the west coast in the quiet harbors and bays it is slowly encroaching and, according to Professor Harshberger, filling up the estuaries. At White Water Bay, he states, the trees have completely invaded the area so that now there are only small tortuous channels between the mangrove islands. This observation brings before our attention the subject discussed under the next head.

Geological Considerations.

In the first place it may be well to state that there are no fossil evidences of mangroves, but this is only to be expected, since the conditions of a mangrove swamp are very favorable to decay on account of the heat and the very large numbers of bacteria of all kinds in the water and swamp-mud. The water here has no preservative action on woody tissues as has the water of peat formations and sphagnum bogs, and so debris in the swamp quickly decomposes into mud and soil, not to mention the activity of the hosts of tiny crustaceæ, mollusca, worms and cœlenterates, etc., in the life-filled environment, which all help to disintegrate such organic material.

The effect of the mangroves themselves on their habitat is very remarkable, as has been mentioned before in this paper and also has

[160] Swick, Clarence H., "Triangulation Along the West Coast of Florida," U. S. Coast and Geodetic Survey, Sp. Pub. No. 16, 1913.

been observed by numerous other naturalists. This effect is mainly the addition to and the extension of the land areas in the regions in which mangroves grow. As remarked in the preceding chapter, White Water Bay has been almost filled up by the activity of this plant and many islands and keys have been elevated from merely submerged coral shoals and reefs to a condition of dry and now even habitable land. This growth of the land area may be very well studied in Florida and the Keys and several geographers and geologists have commented upon the large rôle played by *Rhizophora* in the geological history of Florida. This history is rather recent, as geologists have discovered by borings and other investigations, and Britton[161] says that all the flora of Florida and the Bahamas has developed since Tertiary times. More recently Phillips[162] and especially Vaughan[163] have added to the knowledge of the formation of land in Florida by their observations. Vaughan has spent much time in the tropics and the particular region concerned in this paper, and so his work may be regarded as of extraordinary value. He takes the view that one half to one third of the total area of the Florida Keys is occupied by the mangrove and in the work of forming islands there are several stages which may be noted. From a geologist's point of view the roots, of course, are the most important part of the tree to be considered, since it is in the tangle of roots that the debris washed in by the currents is held.

The three ecological formations are recognized, *i. e.,* the banks of the rivers, margins of keys, whose surfaces are already elevated above sea-level, and the pure mangrove islets. In all of these, but particularly the two latter ones, seedlings are noted at a distance of a few feet to several hundred feet from the shore. This fact is of important significance in the formation of land. This process, to quote from Dr. Vaughan's paper at length, is as follows: "When they (the trees) have grown sufficiently for the development of a tangle of roots they catch and hold sediment and any floating debris, by the successive accumulation of such material ultimately bringing

[161] Britton, N. L., *Science,* XXI., April, 1905, p. 628.

[162] Phillips, O. P., "How Mangrove Trees Add New Land to Florida," *Jour. of Geog.,* II., 1–4.

[163] Vaughan, T. W., "The Geologic Work of Mangroves in Southern Florida," *Smithsonian Misc. Coll.,* Vol. LII., Quart. Issue, Vol. V., p. 461, 1910.

the level of the land above that of the water. . . . Behind the keys, in the regions of slack water, deposition of sediment is taking place, forming banks of soft calcareous ooze. After these shoals have been built up to within a foot of the water level (at low tide) young mangroves begin to catch and grow. . . . The plants become still more numerous and ultimately form a mat of interlocking roots and branches resulting in keys. . . . When the plants become thick they catch and retain sediment ocean drift and are a constructive agent in the formation of land."

"After a time whether it be a newly formed key or the margin of a land area, the mangroves, by the accumulation of sediment and drift, form land, and this cuts off their roots from the necessary supply of salt water causing their own death. The land surface then acquires another vegetation, but the marginal fringe of mangroves persists to protect the young island from the erosive action of the ocean waves, and young mangroves spread seaward to add new land to that already formed, thus these plants are among the most important constructive geologic agents of southern Florida." The process, as thus described, of course, takes place according to geological periods of time and the death of the *Rhizophoras* as indicated above by Vaughan, due to the cutting off of the salt-water supply does not take place quickly, for the trees may persist for years in such a situation without the tides actually bathing the roots, as the ecologic observations and the physiologic experiments, set forth in preceding chapters, have demonstrated.

Economic Aspects.

The uses to which the *Rhizophora* may be put are various, though, on a whole, its importance has not been large in its applications to man's needs. The chief use has been as a source of tannic acid in the past, although another sphere of usefulness has been lately found for the trees which is perhaps destined to become of great importance in tropical coastal engineering. By the natives it was used for the tannin contained in the bark, as mentioned in the ancient chronicles of Abou 'l Abbas en-Nebaty and Ray, etc. Some travellers tell of its being used by natives as food, for the starch in the hypocotyls, *e. g.*, Ovieda, Ray, etc., while many have observed its use as a fuel, as Labat and Sloan. But the most general use outside of its employment in tanning leather was in medicine. Abou 'l Abbas says that in Arabia it was used in making lotions for sore mouth and as styptic, the astringent property of the tannic acid being doubtless very effective in its use as a drug. Van Reede gives it as a drug indicated in diabetes and Ray says the Indians used it as a poultice for a fish bite with good results. Sloan recounts its employment as a dye for clothes and the foliage as a green manure or fertilizer for soil. He likewise gives two other and rather amusing remedies, when considered from a pharmacological standpoint, for he says that "mixed with Oyle like Dirt it is good against Weariness" and with milk or fresh butter "outwardly applyd" "helps them who are diseased in their livers." The most peculiar, however, of all these quaint uses of ancient times is that attributed by Plutarch to the natives of Arabia, where he says the "anacampserotes" were used in making love philters and potions, and intimates a belief in their having an effect as an aphrodisiac.

At a much later period Arnott[164] made the observation that the natives of the West Indies used the fruits of the mangrove to make a light wine. This, however, was only reported to him by travellers from the West Indies. The same use is mentioned by Le Maut and Decaisne[165] as prevalent in the West Indies. In the recent paper by Crossland (155, *loc. cit.*) he notes the fact that the Arabs of Zanzibar use the mangrove wood extensively in the building of their houses and furniture, since they have learned that it is the only wood which is so hard and perhaps contains some unpleasant substance, so that the termites will not chew into it.

Dr. A. G. Mayer has told the writer that he has observed the natives of Tahiti and other South Sea Islands using the red extract from the cortex regions in making a dye, while Schimper, in Engler and Prantl, records the observance of the custom of these same natives and those of the Malay Archipelago of using the prop roots for making bows.

Until comparatively recent times there was practised in the Florida Keys and to some extent still in Cuba, Porto Rico and other

164 Arnott, G. A. W., *Proc. Linn. Soc.*, 1869, 101–102.

165 Le Maut, E., et Decaisne, J., Traite de Botanique General, 1876, p. 419.

West Indian Islands the manufacture of charcoal from mangrove wood. On the Marquesas atoll there are now remnants of old charcoal burners' huts. The hard, dense quality of the wood and the plentiful supply at hand stimulated the industry in the days when charcoal was used more largely as a fuel, mangrove charcoal being of a very good quality.

As noted before the main application of the mangrove to man's wants has been for ages its utilization as a source of tannic acid. This is still carried on in a fairly large scale and there are several places in Florida in which there are factories for the manufacture of tannic acid from mangrove bark. Mr. Mills has told the writer of a factory at Charleroi, Fla., which produced large quantities of tannic acid from the bark.

The latest use of the mangrove in a practical way and one of which the writer has personal knowledge is the use of these trees as ballast retainers. This has been effectively demonstrated by the Florida East Coast Railway which has used the peculiar habit of the mangrove to advantage in their great feat of engineering, viz., the Oversea extension. At certain places these keys are connected by embankments supporting the road bed or where the bed is built high over a low, flat key the mangroves have been planted to prevent the erosive action of the sea on the ballast. This has been of greatest importance to the railroad and has protected the dykes just as the mangroves naturally sown have formed and protected young islands. Still more recently the writer has been of some small service to a large asphalt company concerning their engineering projects in Venezuela in which it is proposed to plant *Rhizophora mangle* along the dykes and jetties, etc., as a ballast retainer. This, it is hoped, will prove as efficient as the plantings of the Florida East Coast Railway have been in aiding the engineer in the tropics.

Summary.

1. The historical references to the mangroves are well authenticated and fall into three periods, viz., the classical references from Nearchus (325 B.C.) and Theophrastus to Arrian (136 A.D.); the Middle Age and later references from Abou 'l Abbas en-Nebaty

(1230) to Catesby (1731) and the references in the taxonomic and systematic writers from Linnæus (1736) to the present. The allusions to mangroves in the writings of the first two periods are mainly quaint and interesting descriptions by travellers, explorers and voyagers, while those of the last period are largely systematic.

2. In the morphology of the root, a study of the cortex cells of the submerged absorptive roots showed the thickenings or "verdickungsleisten" of Warming to be really an artefact brought about by a slight shrinkage of the walls of the delicate transfusion cells, which are lightly connected with each other.

3. The mechanical arrangement for the shedding of the pollen from the multilocular anthers consists of two systems of cells in the anther, the thin exothecial cells forming outer deciduous flaps, and the heavily reinforced cells of the expanded connective area, which have hitherto been overlooked. Dehiscence occurs by a rupture along a definite line due to the strain on the exothecial cells produced by their shrinkage and the resistance offered by the reinforced cells.

4. A conception of the endosperm is here maintained in agreement with that of Haberlandt, viz., that it functions as a placental organ rather than as reserve material.

5. By experiment the growth rate of emerging hypocotyls is seen to be 4.7 centimeters in 34 days in Florida.

6. In specially concentrated media a high mortality of seedlings is shown to be due to the increased hydrogen ion concentration in H_2S mud cultures; and in cultures of 140 per cent, hyperconcentrated sea water the mortality is due to the difficulty of absorption and retarded metabolism.

7. The transpiration rate records of this work show, first, for the moist soil cultures, the rate of transpiration to be delicately balanced with the amount of available moisture in the soil; second, the concentration-culture rates show that plants in dilutions above 35 per cent. sea water, growing in New Jersey soil, transpire more rapidly than plants in shell sand; that for cultures in 35 per cent. concentration of sea water and fresh water the transpiration is of equal rate for either soil and finally that cultures in dilutions under 35 per cent. transpire more rapidly when growing in shell sand. The same balance of relations is seen in the moist soil cultures at a

concentration of 88.5 per cent. dilution of salt and fresh water. An explanation of these phenomena seems to be offered in the experiments of Haas on the hydrogen ion concentration and the behavior of sea water on the addition of alkali.

8. The relations of tannic acid and dextrose in the hypocotyl, as deduced from the experiments, show that there is no definite decrease in the quantity of tannin with a corresponding increase in the amount of dextrose as growth of the seedling progresses. The relation is constant and in plants of successively large growth a ratio exists between the two substances approximating ⅔ to 1 per unit increase. A series of tests for the enzyme, tannase, showed this enzyme to be absent, thus tending to confirm the view that the tannin in the hypocotyl is not a reserve food.

10. It is set forth that the red mangrove is facultative in its growth, regarding salinity of water and inshore and offshore situations, as shown in a comparative study and measurements of leaf sections.

10. It is set forth that the red mangrove is facultative in its physiologic relations to fresh and salt water, but that it needs salt water for its optimum development and that there is a correlation between the height and abundance of trees and the salinity of the water in which they grow. By experimental methods it was determined that the condition of the trees and their distribution in estuaries depends on the presence of top and bottom layers of fresh and salt water moving in opposite directions.

11. Finally, by means of data secured from various sources it is shown that the red mangrove may be regarded as a plant of economic importance, not only as a source of tannic acid and charcoal, but also as a ballast-retaining plant in tropical coastal engineering work.

EIGHTEEN NEW SPECIES OF FISHES FROM NORTHWESTERN SOUTH AMERICA.[1]

By CARL H. EIGENMANN.

(*Read October 5, 1917.*)

In preparing a monograph on the fresh-water fishes of the northwestern corner of South America, the region west of the Andes from Peru to Panama, the species described in this paper were found to be new. Other preliminary accounts of new species from the same region have been described in Indiana University Studies, Nos. 16, 18, 19, 20, 23, 24 and 25, and in articles No. V., VI., VII., and IX. of the *Annals of the Carnegie Museum,* Vol. X.

The specimens were collected by Manuel Gonzales, Charles Wilson, Arthur Henn and myself.

Manuel Gonzales collected in part under the auspices of Indiana University, and in part under the joint auspices of Indiana University and the Carnegie Museum. He collected for Indiana University in the lower levels of the Magdalena Basin at and near Puerto Berrio and at Apulo. Also, along the route from Bogotá to Villavicencio and Barrigona, on the Meta River, largely at Villavicencio and Barrigona. He collected for Indiana University and the Carnegie Museum along the routes from Honda on the Magdalena River eastward to Facatativa, from Bogotá north to Mogotes in the Province of Santander and eastward from Bogotá along the route to Villavicencio. Along these routes he secured an unequalled collection of fishes from the mountain rivulets of the eastern Andes, both on the eastern and western slope.

Messrs. Wilson and Henn collected under the auspices of Indiana University chiefly through the generosity of Mr. Hugh McK. Landon, of Indianapolis, assisted also by Mr. Carl G. Fisher of Indianapolis.

[1] Contribution from the Zoölogical Laboratory of Indiana University, No. 160.

Mr. Charles Wilson accompanied Mr. Arthur Henn to the Patia River of southern Colombia, later ascended the San Juan River emptying into the Pacific Ocean just north of Buenaventura, crossed over the divide and descended the Atrato River to its mouth. Mr. Arthur Henn went with Mr. Wilson to the Patia River; after separating from Wilson he collected in the lower San Juan Basin, in Colombia, about Puerto Viejo, Ecuador, the lower Guayaquil Basin, Ecuador, and along the line from Guayaquil to Quito and northward to the upper Patia Basin in Colombia.

My own collecting was done along the line from Cartagena to Bogotá, from Bogotá to Buenaventura, up the San Juan River to Istmina and down the Atrato to its mouth. Detailed accounts of these trips will be published with the monograph mentioned above.

The letter "I." after the catalogue number indicates that the specimens are in the collections of Indiana University, "C." indicates the collections of the Carnegie Museum at Pittsburgh.

Astroblepidæ.

1. **Astroblepus latidens** spec. nov.

This species is similar to *A. trifasciatus* from the Rio Dagua. It is, as far as known, found only on the eastern slope of the eastern Andes of Colombia. All the specimens recorded below are from along the route between Bogotá and Villavicencio and Barrigona, and were collected by Manuel Gonzales and under his direction. This species ranges through the same gamut of color as *A. trifasciatus,* some specimens having conspicuous cross bands, others being uniform in color. The adults are readily distinguished from *A. trifasciatus* by the very broad teeth in the outer row of the premaxillary, a difference not evident in the young.

Specimens Examined.

Catalog Number.	Number of Specimens.	Length in Mm.	Locality.
7362 C., type	1 ♀	57	Piperel.
13677 I., 7363 C.	10	28–58	Piperel.
13678 I., 7364 C., paratypes	5	48–73	Caqueza.
13679 I., 6365 C., paratypes	18	27–60	Quebrada Hirajara.
13680 I., 6366 C.	33	largest 79	Quebrada Perdizes.
13681 I., 7367 C.	12	20–18	Rio Fosco.

Head 3.5; depth 5. Adipose fin consisting of a fleshy spine and an insignificant membrane. Dorsal and pectoral spines produced, if at all, by not over a millimeter beyond the rest of the rays; both lips very broad; outer teeth of the premaxillary of the adults chisel-shaped, broad tipped, the middle pair or two middle pairs sometimes bifid, about seven teeth on each premaxillary; teeth in the young much more slender; maxillary barbel usually not extending beyond the posterior margin of the lip, sometimes falling considerably short of that point, extending beyond the margin only in some of the largest specimens from Perdizes and Fosco; nasal flap short, not continued as a barbel; pectorals reaching a little beyond origin of ventrals; pectoral spine equal to the length of the head less the portion in front of the nares; ventrals inserted under the origin of the dorsal, extending little if any more than half way to the anal; anus usually about half way between tips of ventrals and origin of the anal, very rarely reached by the ventrals; dorsal spine a little shorter than pectoral spine, the rays graduate or coterminal; interocular space less than the distance from the eyes to the posterior nares, 4–5 in the length of the head; distance between tip of snout and dorsal 2.25–2.5 in the length; anal membranes in the male uniform, or the first two membranes a little wider; a light spot covering adipose spine and its membrane, sometimes a light bar at this point as in *unifasciatus*; body uniform dark or obscurely spotted; base of caudal and a distal bar or some distal spots dark, sometimes uniform; dorsal and pectoral sometimes with dark markings.

2. **Astroblepus cyclopus santanderensis** var. nov.

Specimens Examined.

Catalog Number.	Number of Specimens.	Length in Mm.	Locality.
7430 C.	1	33	Quebrada de Guapota.
13740 I., 7429 C.	4	27–32	Quebrada Guadelupe.
7428 C.	2	44–55	Quebrada la Pava.
13741 I.	3	21–54	Quebrada Callejona
13682 I., 7368 C.	21	20–63	Quebrada de Suescum.
13683 I., 7369 C.	6	41–76	San Gil.
13684 I., 7370 C.	8	32–75	Rio Mogotes.
13685 I., 7371 C.	7	37–62	Quebrada Chavala.
7424 C.	3	22–41	Quebrada de la Pelada.
7425 C.	2	28–36	Quebrada Variri.

These specimens were all collected by Manuel Gonzales in Santander, Colombia, in tributaries of the Rio Suarez at an elevation of from 1,000–2,000 M. They agree in all essential respects with *A. unifasciatus.* They differ uniformly, but not always greatly in having the thin membrane of the adipose oblique from the tip of the spine to the most posterior point of its attached base. This is characteristic of even the smallest specimens from Suescum, but in the three specimens from Callejona the membrane is truncate as in *A. unifasciatus.* In color they approach *A. orientalis,* there being conspicuous, irregular, sometimes confluent spots on a light background, usually there is a band across the body in the region of the adipose fin. The ventrals extend to or even beyond the anus in the very small individuals but usually fall short of it in the larger.

3. **Astroblepus frenatus** spec. nov.

Among many specimens of *Astroblepus micrescens* from Santander there is one that probably represents another species.

7380 C., type, a female 43 mm. Quebrada de San Joaquin, Santander. Gonzales.

Head 3.25; D. I, 6; A. 7; interocular less than distance between eye and nostril, 4.5 in the length of the head; nasal flap moderate; barbel not extending beyond the posterior margin of the lip; pectoral rays extending considerably beyond the base of the ventrals, the outer rays to almost its middle; origin of ventrals just in advance of the dorsal ray, reaching not quite to the anus, which is .75 of the distance from the origin of the ventrals to the anal; anal obliquely truncate, not reaching the caudal; caudal symmetrically lunate, the outer rays slightly produced; adipose fin a very low fold, with a minute spiniferous spine, evident externally through its spinules, which project beyond the margin of the fin; dorsal spine equal to head less region in front of nares, the rays all coterminous when the fin is depressed; distance of dorsal from snout about 2.3 in the length; premaxillary with one bicuspid tooth, the rest all pointed. A dark streak from eye to base of barbels; sides with a few large spots; a light bar down from behind the spine of the adipose; base of caudal and two rows of spots dark.

4. **Astroblepus grixalvii micrescens** var. nov.

The following specimens came from the western slope of the eastern Andes, north of Bogotá. They were collected by Manuel Gonzales.

SPECIMENS EXAMINED.

Catalog Number.	Number of Specimens.	Length in Mm.	Locality.
7372 C., type......	1 ♂	69	Quebrada de Agua Larga.
13686 I., 7373 C., paratypes.......	25	32–64	Quebrada de Agua Larga.
13687 I., 7374 C....	2	68–76	Quebrada Densino, Santander.
13743 I.	3	30–52	Quebrada de la Pelada, Santander.
13688 I., 7375 C....	5	30–95	Rio Susa, Santander.
13689 I., 7376 C....	6	31–89	Quebrada de Potrero, Santander.
13690 I., 7377 C....	3	41–74	Quebrada de Siachia, Santander.
13691 I., 7378 C....	19	27–89	Quebrada de San Joaquin, Santander.
13692 I., 7379 C....	13	23–80	Rio de Ducho, Norte.
13737 I., 7427 C....	5	37–50	Rio de Pacho, western slope, eastern Andes.
13693 I., 7382 C....	4	32–49	Quebrada de Cabarachi, Santander.

This variety greatly resembles *A. unifasciatus* and *A. orientalis*; it differs from the former in the nature of the adipose fin, and from the latter at least in the length of the pectorals and ventrals.

Head 3.75–4; D. I, 6; A. 7; interocular 4–4.5 in the head, slightly less than the distance between posterior nares and eye; nasal flap broad, its outer angle slightly produced or not; barbel about reaching the gill-opening, sometimes falling a little short and sometimes extending a little beyond; pectorals broad, the divided rays fan-shaped, extending about to the ventrals, the outer ray reaching almost to the second third of the ventrals; ventrals lanceolate, their origin under the first dorsal ray; the outer ray reaching nearly to or beyond the anus, which is two thirds to three fourths the distance from the origin of the ventrals to the anal; anal obliquely truncate, the anterior ray always extending beyond the following one in the female; the first and second membranes in the male very wide, the third, fourth and fifth rays close together and extending beyond the first two and the last two, not near reaching the caudal; caudal symmetrically emarginate, the outer rays prolonged; adipose fin in the young an adnate or subadnate spiniferous spine, with age a dermal ridge develops in which the spine disappears or is retained as a non-spiniferous stay. (The process does not take place at the same rate in all specimens so that in two specimens of the same size, one may have an apparent spine while in the other it may be hidden. The smaller ones in which the spine is especially well developed may not be distinguishable from *A. unifasciatus*.) Dorsal spine very slightly, if at all, produced, almost two thirds the length of the head; distance between snout and dorsal 2.66–2.75 in the length; teeth of the premaxillary all single pointed, or one or two pairs bicuspid. Sides variously spotted, a V-shaped light area in front of the dorsal, frequently a bar across the sides below the adipose as in *A. unifasciatus*; base of caudal and one or two rows of spots parallel with the margin.

The paratypes differ but little from each other, and the specimens from the Ducho are very similar to them.

Loricariidæ.

5. **Hemiancistrus Wilsoni** spec. nov.

For Mr. Charles Wilson who made large collections in the Rio Truando, a tributary of the Rio Atrato.

7570 C.; 13921 I., eight, 90–133 mm. Truando. Wilson. The largest the type. Similar to *H. holostictus* from the San Juan.

Head 3–3.25; depth 4.5–5; D. I, 7; A. I, 4; 27 scutes, six or seven between the dorsals, 11 + 3 between the anal and caudal; depth at tip of occipital equals snout and half the eye; width above base of pectoral almost equal to length of the head; mandible 3–3.6 in the interorbital; eye 4.25 in snout, 3 in interorbital, 7 in the head; interorbital with 3 minute spines or none.

Occipital with a high keel, median plate behind it feebly bicarinate, plates of the sides well carinate; dorsal spine equal to head and two or three scutes behind it, reaching to the adipose spine or the plate in front of it, the last ray reaching the spine of the adipose; caudal deeply emarginate, the lower lobe considerably longer, 2.2 in the length; the middle rays about 1.4 in the lower; ventral surface in a specimen about 115 mm. long mostly naked, in the larger ones granulose except in a small area in front of the ventral.

Everywhere covered with round spots, a double row of about twelve on the anterior dorsal membranes, about five series on the last, fewer rows in the smaller; about twelve series of spots on the caudal; in all but one the outer caudal rays spotted.

6. **Pseudancistrus pediculatus** spec. nov.

The following specimens were collected by Manuel Gonzales on the eastern slope of the Andes between Bogotá and the Rio Meta.

SPECIMENS EXAMINED.

Catalog Number.	Number of Specimens.	Length in Mm.	Locality.
13664 I., 7348 C., paratype and type	2	60 and 118	Rio Negro, Villavicencio.
13927 I., 7586 C., paratypes	6	largest 95	Villavicencio.
13928 and 13663 I., paratypes	10	largest 120	Quebrada Cramalote, Villavicencio.
13929 I., paratypes	3	largest 103	Barrigona, Rio Meta.
13932 I., 7587 C., paratypes	7	largest 95	Tengavita.

Head 2.7–3; depth 6.5–7; D. I, 7 in five, I, 8 in forty-six, I, 9 in two; A. I, 4; scutes usually 25, rarely 24 or 26; eye about 6 in snout, 10 in head, a little over 3 in the interorbital; ramus of lower jaw about equal to the interorbital; interopercle with two principal spines, the longer .6 of the head, extending much beyond the head; sometimes 4 or 5 graduated spines follow each other, besides these there is with age, an increasing number of smaller spines about the edge or below the hispid portion of the interopercle; snout with many bristles in the male, short spines from the eyes forward, around the nares and forward along the middle to the snout; dorsal spine equal to the snout or shorter, the last ray reaching the adipose spine or the second scute in front of it; caudal very obliquely emarginate, the lower ray 3.33 in the length; pectoral reaching tip or middle of ventrals.

Back and sides with faint spots; dorsal and caudal with numerous spots on the rays, more rarely uniform; ventrals and pectorals more faintly spotted.

7. **Ancistrus triradiatus** spec. nov.

Specimens Examined.

Catalog Number.	Number of Specimens.	Length in Mm.	Locality.
13935*a* I., type	1♂	113	Quebrada Cramalote, Villavicencio.
13935*b–e* I., paratypes	4	61–85	Quebrada Cramalote.
7591 C.	2	78♂ and 81♀	Quebrada Cramalote.
13937*a* I.	1♂	77	Barrigona.
13937*b–c* I.	2♀	43 and 70	Barrigona.
7578 C.	1	52	Villavicencio.

All the specimens were collected by Manuel Gonzales at the base of the Andes east of Bogotá.

Head 2.6–2.75; depth 6.5; D. I, 7; A. I, 3; scutes 24 or 25, 4 + 1 or 2 in front of the adipose, 9–11 + 3 between anal and caudal; eye 7–9 in head, 3–5 in interorbital, 5 in snout; width of head about 1.25 in its length; mandibular ramus 1.8–2.33 in the interorbital; interopercle with 15–20 or more spines; tentacles profuse, fully developed in a specimen 78 mm. long, consisting in the male of a row along the margin of the snout and up the sides of the head in front of the preopercle and the usual Y-shaped series on the snout; the snout very narrowly naked in the female; dorsal reaching plate in front of adipose spine, its base equal to its distance from some part of the adipose spine, pectoral spine in the male reaching to the second third of the ventrals; depth of caudal peduncle about 2.5 in its length. Caudal rounded, more obliquely so in young than in adult.

Color of the type: body including head and belly, with faint, roundish, light spots; dorsal with about five series of comma-shaped black spots in broken series lengthwise of the fin; caudal with similar but shorter spots which merge into two continuous bars at the base; pectorals and ventrals with similar but larger spots, those of successive rays alternating, outer angles of caudal light. In other specimens sometimes the tip of the first two dorsal rays, and in the young the margin of the caudal light, the markings on the fins confined to the rays. Ventral surface in the small specimens plain.

8. **Chætostomus leucomelas** spec. nov.

13652 I.; 7340 C., three, 116–143 mm., the largest the type. Rio Patia, halfway between the Rios Magui and Telembi. April 5 and 6, 1913. Henn.

Head 3.33–3.5; depth 6–6.5; D. I, 8 in two, I, 9 in one; A. I, 5; scutes 24–25; eye 2.5 in the interorbital, which is 3 in the head; depth of the head 2 in its length, its width about .8 of its length; interopercle with 3–5 strong, recurved, graduate spines; dorsal spine about .8 as long as head, base of dorsal equal to its distance from the middle of the adipose spine; caudal deeply emarginate, the lower lobe longest; depth of caudal peduncle 3 in its length.

Back and sides light olive, faintly mottled. All fins but the anal with light bands across the rays, the membranes hyaline, margin of caudal light. The contrast between light and dark bars strongest on dorsal and caudal. No spot on the second membrane of the dorsal in one of the specimens; a spot on the base of the second membrane of the dorsal in two of the specimens.

MUGILIDÆ.

9. **Joturus daguæ** spec. nov.

7458 C., type, 195 mm.; 7459 C.; 13846 I., paratypes, five, 167–225 mm. Rio Dagua at Caldas, Colombia. Eigenmann.

Head 4.1; depth 3.5; D. IV–I, 8; A. III, 9; scales 44–46, 13 or 14 between dorsal and anal; eye 5 in the head; interorbital 2.5; snout 3.25–4; snout conical, the maxillary reaching to the anterior margin of the eye; teeth of the upper jaw mostly bicuspid, more rarely tricuspid or unicuspid, a series of larger pointed teeth from an anterior row in some specimens; teeth in the lower jaw mostly unicuspid, a few bicuspid; snout conical, length of the mouth about 1.5 in its width; scales decreasing in size forward on the head but without supplemental scales; no accessory scales on the body; preorbital serrate on its posterior edge and on the posterior part of the lower edge; upper lip very broad in front, forming the tip of the snout; spinous dorsal naked, a few scales on the base of the membranes of the soft dorsal, caudal and anterior part of the anal; gill-membranes free from each other to below the posterior margin of the eye; pectoral five sevenths to three fourths as long as the head, not reaching to the dorsal; first dorsal spine a little over half the length of the head, reaching to the tip of the second spine when depressed, the third spine not reaching the tip of the second and the fourth not to the tip of the third; a dark spot on base of caudal, and another on base of the pectoral; an ill-defined lateral band; dorsal spines and a streak on the membranes dark; dorsal dusky.

This species greatly resembles *Agonostomus monticola* which has a narrower and longer snout.

Stolephoridæ.

10. **Stolephorus branchiomelas** spec. nov.

7491 C., type, 68 mm.; 7492 C.; 13875 I., paratypes, three, largest 54 mm. Mouth of Rio Dagua. Eigenmann.
13880 I., ten, largest 83 mm. Tumaco? Henn & Wilson?

Head 3.33; depth 4; D. 14; A. 29 or 30; eye 3.5 in the head, .5 in snout; teeth very minute; maxillary not quite reaching gill-openings; gill-rakers about two thirds as long as the eye, 55 on the upper, 70 on the lower part of the arch; origin of dorsal equidistant from anterior margin of eye and caudal; caudal lobes equal; a silvery band, well defined between dorsal and anal, diffuse in front and behind; inner face of mandible dark, darkest near symphysis; inner lining of shoulder girdle black; gill-filaments with black chromatophores; tips of caudal dusky.

Sciænidæ.

11. **Stellifer melanocheir** spec. nov.

7520 C., type, 120 mm. Tumaco. Henn & Wilson.

Head 3.44; depth 3.1; D. XI, 23; A. II, 8; scales from middle of back in front of dorsal to lateral line 7, from lateral line to vent 10; 50 pores to origin of caudal rays; eye about 4 in the head, interorbital 2.5, snout 4.5; maxillary-premaxillary border 1.8.

Mouth oblique, lower jaw included, the premaxillary on a level with the lower edge of the pupil; interorbital slightly convex, chin with a small knob, the pores evident; teeth in two irregular series, the outer series of the upper jaw and the inner series of the lower jaw enlarged. Gill-rakers 15 or 16 in upper, 25 or 26 in lower arch (21 + 27 in *S. oscitans*), preopercular spines strong, the upper directed backward, the lower downward and backward; first and second dorsal spines strong, pungent; second dorsal spine nearly half the length of the head; tenth dorsal spine shortest, the third to the seventh spines weak, flexible, the rest becoming strong pungent, the third dorsal spine higher than any of the rays; second anal spine 1.17 in the length of the head, its tip reaching tip of fourth anal ray; caudal narrowly rounded, its middle rays equal to the length of the head; pectorals reaching to above the first anal spine, the ventrals to the vent; caudal, soft dorsal and anal scaled to near the tip; a row of scales along the back of the dorsal spines to near the tip. Caudal, soft dorsal and all but part of last three anal rays densely punctate; upper surface of first two ventral rays less densely punctate; spinous dorsal and all but lowest rays of the pectorals nearly black, much darker than the other fins. Scales of sides and back with punctulations forming faint streaks, oblique between the lateral line and the spinous dorsal, horizontal elsewhere.

Hæmulidæ.

12. **Pomadasys sinuosus** spec. nov.

Type, 13892 I., 161 mm. Patia, between Magui and Telembi. Henn.

Head 3; depth 3.3; D. XIII, 12; A. III, 8; 51 pores in the lateral line to the base of the caudal, 12 pores on the caudal; eye 4.4 in the head, snout 3.1, bony interorbital 7, interocular 5, preorbital 7.3.

Profile sinuous, slightly depressed in front of the dorsal and over the eye; snout pointed, the maxillary reaching just to the anterior margin of the eye; teeth in broad bands, the outer series of both jaws a little enlarged; spine at angle of preopercle broad, flat; gill-rakers in both arches 17, the lower four or five rudimentary, the upper three rapidly graduate; pectoral short, not near reaching vent, 1.7 in the head; fourth dorsal spine highest, 2 in the head, the highest ray .84 of the highest spine, length of the base of soft dorsal 2.15 in the base of the spinous dorsal; second anal spine 1.4 in the head; soft dorsal naked, first two membranes of the soft anal naked, the third to the sixth with scales on the basal third. Silvery, dorsals dusky.

Gobiidæ.

13. **Hemieleotris levis** spec. nov.

13865 I., type, 40 mm., paratypes 13866, I.; 7484 C., twenty-three, largest 48 mm. Pools in Buenaventura. Henn.
13867 I., one, 42 mm. Rio Calima. Henn.

Head 3.5; depth 4.5; D. VII–I, 10; A. 10 or 11; scales 34 or 35 + 11, eye 1 in the length of the snout, 4 in the length of the head, interorbital a little greater than the eye.

Heavy, little compressed except on the caudal peduncle; head broad, mouth oblique, the upper lip on a level with the middle of the eye, maxillary reaching just beyond the origin of the eye; teeth in narrow bands, those of the outer series of both jaws considerably enlarged; gill-rakers 5 + 15, the inner ones of the first arch considerably heavier, blunt, about one third as long as those along the outer edge of the arch; head scaled to in front of the eyes; the scales of the head, breast, belly, and those in front of the dorsal cycloid, those of the sides with a series of strong marginal spines; spinous dorsal rounded, the middle spines longest, some of the spines reaching the soft dorsal in some specimens, usually shorter; posterior rays of the soft dorsal sometimes reaching caudal, usually shorter, the margin of the fin rounded; caudal rounded, about 3.5 in the head; anal similar to the soft dorsal; ventrals not reaching the vent; sides clouded, with indistinct cross-bands forward, becoming more distinct on the caudal peduncle; a narrow, faint, dark lateral line, most conspicuous in the male; sometimes a row of dots along a row of scales on the lower part of the sides; a dark spot on the shoulder just above the base of the pectoral; dorsal nearly uniform dusky, without markings.

14. **Sicydium hildebrandi** spec. nov.

7466 C., type, 137 mm.; 13852, I., paratype, 114 mm. Cisnero, Rio Dagua. Eigenmann.

Head 5.25; depth 5.5; D. VI, 11; A. 11; about 70 scales between pectoral and caudal, about 20 between dorsal and anal; eye 6 in the length of the head, interocular 2.5.

Head very blunt, body cylindrical, caudal peduncle compressed; scales in the middle line extending to a point a little in advance of the upper angle of the gill-opening; belly scaled; pectorals large, a little longer than head; all but the first dorsal spines produced, the second, third and fourth of nearly equal extent, reaching the fourth to the seventh dorsal ray; dorsal rays increasing in height to the penultimate which reaches the caudal and is one third longer than the head; anal similar to the dorsal but lower, its origin equidistant from eye and caudal; horizontal teeth of the lower jaw entirely concealed, teeth of the upper jaw truncate.

Scales of sides gray at margin and with a submarginal dark crescent; dorsals dark with numerous light spots, circular near base and middle, becoming elongate or vermiform toward the tip; caudal and pectoral dusky; anal dusky with a darker border.

Named for Mr. S. F. Hildebrand, in recognition of his work with the fresh-water fishes of Panama, and for his discovery of several new genera of Gobiidæ in Panama.

15. **Gobius (Ctenogobius) daguæ** spec. nov.

7481 C., type, 90 mm. to base of caudal, about 133 to end of caudal, paratypes, 7482 C.; 13863 I., three, 65–103 mm. Mouth of Rio Dagua. Eigenmann.

Allied to *Gobius boleosoma and encœomus.*

Head 4–4.2; depth 5.25–6; D. VI–I, 12; A. I, 12; scales 31–34; eye 4 in the head, interocular 6, preorbital very little wider than the eye; head as well as body compressed; heaviest at the ventrals, tapering regularly to the caudal, snout very blunt, narrow; width of the head but little, if any more than half its length; depth of the head 1.5 in its length; mouth low, terminal, horizontal; lips very thin; upper jaw with an outer series of fixed teeth and a few teeth within these near the symphysis; lower jaw with a similar series of slightly smaller teeth and several irregular series behind this near the symphysis; scales large, ctenoid on the area behind the tips of the pectorals, cycloid, smaller and less regularly arranged above the pectoral; nape, region in front of the dorsal, and region above the gill-openings naked. Pectorals and ventrals nearly coextensive, a little shorter than the head; dorsal spines curved, prolonged in filaments, reaching to the base of the fourth ray; the first, second or third longest; soft dorsal reaching to or beyond the origin of the caudal; caudal very long, pointed, 2–2.5 in the length; anal similar and nearly coextensive with the dorsal.

A conspicuous black spot on the upper part of the pectoral; sides with five to eight dull spots, the alternate ones smaller, the last at the base of the caudal; spinous dorsal and lower part of soft dorsal with horizontal dark streaks; middle or upper part of caudal with faint cross bars; ventrals dusky; pectoral and anal light.

16. **Awaous decemlineatus** spec. nov.

SPECIMENS EXAMINED.

Catalog Number.	Number of Specimens.	Length in Mm.	Locality	Collector.
7478 C., type	1 ♂	80	Quibdo.	Eigenmann.
13862 I., 7480*a–e*, C.	21	largest 50	Puerto del Rio Cienega.	Gonzales.
13861 I., 7470*a–d*, C.	8	largest 51	Calamar Cienega.	Eigenmann.

Head 3.33; depth 5.25; D. VI–I, 9 or 10; A. I, 10; scales 57–14; eye a little over 5 in the head; equal to the interocular; maxillary reaching to below middle of the eye; snout nearly 3 in the head; mouth wide, its width equals the postorbital part of the head; teeth of the lower jaw of the type consisting of a series of small, more or less movable ones in an outer row and four strong, recurved, fixed teeth in an inner series, near the symphysis, not parallel with the outer series, and one or two similar teeth on the side of the jaw remote from the rest of the inner series and opposite the end of the outer series; upper jaw with a series of about seven strong, widely spaced, recurved teeth (16 in the young); fifth dorsal spine reach-

ing the fourth ray; the last rays reaching the caudal; caudal narrowly rounded, equal to the length of the head; tip of anal just reaching the caudal.

Ten narrow cross lines on the body, the posterior ones Y-shaped, the upper branches of the Y in contact; a small dark spot at the base of the caudal; two dark lines from the eye forward to the edge of the preorbital; an oblique black band from the first to the second dorsal spine in the second or third fourth of their height; dorsal faintly barred; upper three fifths of the caudal conspicuously barred by lines that become more wavy and less distinct toward the tip of the fin; lower portion of caudal plain.

Easily disinguished from the other species of the genus by its narrow cross lines. In the smaller specimens the teeth of the lower jaw are less differentiated. The outer row of sixteen to twenty teeth are slightly larger at the outer edge of the row, the inner row consists of ten teeth in a series nearly parallel to the proximal half of the outer row.

CHARACIDÆ.

17. **Brycon ecuadoriensis** Eigenmann & Henn, spec. nov.

13470 I., type, 245 mm. from tip of snout to end of lower caudal lobe, 204 to end of scales on middle of caudal. Rio Barranca Alta from Naranjito, Ecuador. Henn.

Head 3.6; depth 3.3; D. 11; A. III, 29.5; scales 9–56–4 to ventrals; eye about 4.1; base of anal equals length of head.

Preventral area rounded, postventral area compressed, not keeled; predorsal area very bluntly keeled; occipital process about 8 in the length from its base to the caudal; interorbital moderately convex; snout rounded; frontal fontanel about one third as long as the parietal; cheeks with an exceedingly narrow naked margin; premaxillary with 6 teeth in the outer series of one side, 7 in the other side; five teeth in the inner series; three teeth in a row from the second tooth of the outer to the third of the inner series, a tooth between the first of the outer and the second of the inner series; 14 teeth in the maxillary to near its tip, the anterior ones which form a continuous series with the inner series of the premaxillary largest;

mandibular teeth slightly graduate in height from the third to the first, the second tooth being the widest; the three first teeth of the two mandibles forming a compact series in an open crescent; fourth tooth slightly recurved, much smaller than the third, the remaining two teeth quite small (on the left side there is an abnormal gap between the third and fourth teeth) ; the inner series of teeth begins just within the last tooth of the outer series and consists of four teeth; symphysial tooth small; maximum width between front and rear series about 5 mm.

Gill-rakers 11 + 14, the longest 5 mm.; longest gill filament 11 mm.

Origin of dorsal 102 mm. from tip of snout, 106 from end of scales at base of middle caudal rays; exposed portion of longest upper caudal ray 47 mm., of longest lower ray 51 mm. First developed anal ray equidistant with last dorsal ray from the end of the scales of the middle caudal rays; first rudimentary ray 128 mm. from tip of snout; origin of ventrals 93 mm. from tip of snout; pectoral just reaching ventrals.

Scales on the middle of the sides with as many as ten subparallel radials, more toward the base of the anal. Lateral line faint; a large axillary scale.

Dark on sides and above, with steel blue to brassy lustre; fins dusky; a large, obscure humeral band; a large black spot on caudal peduncle, most intense toward its end, fading out forward, continued on the membranes of the middle rays to their tip.

18. **Brycon meeki** Eigenmann & Hildebrand, spec. nov.

Many specimens from the Rios San Juan, Dagua, and Patia of western Colombia.

Head 3.8 to 4.55; depth 3 to 3.25; D. 10 or 11; A. 33 to 35; scales 12 or 13–60 to 70–7 or 8.

Body elongate, compressed; profile slightly concave over eyes, elevated at nape; head rather small; snout blunt, 3.5 to 3.85 in head; eye 2.75 to 4; interorbital 2.3 to 3.1; mouth moderate; upper jaw strongly projecting; maxillary reaching opposite middle of eye, 2.1 to 2.4 in head; premaxillary teeth laterally in 3 series, anteriorly in 5 more or less irregular series, the fourth series consisting of only 2 teeth, the fifth or transverse series with 4 teeth; maxillary teeth small, about 13 in number; mandibular teeth quite strong, 8 large ones and abruptly smaller ones at sides in outer series; gill-rakers moderate, 15 or 16 on lower limb of first arch; lateral line complete, curved downward; scales moderate, regularly placed, 22 or 23 rows before dorsal; 17 to 19 vertical rows crossing back between dorsal and adipose; 4 longitudinal rows between lateral line and base of pectoral; dorsal fin in advance of anal, its origin midway between tip of snout and base of caudal or slightly nearer the latter; caudal fin forked, the lower lobe the longer; anal fin long, its base longer than head; ventral fins usually reaching vent, inserted slightly nearer origin of anal than base of pectorals; pectoral fins usually not quite reaching base of ventrals, inserted under margin of opercle.

Color dark blue above, silvery below; a conspicuous black margin on shoulder girdle; no lateral band; no caudal spot. Some specimens with indistinct vertical dark lines. Fins unmarked.

Named in honor of the late Seth E. Meek.

DESCRIPTIONS OF SIXTEEN NEW SPECIES OF PYGIDIIDÆ.[1]

By CARL H. EIGENMANN.

(*Read October 5, 1917.*)

The Pygidiidæ are a family of fishes found from southern Panama to Patagonia, and from sea level to the highest Andes. A monograph of this family, pretty well illustrated, is all but completed but may be delayed in publication. The new species and genera are here described in advance of the publication of the monograph.

Ecologically this family is one of the most interesting ones of South America. Some of the species attain considerable economic importance, especially in the higher altitudes, as on the plains about Bogotá and in Titicaca and other high Andean lakes of Peru. Others are minute and live as parasites in the gill-cavities of other fishes. The new genus, *Branchioica,* belongs to this ecological group. Still others attach themselves to other fishes and bathers like leeches, making slight abrasions in the skin and swallowing the blood. Still others have the evil reputation of entering the urethra of bathers, causing severe complications or even death. The new species *Vandellia sanguinea* belongs to this ecological group.

The specimens were collected in the region and during the expeditions mentioned in the preceding article and by Dr. John Haseman, who travelled in South America for the Carnegie Museum between 1907 and 1910. A map showing his route was published in the *Memoirs of the Carnegie Museum,* Vol. VII., Plate I. Of particular interest is the new genus *Branchioica,* which lives in the gill cavities of other fishes.

The numbers followed by the letter "I." refer to the catalog

[1] Contribution from the Zoölogical Laboratory of Indiana University, No. 16.

of the Indiana University, those with the letter "C." to the catalog of the Carnegie Museum.

SCLERONEMA[2] gen. nov.

Type, *Scleronema operculatum* spec. nov.

Allied to *Pygidium*.

Ventrals nearer snout than caudal, outer pectoral rays shortest, without a filament; opercle with a long dermal flap; interopercular spines in much more restricted area than in species of *Pygidium*; accessory rays of the caudal inconspicuous; maxillary barbel with a large osseous base (maxillary bone). Teeth very narrow incisors; mouth wide, terminal.

1. **Scleronema operculatum** spec. nov.

7077 C., type, 79 mm. 7539 C., paratypes, 3, 65–80 mm. Cacequy, Uruguay Basin. Feb. 1, 1909. Haseman.

Head 5.66; D. 12.5; A. 7.5 counting the rudimentary rays; P. 7; eye in anterior half of the head; interocular 5 in the length of the head; width of the mouth nearly half the length of the head.

Nasal barbel short, reaching just beyond posterior nares; maxillary barbel reaching about half-way to the tips of the opercular spines, the bony base much longer than the soft filament; a broad, free membrane above from near the anterior nares to the tip of the osseous base of the barbel, a narrower membrane along the outer edge of the base of the barbel; six spines in the main row of the interopercle; opercular flap reaching to near base of the last pectoral ray; pectoral about as long as the head; origin of ventrals a little nearer to the snout than to the base of the middle caudal rays; ventrals reaching beyond the anus, not quite to the anal, equal to the portion of the head behind the nasal barbels; origin of anal under the antepenultimate dorsal ray, the distance from the base of its last ray to the caudal four times in the length; caudal narrow and long, equal to the length of the head; its margin slightly obliquely rounded; origin of dorsal over posterior half of ventrals,

[2] σκληρος = hard; νῆμα, τὸ = hard thread, in allusion to the hard base of the maxillary barbel.

the distance from the first ray to the caudal 1.34 in its distance from the snout.

Middle of sides with a series of faint, large spots, similar but smaller spots along the back.

2. **Hatcheria titcombi** spec. nov.

Pygidium areolatum Everman & Kendall (non Cuv. & Val.), Proc. U. S. Nat. Mus., XXXI., 1906, p. 86. (Rio Comajo; tributary of Lake Traful, tributary to Rio Limay.)

11110 I., type, 164 mm. Arroyo Comajo. J. W. Titcomb.

This specimen is one of those mentioned by Everman and Kendall. It differs from the *areolatum* as described by Cuvier and Valenciennes, whose specimen came from Chile, west of the Andes. The origin of the dorsal is further back, and its last ray is beyond the last ray of the anal.

Head 6.33; depth 6.5; D. 17.5 (3 + 14.5); A. 9.5 counting the minute imbedded rays in each case; P. 9; front margin of the eye in the middle of the head; interocular a little over three in the length of the head, eye three in the interocular. Teeth very narrow chisels; nasal barbel reaching to above first preopercular spines, maxillary barbel to middle of opercular spines. Pectoral rounded, its first ray not prolonged, nearly two thirds the length of the head; origin of the ventrals equidistant from snout and last fifth of the middle caudal rays; first anal ray under the sixth dorsal ray, the last anal ray under the fourth from the last ray of the dorsal; distance between anal and caudal 4.75 in the length; origin of dorsal equidistant from tip of caudal and middle of pectorals, its distance from the caudal two in its distance from the snout.

Sides without distinct markings; faint traces of longitudinal lines.

3. **Pygidium heterodontum** spec. nov.

13832 I., type, 83 mm., ♀, Rio Mendoza, Palmira, Argentine, 900 m. Purchased from Rosenberg.

Palmira is probably the southernmost locality on the eastern slope of the Andes from which species of this genus have been taken.

Head 6, as long as broad; D. 10.5 (4 + 6.5); A. 7.5 (2 + 5.5); P. 9; eye in middle of the head, interocular 3.5 in the head; teeth in three series in each jaw, those of the outer row narrow incisors, those of the second row much smaller incisors, those of the third row conic. Head much depressed, interopercular spines numerous, thirteen in the last row.

Nasal barbel extending to the posterior margin of the eye, maxillary barbel to the base of the opercular spines; first pectoral ray scarcely produced, equal to the portion of the head behind the posterior nares; origin of ventrals midway between opercle and caudal, reaching to the vent; origin of anal under posterior part of the dorsal, the distance between its last ray and the base of the middle caudal ray 4.4 in the length; depth of the caudal peduncle 2.5 in its length; caudal narrow, emarginate, a little more than five in the length; origin of dorsal midway between the tip of the caudal and the occiput, over the tip of the ventrals, its distance from the caudal 1.75 in its distance from the snout.

A faint lateral band and obscure spots or marblings.

4. **Pygidium latidens** spec. nov.

13801 I., type, 53 mm. Small creek near the mouth of Rio Calima. May 7, 1913. Henn.

Head 5.5; D. 9.5; A. 7.5; P. 7; posterior edge of eye in advance of the middle of the head; interocular 3.5 in the head.

Nasal barbel extending beyond the tips of the opercular spines; maxillary barbel extending beyond the axil, longer than the head; pectorals broad, as long as head without snout; pectoral filament equal to the distance from the snout to the axil; ventrals not near reaching anus, their origin equidistant from the base of the middle caudal rays and the interopercle; origin of anal about under middle of the dorsal, distance between base of the last ray and the middle caudal rays five and one half in the length; caudal rounded, about six in the length; accessory rays well developed; origin of dorsal over anus, its distance from the middle caudal rays two in its distance from the snout; gill-membrane free to below the anterior spine of the interopercle, without a free membrane across isthmus; both jaws with two series of thin, chisel-shaped teeth.

Color plain, without spots or stripes.

5. **Pygidium metæ** spec. nov.

13770 I., type, 78 mm. Barrigona. March, 1914. Manuel Gonzales.

Head 6.3 in the length; D. 10.5; A. 9.5 counting the rudimentary rays; P. 6; width of head nearly equal to its length; eye entirely in the anterior half of the head, snout 2.75 in the head, interocular 3.5. Teeth conic.

Nasal barbels reaching to tip of opercular spines, maxillary barbel slightly beyond origin of pectorals; pectorals small, equal to the postorbital portion of the head, the first ray with its filament equal to the head, origin of ventrals much nearer base of middle caudal rays than to *tip* of pectorals, their tips reaching the anal; origin of anal under fourth dorsal ray (second fully developed ray); the distance between the base of its last ray and the base of the middle caudal rays six times in the length; caudal rounded; origin of dorsal over tip of ventrals, its distance from the base of the middle caudal rays two and two fifths times in its distance from the snout.

Sides and back densely covered with spots about the size of the eye.

6. **Pygidium straminium** spec. nov.

All of the specimens examined were collected by Gonzales in Santander, Colombia.

Catalog Numbers.	Number of Specimens.	Length in Mm.	Locality.
7101 C., type, 13818 I., paratype	2	46 and 50	Quebrada del Mango.
7089 C., paratype	1	35	Quebrada del Maradat(?).
7090 C., 13804 I., paratypes	7	largest 45	Quebrada da Densino.
7102 C., 13819 I.	15	largest 60	Quebrada de Ocamante.
7103 C., 13826 I.	4	largest 67	Quebrada de la Zuarta.
7104 C.	1	41	Quebrada de la Honda.

Head 4.5–5.33; D. 10.5; A. 8.5–9.5; P. 9; posterior margin of

eye in the middle of the head; interorbital three in the length of the head; teeth bristle-like in about three series.

Nasal barbels reaching base of opercular spines or beyond origin of pectorals, maxillary barbels to tip of opercular spines or axil; pectoral filament a little longer or shorter than the length of the head, the rays equal to the length of the head without the snout; origin of ventrals equidistant from the base of the middle caudal rays and a point between the axil and a little in front of the opercle (and the tips of the opercular spines in the type), tips of the ventrals slightly behind the vent; origin of the anal behind the vertical from the base of the last dorsal ray or under the posterior half of the dorsal, the distance between the base of the last anal ray and the middle caudal rays 4.5–5 in the length; accessory caudal rays very large and numerous; caudal rounded, six and a half in the length; origin of dorsal over the origin of the ventrals or but slightly behind this point, always nearer the eye than the tip of the caudal, sometimes equidistant from tip of snout and tip of caudal, its distance from the base of the middle caudal rays one and a half or less in its distance from the snout.

Uniform straw-colored in alcohol.

7. **Pygidium dorsotriatum** spec. nov.

7093 C.; 13810 I., four, 18–76 mm., the largest the type. Villavicencio. Manuel Gonzales.

Distinguished by the eccentric, dark, lateral band.

Head 5; D. 12.5 (of which 4 minute); A. 9.5; P. 9; center of eye very little in advance of middle of the head, interocular three in the head. Teeth conic.

Nasal barbels extending to or slightly beyond origin of pectoral; maxillary barbel to the axil, equal to the length of the head; pectoral filament equal to the length of the head, the longest ray equal to the length of the head behind the nasal filament; origin of ventrals equidistant from base of middle caudal rays and tip of the interopercular spines, ventrals nearly reaching the anal; origin of the anal under the last quarter of the dorsal, the distance between the base of its last ray and the base of the middle caudal rays about 4.5

in the length; caudal rounded, six and five tenths to seven times in the length; the first rudimentary dorsal ray over the base of the ventrals, its distance from the base of the middle caudal ray equal to its distance from the tip of the opercular spine, 1.47 in its distance from the snout.

A dark band or row of spots from just above the gill-opening to the base of the upper caudal lobe; a few spots below the band in the front half of the body in the larger specimen.

This description is based on the two larger specimens, 68 and 77 mm. long. The two smaller specimens, 18 and 21 mm. long, are uniform in color.

8. **Pygidium latistriatum** spec. nov.

7450 C., type, 46 mm. Quebrada de Pinchote, Santander. Gonzales.

Head 8 mm., length to base of caudal 39 mm.; width of head 6 mm., interocular 2.5 mm., eye a little in front of the middle of the head; distance from snout to origin of dorsal 23 mm., to its last ray 27 mm.; distance between origin of dorsal and base of middle caudal rays 16 mm., distance from snout to origin of ventrals 22 mm., to origin of anal 28 mm., distance between base of last anal ray and base of middle caudal rays 9 mm., maxillary barbel 8 mm., nasal barbel 7 mm., length of outer pectoral ray with its filament 8 and 9 mm., the divided rays 5 mm., D. 8.5; A. 6.5, not counting the imbedded rays in either case; upper caudal rays 8 mm.; lower caudal rays about 6.5 mm. Accessory rays numerous.

A lateral band from above the opercle to the middle of the caudal, increasing in width backward; mid-dorsal line dark; a dark stripe in front of the dorsal between the lateral stripe and the mid-dorsal stripe.

9. **Pygidium regani** spec. nov.

?*Pygidium tænia* Regan (*non* Kner & Steindachner), Ann. and Mag. Nat. Hist. (8), XII., 1913, p. 469 (R. Sipi and Rio Tamana).

13772 I., type, 55 mm. Tado, Rio San Juan. Purchased from Rosenberg.

Head 6; D. 10.5; A. 8.5; P. 8; eye in middle of the head, interorbital 4 in the length of the head.

Nasal barbel as long as the head, reaching beyond axil of pectoral; maxillary barbel reaching to near the end of the lower pectoral ray, considerably longer than the head; outer pectoral ray as long as the head; origin of ventrals equidistant from base of middle caudal ray and tip of opercle, not quite reaching to the vent; origin of anal under posterior half of dorsal, the distance from the base of the last ray to the middle caudal ray contained five and one half times in the length; caudal six times in the length; origin of dorsal equidistant from tip of caudal and opercular spines, over posterior third of the ventrals, its distance from the middle caudal ray one and four fifths in its distance from the snout.

A dark streak from opercular spines to middle of caudal; faint spots above and below the lateral stripe.

10. **Pygidium iheringi** spec. nov.

Trichomycterus punctulatus (*non* C. & V.) Ribeiro, Arkiv. för Zoologi, IV., No. 19, 1908 (Iporanga).

Trichomycterus dispar (*non* Tschudy) Ribeiro, Kosmos, V., 1908, and Fauna Brasiliense, IV. (*A*), 1912, p. 222 (Rio Iporanga, Sâo Paulo).

Habitat, Sâo Paulo in coastal streams and Parana Basin.

Specimens Examined.

Catalog Number.	Number of Specimens.	Length in Mm.	Locality.	Collector.
7071 C......	2	151–160	Sapina, Sâo Paulo.	Haseman.
10785 I......	4	104–161 the largest the type.	Santos.	Von Ihering.

Allied to *P. punctatissimum* from Araguay.

Head 4.5–5 in the length; D. 11.5 or 12.5; A. 7.5 or 8.5 counting the two rudimentary rays in each case; P. 8; width of head equal to its length behing the nasal barbel; eye in middle of the head, interorbital 3.5–4 in the length of the head. Teeth incisors with expanded tips, in bands of four or five series.

Nasal barbels reaching about to middle of eye, maxillary barbel to above middle of opercle; pectoral rounded, very little longer than snout and eye, the first ray not prolonged or with only a trace of a projection; distance between origin of ventrals and eye a little greater or less than that between origin of ventrals and middle caudal rays; the ventrals equal to the snout in the length, not nearly reaching vent, nearly half way to anal; origin of anal on or behind the vertical from the base of the last dorsal ray; distance between bases of last anal ray and middle caudal rays five or a little over five in the length; caudal slightly rounded, seven to seven and a half in the length; dorsal low and long, the distance between its origin and the base of the middle caudal ray about one and a third in its distance from the snout, its first ray over posterior half of the ventrals.

Sides and back with numerous spots, smallest over pectorals, largest over anal, rarely coalescent.

11. **Pygidium paolence** spec. nov.

?*Trichomycterus proops* Ribeiro, Fauna Brasiliense, IV. (*A*), 1912, p. 221 (Ribeiro de Iguape).

Habitat, Sâo Paulo in the Parana Basin and (?) in coastal streams.

7081 C., type, 68 mm. Alto da Serra, Rio Tieté, Sâo Paulo. July 25, 1909. Haseman.

7117 C., ten, 25–27 mm. Mogy das Cruces, Rio Tieté. Haseman, may belong to this species.

Head 6; D. 8.5; A. 6.5 not counting hidden rudiments; P. 6; head nearly as wide as long; eye in anterior half of the head, greater than their distance from the posterior nares; snout 2.33 in the length of the head, interocular 3.5; teeth conic; nasal barbel reaching base of opercular spines, maxillary barbel reaching tip of opercular spines; outer pectoral ray with its filament equal to head behind the posterior nares, the filament extending very little beyond the other rays; ventrals nearly reaching anal, their origin nearer caudal than to tip of pectorals; caudal rounded, six in the length; origin of anal under middle of dorsal, distance between the base of its last ray and the middle caudal ray 5.2 in the length; origin of dorsal equidistant from base of middle caudal rays with middle of ventrals, its last ray over the middle of the anal, the distance between the origin of the dorsal and the base of the middle caudal rays two in the distance between dorsal and snout.

With many faint spots about as large as the eye; a dark streak along the middle of the sides, another along the side of the back, and a third along the edge of the belly.

12. **Pygidium reinhardti** spec. nov.

7078 C., type, 65 mm. Burmier on the Rio Itabira, a tributary of the Rio das Velhas. May 14, 1908. Haseman.

Head 6.5; D. 9.5; A. 8.5 counting the minute rudimentary rays in both dorsal and anal; P. 6; eye in anterior half of head; interocular 3 in the head. Teeth conic.

Nasal barbel nearly as long as the maxillary barbel which reaches the edge of the gill-membrane. First pectoral ray with its filament equal to the length of the head, much longer than the divided rays; ventrals reaching beyond the vent, their origin very little nearer tip of pectorals than base of middle caudal rays; origin of anal under middle of dorsal; distance between the base of the last anal ray and the middle caudal rays five and a half in the length; caudal narrow, a little longer than the head, the accessory rays inconspicuous; origin of dorsal over middle of ventrals, its distance from the middle caudal rays nearly two in its distance from the snout (19 and 36 mm. respectively).

A broad, dark stripe with notched edges from opercle to middle of caudal, bordered above and below by light bands; an irregular series of spots below the lower light band; a series of small spots more or less confluent forming a narrow, dark stripe above the upper light band; back and fins lightly spotted, a short dark bar in front of the opercle, a longer one above the middle of preopercle.

13. **Pygidium vermiculatum** spec. nov.

Pygidium brasiliensis (*non* Lütken) Ribeiro (part), Fauna Brasiliense, IV. (*A*), 1912, p. 225 (the specimens from Juiz to Fora).

Habitat, Rio Parahyba.

7074 C., type, 131 mm. Juiz de Fora. June 9, 1908, presented by Dr. Ribeiro.

In general appearance like Lütken's figure of *brasiliensis,* differing notably in the position of the ventrals.

Head 5.4 in the length; D. 8.5; A. 8.5 counting in each case the two rudimentary rays; P. 7; width of the head nearly equal to its length; eye in middle of the head, interocular three in the length of the head. Teeth conic, in bands. Right nasal barbels reaching to above base of the opercular spines, maxillary barbels of right side nearly as long as head, reaching to the second fourth of the pectoral, both shorter on left side; pectoral rather narrow, the outer ray much prolonged, as long as head behind the nasal barbel, the fin without the filament equal to the part of head behind a point midway between eye and posterior nares; origin of ventrals under origin of dorsal, equidistant between base of middle caudal rays and last third of pectorals, ventrals reaching much beyond vent, almost to anal, equal to the snout in length; origin of anal under penultimate ray of the dorsal, distance between the base of its last ray and the base of the middle caudal ray a little more than five in the length; caudal rounded; six and one third in the length; dorsal short, rounded, the distance between its origin and the base of the middle caudal rays one and sixty-seven hundredths in the distance between its origin and the snout.

Sides and back profusely covered with confluent spots which leave the light color as irregular vermiculations.

14. **Pygidium alternatum** spec. nov.

Pygidium brasiliensis Eigenmann & Eigenmann (part), Proc. Cal. Acad. Nat. Sci. (2), II., 1889, p. 51; id. (part), Occasional Papers Cal. Acad. Sci., I., 1890, p. 332; Ribeiro (part), Fauna Brasiliensis, IV. (*A*), 1912, p. 223.

Habitat, Rio Doce.

It is probable that the young specimens mentioned by E. & E. belong to this species.

7079 C., type and paratypes, 67, largest 81 mm. Rio Doce. May 25, 1908. Haseman.

Head 5–5.75; D. 10.5–11.5; A. 7.5 or 8.5 counting the rudimentary rays; P. 7 or 8; eye in middle of the head or slightly further forward; interocular 3–3.33 in the length of the head. Teeth conic, in bands.

Nasal barbel very little shorter than maxillary barbel which reaches to the base of the pectoral and is equal to the head in length; pectoral rays equal to length of head behind the nasal barbels, the first ray with the filament longer than the head; ventrals reaching to or just beyond the vent; origin of ventrals equidistant from base of middle caudal rays and a point between the posterior nares and the area just behind the eyes; origin of anal under posterior part of dorsal; distance between base of last anal ray and middle caudal rays four and one half to five and one third in the length; caudal subtruncate or rounded, very little longer than head; origin of dorsal over posterior half of ventrals; distance between origin of dorsal and base of middle caudal rays 1.54 in its distance from the snout.

Ten to fourteen large spots along the middle of the sides, an irregular series of much smaller ones below it. Large spots above the median series, frequently alternating with it, sometimes partly confluent into a longitudinal series, sometimes forming with a mid-dorsal series irregular bars across the back.

15. **Vandellia sanguinea** spec. nov.

7082 C., type, 62 mm. San Antonio de Rio Madeira. Nov. 3, 1909. Haseman.

Head 11.66; depth 12; D. 4 + 8.5; A. 3 + 7; P. 7; nearly the entire eye in the anterior half of the head, a little more than four in the length of the head to the tip of the opercular spines.

Maxillary barbel extending to the tip of the interopercular spines, two in the head; the lower barbel minute, only about half a millimeter long as compared with the 2.5 mm. of the maxillary barbel; two, flat, recurved teeth on the end of the maxillary concealed just in front of the barbel; five premaxillary teeth graduated from the long middle one to the minute lateral ones; the mandibles widely separated from each other, each with about five minute teeth; the teeth concealed by the lip; five spines in the main row of the interopercle, the middle ones very strong, directed backward, about five spines in supplementary rows; five spines in the main row of the opercle, about ten in supplementary rows; distance between origin of ventrals and base of middle caudal rays two in its distance form the snout; origin of anal behind the origin of the dorsal, the last dorsal ray over the middle of the anal, distance between anal and base of middle caudal rays five and five tenths in the length; distance between origin of dorsal and base of middle caudal rays two and eight tenths in its distance from the snout; caudal truncate, with numerous accessory rays. Translucent, the eyes black.

Branchioica[3] gen. nov.

Type *Branchioica Bertoni* spec. nov.

It is quite possible that this genus will, on direct comparison of specimens, prove a synonym of *Paravandellia*. It has the same general characters and comes from the lower Paraguay, while *Paravandellia* comes from the upper. The present species was taken from a fish, while *Paravandellia* seems to be free swimming. It is quite possible that teeth will be found in *Paravandellia* at the end of the maxillary (premaxillary?) and on the mandibles when they are examined minutely; *Paravandellia* is said to have the caudal forked, while *Branchiogaeum* has it subtruncate.

No nasal or mental barbels, two barbels at angle of the mouth of which the lower is minute; first pectoral ray not spinous, not prolonged in a filament; gill-openings small, the membrane perfectly confluent with the isthmus; mouth inferior; two series of teeth in the front of the upper jaw, a single series of much smaller teeth laterad of these; maxillary with claw-like teeth at its end, just in front of the barbel and entirely concealed; two short series of teeth on the ends of the mandibles, opposite the lateral series of teeth of the upper jaw; opercular and interopercular patches of spines separate from each other; caudal subtruncate.

[3] βράγχιον, τό = gill, οἶκος, ὁ = a place to live in.

16. **Branchioica Bertoni**[4] spec. nov.

13950 I., type, 24 mm., paratype about the same length over all, much curved. Taken from a large Characin. *Piaractus brachypomus* (Cuvier). Asuncion, Paraguay. Collected by A. de W. Bertoni.

Head about 5.5; depth 5.5; D. 10; A. 7; P. 6; eyes superior, nearly the entire eye in the anterior half of the head, 3.5 in the head, about equal to the length of the snout, considerably larger than the interorbital; maxillary barbel extending to very near the inter-opercular spines, the lower barbel very minute; caudal peduncle slender, abdomen well rounded; premaxillary with two irregular series of slender, pointed teeth, those of the posterior series much the larger, about five in number, subequal, both series graduated from the larger ones nearer the center outward, laterad of the median series (on the premaxillary?), four or five similar but smaller teeth, graduated from the larger proximal one; the rami of the lower jaw widely separated from each other, each with about five, recurved, pointed teeth in two series on its end, in apposition to the lateral series of the upper jaw; gill-opening minute, circular, gill-membranes perfectly confluent with the isthmus; opercle with a bundle of about twelve, subequal, upward directed spines; inter-opercle with about eleven curved, downward directed spines, arranged in two series; distance between origin of ventrals and caudal 1.6 in its distance from the snout, origin of anal behind the origin of the dorsal; distance between anal and caudal about 5 in the length; pectoral falcate, the outer ray not prolonged as a filament, about as long as the head; origin of the dorsal between that of the ventrals and anal; twice as far from snout as from caudal; caudal narrow, obliquely rounded or subtruncate, with few inconspicuous fulcra.

Translucent, eyes black, chromatophores on the snout, along the back, along the base of the anal, on the base of the caudal, along the side of the abdominal cavity and a few on the pectoral.

[4] In honor of the discoverer of the species, Mr. A. de W. Bertoni, of Asuncion, Paraguay.

OBITUARY NOTICES.

SIR WILLIAM RAMSAY, K.C.B.

(*Read May 4, 1917.*)

In the untimely death of Sir William Ramsay the American Philosophical Society has lost one of its most distinguished members, the world of science a leader of rare insight and initiative, England one of her most brilliant men, and his intimates a much prized friend. He possessed a personality of unusual charm, charged with wide interests, keen human affections, and vivid enthusiasms.

The only son of William Ramsay, a well-known civil engineer, and Catherine Robertson Ramsay, the child destined later to develop into a great chemist was born at Glasgow on the 2d of October, 1852. He early turned his attention toward science, and believed his talent in this direction to have been inherited from his grandparents on both his father's and his mother's side—for he came of families of physicians and naturalists. After preliminary education at the Glasgow Academy, he entered the University of Glasgow when only fourteen years old, taking at first a general course, and later turning his attention especially toward chemistry. In 1870, at the age of eighteen, his chemical studies had progressed so far that he was anxious to seek further light in Germany, and in the autumn of that year was able, in spite of the Franco-Prussian war, to go to Heidelberg in order to study under Bunsen. Shortly afterwards he turned toward Tübingen, where he worked for nearly two years under Fittig, and gained his doctor's degree by virtue of a dissertation upon ortho- and meta-toluic acid.

In the autumn of 1872 the young doctor of philosophy of twenty summers returned, full of enthusiasm, to his native city, and became assistant in the "Young" laboratory of technical chemistry there. Two years later he was made tutorial assistant in the University of Glasgow. In spite of his charge of the elementary class of 200 students he found time to undertake investigations concerning many diverse fields of chemistry; for his interest was wide, and only as the years advanced did he put most of his energy into the swiftly growing branch of physical chemistry, which finally came to claim most of his attention.

His studies on picolin and quinine were partly ready for publication in 1876, and in 1879, while still at Glasgow, he published an important investigation concerning molecular volumes of liquids at their boiling points, a research for which he devised peculiarly ingenious apparatus. His interesting preliminary study of the chemistry of the sense of smell dates from about the same time, and, taken together with the others, shows the breadth and scope of his interest.

In the next year Ramsay was called to the professorship of chemistry in the University of Bristol, where he remained seven years, and where he found Sydney Young, an able collaborator, with whom he published many papers between 1882 and 1889. These papers especially concerned vapor pressure, and dealt not only with the vapor pressure of solid and liquid substances, but also with the dissociation of ammonia and nitrogen trioxide, as well as with the critical point. During the last six of his years at the University College, Bristol, Ramsay was principal as well as professor of chemistry.

In 1887 he resigned both positions in order to accept the chair of chemistry in University College on Gower Street in London, this chair having been left vacant by the death of Williamson. Ramsay was one of the first to see the far-reaching importance of the new theory of solutions brought forward by van't Hoff and Arrhenius, as was shown by the fact that he published in the *Philosophical Magazine* an English translation of van't Hoff's epoch-making paper. Not only in this way, but also by his own researches Ramsay advanced the new doctrines, and his investigations on the diminution of the vapor pressure of mercury by the presence of dissolved metals, as well as his interesting and important work on surface tension, bore witness to his faith in the new point of view.

At University College, where he remained until 1913, he carried out also the series of brilliant researches which constitute his chief title to fame, namely, those concerning the inert gases of the atmosphere. Lord Rayleigh, in a research which is a model of experimental acumen and conscientious execution, was the first to suspect the existence of such gases; his careful study of the density of nitrogen from different sources had proved chemical nitrogen (prepared from nitric acid and ammonia) to be distinctly less in density than the residue of the atmosphere from which oxygen and carbon dioxide had been separated. Lord Rayleigh had shown that the difference was not due to any impurity of hydrogen in the chemically prepared nitrogen, and that hence it must probably be due to an unknown impurity in the atmospheric nitrogen. He had begun on the task of burning this rather incombustible gas with the help of the electric spark, in order to discover the nature of the residue, a task which Cavendish long before had crudely attempted, and which is now executed on a huge scale commercially. Ramsay, stimulated by Lord Rayleigh's experiments and by the latter's request for air from chemists, suggested another method of fixing atmospheric nitrogen by conducting the gas over heated magnesium. The two investigators worked in harmony, and in 1894 succeded in showing that the residues left after the nitrogen was combined by these two different methods were identical; and that this common residue consisted primarily of a hitherto unsuspected gas, which they named argon, existing to the extent of about 1 per cent. in the atmosphere. Sir William once told me that on hearing of Lord Rayleigh's first experiments and turning to the original description of Cavendish's experiments in his own library, he found the pencilled annotation, "Look into this matter," placed opposite the line where Cavendish states that a small bubble, not over 1 per cent. of the whole, remained unconsumed by the sparking with oxygen. If Ramsay had followed this early suggestion of his own, he, instead of Lord Rayleigh, might have been the first to point out that the small bubble remaining in Cavendish's experiment, was probably a hitherto unknown gas. As it was, Ramsay's greatest credit lay especially in his later work in this field. Remembering a discovery of Hillebrand's that an inert gas had been found to exist included in a certain ore of uranium, Ramsay secured a specimen of this ore in order to discover if this gas might not be argon. To his amazement he found that the gas possessed a different spectrum, the chief yellow line in which was identical with that in the spectrum of the sun ascribed to an element, unknown on earth, called helium. Before Ramsay's discovery this substance had indeed been suspected in the spectrum of volcanic ejections from Vesuvius, but no one had any idea of its nature. The excitement of the discovery was so great that Ramsay was obliged to voyage to Iceland for a long rest.

The existence of two inert gases with atomic weights respectively about 4 and 40 suggested to Ramsay the possibility that there might also be others fitting in to other corresponding places in the periodic system of the elements; and after an eager search, in a brilliant investigation, Ramsay announced the discovery of the whole series, including neon, crypton and xenon, obtained by fractional distillation at very low temperatures of the residues from large amounts of liquid air or liquid argon. This work was carried out with the help of Travers, using the methods for the liquefaction of the so-called permanent gases which had only recently been developed by others. It was about this time, between 1895 and 1898, that I remember Sir William's having said to me: "Nothing in this world is too strange to be true if properly substantiated by adequate experiments." This feeling animated Ramsay in all his researches, and was a good preparation for the yet more astounding things which were to come. For during these years the extraordinary properties of radium and the revolutionary phenomena of radio-activity began to become known to mankind, and Ramsay, with eager interest in anything capable of throwing new light upon the processes of nature, welcomed to his laboratory Frederick Soddy, who had just come from Montreal, where he had helped Rutherford in his epoch-making studies concerning this subject. It was Ramsay's admirable technique in dealing with small quantities of gases that enabled him, in collaboration with Soddy in 1903, to give the first experimental evidence that helium is formed from radium—a phenomenon suspected by Rutherford, but not experimentally proved by him. Soon afterwards, in 1908, with the help of Cameron, Ramsay showed that the emanation from radium, which had been proved by Ramsay's earlier work with Gray to be a heavy but unstable gas, had, in spite of its instability, a spectrum of its own.

It is not surprising that an enthusiast confronted with the decomposition of so many substances, which in so many respects appeared to be classed among the elements, should push the idea too far and fall into an almost alchemical state of mind. Ramsay's later experiments, in conjunction with Cameron and Usher, in which they thought that radium emanation could decompose copper into lithium and thorium into carbon, have not been verified by other experimenters. Perhaps it is premature to judge the outcome; but if the conclusion was an error, it must be remembered that the person who has never made a mistake is one who has never attempted any serious work.

More fortunate, as it appears at present, was Ramsay's later research with Gray on the density of the radium emanation, called by him "niton." This important investigation, carried out with extraordinarily small quantities of material, proved the transitory "niton" to be the heaviest member of the argon series, and showed that it fits satisfactorily into its appointed place in the periodic system, as well as into the expected niche in the Soddy-Fajans disintegration series.

The work indicating the true nature of niton appropriately crowned Ramsay's work upon the series of inert gases, the discovery of which was so largely due to his insight, enthusiasm and perseverance.

In addition to all his brilliant researches Ramsay found time to publish a number of books, the chief of which were: "A System of Chemistry" (1891); "The Gases of the Atmosphere" (1896); "Modern Chemistry" (1901); "Essays, Biographical and Chemical" (1908); and (as editor) a series of very valuable textbooks upon the different subdivisions of physical chemistry. In 1911 he was president of the British Association for the Advancement of Science, and his address, which began with a review of the amazing discoveries of recent years, ended with an impressive warning as to the impending failure of the world's coal supply, especially that of Britain, with its direful consequences; but this warning has fallen largely upon deaf ears, and the world continues to squander the stored energy of the ages with reckless prodigality.

As would be expected, honors were showered upon this rare intellect from all sides. He was created K.C.B. in 1902 and received the Nobel prize in chemistry in 1904, besides having had various orders and medals conferred upon him, and having been made an honorary member of nearly all the learned academies and chemical societies of the world. Many of these distinctions came from Germany, where he formerly had warm friends; but on the outbreak of the war his patriotism and his sense of justice and honor made him a firm and outspoken upholder of the cause of the Entente Allies, and even during his lingering and painful illness he did all in his power to help his country in her time of need. In 1881 he married Miss Margaret Buchanan, who survives him, with one son, one daughter, and three grandchildren. He died, all too soon, on the 23d of July, 1916, in his sixty-fourth year, at his country estate at Haslemere in Bucks, England.

Ramsay, in his own brief autobiographical sketch, has acknowledged freely the debt which he sometimes owed to others for ideas and suggestions, proclaiming his belief that scientific men should help one another and seek help whenever they could, and adding that he always endeavored to acknowledge specific cases of indebtedness to others whenever possible. Nevertheless, he was full of initiative and originality himself. The study of his work shows that the following were among the attributes of his genius: an intense curiosity and enthusiasm with regard to everything new, an excellent experimental technique in dealing with gases, a great fertility of fruitful ideas, a daring scientific imagination, and devoted persistence in any promising line of work. The happy aggregation of these and other qualifications led Ramsay to successes significant enough to put his name high on the roll of the leaders of chemistry for all time. To him science owes a priceless debt for investigations which, in the short space of a score of years, made an unparalleled contribution, in that they revealed to the world a whole group of hitherto unknown elements possessing properties both unexpected and unique.

THEODORE W. RICHARDS.

CLEVELAND ABBE, 1838–1916.

(*Read May 4, 1917.*)

Cleveland Abbe, astronomer, meteorologist, philosopher, for forty-six years an active member of the American Philosophical Society, esteemed and honored by his colleagues in science for his achievements in the fields of meteorology, and the application of that science to the welfare of man, is beloved and mourned by all his friends for the gentle kindliness of his spirit and the unfailing aid, encouragement and inspiration flowing from his inexhaustible stores of information, suggestion and boundless enthusiasm.

More than thirty years ago it was my pleasure to enter upon my official life in Washington as a civil service probationer under the immediate instruction and supervision of Professor Abbe, who was at that time in charge of the so-called Study Room of the Office of the Chief Signal Officer. Although independently, I have nevertheless worked literally side by side in close association with him throughout all the years that have followed our first acquaintance, and to my feelings of esteem and respect for the scholar and devotee have been added my affection, for the man of gentle and generous ways and a spirit refined and purified by his unselfish promotion of the pleasure and welfare of all around him. Embracing the Christian faith at the age of fifteen, the true spirit of Christ moulded and guided his conduct ever thereafter and, although brought up in the Baptist church, in his later years he enjoyed with his second wife the comfort and inspiration of the beautiful ritual of the Episcopal Church.

Cleveland Abbe was born in the city of New York at the home of his parents in Madison Street, December 3, 1838, and died October 28, 1916, at his home in Chevy Chase, Md., after a somewhat protracted affliction of partial paralysis, which though limiting his bodily activity, left his spirit and mental faculties wholly unimpaired to the last. He was the eldest of a family of seven children, five sons and two daughters, born to George Waldo and Charlotte Colgate Abbe. Three of his brothers and his two sisters still survive him. His ancestry on both sides was of pure English stock of liberty-loving English and Huguenot emigration. His Colonial ancestor, John Abbe, was born in England about 1613 and settled in Salem, Mass., about 1635. Professor Abbe's father was prominent in the mercantile and charitable affairs of New York at a time when public schools were rare and the city was primitive enough for Abbe and his boyhood companions to gather shells on Battery beach. His early education was gained in private schools, later in the David B. Scott Grammar School, No. 40, on 20th Street. From this he entered the New York Free Academy, now the College of the City of New York, in 1851. After making an honorable record in mathematics and the sciences he graduated in 1857, taking, as he says, "the year 1853 over again to my great advantage as a student."

Inspired by his parents with a love of nature, his predilections for scientific pursuits followed naturally, and after graduation his progress toward his life work was rapid and consistent. While teaching mathematics in Trinity Latin School and later in Ann Arbor, Mich., he further perfected his own education in astronomy, spending four years at Cambridge, Mass., in association with Dr. B. A. Gould and assisting in the telegraphic longitude work of the United States Coast and Geodetic Survey. The two years, 1865 and 1866, were spent delightfully at the great Russian observatory at Pulkova, then under the illustrious Otto Struve. Here, under new laws of the autocratic Russian Empire, a few young men of civilian rank, while at liberty to devote their whole time to their own studies, were nevertheless permitted to participate if they so desired in some of the regular work of the observatory, for which a small compensation was allowed. The years of his happy associations and congenial work at this great institution remained thereafter a delightful and vivid memory to him, to which he always referred with sympathy and feeling.

A little incident serves to show the warmth of the hospitality which greeted him and also goes far to explain the mystic charm seeming to surround these impressionable years of his early life. It seems his arrival at Pulkova occurred at about Christmas time.

Imagine his astonishment when he was shown his name on a handsome samovar standing among the gifts beside the Christmas tree. To further prepare him for the astronomical work in which he would be engaged during the long and rigorous winters of northern Russia, arrangements had been made for his advantageous purchase of a splendid great coat lined with native fur. It is easy to understand the deep impression incidents and associations of this kind would make upon the gentle and sympathetic nature of Abbe. Unfortunately the samovar was early stolen from him, but the great coat is still serviceable and among his effects. During the winter of 1909–1910 he resided at the Weather Bureau station at Mount Weather, Va., where the severe atmospheric conditions gave frequent occasions for the use of the great fur coat. The writer, himself, was snow-bound at Mt. Weather on one of these occasions and after the storm, during a nine mile drive through the snow drifts to the railway station, he enjoyed the warmth and protection of the great fur coat, which was even then, after the lapse of about thirty-four years, in perfect preservation, a tribute to the perfected art of tanning furs in Russia.

Returning to the United States Abbe entered upon work at the Naval Observatory at Washington, D. C., in 1867. As early as February in 1868, however, he had accepted the position of director of the Cincinnati Observatory, to which place he removed in June of the same year. A member of Abbe's family relates to me an interesting incident not generally known, concerning his election to the directorship of the Cincinnati Observatory and that well illustrates Abbe's gentle temperament and kindly solicitude for others. During the transatlantic passage on his return from Russia he made the casual acquaintance of an elderly woman of culture and refinement. Ocean travel at that time lacked many of the comforts we are now accustomed to enjoy and during the prolonged passage Abbe found pleasure in telling his sympathetic acquaintance of his hopes and ambitions, and his devotion to astronomy. We can well imagine the frequent opportunities embraced by Abbe to extend his kindly courtesies and contribute to the comfort and welfare of his older companion. The journey ended with the customary partings and exchange of sentiments and sympathies incident to travel and nothing more was expected to occur. When, however, a year or more thereafter Abbe had moved to Cincinnati, he learned with pleasure and surprise that his selection for the observatory had been suggested and promoted by the flattering representations of his acquaintance of the transatlantic trip. Abbe, it seems, has recited this story chiefly to his own sons, with the admonition that thus they may see the benefits resulting from kindness and courtesies shown to the elderly.

Professor Abbe's wedded life began May 10, 1870, in his marriage to Frances Martha Neal, daughter of David Neal, a resident of Cincinnati. The children of this union were three sons, all born in Washington, D. C., namely: Cleveland Abbe, Jr., born March 25, 1872, married Frieda Dauer; Truman Abbe, born November 1, 1873, married Ethel W. Brown; William Abbe, born June 27, 1877, married Louisa Hart Howson. The mother was a woman of strong character and personality with simple home-loving tastes, opposed to shams, frivolities and ostentations, always hungry for knowledge and intensely proud of her home and children, to whose rearing and education she gave her love and assiduous attention. In this she enjoyed the complete and earnest support of her devoted husband.

At an early period of his life in Washington he purchased an old and historic residence with great rooms and lofty ceilings, located at 2017 I Street, N. W. Here for many years with simple but sincere and hearty hospitality he entertained visiting scientists and others of his acquaintance, always availing himself of such opportunities to increase, if possible, his stores of knowledge by questions and discussions of scientific topics. A frequent visitor to the house in the earlier days when the boys were at home writes in a recent letter: "I have always had a most delightful impression of Prof. Abbe as the head of a family. He was always full of fun and delighted in the pleasure of his children and their friends, or of any guest who came into his house. I never saw him in any mood except one of kindness and cheerfulness. All that I can say is to confirm what all his friends already know—that no man of such learning and such great scientific activities has shown a gentler disposition and kindlier heart than Professor Cleveland Abbe."

The extent of his charities can doubtless never be fully known but the cases of record testify to his disposition to single out deserving and meritorious instances where the bestowal of aid, necessarily limited by his own simple resources, would bear the best fruit. Each of these doubtless meant a definite personal sacrifice, significant of the sincerity and unselfishness of his motives.

The long years of his official life under the government inevitably brought a number of vicissitudes which Abbe's boundless devotion to his beloved science enabled him to bear with patience and toleration; whereas they brought a deeper sadness and resentment to the declining years of his devoted wife. In the early part of 1900 her health began visibly to fail, ending in death in Canton, N. Y., July 24, 1908.

At this date his sons were each married and already established in a home of his own. The father doubtless perceived and felt the loneliness of his situation, in spite of the solicitude and hospitality extended by his sons., Consequently, although then at the age of seventy, it was not surprising to those acquainted with the affectionate and sympathetic spirit of Abbe to learn of his second marriage in Philadelphia, Pa., April 12, 1909, to Miss Margaret Augusta Percival of Basseterre, St. Kitts, British West Indies. In renewed health, after a severe illness following his constant and patient attention to the needs of his first wife in her last illness, Abbe entered upon his new happiness with much of the spirit and romance of youth but, yet, with the sincerity and seriousness of maturity. Each found in the other the great need of all humanity, sacred love, completely satisfied, moulding their separate lives into unselfish reciprocal devotion. There was thus fittingly provided in the tender care and solicitude of this capable wife of a stronger vigor of life than he, both the affection and the attention that were needful when his own bodily strength, which he had so lavishly bestowed in the interests of science and humanity, failed longer to fully sustain him.

The horrors of the European war were a great mental distress to Professor Abbe in his last days and added to the pains his bodily illness brought upon him. His mind, however, was singularly clear and cheerful even at the last moments, as I am told by those around him.

I have thus dwelt at some length upon events of Abbe's early career and his family life and last days, as heretofore these have been known only to the family and intimate friends, whereas many of his labors in the field of meteorology and his achievements in the interests of the public welfare have frequently been recorded and published. The more notable of these events will now be mentioned briefly in review.

His life and work up to the time he assumed charge of the Cincinnati Observatory must be looked upon as a period of education and preparation. The subsequent years were years of production and harvest. His inaugural address June 30, 1868, at the Cincinnati Observatory presents an outline and program of work in astronomy, meteorology, terrestrial magnetism, surveying and engineering, all characterized by a regard for public welfare that could be accomplished in full only with prolonged labor and resources far beyond those of the observatory itself. This very comprehensiveness, this all inclusiveness of treatment was characteristic of Abbe's view of matters and his method of handling problems he attacked. Among the suggestions in his address was his proposal for the creation of a system of storm warnings and forecasts by means of weather reports collected by electric telegraph. More than a year elapsed before Abbe was able to make a practical demonstration of his plans for forecasting the weather. How well he succeeded in this undertaking is best shown by his own words quoted from his annual report to the Board of Control of the Cincinnati Observatory, June, 1870:

"This subject having been brought, by myself, to the attention of the Chamber of Commerce of this city, that body, in June last (1869), authorized me to organize a system of daily weather reports and storm predictions. Experienced observers at distant points offered their gratuitous coöperation. The Western Union Telegraph Company offered the use of their line at a nominal price. The Bulletin began to be issued September 1, in manuscript form, for the special use of the Chamber of Commerce, and began to be printed a week later as an independent publication.

"This Bulletin was supported for three months, as at first agreed on, by the Chamber of Commerce; its conduct then passed entirely into the hands of the Observatory, and has thus continued until the past month. The independent publication of the Bulletin was, however, discontinued, and it has, since December 1, only appeared in the morning papers. The daily compilation of this Bulletin for the newspapers was undertaken two weeks ago by the Cincinnati Office of the Western Union Telegraph Company, and will so continue, thus relieving the Observatory of all further responsibility.

"In February the manager of the Cincinnati office undertook the publication of a daily weather chart, and the favor that this has met with insures its continuation in the future. The Daily Weather Bulletin and Chart are, therefore, now supported solely by the Western Union Telegraph Company, and must be considered as a very important contribution to meteorology. It would have been highly to the credit of the Observatory could these publications have been maintained in its own name; but this was impossible owing to the want of funds and assistants."

Writing of this matter to his father in New York, he said prophetically "I have started that which the country will not willingly let die."

Other forces and influences were also at work to perpetuate and nurture this embryo Weather Bureau for the benefit of the nation. The Executive Documents and the Congressional Globe of the 41st Congress, 2d session, show that on December 14, 1869, Hon. Halbert E. Paine, Member of Congress from Wisconsin, introduced a bill to create a weather warning service under the Secretary of War. The Document accompanying this bill consisted of a Memorial of Prof. Increase A. Lapham of Milwaukee, Wis., entitled "Disasters on the Lakes," and comprised a record of the marine disasters on the Lakes for 1869. The legislation finally enacted was the passage of a Joint Resolution, also introduced by Mr. Paine, which passed the House of Representatives February 2, 1870; the Senate on February 4, 1870; and was signed and approved by the President February 9, 1870. We may therefore conclude that the passage of the legislation establishing meteorological observations and reports in the United States was accomplished chiefly by the Hon. Halbert E. Paine upon the representations of Prof. I. A. Lapham.

No one has been more scrupulously careful than Abbe himself, as can be shown by documentary evidence, to give Professor Lapham the fullest measure of credit for the work done by him which practically ended with the enactment of the law which imposed upon the Secretary of War the task of organizing meteorological observations throughout the United States and the giving of notice on the northern Lakes and sea-board of the approach of storms.

When the Secretary of War sought to put these provisions of law into operation he endeavored to enlist the services and council of Lapham, Abbe, and others. Lapham declined but Abbe, whose work began with his Cincinnati Weather Bulletin, responded heartily and was appointed the assistant or meteorologist of General Albert J. Myer, chief signal officer of the Army, in charge of this work.

The following quotations from the *Popular Science Monthly* for January, 1888, cite important features of Abbe's subsequent service while the Weather Bureau was under the War Department:

"In this position, Professor Abbe, during 1871, organized the methods and work of the so-called 'probability' or study-room, in making weather maps, drawing isobars, ordering storm signals, etc., and dictated the published official tri-daily synopses and 'probabilities' of the weather. In the same year he began and urged the collection of lines of leveling, and in 1872, by laborious analysis, deduced the altitudes of the Signal-Service barometers above sea level. He instituted in 1872, and reorganized in 1874, the work of publishing a monthly weather review, with its maps and studies of storms. He urged the extension of simultaneous observations throughout the world, as the only proper method of studying the weather; and, as General Myer distinctly avowed, the success of the negotiations of the Vienna Congress of 1874 was due to following his advice. And he organized, in 1875, the work of preparing the material and publishing the 'Daily Bulletin of Simultaneous International Meteorological Observations.' Especially is the organization of the numerous state weather services of the country due to his advocacy, and to the letters sent by his advice by General Hazen to the governors of the states."

"As chairman of the standard time committee of the American Metrological Society, and later delegate of the United States to the International Meridian and Time Conference, which met at Washington in October, 1884, Abbe took an active part in all those conferences, discussions and studies, which culminated in the adoption by the railroads of the United States of the present system of standard times.

"Professor Abbe's unselfish devotion to the pursuit of science for its advancement and not for his own has prevented his name from appearing as prominently in connection with the work of the Weather Bureau as it deserved to do; but there is a general concurrence of testimony that he has been its guiding spirit. . . . He kept well read up on all meteorological matters, and had a very high appreciation of much that he read; and, when this was the case, he was always very desirous of bringing the matter and the author into notice by means of translations and republications. In fact, he seemed to me to be more desirous of bringing the works and the claims of others into notice than his own. His notes on meteorological subjects, published in the Smithsonian Reports, sprung from his extensive reading and desire to communicate to the public whatever he found of value in the course of his reading. . . . When General Hazen was put at the head of the service and a more liberal policy toward civilians, and in the encouragement of scientific work, was adopted, he seemed to wish that all the leading meteorologists of the country could have a part in what he considered the great work of the country, and he especially interested himself in endeavoring to give a chance to promising young men of the country to have a part in this work. In pursuance of this idea he secured the appointment of the eminent physicist, Professor T. C. Mendenhall, and certain steps were taken toward the organization of an experimental laboratory in atmospherics. The beginning was necessarily a very modest one, although the plan of a great experimental laboratory was one that Professor Abbe cherished for many years and let no opportunity escape of urging it upon federal officials and university faculties. At that date (1885–86) the attitude of departmental officials, not to mention members of Congressional committees, was perhaps lukewarm, if not antagonistic to what seemed to be investigations in pure science, and it is not surprising that in this unfavorable atmosphere the project of a physical labotory flourished only very feebly, and in fact terminated with Professor Mendenhall's election to the presidency of Rose Polytechnic Institute, Terre Haute, Ind.

. . . .

"For the good work done by the United States Weather Service, and for the high estimation in which it has been held by Europeans generally, the country is indebted to Professor Abbe more than to any other one man. . . . On all important questions touching the scientific work of the service, his advice has been sought by the chief signal officer; most plans for its improvement and extension have originated with him, and he has done much to stimulate the study of meteorology outside of the service as well as within it.

. . . .

"We are informed by Mrs. Hazen, widow of the late chief of the Signal Office, that Professor Abbe was always held in high esteem by her husband, 'and relied on not only as a very scientific man but as a loyal friend.' This sentence brings out another salient trait in his character—his loyalty to his chief. Readers of the *Monthly* will recollect the tribute which he improved the first opportunity after General's Hazen's death to pay to his character and the worth of his work for science; but they do not know, for that is matter of personal confidence, that he was extremely anxious that General Hazen should receive full credit for all that he did, all that he helped to do, and all that he was in any way the means of having done for science; and particularly that he should be vindicated from the unfriendly criticisms which the newspapers had cast against him—all of which Professor Abbe believed to be unjust and unfounded."

General A. W. Greely, chief signal officer in command of the signal corps at the time the civilian duties thereof comprising the Weather Bureau were segregated and transferred to the Department of Agriculture, published in *Science* (Nov. 17, 1916) a fitting tribute to Professor Abbe from which we may quote as follows:

"During twenty years of his service I was intimately associated with Abbe as his subordinate and pupil, as a co-worker, and as his administrative chief. During this term of years there inevitably developed situations which were complex, annoying and embarrassing to the scientific force. Yet in all such conditions I never knew him to display bad temper, to unduly prolong discussions, to advance personal interests, nor to abate his most strenuous efforts to carry out such policies as were judged needful for the good of the service—even though they had not originally met with his approval."

In August, 1893, Professor Abbe was made the responsible editor of the *Monthly Weather Review,* a work he found most congenial. Editorial comments, annotations and original articles therein contribute much of value to the publication and constitute a lasting monument to his fame.

It is quite impossible, in this brief memoir, even to indicate the number, scope and character of his literary works. The list is a very long one and includes a wide range of scientific subjects. His enthusiasm led him to undertake many tasks which the inevitable lack of strength and opportunity prevented him from bringing to completion. Notably among these must be mentioned a study of clouds and atmospheric motions observed by him with a special marine nephoscope of his own invention while on a trip to the west coast of Africa to witness the solar eclipse of 1889. Similarly the scientific papers presented at the International Meteorological Congress, held in Chicago in August, 1893, were only partly published for lack of funds, to Abbe's lasting regret, and he never ceased to urge the fulfillment of the obligation upon American meteorologists to complete this work.

However the genealogy of the Abbe family, the preparation of which received his most feeling and sympathetic attention for many years, and which was so dear to his heart, fortunately was submitted to the publishers in the very last months of his long life.

The scientific societies in which he held membership would also make up another long list. During the active portion of his life he accumulated a very large library dealing with meteorology and related sciences, the care of which in the later years of his life became so great a responsibility that with commendable foresight for the preservation of such an invaluable collection he arranged to make it an integral part of the library of Johns Hopkins University under the designation of "The Abbe Meteorological Library."

The eminence he never sought for himself has been bountifully bestowed upon him by others. The University of Michigan, in 1886, conferred upon him the degree of LL.D., and in 1896 he received the same degree from the University of Glasgow, the presentation being made by Lord Kelvin, by whose wish Lady Kelvin herself made the Doctor's hood bestowed on that occasion. Naturally his modest nature was profoundly touched by this tribute, and this symbol of his achievements was worn to his grave. He was awarded the medal of the Royal Meteorological Society of England in 1912 and in the spring of 1916 the National Academy of Sciences, of which he was long an active member, awarded him the Marcellus Hartly Medal "for eminence in the application of science to the public welfare." Coming, as this award did, from those he counted as his most intimate friends and associates in scientific endeavor and at a time when he recognized that his strength and force were almost spent, it bore the welcome message: "Well done thou good and faithful servant," and within the year he entered into the joy of his Master's presence.

Charles Frederick Marvin.

Washington, D. C.,
March 24, 1917.

MINUTES.

MINUTES.

Stated Meeting, January 5, 1917.

William W. Keen, M.D., LL.D., President, in the Chair.

Prof. Douglas W. Johnson, of New York, read a paper on "The Strategic Geology of the Balkan Campaign."

The Judges of the Annual Election held on this day between the hours of 2 and 5 in the afternoon, reported that the following named members were elected, according to the laws, regulations and ordinances of the Society, to be the officers for the ensuing year:

President.

William W. Keen.

Vice-Presidents.

William B. Scott,
Albert A. Michelson,
George Ellery Hale.

Secretaries.

I. Minis Hays,
Arthur W. Goodspeed,
Amos P. Brown,
Harry F. Keller.

Curators.

Charles L. Doolittle,
William P. Wilson,
Leslie W. Miller.

Treasurer.

Henry La Barre Jayne.

Councillors.

(To serve for three years.)
Henry Fairfield Osborn,
Elihu Thomson,
Samuel M. Vauclain,
Henry B. Fine.

Stated Meeting, February 2, 1917.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of Prof. Paul Leroy-Beaulieu in December, 1916.

The following papers were read:

"On Some Aspects of Costa Rica and its Natural History," by Professor Philip Calvert. (Introduced by Prof. Henry Kraemer.)

"The Geology of Sergipe and Northeastern Bahia, Brail," by Mr. Ralph H. Soper. (Communicated by Prof. John C. Branner.)

Stated Meeting, March 2, 1917.

William W. Keen, M.D., LL.D., President, in the Chair.

A communication was received from the Société Imperiale Russe de Mineralogie, announcing the centenary of its foundation.

Dr. Francis G. Benedict read a paper on "Human Energy and Food Requirements."

Stated General Meeting, April 12, 13 and 14, 1917.

Thursday, April 12.

Opening Session—2 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease of the following members was announced:

Prof. Jean Gaston Darboux, at Paris, in February, 1917, æt. 74.
Ambrose E. Lehman, at Philadelphia, on April 5, 1917, æt. 65.
Hon. Richard Olney, at Boston, on April 8, 1917, æt. 82.

The following papers were read:

"The Trial of Animals—A Little Known Chapter of Medieval Jurisprudence," by Hampton L. Carson, LL.D., of Philadelphia.

"Medieval Sermon-Books and Stories and their Study since 1883," by Thomas Frederick Crane, Ph.D., Litt.D., Professor Emeritus of the Romance Languages and Literature, Cornell University.

"Some Recent Acquisitions to the Yale Collection," by Albert T. Clay, LL.D., Professor of Assyriology and Babylonian Literature, Yale University.

"Vision as a Physical Process," by Herbert E. Ives, of Philadelphia. (Introduced by Dr. A. W. Goodspeed.)

"The Diagnostic Method of Training Intelligence: an Education for the Fortunate Few (With a Demonstration)," by Lightner Witmer, Ph.D., Director of the Laboratory of Psychology, University of Pennsylvania.

"Historical Notes on 'The Armament of Igor,'" by J. Dyneley Prince, Ph.D., Professor of Slavonic Languages, Columbia University.

"A New Translation of the Hebrew Bible," by Cyrus Adler, Ph.D., President of Dropsie College for Hebrew and Cognate Learning, Philadelphia.

Friday, April 13.

Executive Session—9.30 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

Dr. Erwin Frink Smith, of Washington, and Dr. Edward Murray East, of Forest Hills, Mass., subscribed the Laws and were admitted into the Society.

The Proceedings of the Officers and Council were submitted.

The following nominees for membership were recommended for election this year.

Residents of the United States.

William Frederick Durand, Ph.D., Stanford University, Cal.

Pierre Samuel duPont, Mendenhall, Pa.

Carl H. Eigenmann, Ph.D., Bloomington, Ind.
Charles Holmes Herty, Ph.D., New York.
Herbert E. Ives, Ph.D., Philadelphia.
Waldemar Lindgren, M.E., Ph.D., Sc.D., Cambridge, Mass.
Walton Brooks McDaniel, A.B., Ph.D., Philadelphia.
Winthrop J. V. Osterhout, A.M., Ph.D., Cambridge, Mass.
Harold Pender, Ph.D., Philadelphia.
Frederick Hanley Seares, B.S., Pasadena, Cal.
George Owen Squier, Ph.D., Washington, D. C.
Charles P. Steinmetz, Ph.D., Schenectady, N. Y.
Oscar S. Straus, A.M., Litt.D., LL.D., New York City
Alonzo Englebert Taylor, M.D., Philadelphia.
Edwin Bidwell Wilson, Ph.D., Cambridge, Mass.

Foreign Residents.

Archibald Byron Macallum, M.B., Ph.D., D.Sc., LL.D., F.R.S., Toronto.
Sir David Prain, M.A., LL.D., F.R.S., Kew.

Morning Session—9.35 o'clock.

George Ellery Hale, Ph.D., Sc.D., LL.D., F.R.S., Vice-President, in the Chair.

The following papers were read:

"Lighting in its Relation to the Eye," by Clarence E. Ferree, Ph.D., Professor of Psychology, Bryn Mawr College. (Introduced by Dr. W. W. Keen.)

"Factors Influencing the Sex Ratio in the Domestic Fowl," by Raymond Pearl, Ph.D., Biologist, Maine Agricultural Experiment Station, Orono, Maine.

"Significant Results of Scientific Investigations Applied to Fishery Problems," by Hugh M. Smith, M.D., LL.D., Commissioner of Fisheries, Washington, D. C. (Introduced by Dr. Clarence E. McClung.)

"A Description of a New Photographic Transit Instrument," by Frank Schlesinger, Ph.D., Director of the Allegheny Observatory, University of Pittsburgh.

"Probable Masses of Comets," by Henry Norris Russell, Ph.D., Professor of Astronomy, Princeton University.

"The Relationship of Stellar Motions to Absolute Magnitudes," by Walter S. Adams, A.M., Sc.D., Assistant Director of Mt. Wilson Solar Observatory, Pasadena, Cal., and G. Strömberg.

"Nebulae," by V. M. Slipher, Ph.D., Director of the Lowell Observatory, Flagstaff, Arizona. (Introduced by Prof. C. L. Doolittle.)

"Early Man in America," by Edwin Swift Balch, A.B., of Philadelphia.

"The Influence of the Admixture of Present Immigrant Races Upon the More Original Stock," by Charles B. Davenport, S.B., Ph.D., Director, Station for Experimental Evolution, Cold Spring Harbor, Long Island.

"A New Babylonian Account of the Creation of Man," by George A. Barton, Ph.D., LL.D., Professor of Biblical Literature, Bryn Mawr College.

Afternoon Session—2 o'clock.

ALBERT A. MICHELSON, Ph.D., Sc.D., LL.D., F.R.S., Vice-President, in the Chair.

Mr. Percy W. Bridgman, of Cambridge, Mass., a recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Crushing of Crystals," by Percy W. Bridgman, Assistant Professor of Physics, Harvard University.

"Structure of the Spectra of the Phosphorescent Sulphides (Describing Measurements by Drs. H. E. Howe, H. L. Howes and Percy Hodge)," by Edward L. Nichols, Ph.D., D.Sc., LL.D., Professor of Physics, Cornell University.

"The Corbino Effect in Liquid Mercury," by Edwin Plimpton Adams, Ph.D., Professor of Physics, Princeton University.

"Spontaneous Generation of Heat in Recently Hardened Steel," by Charles Francis Brush, Ph.D., Sc.D., LL.D., of Cleveland.

I. "Condensation and Evaporation of Metal Films."

II. "The Minimum Potential for Excitation of the 'D' Lines of Sodium," by Robert Williams Wood, A.B., LL.D., Professor of Experimental Physics, Johns Hopkins University.

"Growth and Imbibition," by D. T. MacDougal, Ph.D., LL.D., Director of Department of Botanical Research, Carnegie Institution of Washington, and H. A. Spoehr.

"The Mechanism of Overgrowth in Plants," by Erwin F. Smith, B.S., Sc.D., of Bureau of Plant Industry, Dept. of Agriculture, Washington, D. C.

"The Behavior of Self-Sterile Plants," by Edward M. East, Ph.D., Professor of Experimental Plant Morphology, Harvard University.

"Twin Hybrids from *Œnothera lamarckiana* and *franciscana* when crossed with *Œnothera Pycnocarpa,*" by George F. Atkinson, Head of the Department of Botany, Cornell University.

"Naming American Hybrid Oaks," by William Trelease, Sc.D., LL.D., Professor of Botany, University of Illinois, Urbana.

"The Wild Relatives of our Cultivated Plants and their Possible Utilization," by W. T. Swingle, Ph.D., of U. S. Department of Agriculture. (Introduced by Dr. William P. Wilson.)

"An Annotated Translation of de Schweinitz's Two Papers on the Rusts of North America," by Joseph C. Arthur, Professor Emeritus of Botany, Purdue University, Lafayette, Indiana, and G. R. Bisby. (Introduced by Prof. John M. Coulter.)

"Ecology and Physiology of the Red Mangrove," by H. H. Bowman, Fellow in Botany, University of Pennsylvania. (Introduced by Prof. Harshberger.)

Evening Session—8 o'clock.

George Ellery Hale, Ph.D., Sc.D., LL.D., F.R.S., Director of the Solar Observatory of the Carnegie Institution of Washington, at Mt. Wilson, California, gave an illustrated lecture on "The Work of the Mt. Wilson Observatory."

Saturday, April 14.

Executive Session—9.30 o'clock.

William W. Keen, M.D., LL.D., President, in the Chair.

Dr. William Diller Matthew, of New York, Prof. Edwin Plimpton Adams, of Princeton, and Prof. William Morton Wheeler, of Forest Hills, Mass., recently elected members, subscribed the Laws and were admitted into the Society.

Pending nominations for membership were read. Secretary Keller and Dr. L. A. Bauer were appointed Tellers of Election and the Society proceeded to ballot for members.

The Tellers reported that the following nominees had been elected to membership:

Residents of the United States.

William Frederick Durand, Ph.D., Stanford University, Cal.
Pierre Samuel duPont, Mendenhall, Pa.
Carl H. Eigenmann, Ph.D., Bloomington, Ind.
Charles Holmes Herty, Ph.D., New York.
Herbert E. Ives, Ph.D., Philadelphia.
Waldemar Lindgren, M.E., Ph.D., Sc.D., Cambridge, Mass.
Walton Brooks McDaniel, A.B., Ph.D., Philadelphia.
Winthrop J. V. Osterhout, A.M., Ph.D., Cambridge, Mass.
Harold Pender, Ph.D., Philadelphia.
Frederick Hanley Seares, B.S., Pasadena, Cal.
George Owen Squier, Ph.D., Washington, D. C.
Charles P. Steinmetz, Ph.D., Schenectady, N. Y.
Oscar S. Straus, A.M., Litt.D., LL.D., New York City.
Alonzo Englebert Taylor, M.D., Philadelphia.
Edwin Bidwell Wilson, Ph.D., Cambridge, Mass.

Foreign Residents.

Archibald Byron Macallum, M.B., Ph.D., D.Sc., LL.D., F.R.S., Toronto.

Sir David Prain, M.A., LL.D., F.R.S., Kew.

Morning Session—10 o'clock.

William B. Scott, Sc.D., LL.D., Vice-President, in the Chair.

Dr. W. F. Durand, of Leland Stanford University, California, and Mr. Herbert E. Ives, of Philadelphia, newly elected members, subscribed the Laws and were admitted into the Society.

The following papers were read:

"Biochemical Studies of the Pitcher Liquid of Nepenthes," by Joseph S. Hepburn, M.S., Ph.D. (Introduced by Prof. Harry F. Keller.)

"The National Research Council and Its Opportunities in the Field of Chemistry," by Marston T. Bogert, Ph.B., LL.D., Professor of Organic Chemistry, Columbia University.

"The South American Indian in His Relation to Geographic Environment," by William Curtis Farabee, A.M., Ph.D., Curator of American Section of Museum, University of Pennsylvania. (Introduced by Mr. Henry G. Bryant.)

"Inter-relations of the Fossil Fuels," by J. J. Stevenson, Ph.D., LL.D., Emeritus Professor of Geology, New York University.

"The Distribution of Land and Water on the Earth," by Harry Fielding Reid, Ph.D., Professor of Dynamic Geology and Geography, Johns Hopkins University.

"Uplifted and Dissected Atolls in Fiji" (Illustrated), by William Morris Davis, Ph.D., Emeritus Professor of Geology, Harvard University.

"The Slides on the Panama Canal," by George W. Goethals, LL.D., Maj.-Gen. U. S. A., Late Chief Engineer, Panama Canal.

"Application of Polarized Light to Study of Ores and Metals," by Frederick E. Wright, Ph.D., of Geophysical Laboratory of Carnegie Institution of Washington.

"Astrapotheria," by William B. Scott, Sc.D., LL.D., Professor of Geology, Princeton University.

"Diatryma, a Gigantic Eocene Bird," by William Diller Matthew, A.M., Ph.D., Curator of Vertebrate Paleontology, American Museum of Natural History, New York. (Introduced by Prof. W. B. Scott.)

"The Waters of Death," by Paul Haupt, Professor of Semitic Philology, Johns Hopkins University.

Executive Session—1:45 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The Clerk of the Council certified that the Officers and Council, by unanimous vote, had nominated for membership the Rt. Hon. Arthur Balfour, LL.D., D.C.L., of London, England, and it was ordered, in accordance with the unanimous recommendation of the Officers and Council, that a special election for a foreign member be held at the next Stated Meeting.

Afternoon Session—2 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

A portrait of I. Minis Hays, M.D., Dean of the Wistar Association, was presented by J. G. Rosengarten, LL.D., on behalf of the Wistar Association, and in the twenty-first year of Dr. Hays's Secretaryship of the Society.

President Keen, on behalf of the Society, accepted the portrait with thanks.

The following papers were read:

Symposium on Aëronautics:

"Dynamical Aspects," by Arthur Gordon Webster, Ph.D., D.Sc., LL.D., Member of Naval Consulting Board.

"Physical Aspects," by Brigadier General George O. Squier, Ph.D., Chief of Signal Corps, U. S. Army. (Introduced by Dr. Keen.)

"Mechanical Aspects," by William Frederick Durand, Ph.D., Chairman of National Advisory Committee for Aëronautics. (Introduced by Dr. Walcott.)

"Aërology in Aid of Aëronautics," by W. R. Blair, Ph.D., assistant, U. S. Weather Bureau.

Discussion:

"Mathematical Aspects," by Edwin Bidwell Wilson, Ph.D., Professor of Mathematics, Massachusetts Institute of Technology. (Introduced by Dr. E. W. Brown.)

"Engineering Aspects," by Jerome C. Hunsaker, Eng.D., Assistant Naval Constructor, U. S. Navy. (Introduced by Dr. Bauer.)

Stated Meeting, May 4, 1917.

William W. Keen, M.D., LL.D., President, in the Chair.

Messrs. Walton Brooks McDaniel and Harold Pender, newly elected members, subscribed the Laws and were admitted into the Society.

Letters accepting membership were received from

William Frederick Durand, Ph.D., Stanford University, Cal.
Pierre Samuel duPont, Wilmington, Del.
Carl H. Eigenmann, Ph.D., Bloomington, Ind.
Charles Holmes Herty, Ph.D., New York.
Herbert E. Ives, Ph.D., Philadelphia.
Walton Brooks McDaniel, A.B.. Ph.D., Philadelphia.
Winthrop J. V. Osterhout, A.M., Ph.D., Cambridge, Mass.
Harold Pender, Ph.D., Philadelphia.
Frederick Hanley Seares, B.S., Pasadena, Cal.
George Owen Squier, Ph.D., Washington, D.C.
Charles P. Steinmetz, Ph.D., Schenectady, N. Y.
Oscar S. Straus, A.M., Litt.D., LL.D., New York City.
Alonzo Engelbert Taylor, M.D., Philadelphia.
Archibald Byron Macallum, M.B., Ph.D., D.Sc., LL.D., F.R.S., Toronto.

The decease was announced of Caspar René Gregory, Ph.D., D.D., LL.D., at Leipzig, on April 9, 1917, æt. 70.

Obituary notices of members deceased were read as follows:

Sir William Ramsay, K.C.B., Sc.D., LL.D., by Prof. Theodore William Richards.
Cleveland Abbe, Ph.D., LL.D., by Prof. Charles F. Marvin.

The following paper was read:

"The Study of Inheritance in *Pisum,*" by Orland E. White, of Brooklyn (communicated by Prof. E. M. East.)

Pending nomination for membership No. 1051 was read and, in accordance with a resolution unanimously adopted at the Executive Session held on April 14 last, the Society proceeded to an election.

The tellers reported that the Right Hon. Arthur James Balfour, LL.D., D.C.L., was elected to membership by unanimous vote.

Stated Meeting, October 5, 1917.

William W. Keen, M.D., LL.D., President, in the Chair.

Letters accepting membership were read from Sir David Prain, Rt. Hon. Arthur James Balfour and Mr. Waldemar Lindgren.

The decease was announced of

James Mason Crafts, B.S., LL.D., on June 20, 1917, æt. 78.

William Bullock Clark, Ph.D., LL.D., at North Haven, Maine, on July 27, 1917, æt. 57.

Marion D. Learned, Ph.D., Litt.D., at Philadelphia on August 1, 1917, æt. 60.

Patterson DuBois, Esq., at Philadelphia on August 8, 1917, æt. 69.

Adolf von Baeyer, Ph.D., M.D., on August —, 1917, æt. 82.

The following papers were read:

"Principles of the Treatment of Wounds," by Dr. Alexis Carrel, Member of the Rockefeller Institute and Chief Surgeon of Temporary Hospital No. 21, Compiègne, France.

"The Mathematical Study of the Cicatrization of Wounds," by Capt. Lecomte du Noüy, of Temporary Hospital No. 21; Compiègne, France.

"Eighteen New Species of Fishes from Northwestern South America" and

"Description of Sixteen New Species of Pygidiidæ," by Carl H. Eigenmann, Professor of Zoölogy, Indiana University.

Stated Meeting, November 2, 1917.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of Amos P. Brown, B.S., Ph.D., one of the Secretaries of the Society, at Atlantic City, N. J., on October 9, 1917, æt. 53.

The following papers were read:

"Two Years in the Arctic with the Crocker Land Expedition," by Edmund O. Hovey, Curator of Geological Department, American Museum of Natural History, New York.

"The Interrelations of the Fossil Fuels. The Jurassic and Triassic Coals," by J. J. Stevenson, Ph.D., LL.D., Professor Emeritus of Geology, New York University.

Stated Meeting, December 7, 1917.

William W. Keen, M.D., LL.D., President, in the Chair.

The decease was announced of Franklin Paine Mall, M.A., Sc.D., M.D., LL.D., at Baltimore, on November 17, 1917, æt. 55.

The following papers were read:

"The Archæological Significance of an Ancient Dune," by Dr. Charles C. Abbott, M.D.

"American Sanitation in the Philippines and its Influence on the Orient," by Victor George Heiser, M.D., Sc.D., which was discussed by Doctor Harshberger and Mr. S. Hudson Chapman.

Mr. S. Hudson Chapman, introduced by the President, made some remarks on "Sanitation in Ancient Times as Recorded on Coins issued by the City of Selinus in Sicily, from B.C. 466 to 406."

A communication entitled "Lusitanian Boat Tackle" was presented for the Magellanic Premium, and referred to the Officers and Council for report.

The annual address of the president was read by Dr. Keen.

The Minutes of the Meeting of the Officers and Council were submitted.

Dr. Hays, in connection therewith, made the following statement:

He regretted to be obliged to report to the Society that its Minutes for the year 1780 are found to be imperfect. Close examination tends to the conviction that the record which has been embodied in the Minute Book is a copy, made at some later date, of such loose records as were then available and is written in a different hand from that of the Minutes of 1779 and of 1781. Moreover, the record of the meeting of the 21st of July, 1780, begins "At a meeting of the Society the 21st of July, 1830," which slip of the pen leads one to the belief that these Minutes must have been transcribed in or after 1830, for this error could scarcely have been made in 1780.

Owing to the lack of any record of certain meetings which, under the Laws, should have been held, and particularly in the absence of any record of the election of members who were believed to have been elected in that year, Dr. Hays requested Miss Kirkpatrick, the Assistant to the Secretaries, to make a search through the files of that period of the *Pennsylvania Packet, The Pennsylvania Journal* and *The Pennsylvania Gazette* for any notices which they might contain of the Society's meetings of that year, so as to supply, as far as possible, the deficiencies in the Minutes. This she did with the following interesting results.

In the issue of the *Packet* for September 16, 1779, there appears an advertisement of a meeting of the Society, as follows:

"The American Philosophical Society are to meet at the College to-morrow evening at Seven o'clock agreeable to their Laws."

In the issue of December 2, 1779, appears the following advertisement of a meeting to be held on December 3:

"The Members of the American Philosophical Society, are to meet at Six o'clock to-morrow evening agreeable to their rules; and are requested to be punctual in their attendance."

Further, an advertisement in the *Pennsylvania Journal and Weekly Advertiser* of February 9, 1780, gives notice that

"the Assembly has granted the Members permission to bring in a Bill to incorporate the Society; a draught has been prepared by a Committee appointed for that purpose, and the Society stands adjourned until this evening when it is expected there will be a general attendance of members, at the University, to consider the same."

The Minutes contain no record of these meetings. It is, of course, possible, although improbable, that no quorum was present and that there were no Minutes to be recorded, but it seems desirable at least to preserve the record that these meetings of September 17 and December 3, 1779, and February 9, 1780, were duly called, and possibly the proceedings at them may be discovered later.

The Minutes of 1779 appear to have been carefully kept, although written by another hand and all at the same time, which leads to the belief that they, too, were copied at a later date from contemporaneous data and incorporated into the Minute Book.

Miss Kirkpatrick also found in the issue of *The Packet* for Thursday, January 20, the following advertisement:

"The American Philosophical Society are desired to meet at the University next Friday evening, when it is intended to ballot for such persons as have been proposed to be admitted as new members into the Society, agreeable to their Laws."

And in the issue of January 27 appears the following record of this meeting:

PHILADELPHIA, January 27th.

"At a meeting of the American Philosophical Society, the 21st inst. the following Gentlemen were chosen Members, viz.

"His Excellency George Washington, Esq; General and Commander in Chief of the Armies of the United States of North America.

"His Excellency the Chevalier de La Luzerne, Minister Plenipotentiary of France.

"Monsieur Marbois, Secretary of the Embassy of France.

"His Excellency Thomas Jefferson, Esq; Governor of the State of Virginia.

"His Excellency John Jay, Esq; Minister of the United States at the Court of Madrid.

"His Excellency Henry Laurens, Esq; late President of Congress.

"The Honorable John Adams, Esq; late Member of Congress.

"The Honorable William Carmichael, Esq; Secretary of the Embassy to the Court of Madrid.

"Major General Arthur St. Clair.

"Major General Anthony Wayne.

"Col. William Grayson, of the Board of War.

"Col. Hamilton, and Col. John Laurens, Aids du Camp to His Excellency General Washington.

"Baron de Steuben, Inspector General of the American Army.

"Major Vallancey, Second Engineer of Ireland, and Secretary to the Society of Antiquarians in Dublin.

"Timothy Matlack, Esq; Secretary of the Supreme Executive Council of the State of Pennsylvania.

"The Rev. John C. Kuntze [Kunze], Rector of the German Lutheran Congregation, Philadelphia.

"The Rev. James Madison, President of William and Mary College, Virginia.

"William Churchill Houston, Esq; Professor of Mathematics of Nassau College, and Delegate in Congress for the State of New Jersey.

"Dr. William Brown, of Virginia.

"Mons. [John] Tournon [Ternaut] Engineer of the Southern Army. And

"Robert Erskine, Esq; Geographer of the United States."

This is a particularly important historical discovery inasmuch as the Society's Minutes show no record of that meeting, or of any meeting in that year prior to February 25, and the announcement, unquestionably, bears the internal evidence of having been furnished to *The Packet* by some one in authority.

Moreover, in its printed "List of Members" of the Society from its foundation, eleven members are entered as having been "elected between April 6, 1779, and January 19, 1781?" which covers the period during which, apparently, the original records of the meetings have been lost, but in this record in the *Packet* we find that twenty-two members were elected on January 21, 1780, of whom nine are not on the Roll, and four who were either previously or subsequently elected are erroneously ascribed to that year, viz.,

Hon. John Jay (who appears to have been again elected to the Society on January 19, 1787).

His Excellency Henry Laurens (who had been previously elected on April 17, 1772).

The Hon. John Adams (who was again elected on January 18, 1793, when Vice President of the United States).

Col. Alexander Hamilton (who was again elected on January 21, 1791, when Secretary of the Treasury).

And the following nine, none of whom appear in the Society's "List":

Hon. William Carmichael.
Major General Arthur St. Clair.
Col. William Grayson.
Col. John Laurens.
Baron de Steuben.
Major Vallancey.

William Churchill Houston.
Dr. William Brown, of Virginia.
Robert Erskine, Esq.

In view of the undoubted accuracy of the *Packet's* list of those elected on January 21, 1780, the question naturally arises whether the names of those elected who do not now appear on the record should not be added to it.

The election a second time of some of the members can readily be accounted for by the unsystematic way in which the records were kept at that date. And to have the exact date upon which were elected all the members in this part of 1780 for which the Minutes are defective certainly is an important addition to our records.

The *Packet's* list does not, however, explain the appearance in the Society's List of the Members elected in 1779 and 1780 of the names of Colonel Charles Pettit and M. Sue, Professor Royal of Anatomy. M. Jean Baptiste Sue's omission is accounted for by the fact that he was not elected until January 21, 1785, as is shown by the Minutes of that date. In examining the Minutes for the election of Col. Pettit, it was found that those of the meeting of January 21, 1785, show two very curious errors. There is loosely placed between the leaves of the Minutes of that meeting a sheet of four pages signed "Extract from the Minutes. Samuel Magaw, one of the Secretaries," and endorsed in his handwriting "New Members of the Philosophical Society, elected January 21, 1785"; the twenty-second name in that list is that of Charles Pettit, Esq., of Philadelphia. This name, in the transcription into the engrossed Minutes, has been accidentally omitted, and this accounts for the doubt in our record as to the date on which Mr. Pettit was elected. As regards the fact of his election there can be no doubt, as he actually subscribed the Laws about that period.

Secondly, in the list of twenty-eight members then elected, the tenth is "Dr. William Griffiths, of Philadelphia," under this entry is written in pencil "this name probably ought to be Dr. Samuel Powel Griffiths, [signed] F.B.," which initials are presumably those of Dr. Franklin Bache, who was Secretary of the Society from 1825 to 1842, when he was elected to the Vice-Presidency. This pencil note is almost certainly correct because in the manuscript list of members, made in 1792, Dr. Samuel Powel Griffitts is entered as having been elected on January 22, 1785. Then, too, the treasurer's books for 1786 show an entry on January 18: "By Dr. Samuel Griffiths his deposit and subscription £1," and Samuel Powel Griffitts signed the Laws about that time—all of which seems to definitely determine that it was Dr. Samuel Powel Griffitts who was intended to be elected in January, 1785, and who actually became a member in consequence thereof. Moreover, no such person as Dr. William Griffiths is now known to have existed at that time, nor does his name appear upon the rolls of the Society at anytime; nor does Dr. Samuel Powel Griffitts appear by the official Minutes to have been elected on any other date.

I may also incidentally call your attention to the fact that the transcribed Minutes incorrectly give the date of the meeting as January 22, whereas the loose inset heretofore referred to gives it as January 21, which was Friday evening, the regular meeting night of the Society.

In accordance with the recommendation of the Officers and Council the Society ordered

1. That in order to make a more complete record of the Proceedings of the Society the Secretaries be instructed to interleave in the Minutes all notices of calls for meetings which have appeared in the newspapers issued during the time in which the Society's Minutes do not appear to have been original records, with the name and date of the newspapers in which said notices have appeared.

2. That the Minutes of the meeting of January 21, 1780, be accepted as a correct minute of that date and be interleaved in the Minutes as the record of that meeting, with the reference to the *Pennsylvania Packet* of January 27, 1780, as authority for the same.

3. That the roll of members be corrected in accordance with the data thus obtained.

4. That the loose sheet signed "Samuel Magaw one of the Secretaries" be interleaved in the Minute book under its proper date and that Charles Pettit's name be inserted in the roll of members as having been elected on January 21, 1785.

INDEX.

THE LIST

OF THE

American Philosophical Society

HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

(Founded 1727)

August, 1917

OFFICERS

1917

PATRON

The Governor of Pennsylvania

PRESIDENT

William W. Keen, M.D., Sc.D., LL.D.

VICE-PRESIDENTS

William B. Scott, Ph.D., D.Sc., LL.D.
Albert A. Michelson, Ph.D., Sc.D., LL.D.
George Ellery Hale, Sc.D., Ph.D., LL.D.

SECRETARIES

I. Minis Hays, A.M., M.D.
Arthur W. Goodspeed, A.B., Ph.D.
Amos P. Brown, B.S., Ph.D.
Harry F. Keller, Nat. Ph.D., Sc.D.

CURATORS

Charles L. Doolittle, C.E., Sc.D., LL.D.
William P. Wilson, Dr.Sc.
Leslie W. Miller

TREASURER

Henry La Barre Jayne, A.B.

COUNCILLORS

Elected in 1915

Henry H. Donaldson, Ph.D., D.Sc.
Theodore W. Richards, Sc.D., LL.D.
Robert A. Harper, M.A., Ph.D.
Edwin G. Conklin, Ph.D., Sc.D.

Elected in 1916

Louis A. Bauer, Ph.D., D.Sc.
Edward P. Cheyney, A.M., LL.D.
Russell H. Chittenden, Ph.D., LL.D.
Charles D. Walcott, Sc.D., LL.D.

Elected in 1917

Henry Fairfield Osborn, Sc.D., LL.D.
Elihu Thomson, Ph.D., D.Sc.
Samuel M. Vauclain, Sc.D.
Henry B. Fine, Ph.D., LL.D.

MEMBERS RESIDING WITHIN THE UNITED STATES

Date of Election

Abbot, Charles Greeley, M.Sc., D.Sc. Director of Astrophysical Observatory, Smithsonian Institution. Mem. Nat. Acad. Sci., Am. Astronom. and Astrophys. Soc., Soc. Astronom. de France, Astronomical Society of Mexico, Acad. de Ciencias, Mexico, Deut. Meteorol. Gesell. **Medals**—Draper (Nat. Acad. Sci. 1910); Rumford (Am. Acad. Arts and Sci. 1915). *Smithsonian Institution, Washington, D. C.* 1914

Abbot, Henry Larcom, LL.D. Major-General U. S. A. Mem. Nat. Acad. Sci., Am. Acad. Arts and Sci., Corr. Mem. Imp. Roy. Geolog. Instit. Austria. *23 Berkeley St., Cambridge, Mass.* 1862

Abbott, Alexander Crever, M.D., Sc.D., Dr. P.H. Prof. of Hygiene and Bacteriology, Univ. Penna., Chief of Bureau of Health and President of Board of Health of Philadelphia 1903–09. Mem. Assoc. Am. Phys., Am. Physiolog. Soc., Am. Soc. Pathol. and Bacteriol., Fell. Coll. Phys., Phila. *Laboratory of Hygiene, University of Pennsylvania, Philadelphia.* 1897

Abbott, Charles Conrad, M.D. Asst. Archæologist Peabody Mus., Cambridge, Mass., 1876–89. Mem. Royal Soc. of Antiquaries of the North, Copenhagen; Boston Soc. of Nat. Hist., Linnaean Soc., N. Y., N. Y. Acad. of Sci. *907 Radcliffe St., Bristol, Pa.* 1889

Abel, John Jacob, A.M., Sc.D., M.D. Professor of Pharmacology, Johns Hopkins University. Mem. Nat. Acad. Sci., Assoc. Am. Phys., Am. Physiol. Soc., Soc. for Pharmacol. and Exp. Therap. *Johns Hopkins Medical School, Baltimore.* 1915

Adams, Edwin Plimpton, M.S., Ph.D. Professor of Physics, Princeton University. *Princeton, N. J.* 1915

Adams, Walter Sydney, A.M., Sc.D. Astronomer and Assistant Director of Mt. Wilson Solar Observatory, Carnegie Institution of Washington. Mem. Am. Astronom. Soc., Fell. Roy. Astronom. Soc. *Observatory Office, Pasadena, Cal.* 1915

Adler, Cyrus, M.A., Ph.D. President of Dropsie Coll. for Hebrew and Cognate Learning. Formerly Librarian and Assist. Sec'y Smithsonian Institution, Hon. Assoc. U. S. Nat. Museum, Member Am. Jewish Hist. Soc., (President) Am. Anthrop. Assoc., Am. Philol. Soc., Am. Oriental Soc., Washington Acad. Sci. *2041 N. Broad St., Philadelphia.* 1900

Date of Election

Allen, Joel Asaph, Ph.D. (Hon.). Curator of Department of Mammalogy and Ornithology, American Museum of Natural History, N. Y. Mem. Nat. Acad. Sci., Am. Acad. Arts and Sci., Am. Ornith. Union (Pres't, 1883–90); Zool. Soc., Lond., Deutsche Orn. Gesell., Berlin. **Medal**—Linn. Soc. Nat. Hist., N. Y., 1916. *American Museum of Natural History, New York.* 1878

Ames, Joseph Sweetman, A.B., Ph.D., LL.D. Professor of Physics and Director of Physical Laboratory, Johns Hopkins University. Mem. Nat. Acad. Sci., Am. Phys. Soc., Soc. Franç. de Phys., Nat. Advisory Comm. for Aeronautics; Fell. Am. Acad. Arts and Sci., Hon. Mem. Roy. Inst. of Gt. Br. *Johns Hopkins University, Baltimore.* 1905

Anderson, George Lucius, A.M. Colonel U. S. A. *Palo Alto, Cal.* 1886

Appleton, William Hyde, A.M., Ph.D., LL.D. Formerly Professor of Greek and President of Swarthmore College. Mem. Arch. Inst. of Am. *The Clinton, 10th and Clinton Sts., Philadelphia.* 1893

Atkinson, George Francis, Ph.D. Professor of Botany, Cornell University. Mem. N. Y. Acad. Sci., Bot. Soc. of Am. (Pres't, 1907). *Department of Botany, Cornell University, Ithaca, N. Y.* 1913

Atterbury, William Wallace, Ph.B., M.A. Vice-President (in charge of operation) Pennsylvania R. R. Co.; Pres't Am. Rwy. Assoc.; Mem. Am. Soc. Mechan. Eng., Am. Soc. Civil Eng. *Radnor, Pa.* 1916

Bailey, Liberty Hyde, M.S., LL.D. Late Professor of Horticulture and Director of N. Y. State College of Agriculture, Cornell University, Fell. Am. Acad. Arts and Sci. *Ithaca, N. Y.* 1896

Balch, Edwin Swift, A.B. Mem. Geog. Soc. of Phila. (Pres't, 1895–96). Fell. Am. Geog. Soc., Roy. Geog. Soc., Corr. Mem. Soc. Antonio Alzate, Mexico. *1412 Spruce St., Philadelphia.* 1899

Balch, Thomas Willing, A.B. Mem. Am. Antiq. Soc., Hist. Soc. of Penna. (V. P.). Corr. Mem. Colonial Soc. of Mass. *1412 Spruce St., Philadelphia.* 1901

Baldwin, James Mark, M.A., Ph.D., D.Sc., LL.D. Late Professor of Psychology, Johns Hopkins Univ., For. Corr. Inst. de France, Mem. Am. Psychol. Assoc. (President, 1907–08). **Medal**—Roy. Acad. Denmark. *Care of Harris Forbes Co., 56 William St., New York.* 1897

Baldwin, Simeon Eben, A.M., LL.D. Justice, Governor of Connecticut. Professor of Law in Yale University. Mem. Am. Soc. Sci. Assoc. (Past-President), Am. Polit. Sci. Assoc., Am. Hist. Assoc., Internat. Law Assoc. (Lond.), Am. Antiq. Soc.; Fell. Am. Acad. Arts and Sci., Corr. Mem. Mass. Hist. Soc., Colonial Soc. of Mass., l'Institut de Droit Comparée, Brussels. *New Haven, Conn.* 1910

Date of Election

Barker, Wharton, M.A. *Port Royal Ave., Roxborough, Philadelphia.* 1884

Barnard, Edward Emerson, M.A., D.Sc., LL.D. Professor of Practical Astronomy, University of Chicago, Astronomer of Yerkes Observatory; Fell. A. A. A. S. (V.P., 1898). Mem. Nat. Acad. Sci., Astron. and Astrophys. Soc., Assoc. Fell. Am. Acad. Arts and Sci., Hon. Mem. R. Astron. Soc. of Canada; For. Assoc. Royal Astron. Soc., Soc. Astron. de France. **Medals**—Lelande (Paris Acad., 1892); Arago (1893); Roy. Astron. Soc. (1897). Janssen Prize Soc. Astron. de France, 1906). *Yerkes Observatory, Williams Bay, Wis.* 1903

Barton, George Aaron, A.M., Ph.D., LL.D. Professor of Biblical Literature and Semitic Languages, Bryn Mawr College. Mem. Soc. of Biblical Lit. and Exegesis (Pres't, 1916–17), Am. Oriental Soc., Arch. Inst. of Am., Soc. of Biblical Archaeol. (Lond.), Deutsche Morgenländ. Gesell., Orient-Gesell., Vorderasiat. Gesell., Corr. Mem. Soc. Archéol. de France. *237 Roberts Road, Bryn Mawr, Pa.* 1911

Barus, Carl, Ph.D., LL.D. Professor of Physics, Brown University. Formerly Physicist, U. S. Geolog. Surv., and Smithsonian Inst. Mem. Nat. Acad. Sci., Fell. Am. Acad. Arts and Sci., Am. Phys. Soc. (Pres't, 1904–06), Hon. Mem. Royal Institution of Gt. Br. **Medal**—Rumford (1900). *Brown University, Providence, R. I.* 1903

Bauer, Louis A., C.E., M.S., M.A., Ph.D., D.Sc. Director of Department of Terrestrial Magnetism, Carnegie Inst. of Washington. Formerly Chief of Div. of Terrestrial Magnetism, U. S. Coast & Geodetic Survey. Halley Lecturer in Terrestrial Magnetism (Oxford, 1913). Fell. Am. Acad. Arts and Sci., Corr. Mem. Soc. d. Wissenschaft. (Göttingen), Acad. das Scien. (Lisbon), Hon. Mem. Royal Cornwall Polytech. Soc., Soc. Cient. "Antonio Alzate," Mexico, Mem. Washington Acad. Sci., Philos. Soc. of Wash. (Pres't, 1908), Am. Phys. Soc., Am. Astron. Soc., Assoc. of Am. Geog., Mem. Perm. Comm. on Terrestrial Magnetism of Inter. Meteorological Conference, and of Inter-Assoc. of Academies. **Medal**—Charles Lagrange Prize, Acad. Roy. Belgique (1909). Georg Neumeyer (Berlin, 1913). *301 The Ontario, Washington, D. C.* 1909

Baugh, Daniel. *1601 Locust St., Philadelphia.* 1899

Becker, George Ferdinand, B.A., Ph.D. (Heidelb.). Geologist in charge of U. S. Geol. Survey. Mem. Nat. Acad. Sci., Geol. Soc. of Am. (Pres't, 1914), Am. Inst. of Mining Engineers. *U. S. Geological Survey, Washington, D. C.* 1907

Bell, Alexander Graham, LL.D., Ph.D., Sc.D., M.D. Mem. Nat. Acad. Sci., Am. Acad. Arts and Sci., Boston Soc. of Nat. Hist., Am. Inst. Electrical Eng. (Past-Pres't), Antiq. Soc. of Mass., Wash. Acad. Sci., Nat. Geog. Soc. (Past-Pres't), Roy. Soc. of Arts (Lond.); 1882

Date of Election

Soc. of Telegraph Eng. and Elect. (Lond.); Inst. of Elect. Eng. (Lond.), Soc. de Physique (Paris). **Medals**—Centennial Expos. of Phila., for speaking telephone (1876); Soc. of Arts of Lond. Roy. Albert (1878); République Française Exposition Universelle, Paris (1878); awarded by the Government of France the Volta Prize of 50,000 francs for the electrical transmission of speech (1880). *1331 Connecticut Ave., Washington, D. C.*

Bell, J. Snowden, LL.D. *P. O. Box 629, New York City.* 1882

Bement, Clarence S. *3907 Spruce St., Philadelphia.* 1895

Benedict, Francis Gano, A.M., Ph.D. (Heidelb.), Sc.D. Director of Nutrition Laboratory of Carnegie Institution of Washington. Formerly Professor of Chemistry, Wesleyan Univ. Mem. Nat. Acad. Sci., Am. Chem. Soc., Fell. Am. Acad. Arts and Sci. *Nutrition Laboratory, Vila St., Boston, Mass.* 1910

Bennett, Charles Edwin, B.A., Litt.D. Professor of Latin, Cornell University. Mem. Am. Philol. Assoc. (Pres't, 1908–09). *1 Grove Place, Ithaca, N. Y.* 1913

deBenneville, James S., A.B. *26 D Bluff, Yokohama, Japan.* 1897

Blair, Andrew A. *406 Locust St., Philadelphia.* 1889

Bloomfield, Maurice, A.M., Ph.D., LL.D., L.H.D. Professor of Sanskrit and Comparative Philology, Johns Hopkins University. Mem. Am. Orient. Soc. (Pres't, 1905–11); Fell. Am. Acad. Arts and Sci. **Medals**—Hardy Prize, K. Bayer. Akad. d. Wiss. *Johns Hopkins University, Baltimore, Md.* 1904

Boas, Franz, Ph.D., LL.D., Sc.D. (Oxon.). Professor of Anthropology, Columbia University. Mem. Nat. Acad. Sci., Am. Antiq. Soc., N. Y. Acad. Sci. (Pres't, 1910), Am. Anthrop. Soc. (Pres't, 1907–08), Hon. Mem. Anthrop. Gesell. Vienna, Hon. Fell. Anthrop. Soc. of Gt. Br., Corr. Mem. Anthrop. Societies of Berlin, Brussels, Florence, Moscow, Paris, Rome, Stockholm and Washington, and of Deut. Anthrop. Gesell., Soc. des Americanistes, Paris, and Soc. for Oriental Languages, Frankfort. *230 Franklin St., Grantwood, N. J.* 1903

Bôcher, Maxime, A.B., Ph.D. Professor of Mathematics, Harvard University. Mem. Nat. Acad. Sci., Am. Math. Soc. (Past-Pres't). *48 Buckingham St., Cambridge, Mass.* 1916

Bogert, Marston Taylor, Ph.B., LL.D. Professor of Organic Chemistry, Columbia University. Mem. Nat. Acad. Sci., Soc. Chem. Industry (Past-Pres't), Am. Chem. Soc. (Past-Pres't), Washington Acad. Sci., Nat. Research Council, Chem. Soc., Lond., Deutsche Chem. Gesell., Soc. Chim. Ital., Soc. Chim. de France. *Columbia University, New York City.* 1909

Date of Election

Boltwood, Bertram B., Ph.D. Professor of Radio-Chemistry, Yale University. Mem. Nat. Acad. Sci., Am. Chem. Soc., Am. Phys. Soc., Am. Acad. Arts and Sci. *P. O. Box 1038, Yale Station, New Haven, Conn.* 1911

Branner, John Casper, B.S., Ph.D., LL.D., D.Sc. President Emeritus of Stanford University. Mem. Nat. Acad. Sci., Am. Inst. Mining Eng., Indiana Acad. Sci. (Past-Pres't), Am. Soc. Naturalists, Washington Acad. Sci., Calif. Acad. Sci., Geological Soc. Am. (Past-Pres't), Calif. Earthquake Comm., Seismological Soc. Am. (Past-Pres't), Soc. Geol. de France, Geol. Soc. Lond., Hon. Mem. Acad. Pernambucana de Letras., Inst. Geog. e Hist. da Bahia, Soc. Belge de Geol., Inst. Hist. e Geog., Rio, For. Mem. Acad. Brasil. **Medals**—Louisiana Purchase Exposition (1905); Hayden (Acad. Nat. Sci. of Phila.). *Stanford University, Cal.* 1886

Brashear, John Alfred, LL.D., Sc.D., D.Eng. Mem. Eng. Soc. Western Penna. (Past-Pres't), Am. Soc. Mech. Eng. (Past-Pres't), Pittsburg Acad. Science and Arts (Past-Pres't), Am. Astron. Soc., Roy. Astron. Soc., British Astron. Soc., Soc. Astron. de France, Soc. Astron. de Belge, Roy. Astron Soc. Canada. **Medal**—Franklin Inst. *1954 Perryville Ave., Pittsburgh, Pa.* 1902

Bridgman, Percy Williams, A.M., Ph.D. Assistant Professor of Physics, Harvard University. Fell. Am. Acad. Arts and Sci., Mem. Washington Acad. Sci. *Jefferson Physical Laboratory, Cambridge, Mass.* 1916

Bright, James Wilson, Ph.D., Litt.D., LL.D. Professor of English Literature, Johns Hopkins University. *246 W. Lanvale St., Baltimore, Md.* 1914

Brown, Amos Peaslee, B.S., E.M., Ph.D. Professor of Mineralogy and Geology, University of Pennsylvania. Mem. Am. Inst. Mining Eng., Fell. Geol. Soc. of Am. *20 E. Penn St., Germantown, Philadelphia.* 1901

Brown, Ernest William, M.A., Sc.D. (Cantab.). Professor of Mathematics, Yale University. Fell. Roy. Soc., Am. Acad. Arts and Sci., Roy. Astron. Soc., Cambridge Philos. Soc., Mem. Lond. Math. Soc., Am. Math. Soc., Am. Astron. and Astrophys. Soc. **Medals**—Royal (Royal Soc., 1914); Gold (Royal Astron. Soc., 1907); Adams Prize, Cambridge (1907); De Pontécoulant Prize (Paris 1908). *116 Everit St., New Haven, Conn.* 1898

Brubaker, Albert P., A.M., M.D., LL.D. Professor of Physiology and Medical Jurisprudence, Jefferson Medical Coll., Phila. Mem. Am. Physiol. Soc., Fell. Coll. of Phys. of Phila. *3426 Powelton Ave., Philadelphia.* 1895

Date of Election

Brumbaugh, Martin Grove, M.E., D.Sc., A.M., Ph.D., LL.D., D.Litt. Governor of Pennsylvania. Formerly Superintendent of Public Schools, Phila., Mem. Nat. Educational Assoc. *Executive Dep't, Harrisburg, Pa.* 1908

Brush, Charles Francis, M.E., M.S., Ph.D., Sc.D., LL.D. Mem. Am. Soc. of Mech. Eng., Am. Inst. Elec. Eng., Nat. Elec. Light Assoc., Am. Chem. Soc., Am. Phys. Soc., Brit. Assoc. of Mech. Eng., Roy. Soc. of Arts. **Medals**—Rumford (1899), Edison (1913). *481 The Arcade, Cleveland, O.* 1910

Bryant, Henry G., M.A., LL.B. Mem. Geog. Soc. of Phila. (Pres't), Am. Alpine Club (Pres't), Fell, Roy. Geog. Soc., Corr. Mem. Geog. Soc. of Geneva, Anthrop. and Geog. Soc. of Stockholm, Appalachian Mt. Club, Officier de l'Académie (France). *2013 Walnut St., Philadelphia.* 1898

Bumpus, Hermon Carey, Ph.D., Sc.D., LL.D. President of Tufts College. Mem. Am. Morphol. Soc. (Past-Pres't), Am. Soc. Zool., Am. Soc. Naturalists, N. Y. Acad. Sci., Fell. Am. Acad. Arts and Sci., K. K. Oest. Fisch. Gesell. (Vienna), Corr. Mem. Senckenberg. Naturforsch. Gesell. *Tufts College, Mass.* 1909

Cadwalader, John, A.M., LL.D. *263 S. Fourth St., Philadelphia.* 1899

Campbell, Douglas Houghton, Ph.D. Professor of Botany, Stanford University. Mem. Am. Botan. Soc. (Past-Pres't), Nat. Acad. Sci., Fell. Am. Acad. Arts and Sci., For. Mem. Linnean Soc., Deut. Botan. Gesell., Royal Soc. Edin., Internat. Botanical Soc. *Leland Stanford University, Cal.* 1910

Campbell, William Wallace, M.S., Sc.D., LL.D. Director of Lick Observatory, University of California. Mem. Nat. Acad. Sci., A. A. A. S. (Past-Pres't), Am. Astron. Soc., Astron. Soc. of Pacific, Fell. Am. Acad. Arts and Sci., For. Assoc. Royal Astron. Soc. Lond., For. Mem. Soc. Spettros. Ital., Astron. gesell., Montpellier Acad. des Sci., Soc. Roy. des Sci. à Upsal, K. Svenska Vetenskaps Akad. (Stockholm), R. Acad. de Cien. Madrid. **Medals**—Lalande (Acad. des Sci. Paris, 1903); Royal Astron. Soc. (1905); Draper (Nat. Acad. Sci. 1906); Janssen (Acad. de Sci. Paris, 1910); Bruce (Astron. Soc. of Pacific 1915). *Lick Observatory, Mt. Hamilton, Cal.* 1903

Cannon, Walter Bradford, A.M., M.D. Professor of Physiology, Harvard University. Mem. Nat. Acad. Sci., Am. Phys. Soc. (Past-Pres't), Soc. for Exper. Biol. and Med., Am. Psych. Assoc., Fell. Am. Acad. Arts and Sci. *Harvard Medical School, Boston, Mass.* 1908

Carnegie, Andrew, Dr. Polit. Sci., LL.D. Mem. Am. Geog. Soc., Am. Statist. Assoc., Hon. Mem. Astron. Gesell. at Treptow Sternwarte, 1902

Date of Election

Nat. Hist. Soc., Glasgow, Philos. Inst., Edin., Roy. Geog. Soc. of Australasia, Royal Inst. of Gt. Br. *2 East 91st St., New York City.*

Carrell, Alexis, M.D., Sc.D. Mem. Rockefeller Inst. for Med. Research, Fell. Am. Surg. Assoc., Nobel Laureate, Medicine (1912). *Rockefeller Institute for Medical Research, 66th St. and Avenue A, New York City.* 1909

Carson, Hampton Lawrence, M.A., LL.D. Late Attorney-General of Pennsylvania, Professor of Law in University of Pennsylvania, Chancellor of Law Assoc. of Phila., Mem. Penna. State Bar Assoc. (President), Am. Bar Assoc. (V.P.), Historical Soc. of Penna. (V.P.), Swedish Colonial Soc. *1524 Chestnut St., Philadelphia.* 1880

Castle, William Ernest, A.M., Ph.D. Professor of Zoology, Harvard University. Mem. Nat. Acad. Sci., Boston Soc. Nat. Hist., Fell. Am. Acad. Arts and Sci. *186 Payson Road, Belmont, Mass.* 1910

Castner, Samuel, Jr. *3729 Chestnut St., Philadelphia.* 1887

Cattell, James McKeen, A.M., Ph.D., LL.D. Mem. Nat. Acad. Sci., N. Y. Acad. Sci. (Past-Pres't), Am. Psychol. Assoc. (Past-Pres't), Am. Soc. Naturalists (Past-Pres't). *Garrison-on-Hudson, N. Y.* 1888

Chamberlin, Thomas Chrowder, A.M., Sc.D., LL.D. Professor and Head of Dept. of Geology and Director of the Walker Museum, University of Chicago. Comm. Illinois Geol. Surv., Consulting Geologist U. S. Geol. Surv., Research Assoc. Carnegie Inst. of Wash., Mem. Nat. Acad. Sci., A. A. A. S. (Pres't, 1908), Chicago Acad. of Sci. (Pres't, 1898–1914), Illinois Acad. Sci. (Pres't, 1907), Geol. Soc. of Am. (Pres't, 1895). **Medals**—Paris Expos., 1878, 1893; Helen Culver (Chicago Geog. Soc., 1910). *Rosenwald Hall, University of Chicago, Chicago, Ill.* 1905

Chance, Henry Martyn, C.E., M.D. Mem. Mining and Metal. Soc. Am. (Pres't, 1913). *837 Drexel Bldg., Philadelphia.* 1880

Chandler, Charles Frederick, A.M., Ph.D., LL.D. Professor of Chemistry, Columbia University. Mem. Nat. Acad. Sci., Am. Chem. Soc. (Pres't, 1881–89), Brit. Soc. Chem. Indust. (Pres't, 1899), Chem. Soc. Lond., Deut. Chem. Gesell., Soc. Chim. de France, N. Y. Acad. Sci., Am. Inst. Elec. Eng., Am. Soc. Mining Eng. *Columbia University, New York City.* 1875

Cheyney, Edward Potts, A.M., LL.D. Professor of European History, University of Pennsylvania. Mem. Am. Hist. Assoc. *259 S. 44th St., Philadelphia.* 1904

Chittenden, Russell H., Ph.D., LL.D., Sc.D. Professor of Physiological Chemistry, Sheffield Scientific School, Yale University. Mem. Nat. Acad. Sci., Am. Physiolog. Soc. (Past-Pres't), Am. Soc. Biolog. Chemists (Past-Pres't), Am. Soc. of Naturalists (Past-Pres't). *83 Trumbull St., New Haven, Conn.* 1904

Date of Election

Clark, William Bullock, Ph.D., LL.D. Professor of Geology, Johns Hopkins University, State Geol. of Maryland, Dir. (Maryland) Weather Service, Mem. Nat. Acad. Sci., Geol. Soc. Am., Assoc. of State Geologists (Past-Pres't), Washington Acad. Sci., Am. Inst. Mining Eng., Mining and Metallurg. Soc. Am., Fell. Am. Acad. Arts and Sci., For. Corr. Geol. Soc. of Lond., Deutsche Geolog. Gesell. *Johns Hopkins University, Baltimore, Md.* 1902

Clarke, Frank Wigglesworth, S.B., D.Sc., LL.D. Chief chemist U. S. Geological Survey, Hon. Curator of Minerals, U. S. Nat. Mus. Mem. Nat. Acad. Sci., Am. Chem. Soc. (Pres't, 1901), Philos. Soc. Wash. (Pres't, 1896), Washington Acad. Sci. (Pres't, 1912). Hon. V.P. of Internat. Chemical Congresses at Paris, Berlin and N. Y., Corr. Mem. Edinburgh Geol. Soc., Geol. Soc. Lond., Hon. Mem. Mineralog. Soc. Lond., Chem. Soc. Lond., Manchester Lit. and Philos. Soc., Imp. Soc. Naturalists, Moscow. **Medal**—Wilde, Manchester (1903). *U. S. Geological Survey, Washington, D. C.* 1904

Clarke, John Mason, M.A., Ph.D., Sc.D, LL.D. Director of Department of Science and State Museum, New York. Mem. Nat. Acad. Sci., Geol. Soc. Am. (Pres't), Palaeontological Soc. (Past-Pres't). **Medal**—Hayden (Acad. Nat. Sci., Phila.); Spindiaroff Prize (Internat. Geol. Cong.). *Albany, N. Y.* 1911

Clay, Albert T., A.M., Ph.D., LL.D. Professor of Assyriology and Babylonian Literature and Curator of Babylonian Collection, Yale University. Mem. Am. Orient. Soc., Soc. of Biblical Lit. and Exegesis, Vorderasiatischen Gesell. *401 Humphrey St., New Haven, Conn.* 1912

Collitz, Hermann, A.M., Ph.D., L.H.D. Professor of Germanic Philology, Johns Hopkins University. Mem. Am. Orient. Soc., Am. Philol. Soc., Modern Lang. Assoc. of Am., Verein für Niederdeutsche Sprach., Deut. Morgenländ. Gesell. *1027 N. Calvert St., Baltimore, Md.* 1902

Comstock, John Henry, B.S. Professor Emeritus of Entomology and General Invertebrate Zoology, Cornell University. Fell. Entomolog. Soc. of Am. (Past-Pres't), Hon. Mem. Calif. Acad. Sci., Ent. Soc. of Ont.; Soc. Ent. de Belgique, Mem. Soc. Ent. de France, Hon. Fell. Ent. Soc., Lond. *123 Roberts Place, Ithaca, N. Y.* 1913

Conklin, Edwin Grant, Ph.D., Sc.D. Professor of Biology, Princeton University. Mem. Nat. Acad. Sci., Am. Soc. Nat. (Pres't, 1912); Am. Soc. Zool. (Pres't, 1899), Fell. Am. Acad. Arts and Sci. *Princeton, N. J.* 1897

Coplin, W. M. Late, M.D. Professor of Pathology, Jefferson Medical College, Phila. Mem. Assoc. Am. Phys., Assoc. Am. Path. and Bact., Am. Assoc. for Prevention of Tuberculosis, Fell. Coll. of Phys., Phila. *606 S. 48th St., Philadelphia.* 1911

Date of Election

Coulter, John Merle, A.M., Ph.D. Professor and Head of Dept. of Botany, University of Chicago. Mem. Nat. Acad. Sci., Am. Bot. Soc. (Pres't, 1897–98, 1915–16), Illinois Acad. Sci. (Pres't, 1910), Chicago Acad. Sci. (Pres't, 1915), Assoc. Fell. Am. Acad. Arts and Sci., Corr. Fell. Bot. Soc. of Edin., For. Mem. Linnean Soc., Lond. *University of Chicago, Chicago, Ill.* 1915

Crane, Thomas Frederick, A.M., Litt.D. Professor Emeritus of Romance Languages and Literature, Cornell University. Mem. Royal Acad. Sci. and Arts, Palermo, Italy. *Ithaca, N. Y.* 1877

Crile, George W., A.M., M.D., LL.D. Professor of Surgery, Western Reserve University. Mem. Am. Surg. Assoc., Am. Assoc. Path. and Bact., Soc. Exper. Biol. and Med., Am. Physiol. Soc., Soc. Clin. Surg., Hon. F. R. C. S. (England). **Medal**—Alvarenga Prize (Coll. of Phys. of Phila.); Cartwright Prize (Columbia Univ.); Senn Prize (Am. Med. Assoc.). *1031 Prospect Ave., Cleveland, O.* 1912

Cross, Whitman, B.S., Ph.D. Geologist U. S. Geological Surv. Mem. Nat. Acad. Sci., Geol. Soc. Washington, Fell. Geol. Soc. Am., For. Assoc. Geol. Soc., London. *2138 Bancroft Place, Washington, D. C.* 1915

Culin, Stewart. Curator of Ethnology, Brooklyn Institute Museum. Corr. Mem. Real Acad. de la Historia, Royal Italian Anthrop. Soc., Svenska Sällskapet för Antrop. och Geog. *Brooklyn Institute Museum, Brooklyn, N. Y.* 1897

Cushing, Henry Platt, Ph.D. Professor of Geology, Western Reserve University, Cleveland, O. Mem. Geolog. Soc. Am. (V.P., 1915), N. Y. Acad. Sci. *Western Reserve University, Cleveland, O.* 1916

DaCosta, John Chalmers, M.D. Clinical Professor of Surgery, Jefferson Medical College, Phila. Fell. Coll. Phys. Phila., Mem. Am. Surg. Assoc. *2045 Walnut St., Philadelphia.* 1904

Dall, William Healey, A.M., D.Sc., LL.D. Geologist and Palaeontologist U. S. Geological Survey. Hon. Prof. Invert. Palaeont., Wagner Inst. of Sci., Phila. Mem. Nat. Acad. Sci., Boston Soc. Nat. Hist., Chicago Acad. Sci., Philos. Soc. Wash. (Pres't, 1894), Biolog. Soc. Wash. (Pres't, 1888–89), Fell. Am. Acad. Arts and Sci., For. Mem. K. K. Zoolog.-Bot. Gesell. in Wien, Corr. Mem. Geog. Gesell. Bremen, Gesell. für Erdkunde, Berlin, Svenska Sällsk. für Anthrop. och Geog. Stockholm, Soc. Zoolog. de France, Geolog. Soc. Lond., Naturforsch. Gesell., Leipzig. *Smithsonian Institution, Washington, D. C.* 1897

Daly, Reginald Aldworth, A.M., Ph.D. Professor of Geology, Harvard University. Mem. Geolog. Soc., Am., Seismological Soc., Am., Fell. Am. Acad. Arts and Sci. *23 Hawthorn St., Cambridge, Mass.* 1913

Date of Election

Dana, Edward S. Professor of Physics, Yale University. Mem. Nat. Acad. Sci. *Yale University, New Haven, Conn.* 1896

Davenport, Charles Benedict, S.B., Ph.D. Director of Station for Experimental Evolution, Carnegie Institution of Washington, Cold Spring Harbor, N. Y. Mem. Nat. Acad. Sci., Am. Zool. Soc., Assoc. of Naturalists (Past-Pres't), Eugenics Research Assoc. (Pres't), Boston Soc. Nat. Hist., Fell. Am. Acad. Arts and Sci. *Cold Spring Harbor, Long Island, N. Y.* 1907

Davis, Bradley Moore, A.M., Ph.D. Professor of Botany, University of Pennsylvania. Fell. Am. Acad. Arts and Sci., Mem. Am. Soc. Naturalists, Bot. Soc. Am. *Botanical Laboratory, University of Pennsylvania, Philadelphia.* 1914

Davis, William Morris, S.D., Ph.D. Professor Emeritus of Geology, Harvard University. Mem. Nat. Acad Sci., Geol. Soc. of Am. (Pres't, 1911), Hon. Mem. Geographical Societies of Berlin, Vienna, Madrid, Rome, Budapest, Leipzig, Greifswald, Geneva, Neûchatel, New York, Philadelphia, and Chicago. Corr. Mem. N. Y. Acad. of Sci., Acad. de Wissen., Berlin, Acad. des Sciences, Paris, and of Geographical Societies of London, Paris, Munich and Petrograd. *31 Hawthorn St., Cambridge, Mass.* 1899

Day, Arthur L., Ph.D., Sc.D. Director of the Geophysical Laboratory, Carnegie Institution of Washington. Fell. Am. Acad. Arts and Sci., Mem. Nat. Acad. Sci., Geol. Soc., Am., Am. Phys. Soc., Am. Chem. Soc., Washington Acad. Sci., Philos. Soc., Wash. (Pres't, 1911), Deut. Physikal. Gesell., Deut. Bunsen Gesell., Hon. Mem. Acad. di Sci., Let. ed Arti degli Zelanti (Acireale, Italy). *Geophysical Laboratory, Washington, D. C.* 1912

Day, Frank Miles, B.S., M.A. Lecturer on Architecture, University of Pennsylvania, and Harvard University, Supervising Architect Yale University. Mem. Advisory Board of Archit., Johns Hopkins Univ., Fell. Am. Inst. of Archit. (Past-Pres't), Nat. Inst. of Arts and Letters, Corr. Mem. Russian Imp. Inst. of Archit., Hon. Corr. Mem. Roy. Inst. of Brit. Archit., Assoc. Nat. Acad. of Design. *Mt. Airy P. O., Philadelphia.* 1899

Dercum, Francis X., A.M., M.D., Ph.D. Professor of Nervous and Mental Diseases, Jefferson Medical College, Philadelphia. Fell. Coll. Phys. Phila., Mem. Phila. Neurol. Soc. (Pres't), Phila. Psychiatric Soc. (Past-Pres't), Am. Neurol. Soc. (Past-Pres't), Roy. Medical Soc., Budapest, Corr. Mem. Neurol. and Psychiat. Soc., Vienna, For. Corr. Mem. Neurolog. Soc., Paris. *1719 Walnut St., Philadelphia.* 1892

Dewey, John, Ph.D., LL.D. Professor of Philosophy, Columbia University. Mem. Nat. Acad. Sci., Am. Psych. Assoc. (Past-Pres't), Am. Soc. Naturalists. *Columbia University, New York City.* 1911

Date of Election

Dixon, Samuel G., M.D., Sc.D., LL.D. Commissioner of Health of Pennsylvania. Fell. Coll. Phys., Phila., Mem. Acad. Nat. Sci., Phila. (Pres't). *Bryn Mawr, Pa.* 1892

Dolley, Charles S., M.D. 1886

Donaldson, Henry Herbert, A.B., Ph.D., D.Sc. Professor of Neurology, Wistar Institute of Anatomy and Biology, Philadelphia. Mem. Nat. Acad. Sci., Am. Psychol. Assoc., Am. Neurol. Assoc., Am. Physiol. Soc., Am. Soc. Naturalists, Am. Assoc. Anat. (Past-Pres't). *Wistar Institute, 36th St. and Woodland Ave., Philadelphia.* 1906

Doolittle, Charles L., C.E., Sc.D., LL.D. Professor Emeritus of Astronomy, University of Pennsylvania. Mem. Am. Astron. Soc., Astronom. Gesell. *4523 Pine Street, Philadelphia.* 1881

Doolittle, Eric, C.E. Professor of Astronomy, University of Pennsylvania. Fell. Royal Astron. Soc. *University of Pennsylvania, Philadelphia.* 1903

Dougherty, Thomas Harvey, B.S. *West School Lane, Germantown, Philadelphia.* 1899

Douglas, James, B.A., LL.D. Mem. Am. Inst. Mining Eng. (Past-Pres't), Canadian Mining Inst., Am. Geog. Soc., Royal Soc. Arts, Royal Inst. of Gt. Br., Mining and Metal. Soc. of Gt. Br., Iron and Steel Inst., Inst. of Mining and Metal., North of England Inst. Mining and Mechan. Eng. **Medal**—John Fritz (1915). *99 John St., New York City.* 1877

Draper, Daniel, Ph.D. Late Director, New York Meteorological Observatory, Central Park. *Hastings-on-Hudson, N. Y.* 1880

Duane, Russell, A.B., LL.B. Formerly Junior Council for the U. S. in Behring Sea Arbitration. *1617 Land Title Bldg., Philadelphia.* 1906

DuBois, Patterson. *401 S. 40th St., Philadelphia.* 1880

duPont, Hon. Henry Algernon. U. S. Senator (1906–17), Mem. Military Service Inst. **Medals**—Congressional, for distinguished gallantry during the battle of Cedar Creek. *Winterthur, Delaware.* 1894

duPont, Pierre Samuel, B.S. President of E. I. duPont de Nemours & Co. *duPont Bldg., Wilmington, Delaware.* 1917

Durand, William Frederick, Ph.D. Professor of Mechanical Engineering, Leland Stanford Jr. University. Mem. Nat. Acad. Sci., Am. Acad. Eng., Am. Soc. Mechan. Eng., Am. Soc. of Naval Architects and Marine Eng., Am. Soc. Naval Eng., Soc. Tech. Maritime, Assoc. Mem. Am. Inst. Elect. Eng. **Medal**—Gold, Am. Soc. Naval Eng. *Stanford University, California.* 1917

East, Edward Murray, M.S., Ph.D. Professor of Experimental Plant Morphology, Harvard University. Fell. Am. Acad. Arts and Sci., 1916

Date of Election

Am. Soc. Naturalists. *Bussey Institution, Jamaica Plain, Boston, Mass.*

Eckfeldt, Jacob B. Assayer, U. S. Mint. Mem. Am. Chem. Soc. *U. S. Mint, Philadelphia.* 1880

Eddy, H. Turner, M.A., C.E., Ph.D., Sc.D., LL.D. Professor of Mathematics and Mechanics, College of Engineering, University of Minnesota. *916 S. E. Sixth St., Minneapolis, Minn.* 1877

Edison, Thomas Alva, Ph.D., D.Sc. *Llewellyn Park, Orange, N. J.* 1896

Edmunds, Hon. George Franklin, A.M., LL.D. U. S. Senator 1866–91. *841 S. Orange Grove Ave., Pasadena, Cal.* 1895

Edsall, David Linn, A.B., M.D., S.D. Professor of Clinical Medicine, Harvard University. Fell. Am. Acad. Arts and Sci., Mem. Assoc. Am. Phys. *80 Marlborough St., Boston, Mass.* 1906

Eigenmann, Carl H., A.M., Ph.D. Professor of Zoology, Indiana University. Mem. Ind. Acad. Sci. (Past-Pres't), Am. Micr. Soc. (Past-Pres't), Am. Soc. Naturalists, Wash. Acad. Sci. *Bloomington, Ind.* 1917

Eisenhart, Luther Pfahler, A.B., Ph.D. Professor of Mathematics, Princeton University. Mem. Am. Math. Soc. *22 Alexander St., Princeton, N. J.* 1913

Eliot, Charles W., A.M., M.D., Ph.D., LL.D. President Emeritus of Harvard University. Fell. Am. Acad. Arts and Sci., Mem. Mass. Hist. Soc., Corr. Mem. Acad. Moral and Polit. Sci. (Inst. de France), British Acad. *17 Fresh Pond Parkway, Cambridge, Mass.* 1871

Emerson, Benjamin Kendall, A.M., Ph.D. Professor of Geology and Mineralogy, Amherst College. Fell. Am. Acad. Arts and Sci., Mem. Geol. Soc. Am. (Past-Pres't), Am. Geog. Soc., Wash. Acad. Sci., Deut. Geol. Gesell. *Amherst, Mass.* 1897

Emmet, William LeRoy, Sc.D. Engineer, General Electric Co. Mem. Am. Inst. Elect. Eng., Am. Soc. Mech. Eng., Am. Soc. Naval Eng. **Medals**—St. Louis Expos. for Vertical Shaft Turbine; San Francisco Expos. for Electric Ship Propulsion. *Care of General Electric Co., Schenectady, N. Y.* 1898

Ewell, Marshall Davis, A.M., M.D., LL.D. Mem. Am. Microscop. Soc. (Past-Pres't), Am. Phys. Soc., Fell. R. Microscop. Soc. (Lond.). *Room 619, 155 N. Clark St., Chicago, Ill.* 1895

Farlow, William Gilson, A.M., M.D., Ph.D. (Upsala), LL.D. (Harv., Glasgow and Wisconsin). Professor of Cryptogamic Botany, Harvard University. Fell. Am. Acad. Arts and Sci., Mem. Nat. Acad. Sci., A. A. A. S. (Past-Pres't), Linnean Soc. Lond., Deut. Botan. Gesell., Botan. Soc. of Edinburgh. *24 Quincy St., Cambridge, Mass.* 1905

Date of Election

Field, Robert Patterson. *The Normandie, 36th and Chestnut Sts., Philadelphia.* 1890

Fine, Henry Burchard, A.M., Ph.D., LL.D. Professor of Mathematics, Princeton University. Mem. Am. Math. Soc. (Pres't, 1911–12). *Library Place, Princeton, N. J.* 1897

Fisher, Sydney George, B.A., Litt.D., LL.D. *576 Bourse Bldg., Philadelphia.* 1897

Flexner, Simon, M.D., D.Sc., LL.D. Director of Laboratories, Rockefeller Institute for Medical Research, N. Y. Fell. N. Y. Acad. Med., Mem. Nat. Acad. Sci., Assoc. of Am. Phys. (Past-Pres't), Soc. Exper. Biology and Med. (Past-Pres't), Am. Assoc. of Path. and Bact., Corr. Mem. Medico-Chi. Soc. of Bologna, Soc. Path. Exotique, Imp. Inst. of Experiment. Therapy (Frankfort a/M). *Rockefeller Institute for Medical Research, 66th St. and Ave. A, New York City.* 1901

Fraley, Joseph Cresson, A.M. Mem. Am. Electrochem. Soc. *1815 Land Title Bldg., Philadelphia.* 1880

Francke, Kuno, Ph.D., Litt.D., LL.D. Professor of the History of German Culture and Curator of Germanic Museum, Harvard University. Fell. Am. Acad. Arts and Sci. *Cambridge, Mass.* 1904

Franklin, Edward Curtis, B.S., M.S., Ph.D. Professor of Organic Chemistry, Leland Stanford Jr. University. Mem. Wash. Acad. Sci., Calif. Acad. Sci., Nat. Acad. Sci., Am. Chem. Soc. *Stanford University, Cal.* 1912

Frazier, Charles Harrison, B.A., M.D., Sc.D. Professor of Clinical Surgery, University of Pennsylvania. Mem. Am. Surg. Assoc., Am. Neurolog. Assoc., Soc. Clin. Surg. *1724 Spruce St., Philadelphia.* 1905

Frost, Edwin Brant, A.M., D.Sc. (Cantab.). Professor of Astrophysics and Director of Yerkes Observatory, University of Chicago. Mem. Nat. Acad. Sci., Astron. Gesell., For. Assoc. R. Astron. Soc., Lond., For. Mem. Soc. Spettros. Ital., Hon. Mem. R. Astron. Soc. of Can., Fell. Am. Acad. Arts and Sci. *Yerkes Observatory, Williams Bay, Wis.* 1909

Fullerton, George Stuart, M.A., B.D., Ph.D., LL.D. Professor of Philosophy, Columbia University, New York. Hon. Prof. Univ. Vienna, Mem. Am. Psycholog. Assoc. (Past-Pres't). *Leupoldstrasse 7, Munich, Bavaria.* 1890

Fulton, John. *113 Park Place, Johnstown, Pa.* 1873

Furness, Horace Howard, Jr., A.B., Litt.D. Mem. Am. Inst. Arts and Letters. *2034 DeLancey Place, Philadelphia.* 1897

Date of Election

Furness, William Henry, 3d, A.B., M.D. Fell. R. Geog. Soc., Anthrop. Inst. Gt. Br., Mem. Soc. de Geog. de France, Am. Orient. Soc. *Wallingford, Pa.* 1897

Gates, Merrill Edwards, A.M., Ph.D., LL.D., L.H.D. President of Amherst College, 1890–99. *1309 Rhode Island Ave., Washington, D. C.* 1889

Gies, William J., Ph.D., Sc.D. Professor of Biological Chemistry, Columbia University. Mem. Soc. Exper. Biol. and Med., Am. Soc. Biol. Chem., Am. Chem. Soc., Am. Physiol. Soc., Deut. Chem. Gesell., N. Y. Acad. Sci. *Columbia University, New York City.* 1915

Gilbert, Grove Karl, A.M., LL.D. Geologist, U. S. Geological Survey, Fell. A. A. A. S. (Pres't, 1901), For. Fell. Lond. Geol. Soc., Mem. Nat. Acad. Sci., Geolog. Soc., Am. (Past-Pres't), Soc. of Am. Naturalists, Wash. Geolog. Soc., Philos. Soc. Wash. **Medals**—Wollaston (1899), Walker Grand Prize (Bost. Soc. Nat. Hist.), Nat. Geog. Soc., Am. Geog. Soc. *1919 16th St., Washington, D. C.* 1902

Gildersleeve, Basil Lanneau, Ph.D., LL.D., Litt.D. Professor of Greek, Johns Hopkins University. Hon. Mem. Cambridge Philol. Soc., Philol. Syllogos of Constantinople, Archaeolog. Soc. Athens, Soc. for Promotion of Hellenic Studies, Corr. Fell. British Acad., Mem. Am. Acad. Arts and Sci. *1002 N. Calvert St., Baltimore, Md.* 1903

Goethals, George Washington, LL.D. Major-General U. S. A. (Retired). *43 Exchange Place, New York City.* 1913

Gooch, Frank Austin, A.M., Ph.D. Professor of Chemistry and Director of the Kent Chemical Laboratory, Yale University. Fell. Am. Acad. Arts and Sci., Mem. Nat. Acad. Sci., Conn. Acad. Arts and Sci., N. Y. Acad. Sci., Am. Chem. Soc. *291 Edwards St., New Haven, Conn.* 1907

Goodale, George Lincoln, A.M., M.D., LL.D. Professor Emeritus of Botany, Harvard University. Fell. Am. Acad., Arts and Sci., N. Y. Acad. Sci., Mem. A. A. A. S. (Past-Pres't), Nat. Acad. Sci., Calif. Acad. Sci., Bost. Soc. Nat. Hist. (Past-Pres't). *Cambridge, Mass.* 1893

Goodspeed, Arthur Willis, A.B., Ph.D. Professor of Physics and Director of Physical Laboratory, University of Pennsylvania. Mem. N. H. Antiq. Soc. (Pres't), Am. Phys. Soc., Am. Roentgen Ray Soc. (Past-Pres't), Soc. of Arts, Lond., Soc. Fran. de Phys. **Medal**—Franklin (Boston, 1880). *University of Pennsylvania, Philadelphia.* 1896

Goodwin, Harold, A.M., LL.B. Mem. Am. Acad. Pol. and Soc. Sci. *3927 Locust St., Philadelphia.* 1892

Gordon, George Byron, Sc.D. Assistant Professor of Anthropology and Director of Museum, University of Pennsylvania. Mem. Am. 1910

Date of Election

Anthrop. Assoc. *University Museum, 33d and Spruce Sts., Philadelphia.*

Gorgas, William Crawford, M.D., Sc.D., LL.D. Surgeon-General U. S. A. Fell. Coll. Phys., Phila., N. Y. Acad. Med., Am. Med. Assoc. (Pres't, 1908–09), Am. Soc. Tropical Med. **Medals**—Mary Kingsley (Liverpool School of Tropical Medicine, 1907); Gold (Am. Museum of Safety, 1914). *Surgeon-General's Office, U. S. A., Washington, D. C.* 1913

Gray, Hon. George, A.M., LL.D. U. S. Senator (1885–99). Mem. Paris Peace Comm. 1898, Permanent Court of Internat. Arbitration, Judge U. S. Circuit Court of Appeals, 1899–1904, American-Mexican Joint Comm., 1916. *Wilmington, Del.* 1900

Greeley, Adolphus Washington. Chief Signal Officer U. S. A. 1887–1891. *1914 G St., N. W., Washington, D. C.* 1904

Green, Samuel Abbott, A.M., M.D., LL.D. Mem. Mass. Historical Soc. (V.P.). *Massachusetts Historical Society, Boston, Mass.* 1893

Greene, William Houston, A.M., M.D. *2130 Spruce St., Philadelphia.* 1879

Greenman, Milton J., Ph.B., M.D., Sc.D. Director of the Wistar Institute of Anatomy. Fell. Coll. Phys. Phila., Phila. Neurolog. Soc., Am. Assoc. of Anat. *3618 Woodland Ave., Philadelphia.* 1899

Griffith, J. P. Crozer, A.B., M.D., Ph.D. Professor of Pediatrics, University of Pennsylvania. Mem. Assoc. Am. Phys., Am. Pediatric Soc. (Past-Pres't), Corr. Mem. Soc. de Pediatrie de Paris. *1810 Spruce St., Philadelphia.* 1907

Gummere, Francis Barton, A.B., Ph.D., LL.D., Litt.D. Professor of English Literature in Haverford College. Mem. Nat. Inst. Arts and Letters, Modern Language Assoc. of Am. (Pres't 1905–06). *Haverford, Pa.* 1903

Hadley, Arthur Twining, M.A., Ph.D., LL.D. President of Yale University. Trustee Carnegie Fund for Adv. of Teaching, Mem. Internat. Inst. of Statistics, Am. Economic Assoc. (Pres't, 1898–1900), Am. Acad. Arts and Letters. **Medal**—Paris Expos. (1889) for Advancement of Knowledge of Railroad Economics. *Yale University, New Haven, Conn.* 1902

Hale, George Ellery, Sc.D., Ph.D., LL.D. Director of Solar Observatory, Carnegie Institution of Washington, Mt. Wilson, Cal. Fell. Royal Soc., Lond., Mem. Accad. dei Lincei (Rome), Amsterdam Acad. Sci., Vienna Acad. Sci., Corr. Mem. Inst. de France, Hon. Mem. Vienna Acad. Sci., Royal Soc., Upsala, Accad. Gioena, Catania, Soc. degli Spettros. Ital., Royal Inst., Gt. Brit., Physical Soc., Lond., For. Assoc. Roy. Astron. Soc., Mem. Nat. Acad. Sci., N. Y. Acad. of Sci., Astron. and Astrophys. Soc. of Am. **Medals**—Janssen, 1902

Date of Election

Paris Acad. Sci. (1894); Rumford (1902); Draper (1903); Gold, Roy. Astron. Soc. (1904). *Solar Observatory Office, Pasadena, Cal.*

Hall, Charles Edward. *Calle Glaceres 264, Guadalajara, Mexico.* 1875

Hall, Lyman Beecher, A.B., Ph.D. Professor of Chemistry, Haverford College. Mem. Am. Chem. Soc., Deut. Chem. Gesell. *Haverford College, Haverford, Pa.* 1885

Harper, Robert A., M.A., Ph.D. Professor of Botany, Columbia University. Mem. Nat. Acad. Sci., Bot. Soc. Am. (Pres't), Deut. Botan. Gesell., Phytopath. Soc. Am., Am. Acad. Arts and Sci. *Columbia University, New York City.* 1909

Harrison, Charles Custis, A.M., LL.D. Provost of the University of Pennsylvania, 1894–1911. *400 Chestnut St., Philadelphia.* 1895

Harrison, Ross G., M.A., Ph.D., M.D. Professor of Comparative Anatomy, Yale University. Mem. Nat. Acad. Sci., Am. Soc. Naturalists (Pres't, 1912–13), Am. Assoc. Anat. (Pres't, 1911–13), Am. Soc. Zool., Am. Physiol. Soc., Anat. Gesell., Inst. Internat. d'Embryol. **Medal**—Rainer (K. K. Zoolog. Botan. Gesell. of Vienna, 1914). *Osborne Zoological Laboratory, Yale University, New Haven, Conn.* 1913

Harshberger, John W., A.B., B.S., Ph.D. Professor of Botany, University of Pennsylvania. Fell. Am. Geog. Soc., Mem. Botan. Soc. of Am., Ecological Soc. of Am. *4839 Walton Ave., Philadelphia.* 1906

Hastings, Charles S., Ph.D. Professor of Physics, Sheffield Scientific School, Yale University. Mem. Nat. Acad. Sci., Am. Phys. Soc. *248 Bradley St., New Haven, Conn.* 1906

Haupt, Lewis M., A.M., Sc.D., LL.D. Mem. Am. Soc. Civil Eng., Am. Inst. Min. Eng., Soc. de Geog. **Medals**—Magellanic Premium (A. P. S. 1887), Paris Expos. (1900), St. Louis Expos. (1904). *Cynwyd, Pa.* 1878

Haupt, Paul, M.A., Ph.D., LL.D. Professor of Semitic Languages, Johns Hopkins University. Mem. Am. Orient. Soc. (Pres't, 1913–14), Soc. of Biblical Lit. and Exegesis. (Pres't, 1905–06), Soc. Biblical Arch. (Lond.), Deut. Morgenländ. Gesell., Deut. Orient Gesell., Vorderasiatische Gesell. *215 Longwood Road, Roland Park, Baltimore, Md.* 1902

Hawk, Philip Bovier, M.S., Ph.D. Professor of Physiological Chemistry and Toxicology, Jefferson Medical College, Philadelphia. Mem. Am. Chem. Soc., Am. Physiol. Soc., Am. Soc. Biol. Chemists, Soc. for Exp. Biol. and Med., Wash. Acad. Sci. *Jefferson Medical College, Philadelphia.* 1915

Date of Election

Hayford, John F., C.E. Director of the College of Engineering, Northwestern University. Mem. Nat. Acad. Sci., Astron. and Astrophys. Soc. of Am., Am. Soc. of Civil Eng., Western Soc. of Eng. *College of Engineering, Northwestern University, Evanston, Ill.* 1915

Hays, I. Minis, A.M., M.D. Mem. Assoc. Am. Phys., Coll. Phys., Phila., Hon. Mem. Georgia Med. Soc. *266 S. 21st St., Philadelphia.* 1886

Herty, Charles Holmes, Ph.D., D.Chem. Late Professor of Chemistry, University of North Carolina. Mem. Am. Chem. Soc. (Pres't, 1915), Chem. Soc., Lond., Soc. Chem. Industry, Am. Electrochem. Soc., Soc. Chim. de France, Deut. Chem. Gesell. *35 E. 41st St., New York City.* 1917

Hewett, Waterman T., M.A., Ph.D. Professor Emeritus of the German Language and Literature, Cornell University. Mem. Am. Philolog. Soc., Modern Lang. Assoc. of Am., Soc. of Frisian Hist., Antiq. and Philol., Mem. Extr. Soc. of Frisian Lang. and Lit. *Cornell University, Ithaca, N. Y.* 1893

Hibben, John Grier, M.A., Ph.D., LL.D., Litt.D. President of Princeton University. *Princeton, N. J.* 1912

Hill, David Jayne, A.M., LL.D., Doct. ès Lettres. Formerly Ambassador to Germany. Mem. Am. Hist. Soc., Am. Soc. Internat. Law, National Assoc. for Constitutional Govt. (Pres't). *1745 Rhode Island Ave., Washington, D. C.* 1910

Hillebrand, William Francis, Ph.D. Chief Chemist U. S. Bureau of Standards. Mem. Nat. Acad. Sci., Am. Chem. Soc. (Pres't, 1906), Wash. Acad. Sci., Geolog. Soc., Wash., Am. Soc. for Testing Materials, Corr. Mem. K. Gesell. der Wissen. Göttingen. *2023 Newark St., N. W., Washington, D. C.* 1906

Hiller, Hiram M., B.S., M.D. *9th and Parker Sts., Chester, Pa.* 1897

Himes, Charles Francis, A.M., Ph.D., LL.D. Professor (retired) of Physics, Dickinson College, Pa. Mem. N. Y. Acad. Sci., Maryland Acad. of Sci. *Carlisle, Pa.* 1874

Hirst, Barton C., A.B., M.D., LL.D. Professor of Obstetrics, University of Pennsylvania. Fell. Coll. of Phys., Phila., Mem. Am. Gyn. Soc., Corr. Mem. Paris Obstet. and Gynecolog. Soc. *1821 Spruce St., Philadelphia.* 1899

Hitchcock, Charles Henry, A.M., Ph.D., LL.D. New Hampshire State Geologist 1868–78. Mem. Portland Nat. Hist. Soc., Boston Soc. Nat. Hist., N. Y. Acad. Sci., St. Louis Acad. Sci. *P. O. Box 632, Honolulu, Hawaii.* 1870

Hobbs, William Herbert, D.Sc., A.M., Ph.D. Professor of Geology and Director of Geological Laboratory, University of Michigan. Mem. Mich. Acad. Sci. (Pres't), Washington Acad. Sci. *University of Michigan, Ann Arbor, Mich.* 1909

Date of Election

Holland, James W., A.M., M.D., Sc.D. Emeritus Professor of Medical Chemistry and Toxicology, Jefferson Medical College, Phila. Fell. Coll. Phys., Phila. *2006 Chestnut St., Philadelphia.* 1886

Holmes, William Henry. Head Curator of Department of Anthropology, U. S. National Museum. Mem. Nat. Acad. Sci., Anthrop. Soc., Wash. (Pres't, 1900), Am. Folk-lore Soc., Archaeol. Inst. of Gt. Brit., Am. Anthrop. Assoc. (Pres't, 1909). *National Museum, Washington, D. C.* 1899

Hopkins, Edward Washburn, A.M., Ph.D., LL.D. Professor of Sanskrit and Comparative Philology, Yale University. Mem. Am. Orient. Soc. (Past-Pres't), Am. Philol. Assoc., German Orient. Soc., Royal Asiatic Soc., Fell. Am. Acad. Arts and Sci. *299 Lawrence St., New Haven, Conn.* 1908

Howard, Leland Ossian, M.D., Ph.D., LL.D. Chief of Bureau of Entomology, U. S. Dept. of Agriculture. Curator of Insects U. S. Nat. Museum, Consulting Entomologist U. S. Public Health Service. *U. S. Department of Agriculture, Washington, D. C.* 1911

Howe, Henry Marion, A.M., Sc.D., LL.D. Professor Emeritus of Metallurgy, Columbia University. Fell. N. Y. Acad. Sci., Am. Acad. Arts and Sci., Am. Soc. for Testing Materials (Past-Pres't), Am. Inst. Mining Eng. (Past-Pres't), Internat. Assoc. for Testing Materials (Past-Pres't), Am. Iron and Steel Inst., Hon. Mem. Royal Swedish Acad. of Sci., Russian Imp. Tech. Soc., Russian Metallurg. Soc., Cleveland Inst. Eng. (Eng.), Inst. of Min. and Metallurg. (England), Soc. d'Encouragement pour l'Industrie Nationale (France), Knight of the Order of St. Stanislaus, Russia, Chevalier of Legion of Honor of France. **Medals**—Bessemer (Iron and Steel Inst. of Gt. Br.), Elliot Cresson (Franklin Inst. of Phila.), Gold, Verein zur Befoerderung des Gewerbfl. (Berlin). *Broad Brook Road, Bedford Hills, N. Y.* 1897

Howell, William Henry, A.B., M.D., Ph.D., Sc.D., LL.D. Professor of Physiology, Johns Hopkins University. Mem. Nat. Acad. Sci., Am. Physiolog. Soc. (Past-Pres't). *Johns Hopkins Medical School, Baltimore, Md.* 1903

Huber, G. Carl, M.D. Professor of Anatomy and Director of Anatomical Laboratory, University of Michigan. Fell. Coll. Phys., Phila., Am. Physiol. Soc., Soc. Am. Naturalists, Am. Assoc. Path. and Bact., Am. Assoc. Anat. (Pres't, 1914–15). *1330 Hill St., Ann Arbor, Mich.* 1912

Hulett, George A., A.B., Ph.D. Professor of Physics and Chemistry, Princeton University. Mem. Am. Chem. Soc., Am. Phys. Soc., Am. Electrochem. Soc. *44 Washington Road, Princeton, N. J.* 1913

Hutchinson, Emlen, A.B. *308 Walnut St., Philadelphia.* 1898

Date of Election

Iddings, Joseph Paxson, Ph.B., Sc.D. Geologist U. S. Geological Survey. Mem. Nat. Acad. Sci., Geol. Soc., Am. Hon. Mem. N. Y. Acad. Sci. For. Mem. Geol. Soc., Lond., Scientific Soc. Christiania, Société de Minéral. *Brinklow, Md.* 1911

d'Invilliers, Edward Vincent. Mem. Geol. Soc. Am., Mining and Metall. Soc. Am., Am. Inst. Mining Eng. *518 Walnut St., Philadelphia.* 1893

Ives, Herbert E., B.S., Ph.D. Physicist, United Gas Improvement Co. Mem. Am. Phys. Soc., Illum. Eng. Soc., Am. Inst. Elect. Eng., Am. Gas Inst. **Medals**—Longstreth (Franklin Inst., 1906 and 1914). *229 E. Meade St., Chestnut Hill, Philadelphia.* 1917

Jackson, A. V. Williams, A.M., L.H.D., LL.D. Professor of Indo-Iranian Languages, Columbia University, N. Y. Mem. Am. Oriental Soc. (Pres't, 1915–16). *Columbia University, New York City.* 1909

James, Edmund Janes, A.M., Ph.D., LL.D. President of University of Illinois. Mem. Am. Econ. Assoc., Am. Acad. Polit. and Soc. Sci. (Pres't, 1889–1901), Fell. Roy. Statist. Soc., Dublin, Soc. d'Econ. Polit., Paris. *University of Illinois, Urbana-Champaign, Ill.* 1884

Jastrow, Morris, Jr., M.A., Ph.D., LL.D. Professor of Semitic Languages, University of Pennsylvania. Mem. Am. Orient. Soc. (Pres't, 1914–15), Soc. of Biblical Lit. (Pres't, 1916). *248 S. 23d St., Philadelphia.* 1897

Jayne, Henry LaBarre, A.B. *1035 Spruce St., Philadelphia.* 1898

Jennings, Herbert S., B.S., A.M., Ph.D., LL.D. Professor of Zoology and Director of the Zoological Laboratory, Johns Hopkins University. Mem. Nat. Acad. Sci., Am. Soc. Zool. (Pres't, 1908), Am. Soc. Naturalists (Pres't, 1909), Fell. Am. Acad. Arts and Sci., Hon. Fell. Roy. Micros. Soc., Lond. *Johns Hopkins University, Baltimore, Md.* 1907

Johnson, Alba B., A.B., LL.D. President of the Baldwin Locomotive Works, Phila. Mem. Am. Acad. Polit. and Soc. Sci. *Rosemont, Pa.* 1911

Johnson, Emory R., Litt.M., Ph.D., Sc.D. Professor of Transportation and Commerce, University of Pennsylvania. Mem. Nat. Inst. of Social Sci., Assoc. of Am. Geog., Am. Economic Assoc., Am. Polit. Sci. Assoc., Am. Acad. Polit. and Soc. Sci. *Logan Hall, University of Pennsylvania, Philadelphia.* 1915

Jordan, David Starr, M.S., M.D., Ph.D., LL.D. Chancellor of Stanford University. Mem. Calif. Acad. Sci. (Past-Pres't), A. A. A. S. (Pres't, 1909–10), Biolog. Soc. Wash., Zoolog. Soc., Lond., Acad. Sci., Sweden. **Medals**—Fisheries Congress (Lond., 1883), and for Peace work (Tokio, 1911). *Stanford University, Cal.* 1905

Date of Election

Kane, Elisha Kent. *Silverside Kushequa, Pa.* 1883

Keane, Rt. Rev. John James. Archbishop of Dubuque. *Dubuque, Ia.* 1889

Keasbey, Lindley Miller, A.M., Ph.D., R.P.D. Professor of Political Science, University of Texas. *Box K, University Station, Austin, Tex.* 1899

Keen, Gregory Bernard, A.M., LL.D. *1300 Locust St., Philadelphia.* 1897

Keen, William W., M.D., Sc.D., Ph.D., LL.D. Emeritus Professor of Surgery, Jefferson Medical College. Fell. Coll. Phys., Phila. (Past-Pres't), Am. Surg. Assoc. (Past-Pres't), Am. Med. Assoc. (Past-Pres't), Hon. Fell. Roy. Coll. Surg. (England and Edinburgh), For. Corr. Mem. Soc. de Chirurgie de Paris, Soc. Belge de Chir., Clin. Soc., Lond., Deut. Gesell für Chir., Italian Surg. Soc., Palermo Surg. Soc., Berlin. Med. Gesell. *1729 Chestnut St., Philadelphia.* 1884

Keiser, Edward Harrison, M.S., Ph.D. Professor of Chemistry, National University, St. Louis. Mem. Deut. Chem. Gesell., Soc. Chem. Industry, Am. Chem. Soc. *534 Linden Ave., Clayton, St. Louis Co., Mo.* 1898

Keller, Harry F., Nat. Ph.D. (Strassb.), Sc.D. Principal Germantown High School, Phila. Mem. Am. Chem. Soc. *2313 Green St., Philadelphia.* 1900

Kemp, James Furman, A.B., E.M., D.Sc., LL.D. Professor of Geology, Columbia University. Fell. Geol. Soc. Am., N. Y. Acad. Sci. (Pres't, 1908 and 1911), Mem. Nat. Acad. Sci., Am. Inst. Mining Eng. (Pres't, 1912), Mining and Metal. Soc., Am. (Pres't, 1913), Wash. Acad. Sci. Corr. Mem. Geolog. Soc., Stockholm, Acad. Sci., Christiania, Soc. Cien. "Antonio Alzate," Mex., Soc. Geologico, Mex. **Medal**—Mining and Metal. Soc., Am. (1916). *Schermerhorn Hall, Columbia University, New York City.* 1912

Kennelly, Arthur Edwin, A.M., Sc.D. Director Research Division, Electrical Engineering Dep't, Massachusetts Institute of Technology. Mem. Inst. Electr. Eng., Am. Math. Soc., Am. Phys. Soc., Hon. Mem. N. Y. Electr. Soc., Nat. Electr. Light Assoc., Am. Electrotherap. Assoc. *Harvard University, Cambridge, Mass.* 1896

Kittredge, George Lyman, A.B., Litt.D., LL.D. Professor of English, Harvard University. Fell. Am. Acad. Arts and Sci., Mem. Mass. Hist. Soc., Am. Antiq. Soc., Am. Philol. Soc., Hon. Fell. Roy. Soc. Lit., Corr. Fell. Brit. Acad. *8 Hilliard St., Cambridge, Mass.* 1905

Kraemer, Henry, Ph.D., Ph.M. Professor of Botany and Pharmacognosy, Philadelphia College of Pharmacy. Mem. Internat. Botan. Soc., Bot. Soc. of Am., Am. Soc. of Nat. Corr. Mem. Soc. de Pharm. de Paris. *424 S. 44th St., Philadelphia.* 1899

Date of Election

Lambert, Preston Albert, M.A. Professor of Mathematics, Lehigh University. Mem. Am. Math. Soc., Math. Assoc., Am. *215 S. Centre St., Bethlehem, Pa.* 1904

Landreth, Burnet. Hon. Mem. Imp. Agric. Soc., Japan, Roy. Hort. Soc., Lond., Soc. des Agric. de France. *Bristol, Pa.* 1878

Lanman, Charles R., A.B., Ph.D. LL.D. Professor of Sanskrit, Harvard University. Fell. Am. Acad. Arts and Sci., Am. Philol. Assoc., Am. Orient. Soc. (Pres't, 1907). For. Mem. Roy. Bohem. Soc. of Sci. Hon. Mem. Asiatic Soc. of Bengal, Roy. Asiatic Soc., Soc. Asiatique, Paris, Deut. Morgenländ. Gesell. Corr. Mem. Roy. Soc. of Sci., Göttingen, Imp. Acad. Sci., Russia, Acad. des Inscrip. et Belles Lettres. *9 Farrar St., Cambridge, Mass.* 1906

Lea, Arthur H., A.B. *960 Drexel Building, Philadelphia.* 1912

LeConte, Robert Grier, A.B., M.D. Fell. Coll. Phys., Phila., Mem. Am. Surg. Assoc. (Pres't, 1916), Am. Coll. Surgeons, Soc. Clin. Surg., Int. Soc. of Surg. *1530 Locust St., Philadelphia.* 1905

Lewis, John Frederick, A.M. President of the Pennsylvania Academy of the Fine Arts. *1914 Spruce St., Philadelphia.* 1909

Libbey, William, M.A., Sc.D. Professor of Physical Geography, Princeton University. Mem. Am. Geog. Soc., N. Y. Acad. Sci., Boston Soc. Nat. Hist., Roy. Geol. Soc., Lond., Geol. Soc. of Am., Soc. of Am. Naturalists. Fell. Roy. Geog. Soc. *Princeton, N. J.* 1897

Lillie, Frank Rattray, B.A., Ph.D. Chairman, Department of Zoology, University of Chicago. Mem. Am. Soc. of Zoologists (Past-Pres't), Am. Soc. Naturalists (Pres't, 1914), Nat. Acad. Sci. *University of Chicago, Chicago, Ill.* 1916

Lindgren, Waldemar, M.E., D.Sc. Professor of Economic Geology, Massachusetts Institute of Technology. Mem. Nat. Acad. Sci., Am. Inst. Mining Eng., Min. and Metallurg. Soc., Am., Wash. Acad. Sci. Fell. Am. Acad. Arts and Sci. Corr. Mem. Geol. Soc., Sweden, Mineralog. Soc., Russia. *Massachusetts Institute of Technology, Cambridge, Mass.* 1917

Lingelbach, William E., B.A., Ph.D. Professor of Modern European History, University of Pennsylvania. Mem. Am. Hist. Assoc., Geog. Soc. of Phila. (Pres't, 1915–1916). *4304 Osage Ave., Philadelphia.* 1916

Loeb, Jacques, M.D., Ph.D., Sc.D. Member of Rockefeller Institute for Medical Research, Nat. Acad. Sci., Wash. Acad. Sci., Am. Physiol. Soc., Am. Soc. Biol. Chem. Fell. Am. Acad. Arts and Sci., Corr. Mem. Acad. des Science de Paris, Acad. Sci., Krakau, Soc. de Biol., Paris, Senckenberg. Nat. Gesell. Frankfurt a/M., 1899

Date of Election

Physik-Med. Gesell., Erlangen, Med. Gesell., Wien, Med. Gesell., Budapest. For. Mem. Linnean Soc., Lond., Acad. Roy. des Sci., Brussels. Hon. Mem. Acad. Roy. de Med., Brussels, Soc. Imp. des Amis des Sci. Nat., Moscow, Cambridge Philos. Soc., England. *Rockefeller Institute for Medical Research, 66th St. and Ave. A, New York City.*

Loeb, Leo, M.D. (Zurich). Professor of Comparative Pathology, Washington University, St. Louis. Mem. Am. Physiol. Soc., Am. Soc. Exper. Path., Soc. Exper. Biol. and Med., Assoc. Am. Phys., Am. Assoc. of Path. and Bact. (Past-Pres't), Am. Assoc. for Cancer Research (Past-Pres't). *Washington University Medical School, St. Louis, Mo.* 1910

Lovett, Edgar Odell, A.M., Ph.D., LL.D. President of the Rice Institute. Fell. Royal Astron. Soc. Mem. Am. Math. Soc. and of Math. Societies of France, London and Palermo, Nat. Inst. of Social Sciences, Am. Acad. of Polit. Sci. *Rice Institute, Houston, Tex.* 1904

Lowell, Abbott Lawrence, A.B., LL.B., LL.D., Ph.D. President of Harvard University. *Harvard University, Cambridge, Mass.* 1909

Lyman, Benjamin Smith, A.B., Mem. Am. Inst. Min. Eng., Hon. Mem. Mining Inst., Japan. *708 Locust St., Philadelphia.* 1869

Mabery, Charles Frederic, Sc.D. Emeritus Professor of Chemistry, Case School of Applied Science. Fell. Am. Acad. Arts and Sci., Mem. Am. Chem. Soc. *Case School of Applied Science, Cleveland, O.* 1897

McCay, LeRoy Wiley, M.A., D.Sc. Professor of Chemistry, Princeton University. Mem. Am. Inst. Mining Eng., Am. Chem. Soc., Chem. Soc. of Lond. *Princeton, N. J.* 1897

McClung, Clarence E., A.M., Ph.D. Professor of Zoology, University of Pennsylvania. *Swarthmore, Pa.* 1913

McClure, Charles Freeman Williams, A.M., D.Sc. Professor of Zoology, Princeton University. Mem. Am. Soc. of Naturalists, Am. Zool. Soc., Assoc. Am. Anat., Anatom. Gesell. *Princeton University, Princeton, N. J.* 1897

McCrae, Thomas, B.A., M.D. Professor of Medicine, Jefferson Medical College, Philadelphia. Fell. Roy. Coll. Phys. Lond., Coll. Phys. Phila. Mem. Assoc. Am. Phys., Roy. Coll. Surg. End. *1627 Spruce St., Philadelphia.* 1914

McCreath, Andrew S. Mem. Am. Inst. Min. Eng., Min. and Metal. Soc. Am., Iron and Steel Inst. (Gt. Br.). *121 Market St., Harrisburg, Pa.* 1879

Date of Election

McDaniel, Walton Brooks, A.M., Ph.D. Professor of Latin, University of Pennsylvania. Mem. Am. Philol. Assoc., Classical Assoc. of Atlantic States, Arch. Inst. of Am. *264 S. 44th St., Philadelphia.* 1917

MacDougal, Daniel Trembly, M.A., Ph.D., LL.D. Director of Department of Botanical Research, Carnegie Institution of Washington. Mem. Botan. Soc. of Am., Soc. for Exp. Biol. and Med., Soc. of Am. Naturalists (Pres't, 1910), Hollansche Maatschap. Van Wetenschap. (Haarlem). *Desert Laboratory, Tucson, Arizona.* 1916

Macfarlane, John Muirhead, B.S., D.Sc. (Edin.). Professor of Botany and Director of the Botanic Garden, University of Pennsylvania. Fell. Roy. Soc., Edinburgh, Corr. Mem. Botan. Soc., Edin., Mem. Soc. for Plant Morph. (Pres't, 1898–99). *Botanical Hall, University of Pennsylvania, Philadelphia.* 1892

Maclaurin, Richard Cockburn, M.A., Sc.D., LL.D. President of Massachusetts Institute of Technology. Fell. Am. Acad. Arts and Sci., Mem. Am. Phys. Soc., Am. Math. Soc., Lond. Math. Soc., New Zealand Philos. Soc. *Massachusetts Institute of Technology, Cambridge, Mass.* 1910

Magie, William Francis, A.M., Ph.D., LL.D. Professor of Physics, Princeton University. Mem. Am. Phys. Soc. (Past-Pres't). *Princeton, N. J.* 1896

Mall, Franklin P., M.A., M.D., Sc.D., LL.D. Professor of Anatomy, Johns Hopkins University, Director of Dept. of Embryology, Carnegie Institution. Fell. Am. Acad. Arts and Sci., Coll. of Phys., Phila. Mem. Nat. Acad. Sci., Assoc. Am. Anat. (Pres't, 1905–07), Soc. for Exper. Biology and Med., Am. Soc. Physiol., Am. Soc. of Zool., Inst. Nat. de Embryologie. *1514 Bolton St., Baltimore, Md.* 1906

Manly, John Matthews, A.M., Ph.D., LL.D., Litt.D. Professor of English, University of Chicago. Mem. Modern Lang. Assoc. of Am., Am. Philol. Soc. *1312 E. 53d St., Chicago, Ill.* 1912

Mansfield, Ira F. *108 College Ave., Beaver, Pa.* 1878

Mark, Edward Laurens, A.M., Ph.D., LL.D. Professor of Anatomy and Director of Zoological Laboratory, Harvard University. Dir. of Bermuda Biol. Sta. for Research, Fell. Soc. Biolog. Chem. (Lond.), Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Anatom. Gesell., Boston Soc. Nat. Hist., K. Böhm. Gesell. d. Wissen. (Prag.), Soc. Roy. Zool. et Malacol. Belge. *109 Irving St., Cambridge, Mass.* 1907

Marshall, John, M.D., Nat. Sc.D., LL.D. Professor of Chemistry and Toxicology, University of Pennsylvania. Mem. Am. Chem. Soc., Am. Physiolog. Soc., Am. Soc. Biolog. Chem., Fell. Coll. of Phys. of Phila. *1718 Pine St., Philadelphia.* 1886

Date of Election

Marvin, Charles F., M.E. Chief of U. S. Weather Bureau. Mem. Philos. Soc. of Wash. (Pres't, 1903–04), Wash. Acad. Sci., Seismological Soc. of Am., Am. Phys. Soc. *U. S. Weather Bureau, Washington, D. C.* 1916

Mason, William Pitt, C.E., Sc.D., M.D., LL.D. Professor of Chemistry, Rensselaer Polytechnic Institute, Troy, N. Y. Mem. Am. Chem. Soc., Am. Soc. Civ. Eng., Am. Waterworks Assoc. (Past-Pres't), Am. Inst. of Chem. Eng., Roy. Sanitary Inst. (Lond.). Hon. Mem. Assoc. Gen. Hygien. Munic. (Paris). *Troy, N. Y.* 1896

Matthew, William Diller, A.M., Ph.D. Curator of American Museum of Natural History. Fell. N. Y. Acad. Sci. Mem. Geolog. Soc. of Am., Palaeontological Soc. *American Museum of Natural History, 77th St. and Central Park, W., New York City.* 1914

Matthews, Albert, A.B. Fell. Am. Acad. Arts and Sci. Mem. Am. Antiq. Soc., Am. Geog. Soc., Am. Dialect Soc., Am. Hist. Assoc., Am. Folk-lore Soc., Colonial Soc. of Mass., Mass. Histor. Soc. Corr. Mem. Maine, Virginia and Wisconsin Histor. Societies. *Hotel Oxford, Boston, Mass.* 1899

Mayer, Alfred Goldsborough, M.E., Sc.D. Director of Department of Marine Biology, Carnegie Institution of Washington, Lect. in Biology, Princeton Univ. Mem. Nat. Acad. Sci., Zoolog. Soc. of Am., Wash. Acad. Sci., Bost. Soc. Nat. Hist. *276 Nassau St., Princeton, N. J.* 1914

Meigs, William M., A.M., M.D. *460 Drexel Bldg., Philadelphia.* 1901

Meltzer, Samuel James, M.D., LL.D. Head of Department of Physiology and Pharmacology, Rockefeller Institute for Medical Research. Mem. German Imp. Acad. Sci., Nat. Acad. Sci., Am. Physiol. Soc. (Pres't, 1911–13), Am. Soc. for Pharmacology, Am. Soc. for Exp. Path., Assoc. of Am. Phys. (Pres't, 1915), Soc. for Exp. Biol. and Med. (Pres't, 1904–05), Am. Soc. for Adv. of Clinical Research (Pres't, 1909), Assoc. of Am. Pathol., Am. Soc. of Naturalists. Fell. N. Y. Acad. Sci., N. Y. Acad. Med. *13 W. 121st St., New York City.* 1914

Mendel, Lafayette B., M.A., Ph.D., Sc.D. Professor of Physiological Chemistry, Sheffield Scientific School, Yale University. Mem. Am. Chem. Soc., Am. Physiol. Soc., Am. Soc. of Biol. Chem. (Pres't, 1911), Am. Soc. of Naturalists, Conn. Acad. Arts and Sci., Nat. Acad. Sci., Soc. Exper. Biol. and Med. *18 Trumbull St., New Haven, Conn.* 1916

Mendenhall, Thomas Corwin, Ph.D., D.Sc., LL.D. Super't U. S. Coast and Geod. Surv., 1899–1904. Fell. Am. Acad. Arts and Sci., Mem. Nat. Acad. Sci., A. A. A. S. (Pres't, 1889). **Medals**—Am. Geog. Soc. (1901); Nat. Education Soc. of Japan (1911). *Ravenna, O.* 1899

Date of Election

Mercer, Henry Chapman, A.B., Sc.D. Mem. Ecole d'Anthrop., Paris. *Doylestown, Bucks Co., Pa.* 1895

Merriam, C. Hart, M.D. Research Associate, Smithsonian Institution, Washington. *1919 16th St., Washington, D. C.* 1902

Merriam, John C., B.S., Ph.D. Professor of Palaeontology and Historical Geology, University of California. Fell. Geol. Soc. of Am., Am. Palaeont. Soc., Mem. Palaeont. Gesell., Wash. Acad. Sci. *2401 Bowditch St., Berkeley, Cal.* 1914

Merriman, Mansfield, Ph.D., Sc.D., LL.D. Late Professor of Civil Engineering, Lehigh University. Mem. Am. Soc. Civil Eng., Am. Soc. Testing Materials (Pres't, 1915–16), Am. Math. Soc. *1071 Madison Ave., New York City.* 1881

Michelson, Albert Abraham, Ph.D., Sc.D., LL.D. Professor and Head of Department of Physics, University of Chicago. Fell. Roy. Soc., Roy. Astron. Soc., Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Am. Phys. Soc. (Pres't, 1900), Soc. Française de Physique. For. Mem. R. Acad. dei Lincei, K. Svenska Vetenskaps. Akad., Soc. Holland, des Sci. Corr. Mem. Acad. des Sci. de Paris. Hon. Mem. Roy. Institution, Cam. Philos. Soc. **Medals**—Nobel Laureate, Physics, 1907; Rumford (1889); Grand Prix (Paris, 1900); Matteucci (Soc. Ital., Rome, 1904); Copley (Roy. Soc., Lond., 1907). *University of Chicago, Chicago, Ill.* 1902

Miller, John Anthony, A.M., Ph.D. Professor of Mathematics and Astronomy, Swarthmore College. Mem. Am. Math. Soc., Am. Astron. Soc., Ind. Acad. Sci. *Swarthmore College, Swarthmore, Pa.* 1915

Miller, Leslie W. Principal of Pennsylvania Museum and School of Industrial Art, Philadelphia. *320 S. Broad St., Philadelphia.* 1899

Millikan, Robert Andrews, A.B., Ph.D., Sc.D. Professor of Physics, University of Chicago. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Am. Phys. Soc. (Pres't). **Medal**—Comstock (National Acad., 1913). *University of Chicago, Chicago, Ill.* 1914

Moore, Clarence B., A.B. Mem. Anthrop. Inst. of Am., Arch. Inst. of Am., Am. Anthrop. Assoc. Corr. Mem. Roy. Acad. of Letters, Hist. and Antiq. (Stockholm); Soc. des Americanistes, Paris, Soc. Scientif. Argentina, Berlin, Gesell. für Anthrop., Eth., and Urgesch. Hon. Mem. Anthrop. Soc., Wash., Wis. Nat. Hist. Soc., Soc. of Anthrop. and Geog. (Stockholm). *1321 Locust St., Philadelphia.* 1897

Moore, Eliakim Hastings, A.B., Ph.D., LL.D., Sc.D., Math.D. Professor of Mathematics, University of Chicago. Fell. Am. Acad. Arts and Sci., Mem. Am. Math. Soc. (Pres't, 1901–03), Nat. Acad. Sci. *University of Chicago, Chicago, Ill.* 1905

Date of Election

Moore, George Thomas, A.M., Ph.D. Director of the Missouri Botanical Garden. Mem. Wash. Acad. Sci., St. Louis Acad. Sci., Botan. Soc. of Am., Soc. of Am. Bacteriologists. *Missouri Botanical Garden, St. Louis, Mo.* 1905

Moore, John Bassett, LL.D. Professor of International Law and Diplomacy, Columbia University. Mem. of the Permanent Court at the Hague, Inst. de droit Internat., Inst. Colon. Nac., Hispanic Soc. of Am. *267 W. 73d St., New York City.* 1907

Morgan, Thomas Hunt, B.S., Ph.D., LL.D. Professor of Experimental Zoology, Columbia University. Mem. Nat. Acad. Sci., Soc. Am. Naturalists, Am. Soc. Zool., N. Y. Acad. Sci., Soc. for Exp. Biol. and Med. *409 W. 117th St., New York City.* 1915

Morley, Edward W., A.M., LL.D. Professor Emeritus of Chemistry, Western Reserve University, Cleveland. Hon. Mem. Nat. Acad. Sci., A. A. A. S. (Past-Pres't), Am. Chem. Soc. (Past-Pres't), Roy. Inst. Gt. Br. For. Mem. Chem. Soc., Lond. Fell. Am. Acad. Arts and Sci. **Medals**—Davy (Royal Soc., 1907); Elliot Cresson (Franklin Institute, Philada., 1912). *West Hartford, Conn.* 1903

Morley, Frank, A.M., Sc.D. Professor of Mathematics, Johns Hopkins University. Mem. Am. Math. Soc., Math. Soc., Lond., Circolo Matemat. di Palermo. *Johns Hopkins University, Baltimore, Md.* 1897

Morris, Harrison Smith. Mem. Nat. Inst. Arts and Letters. *Oak Lane Post Office, Philadelphia.* 1899

Morris, James Cheston, A.M., M.D. Fell. Coll. of Phys., Phila. *1514 Spruce St., Philadelphia.* 1883

Morse, Edward S., A.M., Ph.D. Director of Peabody Museum, Salem, Mass. Fell. A. A. A. S. (Pres't, 1885), Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Am. Soc. Naturalists, Am. Soc. Morph., Am. Antiq. Soc., Am. Anthrop. Assoc., Am. Oriental Soc., Boston Soc. Nat. Hist. (Past-Pres't). Corr. Mem. N. Y. Acad. Sci., Soc. of Anthrop. and Geog. (Stockholm), Anthrop. Soc. of Berlin, Japan Soc. of Lond. Hon. Mem. Tokyo Zoolog. Soc. *Salem, Mass.* 1895

Morse, Harmon Northrop, A.B., Ph.D., LL.D. Professor of Chemistry, Johns Hopkins University. Mem. Nat. Acad. Sci. Fell. Am. Acad. Arts and Sci. For. Mem. Prov. Utrecht Genootsch. van Kunst. en Wetensch. **Medal**—Avogadro. *Homewood Apartments, Baltimore, Md.* 1903

Moulton, Forest Ray, A.B., Ph.D. Professor of Astronomy, University of Chicago, Research Assoc. Carnegie Institution of Washington. Mem. Nat. Acad. Sci., Am. Math. Soc. Fell. Roy. Astron. Soc. *University of Chicago, Chicago, Ill.* 1916

Date of Election

Munro, Dana Carlton, A.M., L.H.D. Professor of Medieval History, Princeton University. Mem. Am. Hist. Soc., Wis. Acad. Arts and Sci. *119 Fitz Randolph Road, Princeton, N. J.* 1901

Munroe, Charles Edward, S.B., Ph.D., LL.D. Professor of Chemistry, George Washington University. Mem. Am. Chem. Soc. (Past-Pres't), U. S. Naval Inst., Deut. Chem. Gesell., Soc. of Chem. Ind., Am. Inst. Mining Eng. *George Washington University, 1325 H St., N. W., Washington, D. C.* 1891

Murdock, Joseph B. Rear-Admiral U. S. Navy. *Danbury, N. H.* 1886

Newbold, William Romaine, A.B., Ph.D. Professor of Intellectual and Moral Philosophy, University of Pennsylvania. Mem. Am. Psychol. Assoc. Corr. Mem. Soc. for Psych. Research. *College Hall, University of Pennsylvania, Philadelphia.* 1909

Nichols, Edward Leamington, B.S., Ph.D., LL.D., D.Sc. Professor of Physics, Cornell University. Mem. Nat. Acad. Sci., Am. Physical Soc. (Past-Pres't), A. A. A. S. (Past-Pres't), Am. Inst. Elec. Eng., Ill. Eng. Soc. Fell. Am. Acad. Arts and Sci. *5 South Ave., Ithaca, N. Y.* 1904

Nichols, Ernest Fox, M.A., Sc.D., LL.D. Professor of Physics, Yale University. Mem. Nat. Acad. Sci., Am. Astron. Soc. Fell. Am. Acad. Arts and Sci. **Medal**—Rumford (1905). *Sloane Laboratory, New Haven, Conn.* 1906

Nipher, Francis E., B.S., A.M., LL.D. Professor Emeritus of Physics, Washington University, St. Louis. Mem. Am. Phys. Soc., Acad. of Sci., St. Louis (Past-Pres't), Soc. Franç. de Physique. *Kirkwood, St. Louis Co., Missouri.* 1907

Norris, Isaac, M.D. Fell. Coll. of Phys., Phila. *Fair Hill, Bryn Mawr, Pa.* 1872

Noyes, Arthur A., Ph.D., Sc.D., LL.D. Director of the Research Laboratory of Physical Chemistry and Professor of Theoretical Chemistry, Massachusetts Institute of Technology. Mem. Nat. Acad. Sci. Fell. Am. Acad. Arts and Sci. **Medal**—Willard Gibbs (Am. Chemical Soc., 1915). *Massachusetts Institute of Technology, Cambridge, Mass.* 1911

Noyes, William Albert, A.B., B.S., Ph.D., LL.D. Director of Chemical Laboratory, University of Illinois. Mem. Nat. Acad. Sci., Am. Chem. Soc., Deut. Chem. Gesell. **Medal**—Nichols (1908). *1005 Nevada St., Urbana, Ill.* 1914

Nuttall, Zelia. Hon. Professor of Archaeology, National Museum, Mexico. *Care of Bank of California, San Francisco, Cal.* 1895

Ortmann, Arnold E., Ph.D., Sc.D. Professor of Physical Geography, University of Pittsburgh, Curator Invert. Zool., Carnegie Mus., 1897

Date of Election

Pittsburgh. Mem. Ecological Soc. of Am., Deut. Zoolog. Gesell., K. Leopold.-Carolin. Deut. Acad. der Naturforsch. *Carnegie Museum, Pittsburgh, Pa.*

Osborn, Henry Fairfield, Sc.D., Ph.D, LL.D. Research Professor of Zoology, Columbia University, President Am. Museum Nat. Hist. Mem. Nat. Acad. Sci., Am. Soc. of Naturalists (Past-Pres't), Am. Morpholog. Soc. (Past-Pres't), N. Y. Acad. Sci., Wash. Acad. Sci. Fell. Am. Acad. Arts and Sci. Hon. Mem. Geological, Zoological and Linnean Societies (Lond.), Literary and Philos. Soc. of of Manchester, Imp. Soc. of Nat. (Moscow), Roy. Bavar. Acad. Sci., Senckenberg. Naturforsch. Gesell. Hon. Fell. Roy. Soc. Edinb., Roy. Acad. Sci. (Sweden). **Medal**—Hayden (Acad. Nat. Sci., Phila.). *American Museum of Natural History, New York City.* 1887

Osgood, William Fogg, A.M., Ph.D., LL.D. Professor of Mathematics, Harvard University. Mem. Am. Math. Soc. (Pres't, 1904–06), Nat. Acad. Sci., Deut. Math.-Verein., Math. Soc., Kharkoff, Calcutta Math. Soc., Circolo Mat. di Palermo. *74 Avon Hill St., Cambridge, Mass.* 1915

Osterhout, Winthrop John Vanleuden, A.M., Ph.D. Professor of Botany, Harvard University. Fell. Am. Acad. Arts and Sci. Mem. Bot. Soc. of Am., Am. Physiol. Soc., Am. Chem. Soc., Soc. of Exp. Biol. and Med., Boston Soc. Nat. Hist. *60 Buckingham St., Cambridge, Mass.* 1917

Pancoast, Henry Spackman, M.A., L.H.D. Mem. Modern Lang. Assoc. of Am., Am. Philol. Assoc., Am. Dialect Soc., English Assoc. (England). *Spring Lane, Chestnut Hill, Philadelphia.* 1898

Parker, George Howard, S.D. Professor of Zoology, Harvard University. Mem. Nat. Acad. Sci., Am. Zool. Soc. (Past-Pres't), Fell. Am. Acad. Arts and Sci. *16 Berkeley St., Cambridge, Mass.* 1911

Paton, Stewart, M.A., M.D. Lecturer in Neuro-Biology, Princeton University. Mem. Am. Soc. Naturalists, Assoc. Am. Anat., N. Y. Acad. Med. *Princeton, N. J.* 1914

Patterson, Christopher Stuart, A.M. *1000 Walnut St., Philadelphia.* 1885

Patterson, Lamar Gray. Mem. Am. Chem. Soc. *P. O. Box 147, Montgomery, Ala.* 1898

Patton, Francis L., A.M., D.D., LL.D. Formerly President of Princeton University. *Warwick, Bermuda.* 1897

Paul, John Rodman, A.M. *505 Chestnut St., Philadelphia.* 1899

Pearce, Richard Mills, Jr., M.D., Sc.D. Professor of Research Medicine, University of Pennsylvania. Mem. Am. Assoc. Patholog. and Bact. (Pres't, 1912), Am. Soc. Exper. Path. (Pres't, 1914), 1914

Date of Election

Assoc. Am. Phys., Am. Physiol. Soc. *2114 DeLancey Place, Philadelphia.*

Pearl, Raymond, A.B., Ph.D. Biologist and Head of Department of Biology, Maine Agricultural Experiment Station. Mem. Nat. Acad. Sci., Am. Soc. Zool. (Pres't, 1913), Am. Soc. of Naturalists (Pres't, 1916), Soc. of Exper. Biology and Med., Boston Soc. Nat. Hist. *Orono, Maine.* 1915

Peckham, Stephen F., A.M. Mem. Am. Chem. Soc., Soc. of Chem. Indust., Soc. of Chem. Engin. *1154 Sterling Place, Brooklyn, N. Y.* 1897

Pender, Harold, A.B., Ph.D. Professor in Charge of Electrical Engineering Department, University of Pennsylvania. Fell. Am. Acad. Arts and Sci., Am. Inst. Elect. Eng., Mem. Am. Phys. Soc. *Electrical Engineering Department, University of Pennsylvania, Philadelphia.* 1917

Penniman, Josiah Harmar, A.B., Ph.D., LL.D. Professor of English Literature and Vice Provost, University of Pennsylvania. Mem. Modern Lang. Assoc., Am., Am. Dialect Soc., English Assoc. of Gt. Br. *University of Pennsylvania, Philadelphia.* 1901

Penrose, Charles B., A.M., Ph.D., M.D., LL.D. Professor of Gynecology, University of Pennsylvania, 1893–99. President of Zoological Society of Philadelphia. *1720 Spruce St., Philadelphia.* 1909

Penrose, Richard Alexander Fullerton, Jr., A.M., Ph.D. Professor of Economic Geology, University of Chicago, 1892–1911. Fell. Roy. Geog. Soc., Geolog. Soc. of Am. Mem. Geolog. Soc. Wash., Wash. Acad. Sci., Mining and Metal. Soc. Am. *460 Bullitt Bldg., Philadelphia.* 1905

Pepper, George Wharton, B.A., LL.D., D.C.L. Formerly Professor of Law, University of Pennsylvania. *1438 Land Title Bldg., Philadelphia.* 1897

Pettit, Henry, M.S. *2420 Spruce St., Philadelphia.* 1895

Phillips, Francis C., Ph.D. Emeritus Professor of Chemistry, University of Pittsburgh. Mem. Am. Chem. Soc., Am. Inst. of Mining Eng. *University of Pittsburgh, Pittsburgh, Pa.* 1899

Pickering, Edward C., A.M., S.B., Ph.D., L.H.D., LL.D. Director of Harvard College Observatory. Fell. Am. Acad. Arts and Sci., Royal Soc., Astron. and Astrophys. Soc. of Am. (Pres't). Mem. Nat. Acad. Sci., A. A. A. S. (Past-Pres't), Am. Astron. Soc. (Pres't), Roy. Astron. Soc., Soc. Astron. de France, Soc. degli Spettros. Ital., Royal Inst., Accad. dei Lincei, Royal Prussian and Royal Irish Societies, Inst. de France, Imp. Acad., St. Petersburg. Hon. Mem. Societies at Mexico, Cherbourg, Liverpool, Christiania, Upsala, and Lund. **Medals**—Henry Draper, Rumford (1891); Bruce (1908); Roy. Astron. Soc. (1886, 1901) Knight of German 1896

Date of Election

Order, pour le Mérite. *Harvard College Observatory, Cambridge, Mass.*

Piersol, George Arthur, C.E., M.D., Sc.D. Professor of Anatomy, University of Pennsylvania. Mem. Am. Assoc. of Anat., Am. Soc. Zool. Fell. Coll. of Phys., Phila. *4724 Chester Ave., Philadelphia.* 1897

Pilsbry, Henry A., Sc.D. Curator, Academy of Natural Sciences, Phila., Hon. Mem. Soc. Roy. Zoolog. et Malacol. de Belge, Conchol. Soc. of Gt. Br. For. Corr. Reale Acad. de Ciencias Exactas, Fis. y Nat. (Madrid). *Academy of Natural Sciences, Logan Square, Philadelphia.* 1895

Price, Eli Kirk, A.B., LL.D. Mem. Am. Acad. Polit. and Soc. Sci. *709 Walnut St., Philadelphia.* 1916

Prince, John Dyneley, B.A., Ph.D. Professor of Slavonic Languages, Columbia University. Fell. N. Y. Acad. Sci. Mem. Am. Orient. Soc., Soc. Bibl. Lit. and Exegesis, Maatschap. der Nederl. Letter., Vorderasiat. Gesell. *Sterlington, Rockland Co., N. Y.* 1913

Pritchett, Henry S., A.B., Ph.D, Sc.D., LL.D. President of Carnegie Foundation for Advancement of Teaching. Formerly Superintendent of U. S. Coast and Geodetic Survey, and Pres't of Mass. Institute of Tech. Fell. Am. Acad. Arts and Sci. *22 E. 91st St., New York City.* 1899

Pumpelly, Raphael. Mem. Nat. Acad. Sci., Geol. Soc. Am. (Pres't, 1905). *Newport, R. I.* 1874

Pupin, Michael I., Ph.D., Sc.D. Professor of Electro-mechanics, Columbia University. Fell. N. Y. Acad. Sci., Mem. Nat. Acad. Sci., Am. Phys. Soc., Am. Math. Soc., Am. Inst. Elec. Eng. *The Dakota, 1 W. 72d St., New York City.* 1896

Ravenel, Mazÿck P., M.D. Professor of Bacteriology, University of Missouri. Fell. Coll. Phys., Phila. Mem. Am. Assoc. Path. and Bact. *University of Missouri, Columbia, Missouri.* 1901

Rawle, Francis, A.M., LL.D. Mem. American Bar Association (Pres't, 1902–03). *West End Trust Bldg., Philadelphia.* 1898

Raymond, Rossiter Worthington, Ph.D., LL.D. Mem. Am. Inst. Mining Eng. (Pres't, 1872–74). Hon. Mem. Soc. Civil Eng. of France, Iron and Steel Inst., Australian Inst. of Mining Eng. **Medal**—Inst. Mining and Metal. (1910). *29 W. 39th St., New York City.* 1875

Rea, Samuel, Sc.D., LL.D. President of the Pennsylvania R. R. Co., Mem. Am. Acad. Polit. and Soc. Sci., Am. Geolog. Soc., Am. Soc. Civil Eng., Arch. Inst. Am., Inst. of Civil Eng. (Lond.). *Broad Street Station, Philadelphia.* 1913

Date of Election

Reid, Harry Fielding, C.E., A.B., Ph.D. Professor of Dynamic Geology and Geography, Johns Hopkins University, Special Expert in Charge of Earthquake Records, U. S. Geol. Surv. Mem. Nat. Acad. Sci., Seismol. Soc. of Am. (Pres't, 1913), Am. Phys. Soc., Assoc. Am. Geog., Washington Acad. Sci. Fell. Geol. Soc. of Am. Hon. Mem. Soc. Helvétique des Sci. Nat. *Johns Hopkins University, Baltimore, Md.* 1910

Remington, Joseph Price, Ph.G., Ph.M., Phar.D. Dean of Philadelphia College of Pharmacy; Pres't Am. Pharm. Assoc., Pres't 7th Int. Cong. of Pharmacy, Chairman Comm. of Revision of U. S. Pharmacopeia, 9th Revis., Fell. Chem. Soc., Lond., Linnean Soc., Lond., Roy. Microscop. Soc. Mem. Federation Internat. Pharmaceut. *1832 Pine St., Philadelphia.* 1899

Remsen, Ira, A.B., M.D., Ph.D. (Gött.), LL.D., D.C.L. Professor Emeritus of Chemistry and President Emeritus, Johns Hopkins University. Mem. Nat. Acad. Sci. (Pres't, 1907–13), A. A. A. S. (Pres't, 1903), Am. Chem. Soc. (Pres't, 1902), Soc. of Chem. Industry (Pres't, 1909–10). For. Mem. Chem. Soc. Lond. Hon. Mem. Chem. Soc. of France. **Medals**—Soc. of Chem. Indust. (1904), Willard Gibbs (Am. Chem. Soc., 1913). *Johns Hopkins University, Baltimore, Md.* 1879

Rhodes, James Ford, LL.D., D.Litt. (Oxford). Mem. Mass. Hist. Soc., Am. Hist. Assoc. (Pres't, 1899), Nat. Inst. Arts and Letters, Am. Acad. Arts and Letters. Fell. Am. Acad. Arts and Sci. Corr. Fell. Brit. Acad. **Medals**—Loubat Prize (Berl. Acad. Sci., 1901); Nat. Inst. Arts and Letters (1910). *392 Beacon St., Boston, Mass.* 1910

Richards, Horace Clark, A.B., Ph.D. Professor of Mathematical Physics, University of Pennsylvania. Mem. Am. Phys. Soc., Soc. Franç. de Physique. *4812 Fairmount Ave., Philadelphia.* 1907

Richards, Theodore William, S.B., A.M., Ph.D., Sc.D., Chem.D., M.D., LL.D. Professor of Chemistry and Director of the Wolcott Gibbs Memorial Laboratory, Harvard University. Mem. Nat. Acad. Sci., Am. Chem. Soc. (Pres't, 1914). Fell. Am. Acad. Arts and Sci. Hon. Mem. Royal Inst. For. Mem. Royal Swedish Acad. Corr. Mem. Roy. Pruss. Acad. Sci. **Medals**—Nobel Laureate, Chemistry, 1914; Davy (Roy. Soc., 1910); Faraday (Chem. Soc., 1911); Willard Gibbs (Am. Chem. Soc., 1912); Franklin (Franklin Inst., 1916). *Wolcott Gibbs Memorial Laboratory, Cambridge, Mass.* 1902

Ricketts, Palmer C., C.E., E.D., LL.D. President and Director of the Rensselaer Polytechnic Institute, Troy, N. Y. Mem. Am. Soc. Civ. Eng., Am. Soc. Mech. Eng., Am. Inst. Min. Eng., Inst. of Civ. Eng., (Gt. Br.). *Troy, N. Y.* 1914

Date of Election

Rogers, Robert William, A.B., Ph.D., Litt.D., LL.D., S.T.D. Professor of Hebrew and Old Testament Exegesis, Drew Theological Seminary. Fell. Roy. Geog. Soc. Mem. Deut. Morgenländ. Gesell., Deut. Orient. Gesell., Vorderasiat. Gesell. *Madison, N. J.* 1890

Rolfe, John Carew, A.M., Ph.D. Professor of Latin Language and Literature, University of Pennsylvania. Mem. Am. Philol. Assoc. (Pres't, 1912). *4014 Pine St., Philadelphia.* 1907

Roosevelt, Theodore, A.B., LL.D., Ph.D. (Berlin), D.C.L. (Oxford). 26th President of the United States. **Medal**—Nobel Laureate, Peace (1906). *Oyster Bay, N. Y.* 1904

Root, Elihu, A.M., LL.D., D.C.L. (Oxford). U. S. Senator from N. Y., 1909–15, Mem. Permanent Court of Arbitration at Hague, President Carnegie Endowment for International Peace, Mem. Am. Bar Assoc. (Pres't, 1915). Fell. Am. Acad. Arts and Sci. **Medal**—Nobel Laureate, Peace, 1912. *1 E. 81st St., New York City.* 1906

Rosa, Edward Bennett, Sc.D., Ph.D. Chief Physicist, National Bureau of Standards. Mem. Nat. Acad. Sci., Am. Inst. of Elec. Eng., Am. Phys. Soc., Illum. Eng. Soc., Soc. Franç. de Phys., Wash. Acad. Sci., Wash. Philos. Soc. *National Bureau of Standards, Washington, D. C.* 1912

Rosengarten, Joseph George, A.B., LL.D. *1704 Walnut St., Philadelphia.* 1891

Rothrock, Joseph T., B.S., M.D. Formerly Professor of Botany, University of Pennsylvania, Commissioner of Forestry of Pennsylvania. *West Chester, Pa.* 1877

Rowe, Leo S., A.B., B.S., Ph.D., LL.D. Professor of Political Science, University of Pennsylvania. Mem. Am. Acad. of Polit. and Soc. Sci. (Pres't), Am. Soc. Int. Law, Nat. Inst. of Soc. Sci. Hon. Mem. Mexican Geog. Soc., Nat. Hist. Soc. of Argentina. *University Dormitories, 37th and Spruce Sts., Philadelphia.* 1911

Russell, Henry Norris, A.M., Ph.D. Professor of Astronomy and Director of Observatory, Princeton University. Mem. Astron. Soc. of Am., Internat. Union for Solar Research. For. Assoc. Roy. Astron. Soc. of Lond. *79 Alexander St., Princeton, N. J.* 1913

Sachse, Julius F., Litt.D. *4428 Pine St., Philadelphia.* 1894

Sadtler, Samuel P., S.B., Ph.D., LL.D. Professor Emeritus of Chemistry, Phila. College of Pharmacy. Mem. Am. Chem. Soc., Am. Electro-Chem. Soc., Soc. Chem. Industry, Am. Inst. Chem. Eng. (Past-Pres't). *210 S. 13th St., Philadelphia.* 1874

Sajous, Charles E. de M., M.D., LL.D., Sc.D. Fell. Coll. Phys., Phila., Mem. Am. Laryngol. Soc. *2043 Walnut St., Philadelphia.* 1888

Sampson, Alden. *7 W. 43d St., New York City.* 1897

Sanders, Richard H., M.E. Mem. Am. Inst. Mining Eng., Mining and Metallurgical Soc. of Am. *1225 Locust St., Philadelphia.* 1897

Date of Election

Sargent, Charles Sprague, A.B., LL.D. Director of the Arnold Arboretum and Professor of Arboriculture, Harvard University. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Mass. Soc. for Prom. Agric. (Pres't). For. Mem. Linn. Soc., Lond., Soc. Nat. de Agric. de France. *Jamaica Plain, Mass.* 1882

Schelling, Felix E., M.A., Litt.D., Ph.D., LL.D. Professor of English Literature, University of Pennsylvania. Mem. Modern Lang. Assoc. of Am. (Pres't, 1913–14), Am. Inst. Arts and Letters. *College Hall, University of Pennsylvania, Philadelphia.* 1902

Schlesinger, Frank, B.S., M.A., Ph.D. Director of Allegheny Observatory, University of Pittsburgh. Mem. Nat. Acad. Sci., Am. Astron. Soc. For. Assoc. Roy. Astron. Soc., Astron. Gesell. *Allegheny Observatory, Pittsburgh, Pa.* 1912

Schuchert, Charles, M.A., LL.D. Professor of Palaeontology, Yale University. Mem. Nat. Acad. Sci., Wash. Acad. Sci., Conn. Acad. Sci., Geolog. Soc. of Wash., Biolog. Soc., Wash., Geolog. Soc. of Am. Fell. Am. Acad. Arts and Sci. *Yale University, New Haven, Conn.* 1913

Schurman, Jacob Gould, A.M., Sc.D., LL.D. President of Cornell University. *Ithaca, N. Y.* 1908

deSchweinitz, George E., A.M., M.D., LL.D. Professor of Ophthalmology, University of Pennsylvania. Fell. Coll. Phys., Phila. (Pres't 1910–13), Mem. Am. Ophthalmol. Soc. (Pres't 1916). **Medal**—Alvarenga Prize (Coll. Phys., Phila., 1896). *1705 Walnut St., Philadelphia.* 1912

Scott, Charles Felton, A.B. Professor of Electrical Engineering, Sheffield Scientific School, Yale University. Mem. Am. Inst. Elect. Eng., Engin. Soc. Western Penna. (Pres't, 1902). *284 Orange St., New Haven, Conn.* 1898

Scott, William Berryman, M.A., Ph.D. (Heidel.), D.Sc. (Harvard and Oxford), LL.D. Professor of Geology, Princeton University. Mem. Nat. Acad. Sci., Geol. Soc. of Am., Paleont. Soc. of Am., Geol. Soc., Lond., Zoolog. Soc., Lond., Linnean Soc., Lond. **Medals**—E. K. Kane (Geog. Soc. of Phila.); Wollaston (Geol. Soc., Lond., 1909). *158 Nassau St., Princeton, N. J.* 1886

Seares, Frederick Hanley, B.S. Superintendent, Computing Division, Solar Observatory, Carnegie Institution. Mem. Am. Astr. Soc., Astr. Soc. of Pacific, Wash. Acad. Sci., Soc. Astron. de France, Astron. Gesell. *Solar Observatory Office, Pasadena, Cal.* 1917

Sedgwick, William Thompson, Ph.D., Sc.D. Professor of Biology and Public Health, Massachusetts Institute of Technology. Mem. Soc. Am. Bact., Am. Soc. of Naturalists. Fell. Am. Acad. Arts and Sci. *Massachusetts Institute of Technology, Cambridge, Mass.* 1911

Date of Election

See, T. J. J., A.M., M.Sc., Ph.D. (Berlin). Professor of Mathematics, U. S. N., in charge of Naval Observatory, Mare Island, Cal. Fell. Roy. Astr. Soc. Mem. Astr. Gesell., Lond. Math. Soc., Am. Math. Soc., Deut. Math. Verein., Soc. Math. de France, Circolo Math. di Palermo, Calcutta Math. Soc., Wash. Acad. Sci., Philos. Soc., Wash., Am. Phys. Soc., Soc. Franç. de Phys., Soc. Astr. de France, Astron. Soc. of Pacific, Calif. Acad. Sci., Seismolog. Soc. of Am. *Mare Island, Cal.* 1897

Sellers, Coleman, Jr., M.S. President and Engineer of William Sellers & Co., Inc. Mem, Am. Soc. Mechan. Eng. *3301 Baring St., Philadelphia.* 1899

Sharples, Stephen Paschall, M.S. Fell. Am. Acad. Arts and Sci. Mem. Am. Inst. Mining Eng., Am. Inst. Chem. Eng., Am. Chem. Soc., Soc. of Industrial Chem. *26 Broad St., Boston, Mass.* 1882

Sherwood, Andrew. Corr. Mem. N. Y. Acad. Sci. *The Rosemont, E. 69th St., N., Portland, Ore.* 1875

Sigsbee, Charles Dwight. Rear-Admiral U. S. Navy. *U. S. Navy Department, Washington, D. C.* 1899

Smith, A. Donaldson, A.B., M.D. Medals—Cullum (Am. Geog. Soc.); Kane (Phila. Geog. Soc.); Patron's (Roy. Geog. Soc. Lond.). *Care S. H. Thomas, Esq., 308 Walnut St., Philadelphia.* 1897

Smith, Allen J., A.M., M.D., Sc.D., LL.D. Professor of Pathology. University of Pennsylvania. Fell. Coll. Phys., Phila. Mem. Am. Soc. of Path. and Bact. Corr. Mem. Roy. Soc. of Hygiene (Madrid). *Medical School, University of Pennsylvania, Philadelphia.* 1907

Smith, Edgar Fahs, Ph.D., Chem.D., Sc.D., L.H.D., LL.D. Provost and Professor of Chemistry, University of Pennsylvania. Mem. Nat. Acad. Sci., Am. Chem. Soc. (Pres't, 1898), Deut. Chem. Gesell. **Medal**—Elliott Cresson (Franklin Inst., 1914). *University of Pennsylvania, Philadelphia.* 1887

Smith, Erwin Frink, B.S., Sc.D. Pathologist in charge of Laboratory of Plant Pathology, U. S. Bureau of Plant Industry. Mem. Soc. for Plant Morph. and Physiol. (Past-Pres't), Soc. of Am. Bacteriologists (Pres't, 1906), Botan. Soc. of Am., Am. Phytopath. Soc., Nat. Acad. Sci. *Bureau of Plant Industry, Department of Agriculture, Washington, D. C.* 1916

Smith, Stephen, A.M., M.D., LL.D. Mem. Am. Pub. Health Assoc. (Past-Pres't). *260 W. 76th St., New York City.* 1875

Smith, Theobald, Ph.B., M.D., A.M., LL.D., Sc.D. Director of Department of Animal Pathology, Rockefeller Institute for Medical Research. Mem. Nat. Acad. Sci., Assoc. of Am. Phys., Assoc. of Am. Path. and Bact., Soc. for Exper. Biol. and Med., Fell. Am. 1915

Date of Election

Acad. Arts and Sci., Hon. Fell. Soc. Trop. Med. and Hygiene, Lond. Hon. Mem. Soc. Path. Exotique, Paris. *42 Cleveland Lane, Princeton, N. J.*

Smock, John C., M.A., Ph.D., LL.D. Former State Geologist of New Jersey. Mem. Am. Inst. Mining Eng., Geol. Soc. of Am., Roy. Soc. of Arts, Lond. *Hudson, N. Y.* 1897

Smyth, Charles Henry, Jr., A.B., Ph.D. Professor of Geology, Princeton University. Mem. Geol. Soc. of Am., N. Y. Acad. Sci., Wash. Acad. Sci. *Princeton University, Princeton, N. J.* 1908

Smyth, Herbert Weir, A.B., Ph.D. (Gött.). Professor of Greek Literature, Harvard University. Fell. Am. Acad. Arts and Sci., Mem. Am. Philol. Assoc. (Pres't, 1904–05). *15 Elmwood Ave., Cambridge, Mass.* 1908

Snyder, Monroe B., M.A. Director of Philadelphia Observatory and Professor of Astronomy, Central High School, Phila. *2402 N. Broad St., Philadelphia.* 1884

Spitzka, Edward Anthony, M.D. Late Professor of Anatomy, Jefferson Medical College, Phila. Mem. Assoc. Am. Anatomists. *63 E. 91st St., New York City.* 1908

Squier, George Owen, Ph.D. Brigadier-General and Chief Signal Officer, U. S. A. Mem. Am. Inst. Elect. Eng., Inst. of Radio-Eng. *War Department, Washington, D. C.* 1917

Steinmetz, Charles P., A.M., Ph.D. Professor of Electro-Physics, Union College, Schenectady, Chief Consulting Engineer General Electric Co. Mem. Am. Inst. Elect. Eng. (Past-Pres't), Illum. Eng. Soc., Am. Math. Soc., Am. Phys. Soc., Am. Chem. Soc., Soc. of Mech. Eng., German and English Elect. Eng. Societies. **Medal**—Elliott Cresson (Franklin Institute). *Wendell Ave., Schenectady, N. Y.* 1917

Stengel, Alfred, M.D., Sc.D. Professor of Medicine, University of Pennsylvania. Mem. Assoc. of Am. Phys., Assoc. of Pathol. and Bact. *1728 Spruce St., Philadelphia.* 1903

Stephens, Henry Morse, M.A. (Oxon.), Litt.D. (Harv.). Professor of History, University of California. Mem. Am. Hist. Assoc (Pres't, 1915), Acad. of Pacific Coast Hist., Mass. Hist. Soc. *Faculty Club, University of California, Berkeley, Cal.* 1897

Stevens, W. LeConte, A.B., Ph.D. Professor of Physics, Washington and Lee University, Lexington, Va. Mem. N. Y. Acad. Sci., Roy. Microscop. Soc. *Lexington, Va.* 1884

Stevenson, John James, A.M., Ph.D., LL.D. Professor Emeritus of Geology, New York University. Mem. Geol. Soc. of Am. (Past-Pres't), N. Y. Acad. Sci. (Past-Pres't), Corr. Mem. Academies at Phila., San Francisco, Moscow, Halle, Padua, Palermo, Breslau, 1877

Date of Election

and of Geol. Societies of Edinburgh, Liverpool, Brussels, St. Petersburg and Budapest. *215 W. 101st St., New York City.*

Stevenson, Sara Yorke, Sc.D. Off. d'Instruct. Pub. de la République Française. *237 S. 21st St., Philadelphia.* 1895

Stillwell, Lewis Buckley, Sc.D. Mem. Am. Inst. Elect. Eng. (Past-Pres't), Brit. Inst. Elect. Eng., Am. Soc. Civil Eng. *100 Broadway, New York City.* 1898

Stone, Witmer, A.M., Sc.D. Curator, Academy of Natural Sciences, Phila. Fell. Am. Ornith Union. For. Mem. Brit. Ornith. Union. *Academy of Natural Sciences, Logan Square, Philadelphia.* 1913

Stratton, Samuel W., D.Sc. Director of National Bureau of Standards, Washington. Mem. Am. Inst. Elect. Eng., Am. Soc. Mechan. Eng., Am. Phys. Soc. **Medal**—Elliott Cresson (Franklin Institute). *Bureau of Standards, Washington, D. C.* 1904

Straus, Oscar S., A.M., LL.D., Litt.D. Member of the Permanent Court of Arbitration at the Hague. Formerly Ambassador to Turkey. Mem. Am. Soc. Sci. Assoc. (Past-Pres't), Am. Soc. Internat. Law. *5 W. 76th St., New York City.* 1917

Sulzberger, Mayer, M.A., LL.D., D.H.L. Formerly President Judge of the Court of Common Pleas (No. 2) of Pennsylvania. Mem. Am. Orient. Soc., Am. Bar. Assoc., Am. Jewish Hist. Soc. *1303 Girard Ave., Philadelphia.* 1895

Taft, William Howard, B.A., LL.D., D.C.L. 27th President of the United States. Kent Professor of Law, Yale University. Mem. Am. Bar Assoc. (Pres't, 1913). *Hotel Taft, New Haven, Conn.* 1909

Taylor, Alonzo Englebert, M.D. Professor of Physiological Chemistry, University of Pennsylvania. *School of Medicine, University of Pennsylvania, Philadelphia.* 1917

Tesla, Nikola, M.A., LL.D., D.Sc. *8 W. 40th St., New York City.* 1896

Thaxter, Roland, A.M., Ph.D. Professor of Cryptogamic Botany, Harvard University. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Bot. Soc. of Am. (Past-Pres't), Bost. Soc. Nat. Hist., Am. Phytopath. Soc., Deut. Botan. Gesell. **Medal**—Prix Desmazières. *7 Scott St., Cambridge, Mass.* 1912

Thomson, Elihu, A.M., Ph.D., D.Sc. Consulting Engineer, General Electric Co. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Am. Inst. Elect. Eng. (Past-Pres't), Am. Astron. Soc., Am. Geog. Soc., Inst. of Civil Eng. (Gt. Br.), Inst. of Elect. Eng. (Gt. Br.), Soc. Int. des Electric. (Paris). **Medals**—Grand Prix (Paris, 1889, 1900); Rumford (1901); John Scott Legacy (Franklin Inst., 1888, 1901); Edison (1909); Elliott Cresson (Franklin Inst., 1912); Grand Prize Louisiana Purchase Expos. (St. Louis, 1904), Omaha Expos. (1898); John Fritz (1916). *22 Monument Ave., Swampscott, Mass.* 1876

Date of Election

Titchener, Edward Bradford, D.Sc. (Oxon), Ph.D. (Leipzig), LL.D., Litt.D. Professor of Psychology in Graduate School, Cornell University. Fell. Zoolog. Soc., Roy. Soc. of Med., Aristotelian Soc., Am. Psychol. Assoc. *Cornell Heights, Ithaca, N. Y.* 1906

Tittmann, Otto Hilgard, D.Sc., LL.D. Formerly Superintendent U. S. Coast and Geodetic Survey. Mem. Am. Soc. Civil Eng., Wash. Acad. Sci. (Pres't, 1913), Philos. Soc. of Wash. (Pres't, 1899), Astrophys. Soc. of Am. Hon. Mem. Berlin. Gesell. für Erdkunde. *Leesburg, Va.* 1906

Tower, Hon. Charlemagne, A.B., LL.D. (Glasgow, St. Andrews). Formerly U. S. Ambassador to Germany. Mem. Hist. Soc. of Penna. (Pres't). **Medals**—Grand Officer, Legion of Honor of France, Grand Cordon, St. Alex. Newski, Russia, Grand Cross of Order of Osmanie, Grand Cross of the Order of Merit, Oldenburg. *228 S. Seventh St., Philadelphia.* 1895

Trelease, William, Sc.D., LL.D. Professor of Botany, University of Illinois. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Bot. Soc. of Am. (Past-Pres't), Am. Soc. of Naturalists (Pres't, 1903), Acad. Sci., St. Louis (Pres't, 1909 and 1911), Acad. Internat. de Geog. Bot., Bot. Soc. of Am. (Pres't, 1896). *University of Illinois, Urbana, Ill.* 1903

Trowbridge, Augustus, A.M., Ph.D. Professor of Physics, Princeton University. Fell. Am. Phys. Soc. *Princeton University, Princeton, N. J.* 1911

Trowbridge, John, S.D. Professor Emeritus and (Hon.) Director of the Jefferson Physical Laboratory, Harvard University. Mem. Nat. Acad. Sci. Fell. Am. Acad. Arts and Sci. (Pres't). *Cambridge, Mass.* 1896

Tucker, Richard Hawley, C.E. Mem. Astron. Gesell., Astron. Soc. of the Pacific, Mexican Astron. Soc. *Lick Observatory, Mt. Hamilton, Cal.* 1908

Tyler, Lyon Gardiner, A.M., LL.D. President of William and Mary College. Mem. Am. Antiq. Soc., Am. Hist. Assoc. Corr. Mem. Mass. Hist. Soc. *William and Mary College, Williamsburg, Va.* 1889

Tyson, James, A.M., M.D., LL.D. Professor Emeritus of Medicine, University of Pennsylvania. Fell. Coll. Phys., Phila. (Pres't, 1907–10), Mem. Assoc. Am. Phys. (Pres't, 1907–08). *1506 Spruce St., Philadelphia.* 1887

Van Hise, Charles Richard, B.M.E., M.S., Ph.D. President of the University of Wisconsin. Mem. Nat. Acad. Sci., Wash. Acad. Sci., Scientific Soc. of Christiania, Roy. Swedish Acad. Sci., Geolog. Soc. Am. (Pres't, 1907), Geolog. Soc., Lond., Wis. Acad. Sci., Arts and Letters (Pres't, 1893–96), Bost. Soc. Nat. Hist., A. A. A. S. (Pres't, 1916). *University of Wisconsin, Madison, Wis.* 1909

Date of Election

Vauclain, Samuel M., D.Sc. Mem. Am. Soc. Civil Eng., Am. Soc. Min. Eng., Am. Soc. Mech. Eng., Soc. Civ. Eng., Lond. *500 N. Broad St., Philadelphia.* 1899

Vaughan, Victor Clarence, M.S., Ph.D., M.D., Sc.D., LL.D. Professor of Hygiene and Physiological Chemistry, University of Michigan, Pres't Mich. State Board of Health. Mem. Nat. Acad. Sci., Soc. Française d'Hygiène, Hungarian Soc. of Hygiene, Assoc. Amer. Phys. *221 S. State St., Ann Arbor, Mich.* 1909

Vaux, George, Jr., S.B., LL.B. *Gulph Road, Bryn Mawr, Pa.* 1897

Veblen, Oswald, A.B., Ph.D. Professor of Mathematics, Princeton University. Mem. Am. Math. Soc., Circolo Matemat. di Palermo, Soc. de Mathémat. de France. *Princeton, N. J.* 1912

Venable, Francis P., A.M., Ph.D., Sc.D., LL.D. Professor of Chemistry, University of North Carolina. Mem. Amer. Chem. Soc. (Pres't, 1905), Lond. Chem. Soc., Deut. Chem. Gesell. *Chapel Hill, N. C.* 1905

Wagner, Samuel, A.M. President of Wagner Free Institute of Science. *209 Franklin Bldg., 133 S. 12th St., Philadelphia.* 1885

Walcott, Charles Doolittle, Sc.D. (Cantab. and Harv.), Ph.D. (Roy. Fredericks, Christiania), LL.D. Secretary of the Smithsonian Institution, Director of U. S. Geological Survey, 1894–1907. Mem. Nat. Acad. Sci., Geol. Soc. of Am., Wash. Acad. Sci. (Pres't, 1899–1910), Geolog. Soc., Lond., Accad. dei Lincei, Christiania Scient. Soc., Imp. Soc. of Nat. of Moscow, Astron. Soc. of Mex. Fell. Am. Acad. Arts and Sci. **Medals**—Hayden (Acad. Nat. Sci., Phila.); Bigsby (Geolog. Soc., Lond.). *Smithsonian Institution, Washington, D. C.* 1897

Ware, Lewis S. Mem. Assoc. des Chimistes de Sucrerie (France). *54 Rue de la Bienfaisance, Paris, France.* 1881

Warfield, Ethelbert D., A.M., LL.D., Litt.D. President of Wilson College. Mem. Am. Hist. Soc. *Wilson College, Chambersburg, Pa.* 1897

Webster, Arthur Gordon, A.B., Ph.D., Sc.D., LL.D. Professor of Physics, Clark University. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Am. Phys. Soc. (Pres't, 1903–05), Am. Math. Soc., Deut. Math. Verein., Circolo Matemat. di Palermo. *Clark University, Worcester, Mass.* 1906

Welch, William Henry, A.B., M.D., LL.D. Professor of Pathology, Johns Hopkins University, President State Board of Health, Maryland, Board of Scientific Directors, Rockefeller Inst. for Med. Research. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci. (Past-Pres't), A. A. A. S. (Past-Pres't), A. M. A. (Past-Pres't), Cong. of Am. Phys. and Surg. (Past-Pres't), Assoc. of Am. Phys. (Past-Pres't), Royal Soc. of Med., Lond. **Medals**—Ritter des 1896

Date of Election

Königl. Kronen-Orden 2 ter cl., Order of the Rising Sun, Japan, 3d cl. *807 St. Paul St., Baltimore, Md.*

Wheeler, William Morton, Ph.D., Sc.D. Professor of Economic Entomology, Bussey Institution for Applied Biology, Harvard University. Hon. Cur. of Social Insects, Am. Mus. Nat. Hist. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., N. Y. Acad. Sci., Havana Acad. Sci. *Bussey Institution, Forest Hills, Boston, Mass.* 1916

White, Andrew D., A.B., LL.D., L.H.D., Ph.D. (Jena), D.C.L. (Oxon.). President Cornell University, 1865–85. Hon. Mem. Roy. Acad. Sci. (Berl.). Mem. Am. Soc. Sci. Assoc. (Past-Pres't), Mass. Hist. Soc., Am. Acad. Arts and Letters. **Medal**—Gold of Prussia for Arts and Sci., Officier Legion d'Honneur. *23 East Ave., Ithaca, N. Y.* 1869

White, Israel C., A.M., Ph.D. State Geologist of West Virginia. Mem. Geolog. Soc. of Am., Am. Geog. Soc., Am. Inst. Mining Eng. *141 Willey St., Morgantown, West Virginia.* 1878

Whitfield, J. Edward, Ph.D. *406 Locust St., Philadelphia.* 1905

Wilder, Burt G., B.S., M.D. Professor Emeritus of Neurology and Vertebrate Zoology, Cornell University. Mem. Bost. Soc. Nat. Hist., Am. Neurol. Assoc. (Pres't, 1885), Assoc. Amer. Anat. (Pres't, 1898). *93 Waban Hill Road, Chestnut Hill, Mass.* 1878

Wiley, Harvey W., A.M., S.B., M.D., Ph.D., D.Sc., LL.D. President U. S. Pharmacopoeial Convention. Mem. Am. Chem. Soc. (Past-Pres't). **Medals**—Elliott Cresson (Franklin Inst.); Chevalier du Mérite Agricole; Chev. de Legion d'Honneur. *Cosmos Club, Washington, D. C.* 1904

Willcox, Joseph. *The Gladstone, Philadelphia.* 1895

Williams, Edward Higginson, Jr., B.A., B.S., E.M., Sc.D., LL.D. Mem. Am. Inst. Mining Eng., Geolog. Soc. of Am. *Westerdale, Woodstock, Vt.* 1897

Williams, Talcott, A.B., L.H.D., LL.D. Director of School of Journalism, Columbia University. Mem. Am. Orient. Soc., Am. Acad. Polit. and Soc. Sci. *School of Journalism, Columbia University, New York.* 1888

Willis, Bailey, E.M., Ph.D. (Berl.). Geologist, U. S. Geological Survey. Professor of Geology, Stanford University. **Medal**—Soc. Géog. de France. *Stanford University, California.* 1905

Willis, Henry, A.M. Professor of History, Central High School, Phila. Mem. Am. Hist. Assoc. *4036 Baring St., Philadelphia.* 1890

Wilson, Edwin Bidwell, A.B., Ph.D. Professor of Mathematics, Massachusetts Institute of Technology. Mem. Am. Math. Soc., Soc. 1917

Date of Election

de Mathémat. de France, Deut. Math. Verein., Circolo Matemat. di Palermo, Lond. Math. Soc., Am. Phys. Soc., Soc. Franç. de Phys. *Massachusetts Institute of Technology, Cambridge, Mass.*

Wilson, Harold Albert, M.A. (Cantab.), D.Sc. Professor of Physics, Rice Institute, Fell. Royal Soc. Mem. Cambridge Philos. Soc., Phys. Soc., Lond., Soc. Franç. de Phys., Am. Phys. Soc. *Rice Institute, Houston, Tex.* 1914

Wilson, James Cornelius, A.M., M.D. Professor Emeritus of Medicine in Jefferson Medical College. Mem. Assoc. Am. Phys. (Past-Pres't), Fell. Coll. of Phys., Phila. (Past-Pres't). *1509 Walnut St., Philadelphia.* 1885

Wilson, William Powell, B.S., Dr.Sc. (Tüb.). Director of the Philadelphia Museums. Mem. Botan. Soc. of Am., Wash. Acad. Sci., Deut. Botan. Gesell. *Commercial Museum, 34th St. bel. Spruce St., Philadelphia.* 1887

Wilson, Woodrow, A.M., LL.D., Litt.D. 28th President of the United States. Formerly President of Princeton University and Governor of New Jersey. *The White House, Washington, D. C.* 1897

Wister, Owen, A.M., LL.D., Litt.D. *1004 West End Trust Bldg., Philadelphia.* 1897

Witmer, Lightner, A.M., Ph.D. Professor of Psychology and Director of the Laboratory of Psychology, University of Pennsylvania. Mem. Am. Psycholog. Assoc. *2426 Spruce St., Philadelphia.* 1897

Wood, Robert Williams, A.B., LL.D. Professor of Experimental Physics, Johns Hopkins University. Fell. Am. Acad. Arts and Sci. Mem. Nat. Acad. Sci., Am. Phys. Soc., Am. Astr. and Astrophys. Soc., Solway Inst. of Physics (Brussels). Corr. Mem. Roy. Soc., Göttingen. Hon. Fell. Roy. Microscop. Soc. (Lond.). **Medals**—Rumford (Lond. Soc. of Arts); John Scott (Franklin Institute, Phila.). *Johns Hopkins University, Baltimore, Md.* 1908

Woodward, Robert Simpson, C.E., Ph.D., LL.D., Sc.D. President of the Carnegie Institution of Washington. Mem. A. A. A. S. (Pres't, 1901), Am. Math. Soc. (Pres't, 1898–1900), Geolog. Soc. of Am., Am. Phys. Soc., N. Y. Acad. Sci. (Pres't, 1902), Wash. Acad. Sci. Pres't, 1915), Nat. Acad. Sci., Fell. Amer. Acad. Arts and Sci. *Carnegie Institution of Washington, Washington, D. C.* 1902

Wright, Frederick E., Ph.D. (Heidel.). Petrologist, Geophysical Laboratory, Carnegie Institution of Washington, Geologist, U. S. Geol. Surv. Fell. Am. Acad. Arts and Sci. Mem. Am. Phys. Soc., Am. Chem. Soc., Am. Math. Soc., Geolog. Soc. of Am., Am. Inst. Mining Eng., Wash. Acad. Sci. *2134 Wyoming Ave., Washington, D. C.* 1914

Date of Election

Wurts, Alexander J., Ph.B., M.E. Professor and Head of Department of Electrical Engineering, Carnegie Institute of Technology, Pittsburgh. Mem. Am. Inst. Elec. Eng. **Medal**—John Scott (Franklin Inst., Phila.). *1164 Shady Ave., Pittsburgh, Pa.* 1899

Wyckoff, Ambrose Barkley. Lieutenant U. S. N. (retired). *131 E. H St., Ontario, Cal.* 1886

Zeleny, John, B.S., Ph.D., B.A. (Cantab.), M.A. Professor of Physics, Sheffield Scientific School, Yale University. Mem. Am. Phys. Soc. Assoc. Mem. Cambridge Philos. Soc. *44 Cold Spring St., New Haven, Conn.* 1915

FOREIGN MEMBERS

Adam, Lucien. *41 Bard Sevigné, Rennes, France.* 1886

Adams, Frank Dawson, D.Sc., Ph.D. Professor of Geology, McGill University. *McGill University, Montreal, Canada.* 1916

Arrhenius, Svante August, Dr.Phil. Juris et Med. Director of the Physico-Chemical Department of the Nobel Institute. **Medal**—Nobel Laureate, Chemistry (1903). *Nobel Institute, Experimentalfállet, near Stockholm, Sweden.* 1911

von Baeyer, Adolf, Ph.D. Professor of Chemistry, University of Munich. **Medal**—Nobel Laureate, Chemistry (1905). *Aroisstrasse 1, Munich, Bavaria.* 1910

Balfour, Rt. Hon. Arthur James, LL.D., D.Cl. *4 Carlton Gardens, S. W., London, Eng.* 1917

Bonaparte, Prince Roland. *10 Ave d'Jena 22, Paris, France.* 1895

Broegger, Waldemar Christofer. Professor of Mineralogy and Geology, Kong. Frederiks Universitet. *Christiania, Norway.* 1899

Bryce, Rt. Hon. James, Viscount, O.M., D.C.L. *Hindleap, Forest Row, Sussex, England.* 1895

Budge, E. A. Wallis, M.A., Litt.D. *British Museum, London, England.* 1895

Canizzaro, Tomaso. *Villa San Guiseppe 40, Catania, Sicily.* 1885

Capellini, Giovanni. Professor of Geology and Palaeontology, Bologna University. *Rue Medal Hayden, 1896, Bologna, Italy.* 1873

deCharencey, Comte Hyacinth. *25 rue Barbet de Jouy, Paris, France.* 1886

Cora, Guido. Professor of Geography, R. Università, Rome. *181 Via Nazionale, Rome, Italy.* 1886

Crookes, Sir William, Kt., O.M., LL.D., D.Sc. *17 Kensington Park Gardens, London, W., England.* 1886

Date of Election

Curie, Marie Sklodowska, D.Sc., LL.D. Professor of Physics, University of Paris. **Medal**—Nobel Laureate, Physics (1903); Chemistry, (1911). *12 Rue Cuvier, Paris, France.* 1910

Darwin, Sir Francis, Kt., M.A., Sc.D., LL.D., Ph.D. *10 Madingley Road, Cambridge, England.* 1909

Dawkins, W. Boyd, M.A., D.Sc. Hon. Professor of Geology and Palaeontology, Victoria University, Manchester. *Fallowfield House, Fallowfield, Manchester, England.* 1880

deBar, Hon. Edouard Sêve. *Ramsgate, England.* 1882

Delage, Yves. Professor of Zoology, Université de Paris. *Université de Paris, Station Zoologique de Roscoff, Paris, France.* 1905

Delitzsch, Friedrich, Ph.D. Professor of Assyriology, University of Berlin. *University of Berlin, Berlin, Germany.* 1904

Dewar, Sir James, Kt., M.A., LL.D., D.Sc. Professor of Natural Experimental Philosophy, University of Cambridge. *1 Scroope Terrace, Cambridge, England.* 1899

Diels, Hermann, Dr.Phil., M.D., LL.D. Professor of Classics, University of Berlin. *Nürnbergerstr. 65, II, Berlin W., 50, Germany.* 1909

Engler, Adolf, Ph.D. Professor of Botany, University of Berlin. *Berlin-Dahlem, Botanischer Garten, Germany.* 1906

d'Estournelles de Constant, Baron. *78 bis Ave. Henri Martin, Paris, France.* 1907

Evans, Sir Arthur John, Kt., M.A., D.Litt., LL.D. Extr. Professor of Prehistoric Archaeology, Oxford. *Youlbury, Oxford, England.* 1913

Fennell, C. A. M., Litt.D. *Mayfield, Great Shelford, Cambridge, England.* 1895

Fischer, Emil, Ph.D., M.D. Professor of Chemistry, University of Berlin. **Medal**—Nobel Laureate, Chemistry, 1902. *Hessischestr. 2, Berlin, Germany.* 1909

Forbes, George, M.A. (Cantab.). Formerly Professor of Natural Philosophy, Anderson's College, Glasgow. *11 Little College St., Westminster, S. W., London, England.* 1891

Foster, George Carey, LL.D., D.Sc. Formerly Professor of Physics, University College, London. *Ladywalk, Rickmansworth, Herts, England.* 1907

Geikie, Sir Archibald, O.M., K.C.B., Sc.D., LL.D., D.C.L. Late Director-General of the Geological Survey of Great Britain. *Shepherd's Down, Haslemere, Surrey, England.* 1880

Date of Election

Glazebrook, Sir Richard Tetley, Kt., C.B., M.A., Sc.D. Director of the National Physical Laboratory. *Bushy House, Teddington, Middlesex, England.* 1895

de Gregorio, Marquis Antonio. *Al Molo, Palermo, Sicily.* 1888

Haeckel, Ernst, Ph.D., M.D., LL.D. Professor of Zoology, University of Jena. *Jena University, Jena, Germany.* 1885

Hilprecht, Hermann V., Ph.D., D.D., LL.D. Formerly Professor of Comparative Semitic Philology, University of Pennsylvania. *Leopoldstr. 8, Munich, Bavaria.* 1886

Johannsen, Wilhelm L. Professor of Plant Physiology, Copenhagen University. *The University, Copenhagen, Denmark.* 1916

Jusserrand, Jean Adrien Antoine Jules, LL.D. French Ambassador. *French Embassy, Washington, D. C.* 1907

Kapteyn, Jacobus Cornelius. Professor of Astronomy, Royal University of Gröningen. *Gröningen, Holland.* 1907

Karpinsky, Alexandre Petrovitch. Hon. Director of the Russian Geological Survey. *Geological Survey, Petrograd, Russia.* 1897

Kitasato, Shibasaburo, M.D. Director of the Kitasato Institute for Infectious Diseases. *Kitasato Institute for Infectious Diseases, Tokyo, Japan.* 1914

Krauss, Friedrich S. *vii/2 Neustiftgasse 12, Vienna, Austria.* 1889

Lanciani, Rodolfo, Ph.D., LL.D., D.C.L. Professor of Ancient Topography, University of Rome, Senator of the Kingdom. *24 Piazzo Sallustio, Rome, Italy.* 1897

Lankester, Sir Edwin Ray, K.C.B., M.A., D.Sc., LL.D. Late Director of the Natural History Departments, British Museum. *29 Thurloe Place, S. W., London, England.* 1903

Larmor, Sir Joseph, Kt., M.A., D.Sc., LL.D., D.C.L. Professor of Mathematics, University of Cambridge. *St. Johns College, Cambridge, England.* 1913

Lockyer, Sir J. Norman, K.C.B., LL.D., Sc.D. Director of Hill Observatory. *Hill Observatory, Salcombe Regis, Sidmouth, England.* 1874

Lodge, Sir Oliver Joseph, Kt., D.Sc., LL.D. Principal of the University of Birmingham. *Mariemont, Edgebaston, Birmingham, England.* 1901

Lorentz, Hendrik Antoon. Professor of Physics, University of Leyden. **Medal**—Nobel Laureate, Physics (1902); Franklin (Franklin Institute of Phila., 1917). *76 Zylweg, Haarlem, Holland.* 1906

Macallum, Archibald Byron, M.A., M.D., Ph.D., Sc.D., LL.D. Professor of Biochemistry, University of Toronto. *Room 157 West Departmental Block, Ottawa, Canada.* 1917

Date of Election

Mackenzie, Arthur Stanley. President of Dalhousie University, Halifax, Nova Scotia. *Dalhousie University, Halifax, Nova Scotia.* 1899

McMurrich, James Playfair, M.A., Ph.D., LL.D. Professor of Anatomy, University of Toronto. *Anatomical Laboratory, University of Toronto, Toronto, Canada.* 1907

Marconi, Guglielmo, D.Sc., LL.D. Medal—Nobel Laureate, Physics (1909). *18 Finch Lane, London, E. C., England.* 1901

Mengarini, Guglielmo. *Piazza Quirinale 14, Rome, Italy.* 1898

Meyer, Eduard, LL.D., D.Litt., Ph.D. Professor at the University of Berlin. *Berlin-Gross-Lichterfelde, Mommsenstr. 7, Germany.* 1910

Nansen, Fridtjof, D.Sc., Ph.D., D.C.L. Professor of Oceanography, Christiania University. *Lysaker near Christiania, Norway.* 1897

Nöldeke, Theodor, Ph.D. Professor Emeritus of Semitic Philology, University of Strassburg. *University of Strassburg, Strassburg, Germany.* 1906

Nordenskjöld, Otto, Ph.D. Professor of Geography, University of Gothenburg, *Göteborg 3, Sweden.* 1905

Nys, Ernest, LL.D., D.C.L. Professor of International Law, University of Brussels. *30 Rue Saint-Jean, Brussels, Belgium.* 1908

Onnes, Heike Kamerlingh, Ph.D., D.Sc. Professor of Physics, University of Leyden. **Medal**—Nobel Laureate, Physics (1913); Franklin (Franklin Institute of Phila., 1915). *Huize ter Wetering, Haaweg, Leyden, Holland.* 1914

Osler, Sir William, Bart., M.D., D.Sc. Regius Professor of Medicine, University of Oxford. *13 Norham Gardens, Oxford, England.* 1885

Ostwald, Wilhelm, D.Sc., LL.D. Professor Emeritus of Chemistry, University of Leipzig. **Medal**—Nobel Laureate, Chemistry (1909). *Gross-Bothen b. Leipzig, Germany.* 1912

Peñafiel, Antonio. *Callejón Betlemitas 8, Mexico, D. F., Mexico.* 1886

Penck, Albrecht F. K., Ph.D., D.Sc. Professor of Geography, University of Berlin. *7 Georgenstrasse 34, Berlin N. W., Germany.* 1908

Petrie, William Matthew Flinders, D.C.L., Litt.D., LL.D. Professor of Egyptology, University College, London. *8 Well Road, Hampstead, N. W., London, England.* 1905

Pfeffer, Wilhelm F., Ph.D., M.D., Sc.D. Professor of Botany, University of Leipzig. *Botanisches Institut, Leipzig, Germany.* 1909

Picard, Charles Emile. Professor of Mathematics at the Sorbonne. *4 Rue Joseph Bara VI, Paris, France.* 1910

Postgate, John Percival, Litt.D. Professor of Comparative Philology, University of London. *15 Linnet Lane, Liverpool, England.* 1886

Date of Election

Prain, Sir David, M.A., M.B., LL.D. Director of the Royal Botanic Gardens, Kew. *Royal Botanic Gardens, Kew, England.* 1917

Rayleigh, Rt. Hon. John William Strutt, Lord, O.M., M.A., Ph.D., Sc.D., LL.D. Formerly Professor of Physics, University of Cambridge. **Medal**—Nobel Laureate, Physics (1904). *Terling Place, Witham, Essex, England.* 1886

Redwood, Sir Boverton, Bart., D.Sc. *The Cloisters, 18 Avenue Road, Regents Park, N. W., London, England.* 1898

Retzius, Magnus Gustav, M.D. Late Professor of Anatomy, Caroline Medico-Chirurgical Institute, Stockholm. *116 Drottninggatan, Stockholm, Sweden.* 1912

Richardson, Owen Willans, M.A., D.Sc. Professor of Physics, University of London, King's College. *4 Cannon Place, Hampstead, London, England.* 1910

Rutherford, Sir Ernest, Kt., M.A., D.Sc., Ph.D. Professor of Physics, University of Manchester. **Medal**—Nobel Laureate, Chemistry (1908). *17 Wilmslow Road, Withington, Manchester, England.* 1904

Schuster, Arthur, Ph.D., Sc.D., LL.D. Honorary Professor of Physics, University of Manchester. *Yeldall, Twyford, Berks, England.* 1913

Sergi, Giuseppe. Professor of Anthropology, R. Università, Rome. *Museo e Laboratorio di Antropologia, Rome, Italy.* 1885

Snellen, Herman, Jr. Professor of Ophthalmology, Rijks University. *Utrecht, Netherlands.* 1894

Szombathy, Josef. Keeper of the Anthropologico-Ethnographic Section, K. K. Naturhistorisches Hofmuseum. *Burgring 7, Vienna, Austria.* 1886

Temple, Lt. Col. Sir Richard Carnac, Bart. *The Nash, Worcester, England.* 1886

Thistleton-Dyer, Sir William Turner, K.C.M.G., M.A., Sc.D., Ph.D., LL.D. Late Director, Royal Botanic Gardens, Kew. *The Ferns, Witcombe, Gloucester, England.* 1905

Thomson, Sir Joseph John, Kt., O.M., M.A., Sc.D., Ph.D., LL.D. Professor of Experimental Physics, Cambridge University. **Medal**—Nobel Laureate, Physics (1906). *Holmleigh, West Road, Cambridge, England.* 1903

im Thurn, Sir Everard, K.C.M.G., M.A., LL.D. *39 Lexham Gerdans, W., London, England.* 1885

Trevelyan, Rt. Hon. Sir George Otto, Bart., O.M., LL.D., D.C.L. *Welcombe, Stratford-on-Avon, England.* 1899

Tschermak, Gustav v. Professor of Mineralogy and Petrography, K. K. Universitet, Vienna, Austria. *Universitet, Vienna, Austria.* 1882

Date of Election

Turrettini, Theodore. *Geneva, Switzerland.* 1890

Unwin, William Cawthorne, B.Sc., LL.D. Emeritus Professor of Engineering at Central Technical College, City and Guilds of London Inst. *Palace Gate Mansion, 29 Palace Gate, Kensington, London, England.* 1890

van der Waals, Joannes Diderik, Ph.D. Professor of Theoretical Physics, University of Amsterdam. **Medal**—Nobel Laureate, Physics (1910). *The University, Amsterdam, Netherlands.* 1916

Volterra, Vito, Ph.D. Professor of Physics, University of Rome. *Via in Lucina 17, Rome, Italy.* 1914

de Vries, Hugo. Professor of Plant Physiology, University of Amsterdam. *University, Amsterdam, Holland.* 1903

Waldeyer, Wilhelm. Professor of Anatomy, University of Berlin. *Lutherstr. 35, Berlin W. 62, Germany.* 1904

Woodward, Henry, LL.D. Late Keeper of the Department of Geology, British Museum (Natural History). *13 Arundel Gardens, Notting Hill W., London, England.* 1874

Wundt, Wilhelm, Ph.D. Formerly Professor of Philosophy, University of Leipzig. *Schwägerichen Str. 17, Leipzig, Germany.* 1895